SYMPOSIUM D
D: Materials and Devices for Smart Systems

November 30 - December 5, 2003

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*Invited paper
Engineered domain configuration is one of the domain engineering techniques and makes piezoelectricity of ferroelectric single crystals extremely enhanced. In this study, this engineered domain configuration was induced into barium titanate single crystals as a typical lead-free piezoelectric single crystals, and the piezoelectric property was investigated as a function of (1) crystal structure, (2) crystallographic orientation, (3) domain size. As a result, the orthorhombic barium titanate single crystals, when electric field (E-field) was applied along [010] direction, the maximum piezoelectric property was observed and its piezoelectric properties were larger than those of PZT ceramics. Moreover, domain density of orthorhombic barium titanate single crystals was controlled by temperature and E-field, and their piezoelectric properties were measured. The barium titanate crystals with high domain density exhibited the much higher piezoelectric properties than those of barium titanate crystals with low domain density. The above results revealed that what kind of engineered domain configurations is the best for the piezoelectric application.

9:30 AM #D1.3
Polarizable Charge Equilibration Force Field and Application to Phase Transformation in Molecules. Qingsong Zhang, Tahir Cagin, Alejandro Strachan and William A. Goddard, California Institute of Technology, Pasadena, California.

We present the Polarizable Charge Equilibration force field to include self-consistent atomic polarization and charge transfer in molecular dynamics of materials. The charge on each atom is partitioned into a Gaussian-shaped core with fixed (positive) charge (4 for Si) and a Gaussian-shaped shell with variable charge. The shell charges can flow from one atom to another based on the QEq (Charge equilibration) scheme of Rappe and Goddard. The restoring force between a core and its shell is given by the electrostatic interaction between the two charge distributions. The long range London dispersion and short range Pauli repulsion effects are described by two-body potentials (Morokuma or Lennard-Jones) that act between all atoms (no exclusions). Using the above model, we determined all the parameters in the force field for BiTlO3 directly from Quantum Mechanics calculations (DFT with GGA). We find that the model leads to correct temperature sequence for the transitions between the four phases of BiTlO3. With the model it is possible to simulate combinations of unit cells to study domain boundaries, surface reconstructions, the role of defects and the effects of temperature, pressure, and applied electric fields and stress.

8:30 AM #D1.1
Recent Progress In Transducers Actuators And Sensors For Smart Systems. L. Ece Capanoglu, Materials Research Institute, Penn State University, University Park, Pennsylvania.

All high strain electro active dielectric actuators are basically electrostrictive in nature, and the phenomenon in which a material responds to an applied field is that it will change its shape or size. Current work in the area has been driven by the desire to achieve higher strains than have been obtained in the past. This has led to the development of new materials and the use of new fabrication techniques. One of the most promising materials is polyvinylidene difluoride (PVDF) and its copolymers. These materials have been used in a variety of applications, including actuator and sensor devices. In this talk, we will discuss the recent developments in the field of electroactive dielectric actuators, including the use of new materials and the development of new fabrication techniques. We will also discuss the potential applications of these actuators in a variety of fields, including robotics, aerospace, and medical devices.
forces are required for vibration control in a wide range of applications. This need is rarely satisfied by currently available compact actuators, or on such a family of low cost / high performance disk bend actuators produced by combining efficient design and fabrication methods. The properties of these actuators are intermediate between those of standard bimorphs, used for very large displacements but providing rather small forces. The novel disk stack multilayers, which provide quite large forces but are generally heavier, larger and very expensive for equivalent displacements. The absence of any external mechanical amplification mechanism makes these actuators particularly efficient and ideal for active vibration damping applications within buildings or for noise control by emission of controlled sound in anstraphle. In order to lower the driving voltages, multilayer disk benders can also be fabricated with the same technique. The actuator displacement and force properties are not influenced by the number of layers. Patternning of the internal and external electrodes for the application of appropriate voltage configurations enables the development of actuators with highly specialized applications. The fabrication method enables the downsizing of these devices to satisfy MEMS requirements too.

11:00 AM D16
Novel High Power Piezoelectrics for Transformers and Actuators. Shashank Priya1 and Kenji Uchino2; 1Penn State University, University Park, Pennsylvania; 2Electrical Engineering, Penn State University, University Park, Pennsylvania.

High Power piezoelectric materials are required for numerous devices such as piezoelectric transformers, high frequency actuators, ultrasonic motors and current sensors. All these applications demand a material that exhibits both high power density and high efficiency of the device. For use in piezoelectric, dielectric and electromechanical constant along with low dielectric and electromechanical losses. Further the properties should be nonhysteretic with field and temperature. This study illustrates the development of new family of PZT-PZT based ceramic materials whose property can be tailored to meet these requirements. The results will be shown which conclusively prove that this material can generate high electrical power as compared to other available choices.

11:15 AM D17

The initial idea of a piezoelectric transformer (PT) corresponds to C.A. Rosen, K. Fish, and H.C. Rothenberg and is gathered in the U.S. Patent 2632024, applied in 1954. Fifty years later, this technology has become one of the most promising alternative to replace the magnetic transformers in a wide range of applications. PTs convert electrical energy into electrical energy by making use of acoustic energy. These devices are typically manufactured using piezoelectric ceramic materials that vibrate in resonance. With an appropriate design it is possible to step-up and step-down voltage between the input and output of the transformer without the use of wires or magnetic materials. The technology did not reach commercial success until early the 90s. During this period, several companies, mainly in Japan, decided to introduce PTs for applications requiring small size, high step-down voltages, and low electromagnetic interference (EMI) signature. This type of PTs where developed based on optimization of the initial Rosen concept. That’s why they are typically referred as Rosen-type PTs. Today’s PTs are used for backlighting LCD displays in notebook computers, PDAs, and other handheld devices. The PT yearly sales estimate is about 20 million in 2000 and industry sources report that production of piezoelectric transformers in Japan is growing steadily at a rate of 10% annually. The reliability achieved in this application and the advances in the related technologies (materials, driving circuitry, housing and manufacturing) have currently motivated an enormous interest and confidence in expanding this technology to other applications fields. Currently, the industry is moving in two directions: the low-cost product market and the value-added product market. Prices of PTs have been declining in recent years, and this trend is expected to continue this year that may make this technology a serious candidate to replace the magnetic transformers in cost-sensitive applications. As for the value-added product market, leading makers are reportedly focusing on more value-added products. Two key points are miniaturization and higher output power. Piezoelectric transformers for power applications require lower output impedances, high power capabilities and high efficiency under step-down conditions. Among the different PT design proposed as alternative to the classical Rosen configuration, Transonor’s RD-PTs has been demonstrated as the most promising technology achieving higher output level. Higher powers than 100W, with power densities in the range of 30-40 W/cm2 has been demonstrated. Micro-PTs are currently being developed with sizes of less than 5mm diameter and 1mm thickness allowing up to 8.5W power transduction up to 600 Ohm load. Smaller sizes would be in the future integrated to power MEMS systems. This paper summarizes the state of the art on the PT technology and introduces the current trends of this industry.

11:45 AM D18
Phase field simulations of polarization switching under an applied electric or stress field. Jie Wang1, 4, Q. S. Shi2, Q. L. Chen3 and Hongyi Yang4; 1Department of Mechanical Engineering, Hong Kong University of Science and Technology, Hong Kong, Hong Kong; 2Department of Mechanical Engineering, Hong Kong Polytechnic University, Hong Kong, Hong Kong; 3Department of Materials Science and Engineering, The Pennsylvania State University, University Park, Pennsylvania.

The polarization switching in a ferroelectric subjected to an electric field or a stress field is simulated using a phase-field model based on the time-dependent Ginzburg-Landau equation, in which both the long-range electric and the long-range elastic interactions are taken into account. Domain switching takes place when the electric field or the stress field exceeds a threshold value. The temporal evolution of polarization switching shows that the switching is a process of nucleation new domains following by the disappearance of old domains and growth of new domains, which is accomplished through domain wall motion. An electrical load can induce both 180° and 90° polarization switching, while a mechanical load can produce only 90° polarization switching. The macroscopic polarization or strain is obtained by averaging polarizations and strains over the simulated size and final stable domain microstructure. The electric field or stress load, correspondingly. The simulation results successfully reveal the hysteresis loop of the macroscopic polarization versus the applied electric field, the butterfly curve of the macroscopic strain versus the applied electric field, and the macroscopic strain response to an applied compressive stress.

SESSION D2: Shape Memory Alloys
Chair: Kunyu Ince and Eckhard Quandt
Monday Afternoon, December 1, 2003
Room 202 (Hyatt)

1:30 PM D2.1
Application of Active Materials to Microcantilever. Ruchik Bhattacharyya, Mechanical Engineering and Materials Science, California Institute of Technology, Pasadena, California.

The development of effective microcantilevers remains an important challenge in MEMS. Active materials – shape-memory alloys, ferromagnetic shape-memory alloys and ferroelectric materials – offer promising opportunities. However, many practical difficulties have limited the optimal utilization of such materials. This talk will describe a strategy for microcantilever using active materials which makes explicit and optimal use of the underlying microstructure, it shows that large displacement and force can be generated from small volumes by the manipulation of the underlying microstructure or domain patterns. The talk will describe the theoretical considerations underlying the strategy and current experimental efforts based on ferromagnetic shape-memory alloys and ferroelectric polymers.

2:00 PM D2.2
Elastic and Magnetic Properties of Ni2MnGa and Fe-Pd alloys. Jun Cui1, Qinghen Huang2 and Manfred Wuttig; 1Material Science and Engineering, University of Maryland, College Park, Maryland; 2NIST Center for Neutron Research (856), National Institute of Standards and Technology, Gaithersburg, Maryland.

NiMnGa and Fe-Pd are two prototypical ferromagnetic shape memory alloys that differ in detail of the transformation mechanism and in the state of chemical order in the high temperature state. This talk will be divided into two parts, and address these two alloys respectively. The first part of the talk will focus on the elastic properties of NiMnGa and show that, in addition to the well known softening of C121/C122/2, the elastic constant C11 also softens in the Curie temperature is traversed. The elasticity of polycrystalline NiMnGa film reflects the softening of (C121/C122/2 in the austenitic state as well as magnetoelectric characteristic of the ferromagnetic phase. The second part of the talk will focus on the structural and magnetic transitions in Fe-Pt3 alloy. Evidence shows that after cooling from the Curie temperature [400°C], there are three sudden changes of saturation magnetization near 300°C, 100°C, and 600°C, respectively. Structural transitions are responsible for these three changes, and are studied using high-resolution neutron powder diffraction and Rietveld method. In addition, a study of effects of heat treatments on chemical composition in Fe-Pt3 alloy will be presented. This study was aimed to improve the magnetoresistive uniaxiality which is essential for large field induced strain.
2:30 PM D2.3

Combinatorial Thin Film Synthesis of NiMnAl Ferromagnetic Memory Alloys Using MBE Technique, Hall Hasler,1
Juegen Feydt,1 Sigurd Thiessen,2 René Borowski2, Markus Boese2, Thomas Wohlm1, and Michael Moske1,1 Research center caesar, Bonn, Germany; 2Dept of Chemistry, Bonn University, Bonn, Germany.

Ferromagnetic shape memory alloys have attracted much attention as potential high-performance magnetically controlled actuator materials due to their ability to induce large magnetic field induced strain by the rearrangement of twin variants in the martensite state. So far, numerous candidate systems have been investigated in this respect including binary alloys like FePd or FePt as well as the Heusler-type alloys Ni3MnGa, NiMnAl, or very recently CoMnGa and CoNiGa. In bulk form, these materials come up with high magnetostriuction values comparable or even superior to the value of the giant-magnetostriuctive Terfenol-D. The real challenge now is to fabricate thin films of these materials as this will overcome material constraints making it possible to provide them with the same order of functionality as in the bulk counterparts. In this context, we present a study demonstrating the advantage of combinatorial thin film synthesis by using molecular beam epitaxy. Here, NiMnAl alloy composition spreads were grown onto a four-inch wafer substrates. Compositional variations ranging from 10 to 15 at. % relative to each constituent enable a direct comparison of the chemical-structural relationship with respect to martensitic transformation and to magnetic ordering as well as an efficient identification of the emerging phase stability regions. In our study, we set the primary focus on the structural aspects of the transformation behavior confirmed by X-ray microdiffraction in combination with high-resolution transmission electron microscopy. High-resolution TEM imaging of the respective composition areas reveal patterns of a long periodic stacking order indicating crystallographic orientation in the martensite state. Stress relief upon transformation as observed by thermal processing in a stress apparatus applying a compression bending beam technique ranges from 50 to 200 MPa depending on the composition. Vibrating-sample magnetometry so far suggests magnetic ordering to occur well below ambient temperature. The compositional and microstructural aspects of the phase stability will be discussed.

2:45 PM D2.4

New smart composites composed of ferromagnetic shape memory alloy particles and polymeric matrix for sensors and actuators, Hikaru Hosoda,1 Shunsuke Takeda1,2, Tomohiro Inamura,1 Kenji Wakahara1 and Shigeru Miyazaki,2 Precision and Intelligence Laboratory, Tokyo Institute of Technology, Yokohama, Kanagawa, Japan; 1Institute of Materials Science, University of Tsukuba, Tsukuba, Ibaraki, Japan.

Since most ferromagnetic shape memory alloys (FSMAs) are brittle, the enhancement of ductility is strongly required. In order to improve workability and ductility of FSMAs, a new smart composite composed of FSMa particles (FSMAs) and poly is proposed. The FSMAs are essentially face-centered cubic (FCC) and the isotropic properties of the poly are advantageous for shaping and forming. In this paper, the design concept, mechanical and shape memory properties of the composites are described. Besides, the ability of the composites for sensors and actuators is pointed out.

3:30 PM D2.5

Combinatorial Investigation of ferromagnetic shape memory alloys, Ildiko Takacs,1 Depart of Materials Science and Engineering, University of Maryland, College Park, Maryland; 2Small Smart Systems Center, Department of Materials Science and Engineering and Center for Superconductivity Research, University of Maryland, College Park, Maryland.

We have developed a thin film composition spread technique for rapidly mapping the ternary phase diagrams of metallic alloy systems in search of ferromagnetic shape memory alloys. A UHV three-gun magnetron co-sputtering system is used to deposit composition spreads whose natural compositional distribution contains large fractions of ternary phase diagrams. The spreads are created on 3-inch Si wafers, and the typical thickness of the film ranges from 300 nm to 1 micrometer. For deposition in situ and the deposition of every layer, they are annealed at 500-600°C in vacuum following the deposition. Wavelength dispersive spectroscopy is used to map the exact composition distribution of every layer. Room-temperature low-magnification scanning SQUID microscopy is used to obtain the magnetic field distribution of the spread patterned into 2 mm x 2 mm square grids. Obtained distribution is converted to qualitative remnant magnetization mapping using a numerical algorithm. This allows us to identify composition regions that are ferromagnetic at room temperature. In order to detect composition regions which are reversible martensites, we use wafers where arrays of cantilevers are micromachined prior to the deposition and deposition. Heating and cooling of all the cantilevers on the spread wafer simultaneously by visual inspection, we can detect regions which undergo martensitic transitions. Scanning x-ray diffraction of spread wafer is also used to identify regions which display phase transformations. By combining the information extracted from both types wafers, we can construct functional ternary phase diagrams. To date, we have tested a variety of ternary systems. We have found new composition regions which are both ferromagnetic and reversible martensites in the Gd deficient region of the Ni50Mn50Ga system and the AI deficient region of the Ni50Mn50Al system. A clear relationship between the martensite transition temperature and the Curie temperature has been observed for a wide range of compositions. This work was performed in collaboration with O. O. Fomodu, M. A. Aronov, K.-S. Chang, J. H. Hulm, D. P. Misner, E. L. Offner, F. C. Wellstood, L. Kuzmina, and M. Wuttig.

4:00 PM D2.6

Design of Ferromagnetic Shape Memory Alloy Composites and Their Actuators, Minara Iyengar, Mechanical Engineering, University of Washington, Seattle, Washington.

Recently, strong attention is paid to ferromagnetic shape memory alloys (FSMAs) as key actuator materials, owing to its fast actuation speed, yet providing large force and stroke. FSMAs are driven by applied magnetic field and/or magnetic field gradient, which cause the deformation due to the martensitic phase transformation, and hence can provide very fast actuation speed with reasonably large strain and stability capability. Among the polycrystalline FePd alloy is practically promising to be applied as an actuator material, owing to the good mechanical properties, such as shape memory effects, superelasticity and high ductility, and so on. Since the uniform (constant) magnetic field alone is found to be disadvantageous in this case, we propose so-called "hybrid mechanism" for actuator applications. The key step in the mechanism is the stress-induced martensite phase transformation produced by applied magnetic field gradient, thus enhancing the displacement, as the stiffness of Fe-Pd is reduced from stiff to soft during the martensite to martensite transition. The price of Pd is very expensive, thus, we are searching for alternative FSMA, and come up with FSMA composites which are composed of ferromagnetic material and shape memory alloy (SMA). This talk will discuss the hybrid mechanism of FSMa and SMA composites and present recent results of three-dimensional (3D) phase transformation diagram produced by thermodynamics. This 3D diagram will be used effectively by design engineers who want to design fast responsive FSMA based actuators. This talk introduces also several designs of FMa and SMA composite based actuators.

4:30 PM D2.7

Reversible Martensitic Transformation in a Ferromagnetic CoNiAl Alloy, H. Einwa, K. Fukuda, T. Ohtsuka, and M. J. Sites,1 Department of Mechanical Engineering, Texas A&M University, College Station, Texas; 2Lehrstuhl für Werkstoffkunde, University of Paderborn, Paderborn, Germany.

In recent years ferromagnetic shape memory alloys have attracted increasing interest because of the ability to obtain one order of magnitude higher recoverable magnetic field induced strain (MFIS) than the other active materials. The main requirements for large magnetic field induced strain are: low bound energy, high magnetic field induced strain, high magnetic field induced strain, large pseudostable and light weight memory strain, low pseudostable and high saturation magnetization. A recently discovered ferromagnetic shape memory CoNiAl alloy has promising shape memory characteristics for conventional and magnetic shape memory applications. In this study we have demonstrated that these alloys have low pseudostable stress hysteresis, high stress for dislocation slip, large pseudostable and low weight memory strain, large pseudostable and low weight memory strain, low magnetic field induced strain, and low stress for martensite reorientation. These findings satisfy the thermomechanical requirements to obtain MFIS. Additionally, high melting point, low density, good corrosion and oxidation resistance may result in the replacement of conventional SMAs with CoNiAl in most applications. This work is supported by Army Research Office, Contract No. DAAD 19-02-1-0261.

4:40 PM D2.8

Nonlinear Stress-Based Control of a Rotary SMA-Actuated Manipulator, Mohammad Elhajj, Michael Seigler and Mehdi Ahmadi, Mechanical Engineering, Virginia Tech, Blacksburg, Virginia.

In this paper a nonlinear stress-based controller is designed to position a single-degree-of-freedom shape memory alloy (SMA) actuated manipulator. A three part model was constructed based on the dynamics/kinematics of the arm, the thermomechanical behavior...
of SMA's, and an assumed heat transfer model consisting of electrical heating and natural convection. Both sliding mode control and inverse dynamic control were used to calculate a desired stress, based on the position error. The desired stress is compared with the actual stress which is computed using an Extended Kalman Filter. The stress error is then used for control via a proportional-integral controller.

Numerical simulations are performed to investigate tracking performance as well as other issues such as robustness. The results demonstrate that the variable structure controller design is highly accurate in tracking both stationary and variable input signals.

SESSION D3: Electrorheological Fluids and their Applications
Chair: Ji Su and Qiming Zhang
Tuesday, December 2, 2003
Room 202 (Hynes)

8:30 AM *D3.1* Ferroelectrets: Polymer-film foam-spacer charge layers with exciting fundamental and applications-relevant properties. Reimund Gerhardt-Multhaupt and Michael Wegener, Department of Physics, University of Potzdamer, Potsdam, Brandenburg, Germany.

Recently, the term "ferroelectrets" has been suggested for the new class of highly insulating and suitably foamed polymers with internal space charge that have become a major focus of electret research [1]. The first step in their preparation is foaming and void optimization by means of foaming processes, solvent evaporation, foaming agents, gas expansion, etc. Because of relatively large microvoids, the polymer foams are mechanically quite soft with rather low elastic moduli and acoustic impedances. After charging or poling, they contain stable charge layers on the internal void surfaces. These charge layers form a "giant dipole" whose dipole moment is easily varied by mechanical or electrical stresses. The resulting electrical or mechanical response of the foamed and charged polymer represents a direct or inverse quasi-piezoelectric effect, respectively. Because of the very high deformability of the polymer microvoids, the observed electromechanical effects can be very large, often dwarving the corresponding values of polar piezoelectric polymers and sometimes exceeding the coefficients of commercial piezoelectric materials. In addition to these effects, the new materials exhibit some pyroelectricity which is often quite small and thus makes them rather insensitive to temperature changes. From a general perspective, the novel ferroelectrets are infilled with sufficient quantities of gaseous and/or solid microvoids in a polymer matrix. As in other composite materials, the properties of the material are critically dependent on the size and shape distribution of the voids and on the mechanical and electrical behavior of the interface, i.e. the internal void surfaces. The development of cellular polycarbonate (PP) as an electret-transducer material since the mid-eighties is briefly described, and the most relevant experimental techniques for polymer-film foams and foams are introduced. Porous fluoropolymer electrets and their investigation in single- or multiphase-layer piezoelectrics are also considered in view of their better thermal and temporal stabilities. Typical results are discussed in view of the potential of polymer ferroelectrets for device applications which include flat microphones, loudspeakers, and the noise-cancelling panels, flat and curved ultrasonic transducers without or with patterning of the active area, electromechanical sensors for vibration detection (e.g. machines, musical devices, security systems) and for dynamic biomechanics, etc. [1] Reimund Gerhardt-Multhaupt, "Less can be more - Holes in polymers lead to a new paradigm of piezoelectric materials for electret transducers," IEEE Trans. DieL. Electron. Insul., Vol. 9, No. 5, pp. 851-859 (October 2002). Several contributions by researchers from Austria, China, Finland, Germany and Poland in the Proceedings of the 11th International Symposium on Electrets, IEEE Catalog No. 02CH37283, IEEE Service Center, Piscataway, NJ 2002.


Electrorheoactive polymers (ERPs) offer the potential to overcome limitations of traditional smart material and transducer technologies. A promising class of ERP is dielectric elastomers. Dielectric elastomer transducers are rubbery insulating polymer materials with compliant electrodes that have been shown to change effective electromechanical response to an applied electric field. The strains and elastic energy of dielectric elastomer actuators are larger than those observed in any other field-activated materials. Because of their unique characteristics, dielectric elastomer transducers are under development for a wide range of applications, including multifunctional muscle-like actuators for biomimetic robots, microactuators for MEMS, conformal loudspeakers, hipact displays, shoe-mounted generators for harnessing the energy of walking, replacements for electromagnetic and pneumatic actuators for industrial applications, and shape control of space structures. Dielectric elastomer actuators have a unique promise in each of these applications. The success or failure in a given application will depend on the achievable performance and lifetime as well as the electrical driving requirements.


Anisotropic freestanding films and fibers of nematic elastomers from laterally attached side-chain polymers show promise as linear actuators with large strain and refractive index effects. The orientational order of the liquid crystal side groups imposes a conformational anisotropy in the polymer backbone. When a nematic order parameter occurs, as in the nematic-isotropic phase transition, there is a concomitant loss of order in the backbone which results in a contraction of the film/fiber in the direction of the director orientation. In this presentation we show that induced and strain blocked stress of these elastomers can be easily tuned by varying the nature and composition of the crosslinking material. The effect of multideterminate crosslinkers and hence the mechanical properties of the film will be discussed. We will also present results on the actuation induced by a reorientation of the liquid crystal mesogens by an applied field.

9:45 AM D3.4 A Multiscale Computational Model of Soft Elasticity and Director Reorientation in Nematic Gels. Antonio DeSimone, SISBA, International School for Advanced Studies, Trieste, Italy.

Nematic gels combine large deformations and entropic elasticity of elastomers with tunable optical properties peculiar to nematic liquid crystals. In addition, they exhibit soft elasticity (in analogy with the superelasticity of shape memory alloys) and, as a consequence of a symmetry-breaking phase transformation from an isotropic phase (in which the nematic mesogens are randomly oriented) to a spontaneously deformed uniaxial phase (in which the nematic mesogens are aligned). The phase transformation is controlled by several mechanisms (temperature changes, irradiation by UV light) and the material has been proposed as a suitable candidate for applications such as artificial muscles. The mechanical response of nematic gels is highly nonlinear. Modelling soft elasticity requires the resolution of complex domain patterns which arise in connection with loading-induced phase changes. This is most effectively done through the coarse-grained hyperelastic model, in which fine-scale spatial oscillations are carefully accounted for in the definition of an effective energy density, and then averaged out from the kinematics.

Algorithmically, this amounts to taking a suitable convex envelope of the microscopic free-energy density of the system. Finite element simulations based on the effective energy density are dramatically more effective than those based on the microscopic free-energy. We will report on numerical simulations of stretching experiments on thin sheets of nematic elastomers. The coarse-grained hyperelastic model enables us to simultaneously resolve the microscopic mechanical response (e.g., deformed shape, stress-strain curves) and the underlying microscopic mechanisms (evolution of domain structures, local reorientation of the nematic director). Comparison of numerical results with measured stress-strain diagrams and with X-ray scattering experiments confirms the robustness of our approach.

10:00 AM *D3.5* Molecular Engineering and Morphological Control of Electrorheoactive Graft Elastomers. Ji Su; Advanced Materials and Processing, NASA Langley Research Center, Hampton, Virginia.

Electrorheoactive graft elastomers developed at NASA Langley Research Center demonstrate promising electromechanical properties for lightweight actuation devices. The desired electromechanical properties of the elastomers can be tailored and optimized by molecular engineering (chemically) and morphological control (physically). This presentation will review recent results on 1) the effects of chemical composition and molecular morphology on electromechanical properties, 2) the effects of processing conditions on the material morphology; and 3) a computational study on mechanisms of electroactuation in the material. In addition to the material development, progress in design and fabrication of electrorheoactive polymer (ERP)-based electromechanical devices will also be presented. These include fabrication of polymer-based micro-electro-mechanical systems (MEMS), hybrid electromechanical actuators, and multi-layered ERP actuators as well as other technical issues related to the development of ERP-based devices such as electrodes and configuration design.
11:00 AM D3.6
High-Dielectric-Constant All-Organic/Polymeric Composite Actuator Materials. Cheng Huang1, Ji Su2 and Qiming Zhang3;
1Materials Research Institute and Electrical Engineering Department, The Pennsylvania State University, University Park, Pennsylvania; 2Advanced Materials and Processing Branch, NASA Langley Research Center, Hampton, Virginia.
Among various electroactive polymer (EAP) actuator materials developed recently, the class of EAPs whose responses are stimulated by external electrical fields (often known as the field type EAPs) is especially attractive due to their high strain and elastic energy density. However, for most field type EAPs, dielectric constant is low, generally less than 10. Consequently, these polymers usually require high electric fields (>100 MV/m) to generate high elastic energy density which limits their applications. In this talk, we will investigate some avenues to significantly raise the dielectric constant and electromechanical response in field type polymeric materials. By exploiting an allorganic composite approach in which high-dielectric-constant organic particulates were blended with a polymer matrix, a polymeric-like material can reach a dielectric constant higher than 400, which results in a significant reduction of the applied field to generate high strain with high elastic energy consumption. An allpolymer high-dielectric (dielectric constant K > 1,000 at 1 kHz) percolative composite material was fabricated by the combination of polylethylene (K = 1.0) and a fluoropolymer matrix (K > 50). These high K polymer hybrid materials also exhibit high electromechanical responses under low applied fields. In addition, a threecomponent all-organic composite was designed and prepared to improve the dielectric constant and the electromechanical response, as well as the stability of the composites, in which a high-dielectric-constant organic dielectric phase and an organic conductive phase were embedded into the soft dielectric elastomer matrix.

11:15 AM D3.7
Simulations of High-Strain Electrostrictive Chlorinated Terpolymers. George J. Kambas1 and Tsukasa Kanno2;
1Department of Chemistry, University of Rhode Island, Kingston, Rhode Island; 2Naval Undersea Warfare Center, Newport, Rhode Island.
Chlorinated poly(vinylidene fluoride/trifluoroethylene) terpolymers are remarkable examples of high strain electroactive materials. These polymers are synthesized by copolymerizing vinylidene fluoride and trifluoroethylene with small levels of a third chlorinated monomer. The electromechanical responses of these materials are believed to originate from the chlorine atoms, which, by their presence in the polymer chains and by virtue of its large van der Waals radius, destroys the long-range crystalline polar macro-domains and transforms the polymer into a normal para dielectric ferroelectric polymer. To exploit the strain properties of the terpolymer, it is desirable to understand the structural implications resulting from the presence of the chlorinated monomer. Terpolymer compositions have been performed on model superlattices of terpolymers using quantum-mechanical based force fields. The focus has been on determining the energetics and kinetics of crystallization of the polymers that have been identified by x-ray diffraction and Fourier transform infrared spectroscopy. The chlorinated monomer is shown to act as a defect that can be incorporated into the lamellar structures of annealed terpolymer without a high cost in energy. The degree of incorporation of the chlorinated monomer into the crystal lattice is controlled by annealing conditions and ultimately determines the ferroelectric behavior of the terpolymers. (This work was supported by the Office of Naval Research).

11:30 AM D3.8
Synthesis and Characterization of Cross-Linked Electroactive Polymer Actuator. Nathan Vandesteg3, Timothy Swager2 and Ian Hunter1;
1Materials Science and Engineering, MIT, Cambridge, Massachusetts; 2Chemistry, MIT, Cambridge, Massachusetts; 3Mechanical Engineering, MIT, Cambridge, Massachusetts.
A novel cross-linked conducting polymer has been synthesized for use as an electroactive actuator. The polymer combines a conjugated backbone of phenylene and thiophene rings with a polyurethane-based elastomeric linker. Conducting polymers of a nature similar to the backbone, such as polypyrrole and polyaniline, have been shown to actuate via injection of ions into and out of the polymer upon electrochemical stimulation. For this material, ionic motion is enhanced by the cross-links, which are joined to the backbone with several segments of ethylene oxide, a known ionic conductor. Additionally, the cross-links provide mechanical stability and enable synthesis of freestanding films for active and passive testing. This paper will discuss the synthesis of the novel monomer precursor to the cross-linked conducting polymer. It will then focus on polymerization and cross-linking techniques, followed by active and passive characterization of the material.

11:45 AM D3.9
Large Strain PolyPyrrole Actuators. Patrick A. Angellis2, John Madden3, Derek Rinderknecht1, Nathan Vandesteg3 and Ian Hunter1;
1Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts; 2Electrical and Computer Engineering, The University of British Columbia, Vancouver, British Columbia, Canada.
A typical limitation of polypyrrole based conducting polymer actuators is the low achievable active strains (2% recoverable, 7% max) that they exhibit when activated in a common propylene carbonate/tetraethylammonium tetrafluoroborate electrolyte. Muscle skeletal muscle, on the other hand, exhibits large recoverable strains on the order of 20%. Such large strains are desirable for applications in life-like robotics, artificial prostheses or medical devices. We report herein the design and development of recoverable strains in excess of 16% (21% max) for polypyrrole activated in the 1-butyl-3-methylimidazolium tetrafluoroborate liquid salt electrolyte. This breakthrough in conducting polymer actuator technology will impact many engineering fields, where a lightweight, large displacement actuator is needed. Benefits and trade offs of utilizing ionic liquid electrolytes for higher performance polypyrrole actuator are discussed.

SESSION D4: Ferroelectric, Piezoelectric, and Dielectric Materials and Devices
Chairs: Nwa Setter and Satoshi Wada
Tuesday Afternoon, December 2, 2003
Room 202 (Hyne)

1:30 PM D4.1
Phase Transition-piezoelectric Anisotropy Relations in Perovskite Ferroelectrics: BiTiO3 and PibtO3. Marko Badulin, Dragom Danjumovic and Nwa Setter; Ceramics Laboratory, EPFL, Lausanne, Switzerland.
Enhanced piezoelectric response along a nonpolar direction in complex relaxor ferroelectrics, such as Pb(Zr0.33/Sr0.67)0.53Nb0.47O3 (Pb(Zr/Sr)O3) and Pb(Mg1/3Nb2/3)O3 (PMN), has been in the center of the ferroelectric research in the past several years. This phenomenon is not restricted to relaxor ferroelectrics solid solutions and has been reported in simple perovskites, for example in KNbO3 and BiTiO3. Although the piezoelectric effect is by far largest in relaxor ferroelectrics, the simple compositions can serve as convenient model materials. They exhibit the same sequence of crystal phases ( cubic-tetragonal-orthorhombic-monoclinic- rhombohedral) as the complex solid solutions, the crystal phases are well defined, and they do not exhibit mesoscopic structure often present in complex materials. In this paper, the anisotropy of the longitudinal piezoelectric coefficient d33 is investigated as a function of temperature in BiTiO3 and PbTiO3 using Linhard Ginzburg-Dewsmore approach. We show that phase transition behavior in BiTiO3 leads to large d33 along nonpolar directions. The reason for this is that in the vicinity of a phase transition in which polarization vector changes its direction (tetragonal-orthorhombic-monoclinic, orthorhombic-monoclinic-rhombohedral), the shee piezoelectric coefficient(s) becomes very high resulting in enhanced d33 along a nonpolar axis. The effect is particularly pronounced in the orthorhombic-monoclinic phase where piezoelectic anisotropy is influenced by the presence of both the high temperature tetragonal and the low temperature rhombohedral phase. In PbTiO3, which exhibits only tetragonal ferroelectric phase, the shear piezoelectric effect is weak and d33 has its maximum along the polar axis at all temperatures. The obtained results are general and can be extended to other ferroelectric compositions, including complex relaxor ferroelectrics, where a phase transition can be induced by temperature, composition (morphotropic phase boundary) or electric field.

1:45 PM D4.2
Modified BiFeO3-PbTiO3: Morphotrophic Phase Boundary. Piezoelectric Ceramic for Smart Systems. Jinrong Cheng1,2 and L. Eric Cross1;
1Materials Research Institute, Penn State University, State College, Pennsylvania; 2School of Materials Science and Engineering, Shanghai University, Shanghai, China.
BiFeO3-PbTiO3 (BF-PT) crystalline solutions have been modified by Nb and Ga to enhance the electrical and ionic properties of the BF-PT. The results obtained from the modified BF-PT suggest that the modified BF-PT could be used as a piezoelectric ceramic for smart systems.
BF-PT was a family of morphotrophic phase boundary (MPB) piezoelectric solid solution with excellent piezoelectric properties. Two major problems of earlier BF-PT, high conductivity and switching field, have been solved in our modified systems. In increased the insulation resistance up to $10^{12}$ Ω cm at room temperatures and made BF-PT poled into a completely piezoelectric state. Ga provided more piezoelectricity with an antioxidant. With increased Ga content, the ferroelectrics (FE) to relaxor ferroelectrics (RFE) transformation was observed for the La and Ga co-modified BF-PT. Therefore, it is possible to tailor the performance of BF-PT by different concentrations of the aforementioned components. The P and Sm content can control the Curie temperature ($T_c$) of above 400°C can be achieved in La 10% modified BF-PT, whereas a piezoelectric $d_33$ constant of 265 pC/N was measured for the c-axis with $< 20 \%$. The modified BF-PT showed comparable performances to conventional $Ph_2(Zr,Ti)O_3$ (PZT) ceramics, in significantly load reduced forms. In addition, the dielectric strength of above 100 kV/cm and high coercive field made the modified BF-PT a potential application for high power electromechanical components.

2:00 PM *D4.3

Effect of piezoelectric vibration on electrical properties of YSZ film prepared by MOVCD. N. I. Kajino and Takashi Goto.

Institute for Materials Research, Tohoku University, Sendai, Japan.

Mechanical vibration produced by a piezoelectric actuator was applied to an ion-conducting film to increase the electrical conductivity at low temperature. Yttria-stabilized zirconia (YSZ) ion-conducting films were prepared on MgO substrates by metalorganic chemical vapor deposition (MOCVD) using Zr(acac)2 and Y(III) alkoxides as source materials. Cubic YSZ films containing Sm2O3 with a significant <100> preferred orientation were obtained at 923 K. The films in 1.4 μm thick consisted of fine grains of about 400 nm in size and had a columnar structure. YSZ films showed identical surface properties, and the complex impedance spectra had clear spikes at a low frequency region. The activation energy of electrical conductivity was about 0.99 eV that was almost in agreement to that of YSZ films prepared by other methods. The YSZ film was placed on a multilayer piezoelectric actuator composed of seven sheets of PZT (lead zirconate titanate) films. The effect of piezoelectric vibration on electrical properties of the YSZ film was investigated. The resistivity of the YSZ film decreased with increasing the amplitude of piezoelectric vibration. The electrical conductivity of the YSZ film under the vibration at 115 kHz and 40 V was about $2 \times 10^{-6}$ $\Omega$ $^{-1}$ $m^{-1}$ at 90°C. This value was more than 10 times greater than that of YSZ film without vibration. The cyclic expansion of YSZ lattice might accelerate the jumping of cation ions between vacancy cites.

2:30 PM D4.4


1Electrical and Computer Engineering, The George Washington University, Washington, DC. 2Center for Superconductivity, Dept. of Physics, University of Maryland at College Park, College Park, Maryland.

ZnO, a well-known piezoelectric material, is used to develop micro-scale Surface Acoustic Wave (SAW) delay line sensor. In this work, SAW delay line sensors are fabricated employing ZnO films that are deposited by Pulse Laser Deposition (PLD) and RF sputtering techniques. Precursor materials are characterized prior to device fabrication by X-ray diffraction (XRD) for film crystalline quality, UV-visible transmission spectroscopy for optical characteristics, and Atomic Force Microscopy (AFM) for surface morphology. Intersitgated SAW electrodes producing surface acoustic waves in the hundreds of MHz are developed by photolithography and metalization techniques. SAW delay line sensor device testing, measurement and characteristics on both PLD and RF sputtered ZnO films are presented and compared.

2:45 PM D4.5

Fabrication of lead zirconate titanate thick film disks for micro transducer devices. Takashi Iijima, Shotaro Itou and Hirofumi Matsuda. Smart Structure Research Center, AIST, Tsukuba, Japan.

A combination of the preparation techniques for the piezoelectric lead zirconate titanate (PZT) films and the micro machining of Si is considered to be an effective way to fabricate micro electromechanical systems (MEMS), such as piezoelectric micro transducer devices for the electrical and medical fields. To achieve these devices 5-100 μm-thick PZT films are required. Thin film preparation processes using chemical solutions, like sol-gels, have the advantage of a low firing temperature and dense microstructure despite the low film deposition rate compared with the screen printing process. Therefore, a chemical solution deposition (CSD) process is considered to be an attractive way to ensure compatibility with the Si micro-machining process and to fabricate MEMS devices. In this study, disk shape PZT thick film devices were successfully fabricated. Crack free 5-100 μm-thick PbZr0.27Ti0.73O3 films deposited onto Pt/TiO2/Si substrates using a CSD process. A 0.5 M PZT precursor solution was prepared from trihydrated lead acetate, titanium n-propoxide, zirconium n-propoxide, and 2-methoxyethanol as the solvent. The process of spin coating and pyrolysis at 500°C was repeated five times, and then the precursor films were fired at 700°C for 5 min. This sequence was repeated 10 times. Pt top electrode and PZT layer were etched by reactive ion etching (RIE) process with Ar/CH3F mixture gas, and 100 to 1000 μm diameter PZT micro disks were fabricated. The relative elastic constants and Curie temperatures were about 1310°C and tanδ = 0.02, respectively. The ferroelectric properties and piezoelectric displacement properties of the fabricated disks were measured electrically with atomic force microscopy (AFM). The 100 μm diameter PZT micro disks showed well saturated P-E hysteresis curves and butterfly shape displacement curves with a bipolar applied field of 1500V. The remnant polarization and coercive field were Pr = 14 μC/cm² and Ec = 25 kV/cm, respectively. The piezoelectric constant calculation did not reach a saturation level with AFM was about 220 μV. This means that the ferroelectric and piezoelectric properties of the micro disks were comparable with that of the bulk PZT ceramics. Investigation of the resonance frequency for the PZT micro disk is under study now.

3:30 PM D4.6


Magnetoelastic materials are attractive due to the co-existence of charge polarization and magnetization. The magnetoelastic effect can be used to induce change in magnetization by applying electric field and induce electric polarization from applied magnetic field. One way to obtain magnetoelastic thin films is by using piezoelectric and magnetostrictive materials. Such materials have previously been pursued in bulk composites. We are exploring fabrication of artificial magnetoelastic thin films by creating superlattice structures where piezoelectric materials and magnetic materials are modulated in periods of multiple unitcells. In particular, we fabricate superlattice composition spreads where one end of the spread is a pure piezoelectric material and the other end is a pure piezomagnetic material. This technique allows us to study the coupling of the two properties (at nanometer level and 2) systematically investigate mixing and of the two physical properties as a function of nanoscale composition which continuously varies across the spread. In order to fabricate a superlattice spread, a series of alternating gradient thickness deposition controlled at atomic layer level is performed for two target end compositions using combinatorial pulsed laser deposition. We have thus far fabricated BiFeO3-CeO2:Fe and PZT-Fe3O4-CoFe2O4 spreads. The lattice parameters of these materials are such that they can be grown together in a pseudo hetero-epitaxial manner. Microwave microscopy and scanning SQUID microscopy are used to determine the respective ferroic property across the spread. We have used that the composition of each layer can be systematically varied to observe the effect of magnetoelastics coupling. We have fabricated several superlattice compositions with varying thickness of piezoelectric and magnetic thin films. The results of this study show that the films exhibit ferroic behavior and the coupling of the two properties is observed. The films are expected to have promising applications in the future.

3:45 PM D4.7


We report a novel precursor suspension method where 65PMN35PT ceramics and thick films can be processed at lower temperatures. The precursor suspension is made of PMN powders, Ti-isopropoxide, and Pb-nitrate in an ethylene glycol solution. The sintering temperature for the ceramics occurred at 1100°C and good dielectric and piezoelectric properties were obtained. The formation temperature for the perovskite phase in thick films occurred at 800°C. However, the sintering temperature remains higher than 800°C and the perovskite phase cannot be sustained at such temperatures. The PMN powders used in the PMN-PT thick film were produced using Mg(OH)2-precipitated Nb2O5 powders. The size of the core Nb2O5 particles was found to affect the sintering behavior of Mg(OH)2 and the sintering behavior of PMN-PT. To improve the sintering of PMN-PT thick films, studies involving the control of the solids loading and the dispersion of the particle suspensions will be presented.

4:00 PM D4.8


We report a novel precursor suspension method where 65PMN35PT ceramics and thick films can be processed at lower temperatures. The precursor suspension is made of PMN powders, Ti-isopropoxide, and Pb-nitrate in an ethylene glycol solution. The sintering temperature for the ceramics occurred at 1100°C and good dielectric and piezoelectric properties were obtained. The formation temperature for the perovskite phase in thick films occurred at 800°C. However, the sintering temperature remains higher than 800°C and the perovskite phase cannot be sustained at such temperatures. The PMN powders used in the PMN-PT thick film were produced using Mg(OH)2-precipitated Nb2O5 powders. The size of the core Nb2O5 particles was found to affect the sintering behavior of Mg(OH)2 and the sintering behavior of PMN-PT. To improve the sintering of PMN-PT thick films, studies involving the control of the solids loading and the dispersion of the particle suspensions will be presented.
It was shown that the addition of strontium in the precursor of lead titanate in ethylene glycol improves the rheological properties of the precursor solution, leading to the sol-gel process. Perovskite phase lead strontium titanate (PST) powders and PST films on Ti substrate were obtained after heat treatment at 450°C. Sintering decreases the tetragonality of PT powders and thin films. Dielectric properties of PST are better than that of lead titanate (PT). Deposition of PST films on Si substrate was also studied. Heat treatment of each layer at 450°C followed by a final 650°C annealing resulted in perovskite PST films with good dielectric and ferroelectric properties. Results of different thicknesses as well as films with different strontium concentrations will be presented.

4:15 PM D4.9
PST Thin Film on Silicon Wafer by a Sol-Gel Method for Sensor Applications, Wei-Heng Shih, Zuyan Shen and Wen Y Shih; Materials Science & Engineering, Drexel University, Philadelphia, Pennsylvania.

Piezoelectric unimorph cantilevers have been shown to be excellent sensors for liquid viscosity and density determination, mass detection, in-situ detection of cells, proteins, and specific antigen-antibody binding. In order to fabricate miniaturized microsensor cantilevers, we investigate the synthesis of PST thin films on silicon wafers. Lead acetate, titanium isopropoxide, and zirconium propoxide precursors with ethyleneglycol as solvent were used to deposit PST thin films in a clean room condition. Good ferroelectric PST thin films were obtained with a dielectric constant of 800 and the saturated polarization of 54 μC/cm². By adjusting the precursor concentration, spinning speed and time, micron-thick films can be obtained without excessive repeated depositions.

4:30 PM D4.10
Synthesis and Characterization of Ca₁₋ₓ Srₓ Ca₃Ti₄O₁₂ thin films for dielectric applications, R. Gomaz; Maharrj Singh Tomar and R.E. Melgarejo; Department of Physics, University of Puerto Rico, Mayaguez, USA, Puerto Rico.

There is a great deal of interest in Ca₃Ti₄O₁₂ system for dielectric properties in microwave applications. In the present work we have studied Ca₁₋ₓ Srₓ Ca₃Ti₄O₁₂ system for different compositions i.e. for x = 0, 0.05, 0.1, 0.3, 0.4, 0.5, 0.7, 0.9, 1.0. The material is synthesized by chemical solution route and thin films were deposited by spin coating. Both powder and thin films were investigated by X-rays, Raman spectroscopy and dielectric spectroscopy. The result indicates stoichiometric films for all compositions and high dielectric values have been achieved.

4:45 PM D4.11
Nanoscale Investigation of Polar Structure of (1-x) PbMg₁₂/₃Nb₁/₃O₁₉·xPbTiO₃ single crystals, Vladimir Shvartsman¹; Maciej Wojtasi²; Sergey Vakhshurin³ and Andrei Khokhlov³²; ¹Ceramic and Glass Engineering, University of Aveiro, Aveiro, Portugal; ²Faculty of Chemistry, University of Wroclaw, Wroclaw, Poland; ³A. F. Ioffe Physico-Technical Institute, St. Petersburg, Russian Federation.

Relaxor ferroelectrics based on PbMg₁₂/₃Nb₁/₃O₁₉ (PMN) attract significant interest due to their excellent dielectric and piezoelectric properties. These properties are attributed to the formation of nano-sized polar regions with a short-range order, while macroscopic ferroelectric order does not develop in the absence of sufficient external electric field. In solid solution between relaxors and "classic" ferroelectrics the gradual transformation from relaxor to typical ferroelectric behavior is observed. Even though these compositions were intensively investigated in the past, little attention has been paid to the studies of domain structure and its evolution under varied external conditions. The common opinion states, that such compositions have limited resolution and are inappropriate for the observation of "normal" domains having the sizes of the order of microns. Recently, the ferroelectric Fm-3m microstructure has been successfully applied for the investigation of ferroelectric materials at the nanoscale. The advantages of the FMM are extremely high spatial resolution (down to few nanometers) and high sensitivity to local polarization. In this paper we report on the study of domain structure of (1-x)PbMg₁₂/₃Nb₁/₃O₁₉·xPbTiO₃ (PMN-PT) single crystal by PFM, using a ×1000 PTM microscope. PFM investigations have been carried out in the present work using a new technique of polarization imaging. The results of the present study of the local nano-polarization of PMN-PT were obtained and compared with the results of the previous study. The nature of the observed phenomena is discussed based on the current understanding of the relaxor state in ferroelectrics and possible influence of PFM instrumentation.

SESSION D5: Poster Session: Electroactive Polymer 2
Chair: Cheng Huang
Tuesday, December 3, 2003
8:00 PM
Exhibition Hall D (Hynes)

D5.1
Abstract Withdrawn

D5.2
High-Dielectric-Constant Fluoropolymer-Based Electroactive Polaron Elastomers, Cheng Huang, Sabrina Chowdury and Qiming Zhang; Materials Research Institute and Electrical Engineering Department, The Pennsylvania State University, University Park, Pennsylvania.

Field-type electroactive polymers (EAPs) are promising for high-performance actuators and artificial muscles due to their high electromechanical conversion efficiency. There are two main classes of field-type EAPs, one is [PVDF-TFAE] based relaxor ferroelectric electroactive polymers developed by Penn State, which has high modulus (~1GPa), but relatively low strain (~5%), and the other is soft dielectric elastomers based on Maxwell stress effect developed by SRI, which has high strain (~100%), but low modulus (~1MPa). When field-type EAPs are applied in biomedical field, higher performance such as high strain, modulus and elastic energy required, especially for the development of artificial heart. The key issue is that these polymers usually require high electric fields (~100 MV/m) to generate high elastic energy density which limits their applications. For Maxwell stress (electrostatic force) based electromechanical materials (MSEAP), both the field induced strain and electromechanical coupling factor are proportional to the ratio of the dielectric constant, K to modulus, Y of the electroactive material. Hence, a high strain and high coupling factor under low electric fields require either a high dielectric constant or a high ratio of K/Y. By optimizing the ratio of K/Y, higher strain can be realized under lower electric field. In this paper, with the combination of the electromechanical properties of hard electroactive ferroelectric polymers and soft dielectric elastomers, three methods will be utilized and demystified based on polymer molecular engineering: 1) Improved electromechanical performance from high-dielectric-constant fluoropolymer polaron elastomers by electron irradiation or chemical cross linking; 2) Polymer blends or semi-interpenetrating polymer networks (sIPN) based on high-dielectric-constant fluoropolymers and soft dielectric elastomers; 3) Synthesis and characterization of hard ferroelectric/soft dielectric block and graft copolymer elastomers: new dielectric-ferroelectric polymers with large induced strain under low electric field. In these block elastomers, high-dielectric-constant telechelic fluoropolymer hard segments containing reactive terminal groups in opposite chain ends was first synthesized, which can be extended to long chains by polycondensation with telechelic dielectric soft segments.

D5.3
Nanostructured Actuators: Conducting Polymers Integrated into Polynorbornene-Derived Scaffolds, Huy A Kung and Timothy M. Swager; Chemistry, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Conducting polymer-based electroactive polymer (EAP) actuators have found numerous applications. Well-defined nanostructures are expected to amplify the electrochemical response of EAPs, facilitating greater dimensional changes. Toward this end, efforts are directed to gain control over the microstructures of such materials. Three different norbornene derivatives having electroactive pendant groups were copolymerized with a 7-oxonorbornene derivative via ring-opening metathesis polymerization (ROMP). In addition to understanding mechanical strength and flexibility, the poly(7-oxonorbornene) backbone is expected to facilitate ion transport across the bulk material. The cyclic voltammograms of the electropolymerized block copolymers displayed redox waves over a broad range of potentiostats. Processing of EAPs via electrospinning facilitates fabrication of devices having enhanced switching speed of actuation. The morphologies of these block copolymers studied by various microscopic techniques will be also discussed.

D5.4
Structural and Electrochemical Study of Poly(vinylidene fluoride-trifluoroethylene) Derivatives grown by Chemical Vapor Deposition: Termomers, Bob Klein, James Rust and Qiming Zhang; ¹Materials Research Institute, Pennsylvania State University, University Park, Pennsylvania; ²Materials Science and Engineering, Pennsylvania State University, University Park, Pennsylvania.
The PVDF-TrFE copolymer has found wide application in
electromechanical devices due to its ferroelectric properties. Recently,
high energy electron-irradiated PVDF-TrFE copolymer has been
shown to produce large electrostrictive strain. Results indicate that
the terpolymer made by adding chlorotrifluoroethylene (with varying
arrangements of domains) to the VDF-TrFE chain can improve
upon the irradiated copolymer, with an increase in strain response
and reliability and a decrease in processing cost. Through better
understanding of the relation between termonomer choice,
morphology control, and electrostriction, along with electronic
mechanical properties, the strain and energy density of PVDF-TrFE-based
terpolymer can be further optimized. The conformation and
morphology changes in terpolymer formation from
-poly(vinylidene fluoride-trifluoroethylene) with small amounts of
chlorotrifluoroethylene or chlorotrifluoroethylene were studied by X-ray
diffraction, infrared spectroscopy, differential scanning calorimetry,
and polarization loops. Results indicate that quenching from a high
crystallization temperature to a lower temperature forms a more dense phase.
Crystallization at a lower crystallization temperature produces a more
non-polar phase. Essentially, the termonomer disrupts the VDF-TrFE
polarization coherently enough that the crystalline phase has
conformations with varying degree of polarity, with preference
dictated by the thermal history. The effect of the termonomer appears
to be due to inclusion. The width of the [001] X-ray peak indicates
very thin crystallites, with length-to-thickness ratios which, although
the lamellae thickness is greater than 150 nm. If established by a
properly chosen crystallization temperature, the crystalline regions
can be polarized with applied electric field, or relaxed into a non-polar
state holding the orientational properties which is about 30-50%.
The crystallization arrangement also determines the strain response
and electromechanical coefficients, which are crucial for
electromechanical energy conversion.

D5.5 Device Design and Mechanical Analysis of Conducting
Polymer Actuators. Bryan D. Schmid, Peter Madden, John
Madden, and Ian Hunter; Mechanical Engineering, Massachusetts
Institute of Technology, Cambridge, Massachusetts; Electrical and
Computer Engineering, University of British Columbia, Vancouver,
British Columbia, Canada.

Conducting polymers, specifically poly pyrrole, have tremendous
potential as actuators. Various device designs using poly pyrrole as
an actuator were theoretically investigated and built for potential
advancements in current technology and practice. Two key
limitations to using conducting polymers in practical devices include the need for
actuation out of a liquid electrolyte solution and the small strains
produced by the polymer. Development of a poly pyrrole trimorph design
and various encapsulation techniques were tested as potential
solutions to previous actuation environment limitations. The trimorph design is composed of two mechanoelectric polypyrrole
electrodes separated by a gel electrolyte and ion-permeable layer.
Several encapsulation techniques tested expand the environmental
capabilities using various designs. The trimorph design and encapsulation techniques are proven, viable solutions for actuator
design. Trimorph samples tested in this paper consisted of two 25
mm poly pyrrole sheets, 65 μm thick nylon mesh, and a 124
based electrolyte gel. Final trimorph sample dimensions were 1x5
mm with an average thickness of 280 μm. The trimorph strips
achieved successful actuation out of a liquid electrolyte,
produced forces of 0.2 N and strain curvatures up to 133 mm
−1, while demonstrating a greater than 3 month shelf life.

D5.6 Analysis and Modeling of Electro-Mechanical Coupling In An
Electro-Active Polymer-Based Actuator. Thomas A. Bowers, Neville
Hugueni, Patrick Anquetil, Rachel Zimel and Ian Hunter;
Mechanical Engineering, Massachusetts Institute of Technology,
Cambridge, Massachusetts; Science and Engineering, Massachusetts
Institute of Technology, Cambridge, Massachusetts.

A nonlinear constitutive model is formulated for electro-active
polymer (EAP) to describe the energetic coupling between electrical
and mechanical domains. The polymer is modeled as a multiport
energy storage element with inputs from the electrical and mechanical
domain. Using energy conservation methods, the general relationships
between stress, strain, voltage, and charge are determined. The
solution to this crystallizing behavior depends on the developed fully
d and compared to a linear model published by Madden and a nonlinear
electrochemical model published by Mazzaoli et al. Additionally,
experimentally determined actuator models in conductive polymer actuator
based on poly pyrrole are used to validate the electro-mechanical coupling
model. It is found that the correlation between the model and experimental
data is very good for strains up to 4% and potentials up to 1 Volt; these within the typical operating range of poly pyrrole.
The model is sufficiently simple to allow real-time control while also
exceeding Madden’s linear model in its ability to accurately predict
polymer behavior in normal operating ranges.

D5.7 Synthesis and Characterization of Sulfated
Poly(vinylidene Fluoride Trifluoroethylene) Terpolymer Actuators.
Robert Timmer, Patrick Wil, Timothy Swanger and Ian Hunter;
Materials Science and Engineering, Massachusetts
Institute of Technology, Cambridge, Massachusetts; Mechanical
Engineering, Massachusetts Institute of Technology, Cambridge,
Massachusetts; Chemistry, Massachusetts Institute of Technology,
Cambridge, Massachusetts.

Conducting, electro-active polymers are very promising materials
due to their potential applications in bioelectronics, especially muscle-like
actuators. New molecules exhibiting molecular conformational changes
are being developed, but films synthesized from these new molecules
are often lacking in durability and mechanical robustness compared to
Poly pyrrole. A polymeric dopant can be added to help improve the
mechanical properties of the film. However, the new molecular actuator
systems are not well understood and the effects of the polymeric dopant on actuator properties unknown. For this reason,
Poly pyrrole (a well-studied electro-active polymer) was deposited in
the presence of 0 to 2% (wt sulphated poly(vinylidene
-hydroxyethylene) (SPHE) to form a robust, electro-active polymer composite. The polymeric
mixture contained here has a high molecular weight (1000 g/mol) and a
flexible polymer chain. It replaces the salt typically used to dope the conducting polymer during electropolymerization of the polymer film.
The resulting film’s electrical, passive mechanical and active
mechanical properties were investigated, and it was determined that
this is achieved by an order of magnitude depending on the concentration
of SPHE in the deposition solution. Results have shown that
it is possible to tune the electrical conductivity between 20 S/m and 3
S/m and the elastic modulus between 500 and 1500 GPa through co-deposition of Poly pyrrole and SPHE. In addition, the active strain
can be varied by much as 90% for a given set of electrochemical
conditions.

D5.8 High Strain P(VDF-TrFE) based Terpolymer for BioMEMs
and Microfluidic Devices. Feng Xin, Rob Klein, Francois Bier, Sinarsa Tadigopa
and Q. M. Zhang; The Penn State University, University Park, Pennsylvania; Institut Franco-Allemand de
Recherche de Saint-Louis, Saint-Louis, France.

BioMEMs and microfluidic devices have gained a lot of attention in
recent years due to their emerging applications in biochemistry, medical
analysis, chemical analysis and synthesis, drug discovery and drug delivery, biosensing and biomimetic systems. The
materials requirements for bioMEMS are biocompatible, chemically
modifiable, easy to fabricate, economic, compilable and smart. Among
various materials, the electro polymeric materials can best meet these
requirements. Recently, we developed a group of P(VDF-TrFE) based
terpolymers which have very high strain level and high energy density.
The low longitudinal and transverse strain of these materials can reach
about 7% and 5%, and the elastic energy density is around 1.1
J/cm3, which are very attractive for the development of polymer
pump and valve and other microfluidic components for all polymer-based
bioMEMs and microfluidic integration system. In this talk, we will discuss
the recent efforts on developing these microfluidic components using
the electroactive terpolymers for bioMEMs, including the multilayer
fabrications, surface modification from hydrophilic to hydrophobic
by using oxygen plasma etching, and polymer-based valve and pump.

D5.9 Effects of UV and Gamma Irradiation on the Ferroelectric
Behavior of Poly(vinylidene Fluoride Trifluoroethylene)
Copolymers. Luiz Oliveira de Faris, Casa Welte and Roberto
Luize Moreira, Materials and Nuclear Fuel, Centro de Desenvolvimento
da Tecnologia Nuclear, Belo Horizonte, Minas Gerais (Brazil); Physica, Universidade Federal de Minas Gerais, Belo
Horizonte, Minas Gerais, Brazil.

P(VDF-TrFE) copolymers with 50% of trifluoroethylene were
irradiated with gamma and UV rays in order to investigate the effect
of photodegradation in their ferroelectric properties. Dielectric
and calorimetric investigations have confirmed that gamma-irradiation
provokes the appearance of relaxor ferroelectric features in the
copolymer. These induced relaxor properties are thought to be linked
to the loss of stability of the ferroelectric domains, provoked by
intercalation of the long-range dipolar interaction. FTIR spectrometry
revealed the presence of NH molecules which may take part of gamma
induced cross-linking bonds, possibly affecting the ferroelectric
domains stability. On the other hand, UV irradiation does not
induce relaxor features on the copolymer. However, it was
found that the dielectric loss changes from an Arrhenius to a
Vogel-Fulcher-like behavior during the ferroelectric to paraelectric

phase transition, with a decrease in the activation energy when compared to the gamma irradiated one. These results could have direct impact in the electromechanical response of the copolymer. 

D5.10

Development of Totally Synthetic Glucose-Responsive Polymer Gel for Use as a Novel Type of Insulin Delivery Device. Akira Masumoto and Kazunori Nakada; Graduate School of Engineering, The University of Tokyo, Tokyo, Japan.

Over the past several decades, stimuli-responsive polymer gels have attracted a great deal of research interest. A series of stimuli that includes heat, pH, electric fields and light have been demonstrated to induce abrupt changes in the physical properties of polymer gels. This knowledge led to development of various types of stimuli-responsive, hence "self-regulated" systems so-called "intelligent" materials. Among wide range of their applied fields, applications in the medical field such as in drug delivery systems have been a constant research topic. We attempt to develop a totally synthetic, glucose-responsive gel system, aiming for use in self-regulated insulin delivery system to treat diabetes. As a synthesically available sensor moiety for the blood sugar level, we paid particular attention to the unique ability of phenylboronic acid derivatives to form a reversible, covalent bonding with glucose. We have previously reported that a gel composed of N-isopropylacrylamide and 3-arylamidophenylboronic acid exhibits a reversible volume change synchronized with a change in the glucose concentration, through which the sufficiently controlled and pulse-shaped release of insulin was achievable at 38°C in a pH 9.0. This work is intended to provide a synthetic methodology to optimize the operational conditions of the system. As the approach involves the use of a newly synthesized phenylboronic acid derivative possessing an appreciably low pHs as glucose sensing moiety, as well as the adoption of a different type of main chain structure, it exhibits critical solution behavior in the range close to physiological temperature. Evaluations of glucose dependent changes in the swelling degree of the resultant copolymer gels for varied pH and temperatures revealed a markedly improved sensitivity near the physiological conditions. Discussion will be presented in terms of the effect of the modulated copolymer gel structure on the glucose responsive behavior.

SESSION D6
Poster Session: Ferroelectric, Piezo, and Dielectric Materials and Devices
Chair: Feng Xia
Tuesday, December 2, 2003
8:00 PM
Exhibition Hall D (Hyatt)

D6.1

Study of structural ordering in (0.3)Pb(In1-x-Nbx)O3+(0.7)Pb(Mg1/3Nb2/3)O3 ceramics by transmission electron microscopy. C.W. Tsai and K. Z. Babu-Kish. Department of Applied Physics, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong.

Transmission electron microscopy (TEM) studies of the ceramics (0.3)Pb(In1-x-Nbx)O3+(0.7)Pb(Mg1/3Nb2/3)O3, abbreviated as (0.3)PIN-(0.7)PMN, have revealed long-range ordered (LRO) short-range order (SRO) and mixed-order (MO). The ceramics, synthesized using mixed-oxide route, have important properties exhibiting negligible small P-E loop and non-hysteresis electromechanical behaviour at room temperature. TEM observations of the LRO domains and their anisotropic boundaries imaged along <110> and <112> directions show uniform size distribution ranging from 20 to 150nm across. Domains in the proximity of grain boundaries within a grain are several times larger than the domain at the centers of the grains. High-resolution TEM images taken along [001] show clusters of lattice fringes with different contrast. Simulations indicate that the compositions of the three different cations, Mg2+, In3+ and Nb5+, are mixed in a highly random process and takes place by the combinations of the various cations present, thus creating a superstructure. Diffuse scattering and streaking were also observed in selected-area diffraction patterns along various directions particularly along high order in [110]. The formation of specific mosaic patterns, indicative of short-range ordering, which could partially originate from oxide disorder. In 0.3PIN-0.7PMN, there are three different combinations of the BaO and NiO and MgO and NbO and MnO. The electrical data of the Mg2+Ni5+ and In3+ and Nb5+ pairs are balanced in the ratio 1:2 and 1:1, respectively. The charges of Mg2+ and In3+ cannot simply balance in a perovskite structure, although the overall electrical change of the solid solution is neutral. Such localized order and disorder result in different results with slight misorientations. They give rise to the large diffuse scattering between the fundamental Bragg diffractions instead of a set of distinct reflections generated by long-range periodic structure. In addition to the LRO, which can also be found in some other Pb-based complex perovskite materials, a new mixed state of structural orderings, SRO and cluster order in different scales were observed. This mixed ordering contributes to chemical inhomogeneity, which has implications on the properties. Consequently, the behavior of the ferroelectric relaxor is enhanced, especially affecting the temperature dependence of the dielectric properties.

D6.2

Nanoscale ferroelectric properties of PZN-Pt single crystals studied by scanning force microscopy. Igor Bikin, Vladimir Shvartsman and Andrei Khokhin; Department of Ceramics and Glass Engineering, CICECO, University of Aveiro, Aveiro, Portugal.

The nature of the excellent electromechanical properties of ferroelectric single crystals of solid solutions such as (1-x)Zr0.52Ti0.48O2+x/2PbTiO3 is intensively investigated during last several years. These crystals are expected to replace traditional piezoelectric materials such as Pb(Zr,Ti)O3 in actuators, transducers and smart systems. Recently, the Scanning Force Microscopy has been modified to study the piezoelectric properties at the nanoscale. This new technique, called Piezoresponsive Force Microscopy (PFM), was applied for the visualization of domain structure by means of the piezoelectric effect and for the measurements of local piezoelectric coefficients by applying voltages and measuring the corresponding responses. In this work, piezoresponsive and piezoelectric measurements have been performed on (1-x)Pb(Zr0.52Ti0.48)O2+x/2PbTiO3 (PZN-Pt) single crystal of the composition close to the morphotropic [rhombohedral-tetragonal] phase boundary [x=0.045-0.08]. Irregular domains with sizes 20-150nm had been observed on the [001]-oriented surfaces of unpoled samples. On the contrary, [111]-oriented surfaces exhibited normal micro-size regular domains with the domain boundaries directed along allowed crystallographic planes. The existence of ferroelectric domains in the [001]-oriented crystals was attributed to the relaxor nature of PZN-Pt where small polarization clusters may form under zero-field-cooling (ZFC) conditions. The average size of these polarization clusters is ~10 nm at room temperature, as estimated earlier from neutron scattering. It is hypothesized that the presence of the highly polarizable Ti4+ ions in PZN-Pt promotes interaction between clusters, which can then reorient and merge into the macro-size domains upon cooling. These mechanisms can be, in principle, considered as the nucleation of the opposite polarization state that may switch the processing method for this particular crystal cut. Local piezoelectric hysteresis has been also performed by PFM on the nanometer scale. Similar switching behavior of [111]- and [001]-oriented PZN-Pt crystals suggests that their superior ferroelectric properties are related to the domain wall motion and is not an intrinsic property of the material. Nanoscale data are complemented with conventional dielectric, ferroelectric and piezoelectric measurements. D. L. Orumutqu, J. Tashkun, Z.-G. Ye, W. Chen, R. Erwin, and J. L. Roberts, Phys. Rev. B 67, 134110 (2003).

D6.3


New ferroelectric phase transitions off-center impurities may play an especially important role. In the abstract we report the results of electron paramagnetic resonance (EPR) measurements, performed on lead germanate Pb5-xGe2O8+x (PGO) crystals doped with copper ions. The minority of the Cu2+ EPR spectra shows that paramagnetic ions occupy three structurally equivalent positions of C3 symmetry conjugated by C3 axis. The spectra have been described by spin Hamiltonian with nearly g=2.002 and hyperfine A tensor. For the Cu2+ ions g=2.410, gx =2.696, gy =2.696, gxz =1.188 mT, |A| =0.966 mT, T=293 K. The temperature evolution of Cu2+ spectra have been studied in the interval from 290 to 450 K. On heating the line with broadening occurs in range Cu2+ spectra transform into one broadened line, demonstrating C3 local symmetry. The data obtained give evidence that Cu2+ substitute for Pb2+ host ions in position of C3 point symmetry and occupy three-center positions shifted from trigonal lattice point in [001] plane. Thermally activated hopping of Cu2+ ions between off-center positions motionally averages the low symmetry triclinic spectra. Since the off-center localization has to induce the electric dipole moments, to confirm this assumption we have investigated the dielectric response of PGO-Cu2+ and revealed the dielectric losses peaks typical for thermally activated relaxation processes. EPR and dielectric data testify for Arrenius like temperature behaviour of the Cu2+ hopping rate and permit to estimate its parameters (kT~exp(-10)^2).
Hz, $\Delta E = 0.34$ eV). The static and dynamic properties of Cu$^{3+}$ centers have been attributed to pseudo Jahn-Teller effect. Influence of the orientable Cu$^{3+}$ centers on the PGO properties near ferroelectric phase transition is discussed on the basis of semi-phenomenological approach.

D6.4 Temperature Dependence of Piezoelectricity in Pb$\left(B_{1-x}B_{x}\right)O_3$ based single crystals (B=Zn, Mg).

Park Jung San, Park Hye Min, Yi Jae Yun, Lee Jung San and Hong Koo Sung. 1 School of Materials Science and Engineering, College of Engineering, Seoul National University, Seoul, South Korea, 2 Korea Standards Research Institute, Daedeok, South Korea, 3 Materials Science and Technology Division, Los Alamos National Laboratory, Los Alamos, NM 87545, New Mexico.

Dependence of piezoelectricity on temperature in Pb$\left(B_{1-x}B_{x}\right)O_3$ (B=Zn, Mg) single crystals will be presented. Though ultrahigh piezoelectric properties are observed in (011) oriented rhombohedral Pb$\left(B_{1-x}B_{x}\right)O_3$ - Pb$\left(TiO_2\right)$ (B=Zn, Mg) crystals (PBN - PT), there are a few limitations to prevent the application of piezoelectric relaxor based single crystals. Most of these problems are related with the temperature stability of piezoelectricity, which decreases the reliable operation of piezoelectric materials. In this study, the temperature effect on piezoelectricity is evaluated precisely and the modified material to compensate these shortcomings is investigated. The temperature dependence of piezoelectric properties was found to be consistent with the phase transition behavior of <011> oriented crystals. With decreasing the stability of the ferroelectric state, the piezoelectric properties of crystals deteriorated. Also, the addition of alkali to PBN based crystal lead to stabilization of ordered domain configuration and the piezoelectricity against the temperature.

D6.5 Some Properties of Incommensurably Disordered Rb$_2$ZnCl$_4$ Crystals. Michael P. Truhlar, solid state physics dept., Dnipropetrovsk national university, Dnipropetrovsk, Ukraine.

Applying the radioscopic techniques has allowed to achieve the remarkable progress in studying of the incommensurably modulated phases. Just the local nature determines the successes of the magnetic resonance methods, since the spatial average of structural dislocation wave vector may cancel the interference of the macroscopic experimental methods. In particular, the valuable information on static and dynamic properties of incommensurate systems has been obtained via EPR investigations of Mn$^{3+}$ probe in Rb$_2$ZnCl$_4$(RZC) crystals. It has been shown that Mn$^{3+}$ centers, substituting for Zn$^{2+}$ ions, are localized in chloride tetrahedral complexes whose rotations result in modulation of the structure. The EPR data give evidence that Mn$^{3+}$ is a suitable probe, correctly reflecting the properties of the crystal bulk. In the temperature interval of paraelectric-incommensurate transition point $T_c = 304.4\text{ K}$ the EPR spectra of Mn$^{3+}$ ions have been studied for various orientations of the external magnetic field. The singularity spectra, typical for modulated phases, have been observed on cooling below $T_c$. The computer simulations of the singular line shape permit to estimate the critical exponents of the order parameter $\beta = 0.35$ and correlation length $\nu = 0.64$. It has been shown, that just below $T_c$, the local line width of central peak is enhanced by amplitude fluctuations of the modulation wave whereas the contribution of phase fluctuations dominates in the middle, flat part of the singular spectrum. The values of the critical exponents $\beta$ and $\nu$ confirm the non-classical character of the RZC critical properties corresponding to the universality class of 3d XY Heisenberg systems.

D6.6 Structural and Dielectric Properties of CuCuT$\delta$IO$\delta$ Thin Films. Vinay Gupta, Ram R Das, Pijush Bhattacharya, Yuri I Yuzuyuk, William Perez and Ram S. Kariy. 1 Department of Physics, University of Delhi, Delhi, India, 2 Dept. of Physics, University of Puerto Rico, San Juan, Puerto Rico.

Recently, there is a constant surge for the enhancement of dielectric permittivity of oxide thin films for various functional devices. CuCuT$\delta$IO$\delta$ (CCT) was found to be an interesting material that exhibits bulk dielectric constant over 10^4. In this study we have used pulsed laser deposition technique to grow CCT thin films on Pt/TiO$\delta$/SiO$\delta$/Si and LaAIO$\delta$ substrates. During the thin film deposition, the substrate temperature was varied in the range of 300-550°C. The films were grown with a thickness of 200 nm. As-grown films are post-annealed at 750°C in order to improve the crystalline quality of the films. X-ray diffraction showed polycrystalline nature of the films. A systematic variation of the grain size with substrate temperature was observed by microscopy. Micro-Raman spectroscopy was used to study the vibrational modes of the CCT thin films in comparison with the bulk ceramics. The dielectric properties of the films were studied in metal-insulator-metal configuration. Films grown at higher substrate temperature exhibited highest value of dielectric permittivity (~22000). The temperature dependent dielectric properties were carried out to understand the exact mechanism of the ionic conductivity and the origin of high dielectric constant in CCT thin films. Detailed results on structural and dielectric properties will be discussed in close correlation with the processing conditions.

D6.7 Structural and Dielectric Properties of Cu$\delta$Mg$_{2-x}$Cu$_x$Ti$_4$O$_{12}$. Luis A. Bermudez and Maharaj Singh Tomar. Department of Physics, University of Puerto Rico, Mayaguez, USA, Puerto Rico.

Cu$_{\delta}$Mg$_{2-x}$Cu$_x$Ti$_4$O$_{12}$ is shown to be a novel dielectric ceramic material for microwave applications due to its high dielectric constant value. This material has been synthesized by chemical route for different compositions and thin films have been deposited by spin coating. X-ray diffraction shows highly stoichiometric films for different compositions. Dielectric measurement indicates high value of dielectric constant, results will be presented.


Despite piezoelectric transducers (PTs) being invented in the late 50s, this technology did not reach commercial success until early the 80s. During this period, several companies, mainly in Japan, were decided to introduce PT technology for applications requiring small size and low electromagnetic interference (EMI) signature. Since then, PTs have been used as step-up transformers for the CCFL inverter used for backlighting the liquid crystal displays of notebook computers and personal digital assistants (PDA). In these applications, PTs provide i) high voltage gain ratios, ii) high power density - typically about 10W/cm$^2$, iii) high output impedance, iv) high efficiency and v) low EMI. Currently, PT applications for CCFL are limited to 5.8W. In the last decade, the interest in PTs has moved toward a second group of applications beyond CCFL backlighting. Companies in U.S., Japan, and Europe are now investigating the use of PTs for power applications, including battery chargers, linear and compact fluorescent ballasts, DC/DC converter, power supplies and others. In these applications, compared to the CCFL, the requirements include i) step-down transformers, ii) high power transformers, iii) high efficiency power conversion, iv) low output impedance, v) input to output isolation and v) low content of EMI. New topologies of PTs have been proposed to address higher levels of power conversion than those available with the classical Rosen type PTs (typically used for 5.8W with power densities of about 5.1W/cm$^2$). This is the case for the limited piezoelectric transducers, Transon® developed, patented and commercialized by Face Electronics. In these transducers power densities of over 40W/cm$^2$ have already been reported for step-down applications. A third group of PTs has been recently proposed by Face Electronics and granted under two ongoing SHB projects for use in the new generation of communication satellite systems as well as space research. Among others, these applications include i) high voltage power supplies for pulsed Traction Wave Tube amplifiers used for satellite communication, and ii) high voltage igniters for controlling the ignition process of Pulsed Plasma Thrusters used for positioning the new generation of small satellites. These applications are characterized by a combination of high power and high voltage requirements (making them doubly complex), the need for high reliability and, in some cases, the ability to withstand extreme environmental conditions. This paper introduces the ongoing research on space applications for PTs.
D6.10
PZT-Driven Micromagnetic Optical Devices, Hiroyuki Tani, Masahiro Mizoguchi, Shingo Misawa, Park, Kunihiro Nishihara, Hiroa Akihiko Uchida and Mitsuteru Inoue, Toyohashi University of Technology, Toyohashi, Aichi, Japan.

A spatial light modulator (SLM) is a real-time programmable device capable of modifying amplitude, phase and polarization of an optical wave front by an electrical control signal. So far, various types of reusable SLMs with two-dimensional pixel arrays have been intensively developed. Micromagnetic spatial light modulator (MOSLM) has the advantages of high switching speed, robustness, nonvolatility, and radiative resistance. However, the conventional MOSLM is driven by a large current, high power consumption is required. To improve the disadvantage, we developed two PZT-driven MOSLMs by different fabrication processes for a magnetic garnet film, which were driven by electric field and external magnetic field. In our first PZT-driven MOSLM, a PZT film was fabricated by using a seldgel method [1]. Although a driving current of the PZT-driven MOSLM was less than 1/10 time as compared with that of the conventional MOSLM, a magneto-optic layer (Bi:YIG) was damaged by a high temperature process for crystallization of the PZT film. In second device, an novel deposition method (ADM), which produces a film by using accelerated material particles with impact energy [2], was applied to a PZT film on the YIG layer. Moreover, in order to give effective stress by the PZT film to the YIG layer, we simulated the structure of the PZT-driven MOSLM by using a finite element method. The developed MOSLM was driven by a voltage of 5 V between X and Y drives, and an external bias field of 68 Oe. As the result, the selected pixels in the PZT-driven MOSLM were independently switched [1] J. H. Park, T. J. Kim, J. K. Cho, K. Nishihara, H. Uchida and M. Inoue, J. Appl. Phys. 93, 8525-8527 (2003). [2] J. Aiko and M. Lebedev, J. Crystal Growth 215, 415-420 (2002).

SESSION D7: Shape Memory Alloys-2
Chair: Kaushik Bhattacharya and Musthif Wuttig
Wednesday Morning, December 3, 2003
Room 202 (Hynes)

8:30 AM D7.1 Fabrication and Characterization of TiNi/Al Smart Composites, Guo Chang Lee1, Jun Hee Lee2 and Young Chul Park3.
1Materials & Processes Research Center, Research Institute of Industrial Science & Technology (RIIST), Pohang, Kyungbuk, South Korea; 2Department of Metallurgical Engineering, Dong-A University, Pusan, South Korea; 3Department of Mechanical Engineering, Dong-A University, Pusan, South Korea.

Alloy matrix composite with TiNi shape memory fiber has been fabricated by hot pressing and ingot casting to investigate the effect of processing variables on microstructures and mechanical properties. The main focus is on the reduction ratio of rolling on mechanical properties and diffusion layer formation by heat treatment at the interface between the TiNi fiber and Al matrix. Through SEM micrographs and EDS analysis, good interface bonding has been observed. The stress-strain behavior of the composites was evaluated at temperatures between 363K and room temperature as a function of prestrain. The results showed that yield stress at 363K was higher than that of the room temperature. Furthermore, yield stress of this composite increases with increasing the amount of prestrain, and it also depends on the volume fraction of fiber and heat treatment. The smartness of the composite is given due to the shape memory effect of the TiNi fiber which generates compressive residual stress in the matrix material when heated after being pre-strained. Microstructural observation has revealed that interface reactions occur between the matrix and the fiber, creating two intermetallic layers. Finite element analysis was used to predict the mechanical properties of TiNi/Al composite. The FEA results represented the experimental results very well.

9:00 AM D7.2 Fabrication and characterization of freestanding NiMnGa thin films, Holger Rumpf1, Achim Gillen1, Manfred Wuttig2 and Eckhard Quandt3.
1Smart Materials, Caesar, Bonn, Germany; 2Department of Materials Science, University of Maryland, College Park, Maryland.

Ni55Mn30Ga20 thin films were deposited by DC magnetron sputtering. Freestanding thin films of 3-10 micrometers in thickness were fabricated by depositing on thin glass plates and subsequent removing of the substrate. Thermal annealing led to polycrystalline films revealing shape memory properties as demonstrated by cantilever deflection technique and differential scanning calorimetry. Transformation temperatures and reaction enthalpies of the martensitic transformations were strongly influenced by the applied annealing temperatures. Vibrating sample magnetometer measurements revealed a further dependency of the ferromagnetic hysteresis on the applied thermal annealing. Magnetostriction of Ni55Mn30Ga20 films spacer revealed a small effect of about 300 ppm limited due to the polycrystalline structure of the film. Financial support provided by the Office of Naval Research (N00014-03-1-0291) is gratefully acknowledged.

1University of Maryland, College Park, Maryland; 2NIST, Gaithersburg, Maryland; 3Rensselaer Polytechnic Institute, Albany, New York.

A new concept of bending actuation in which the transformation in a SMA active layer proceeds by the movement of phase interfaces or intermediate two-phase zone is presented. The interface movement is determined by gradient of temperature or composition across the thickness of an active layer. The bending of the film is a result of self-strain in a transformed part of the film. Calculation of the elastic energy of internal stresses show that there is an equilibrium position of interface, which can be shifted by a thermodynamic driving force. Thus, it is possible to obtain an reversible movement of interface by changing temperature. Combining SMA film with top or bottom passive layers of different elastic properties, thickness and misfit is it possible to optimize the actuating deformation. The kinetics of interface movement is quantitatively described by solving a Stefan-type problem with an equilibrium temperature at the interface between phases dependent on interface position. The computational technique has been developed to control dynamic of the actuator through the variation of temperature at the top and bottom of the active layer. The effect of compositional gradient on dynamic of actuation is discussed. The work is supported by AFOSR Grant #F4962001101110.

9:30 AM D7.4 Characterization and Re-Pd Shape Memory Thin Films, Yuki Sugimura and Joost J. Vlassak, DEAS, Harvard University, Cambridge, Massachusetts.
Thermally activated shape memory materials such as Ni-Ti alloys are widely used as functional materials in sensors and actuators. However, heat transfer issues in these materials may limit their utilization in devices that require rapid response. Magnetically driven shape memory effect in select ferromagnetic alloys offers potential for faster response time as well as contactless actuation, expanding the range of application of these materials. Ferromagnetic shape memory alloys such as the Fe-Pd system have been studied in detail in bulk form by a number of researchers. While thin films are more suitable for miniature device research activities in Fe-Pd thin films have begun only recently. The thermomechanical austenite-to-martensite transformation takes place over a composition range of approximately 28 to 32 atomic percent Pd in bulk Fe-Pd alloys. In recently published papers, Fe-Pd thin films were deposited from alloy targets of specific composition to vary the Pd content and form the Fe-Pd alloy in a systematic manner. In this paper we present the results from fabrication and characterization of Re-Pd thin films deposited using Fe and Pd elemental targets. Films are produced by dc magnetron sputtering in an MVD chamber equipped with three independent conical sputter guns. The effect of process parameters and post-deposition thermal treatments on film composition, microstructure and stress are examined by Rutherford backscattering, x-ray diffraction, electron backscatter diffraction and substrate curvature technique.

9:45 AM D7.5 Phase Transformation in Ni-rich Ti-Ni and Ti-rich Ti-Pd Shape Memory Alloys, Masayuki Nishihara, Materials Science and Engineering, Kumamoto University, Kumamoto, Japan.

Near-equipotential Ti-Ni and Ti-Pd alloys undergo thermoelastic martensitic transformation from B2 to B19’ and B19 structures upon cooling, respectively. The former is technologically important materials with their superior shape memory and superelastic properties. The latter is expected to be high temperature shape memory materials, since the transformation temperatures are around 800K. In order to complete the further development of both the alloys, various heat treatment have been proposed so far. In the present study, the phase separation processes in Ni-rich Ti-Ni and Ti-rich Ti-Pd alloys are briefly summarized. Subsequently, the mechanism of multistage martensitic transformation in both the alloys are discussed on the basis of thermal analyses and TEM observations. We demonstrate that the multistage transformation in the Ni-rich TiNi alloy is considered to be a kind of artifact, which strongly depends on heat treatment atmosphere. On the other hand, that in Ti-rich Ti-Pd alloy is closely related to in-situ precipitation of Ti2Pd during the transformation cycles.
10:30 AM D7.6
Thermo-Mechanical Characteristics of Ti-5Ni Cu Shape Memory Alloys Fabricated by Pulse-Current Pressure Sintering Method. Hiroki Kyoegoku1, Takashi Kosumura1, Shinichiro Komatsu2, Shinsuke Yoshida3, and Toshio Suhara3.
1Mechanical Engineering, Kinki University, Higashinakasu, Hirshom, Japan
2Mechanical Engineering, Hiroshim University, Higashinakasu, Hiroshima, Japan
3Central Research Institute of Electric Power Industry, Komne, Tokyo, Japan.

In this research, we attempted to fabricate the Ti-5Ni Cu shape memory alloy by elemental powders by means of a pulse-current pressure sintering method that can produce high-density sintered compacts in a very short sintering time. We investigated the fabrication conditions of Ti-5Ni Cu alloys and the influence of Cu content in the alloys on the tensile and thermo-mechanical characteristics by experiments. The relative density of the as-sintered compacts was around 97% at any Cu content. The microstructure, tensile properties and thermo-mechanical characteristics of the as-sintered compacts were improved greatly by performing a solid-solution treatment and a shape memory treatment. The yield behavior due to the stress-induced martensite in stress-strain curves changed with Cu content, and it became the lowest at some 30% Cu content. The tensile strength and elongation of the alloy with Cu content around 3% were more than 400 MPa and 6%, respectively. The alloys of higher Cu contents shows a superelastic-like behavior, and the shape memory characteristics of the alloys were confirmed to be superior. The recovery stress of the alloys was almost the same level of that of the wrought materials. The cyclic deformation behavior of the alloys became stable after 15 cycles.

10:45 AM D7.7
Crack Tip Fields and Fracture Behavior in a NiTi Shape Memory Alloy Sheet. Wei Tong, Nian Zhang, Changjin Xie and Hong Tao, Yale University, New Haven, Connecticut.

Shape memory alloys such as NiTi are often used in MEMS and other applications in the form of thin strips. Fatigue failure is one of the important degradation mechanisms in NiTi shape memory alloy products. We present an experimental investigation on the crack tip deformation fields and fatigue crack growth kinetics in a NiTi thin sheet of 0.25mm thick. The material is 54.8% Ni and 45.2% Ti with only a trace amount of O, H, and C. External mechanical and thermal loads are controlled to induce various levels and size of crack tip deformation fields in each load cycle. Experimental results on the possible correlation on the crack tip field characteristics and the fatigue crack growth kinetics will be presented for the NiTi sheet. A micromechanical analysis of the crack tip field will also be given to identify some possible mechanisms on the fatigue damage in NiTi shape memory alloys.

11:00 AM D7.8
1Metal & Ceramic Science Program, Ames Laboratory, Ames, Iowa
2Mechanical Science and Engineering, Iowa State University, Ames, Iowa.

Single crystals of Co58Ni19Ga33B10 have been synthesized using the modified Bridgman method. The ability to solidify and retain single phase B2 austenite was found to depend not only on the starting composition and growth rate, but also the ability to maintain sufficiently high cooling rates to avoid the precipitation of a Co-rich FCC phase during post-solidification cooling. DSC measurements on the single crystal found the Ms, Mf, As, and Afto to be 30.7, -1.8, 34.1 and 72.6°C, respectively. On subsequent heating the B2 phase was found to partially decompose into the Co-rich phase at temperatures exceeding 650°C. The decomposition of the B2 phase by DSC was tracked by DSC, high temp power powder, and microstructural observation. Restoration of the crystal to single phase B2 austenite required annealing of the crystal at temperatures above 120°C.

11:15 AM D7.9
High Transition Temperature Shape Memory Alloys for Micro-actuator Systems. Elizabeth Baldwin and Alphonse Rabiei, Department of Mechanical and Aerospace Engineering, North Carolina State University, Raleigh, North Carolina.

A new generation of thin film shape memory alloy (SMA) for MEMS micro-actuator has been developed, in which film structure and chemistry are optimized, for enhanced transition temperature, higher strain, and as well as reduced actuation time by improving the heat transfer rate. Thin film TiNi3 is produced using Ion Beam Assisted Deposition (IBAD) technique followed by post processing heat treatment. Shape memory properties of thin film TiNi3 and their mechanical properties showed a great improvement over conventional NiTi thin films processed using sputtering technique. This is partly due to their higher transition temperature and also reduced thermal time constant, improving the heat transfer rates. Furthermore, the service life of the new thin film SMAs increased by improving their micro structural properties. The desire to introduce this innovative technology to the field of SMA micro-actuators is based on two primary advantages of IBAD process over existing technology used to apply thin film SMAs. First, the chemical composition and grain size of the applied coating can be precisely controlled over a wide range of values. Second, the SMAs can be deposited on thick film substrate as thin film SMA. If the coating has a grain size, much denser than film applied using sputter deposition technology, these coatings can provide a higher interfacial strength and better fatigue resistance than the plasma sprayed coatings. The effects of various processing parameters, and post processing heat treatment, on mechanical, and microstructural properties as well as their SMA properties were studied.

11:30 AM D7.10
Crystallography of Ni-Ti SMA in Austenite and Martensite by X-ray Diffraction Study. Hisao Nozomi and Hajime Kayano, Mechanical Engineering, Meiji University, Kawasaki, Kanagawa, Japan.

The crystal structures of the austenite and martensite in Ni-Ti shape memory alloy (SMA) are studied by X-ray diffraction. First, the program that estimates the crystallographic dta of an alloy and analyzes its x-ray diffraction pattern is developed on the basis of the theory of the intensity of a particular diffraction peak. The patterns by the program are verified by the comparison with the crystal of single crystals of Si, Ni and Ti. Next, we measure the diffraction pattern of Ni-Ti not using powder sample but also wire one by X-ray diffractometer because a wire of Ni-Ti SMA is widely used for application as an actuator and so on. Moreover, the crystal structure should be damaged if powder sample is made of the wire by milling and the curvature of wire surface has the same effect as the aggregate of powder for X-ray scattering. The diffraction pattern of Ni-Ti SMA is measured as the elevated temperature and its crystal structure is austenite phase. This pattern corresponds with the analyzed one by B2 structure using the program. Next, as temperature the diffraction pattern of Ni-Ti SMA that is martensite is measured. This pattern is compared with the B19 crystal structures presented by R. Otuka et al., R. F. Heilmann et al., G. M. Michal et al. and Y. Kudoh and et al. Although the x-ray pattern almost corresponds with that by Kudoh, it remains the peak of B2 structure even though the temperature is below the martensite transformation temperature and the wire shows the shape memory effect. In order to consider the difference of B19 structures by each researcher, the relationship between the unit cell volume and the atomic ratio of Ni and Ti is obtained. The unit cell volume is proportional to the atomic weight percentage of Ti.

11:45 AM D7.11

SMAs are engineering alloys that recover extensive amounts of deformation when subjected to a temperature change. The recovery of deformation is a result of a phase transformation from martensite to austenite, for example, for NITINOL, a very popular SMA. By transformation occurs at 60°C. Actuation is a type of shape memory process that utilizes deformation recovery that is used in smart structural systems. These systems are designed to detect and control structural deformations due to external time varying loads encountered during functional operation. In this paper, the actuating properties of NITINOL are characterized using an analytical, computational, and experimental solution (ACES) methodology. Analytical models are utilized to calculate the deformation under static and dynamic loads. Finite element method (FEM) is used for computational investigations. Optoelectronic holography (OEH) is the experimental method utilized to obtain temperature dependent behavior of NITINOL. As a result of the phase transformation, NITINOL undergoes a stiffness change indicated by a change in the modulus of elasticity from 33 GPa to 73 GPa. Deformations of NITINOL samples subjected to same loads at different temperatures were measured indicating recovery of 85% due to the phase transformation. In addition, amplitudes of vibration were measured as a function of excitation frequency and temperature to determine the effect of phase transformation. The results show effectiveness of NITINOL in development of smart structural systems.

SESSION D8: Electroactive Polymers
Chairs: Roy D. Kornshiek and Mohsen Shafieepoor
Wednesday, December 3, 2010
Room 202 (Hyenas)
130 PM *D8.1
Ionic Polymer-Metal Composites as Smart Materials under Subzero Temperature Conditions. Kwan J. Kim and Jacob Pugnette; Mechanical Engineering Department and Nevada Ventures Nanoscience Program, Univ. of Nevada, Reno, Nevada.

This paper presents a description of Ionic Polymer-Metal Composites (IPMCs) as an alternative solution for cold operation actuators. This is because of their capability for actuation with relatively low voltages, durability and capability of operating within the subzero regime (T ≤ 0°C). The building block material of IPMC actuators experiences phase changes within the base polymer material that result in an alteration of the performance of the material in terms of actuator performance. An experimental apparatus is constructed in order to have a controlled temperature environment in which to analyze the material. The results are presented and interpreted to show that there is a definite promise for these low temperature polymer actuators to operate in practical applications. Also, an effective process technique, namely, fabricate and test, was attended to obtain the optimized properties of the base polymer materials.

2:00 PM D8.2
Hybrid Actuation in Coupled Ionic/Conducting Polymer Devices. Matthew Bennett and Don Leo; Mechanical Engineering, Virginia Tech, Blacksburg, Virginia.

Ionic polymer membrane actuators represent a relatively new and exciting entry into the field of smart materials. Several key limitations of these transducers have prevented them from experiencing widespread use, however. For example, the bandwidth of these devices is limited by the response times of the chemical reactions involved and at high frequencies by the low elastic modulus of the polymer. In this paper, an overview of the initial results of work with hybrid ionic/conducting polymer actuators is presented. These hybrid actuators are devices that combine the electromechanical coupling of ionic polymer actuators and conducting polymer actuators into one coupled device. Initial results show that these hybrid devices have the potential to offer marked advantages over traditional ionic polymer membrane transducers, including increased stress and strain generation and higher actuation bandwidth. Details of the preparation of these devices and performance metrics are presented and comparisons to baseline materials are made.

2:15 PM D8.3
Temperature-Responsive Polymers with Tailored Onset of Response. Evangelos Mavrias and Mindung Hong; Materials Science & Engineering, Penn State University, University Park, Pennsylvania.

Stimul responsive materials are central in applications involving chemical sensing and/or stimul-driven actuation. A systematic series of temperature-responsive polymers were synthesized and studied, and the onset of their T-response was tailored by design of their monomer. Their T-response was studied both for their water solutions, and when they were cast on a surface, a surface for a hydrophobic (ethylene oxide, EO) and hydrophobic (ethylene) segments provides the possibility to fine-tune the lower critical solution temperature (LCST) point. In these studies and phase diagrams were done for the solutions, whereas water contact angle, ellipsometry, and atomic force microscopy were carried out for the end-grafted polymers, as a function of grafting density. A universal dependence of temperature of response on the monomer composition is found, and the onset of the response can be tailored by design in the range of 5-70°C in water. Model microfluidic devices employing these polymers as T-responsive gates were also realized.

2:30 PM D8.4

Piezoelectric unimorph cantilevers were explored for all-electrical soft-tissue elastic moduli measurements. The elastic moduli of soft tissues were obtained by simple electrical means using a dual electrode design: a driving electrode for force generation and a separate sensing electrode for deformation measurement. Accurate Young’s modulus measurements were demonstrated with both indentation and compression tests of calcified tissue samples as well as blood vessel samples. Direct shear modulus measurements were also demonstrated using cantilevers with a L-shaped tip. Potential clinical applications for such a method were studied mainly; the possibility of a stand-alone instrument for non-invasive detection or diagnosis of diseased tissue. The advantages of piezoelectric unimorph soft-tissue stiffness sensors include simple all-electrical measurements, accurate elastic moduli measurements at very small strains (≤1%), local stiffness measurements that offer potential for tissue imaging. Further miniaturization will allow simple electrical soft-tissue stiffness imaging on the micrometer- and nanometer-scale.

2:45 PM D8.5
Exploration of an Electroactive Polymer as an Actuator for MicroRobotics. Christian Biedmeier and Wayne Salters; Department of Mechanical Engineering, Rochester Institute of Technology, Rochester, New York.

The development of lightweight low power consumption actuators is critical to the development of micro-robotics. Electroactive Polymer (EAP) actuators and Electroactive Polymer (EAP), Naft N-117, meets these requirements. In the actuation of an EAP, the current does not remain constant over time. A circuit model for current draw versus time to best predict the current behavior has been developed for Naft N-117. While the material mimics a parallel plate capacitor, it has been found that capacitance plays no role in achieving steady state current levels. This development is critical to understanding and developing the material as a future actuator. This paper discusses the necessary developments required for the EAP actuator to be utilized in microrobotic devices. Specifically, the development of a lightweight reliable electrode for EAP material actuation, the current draw versus time model and equations, and microrobot applications are discussed.

3:30 PM D8.6
Switchable Window Based on Electrochromic(EC) Polymers. Chuming Xu, Lu Liu, Suean E. Legenski, Dai Ning and Minoru Taya; University of Washington, Seattle, Washington.

Switching window technology is a continuously growing field due to its potential for applications in architectural windows and aircraft windows, buildings, sunroofs, eyeglasses, and numerous type of displays. Whether its purpose is energy conservation, functional use or purely aesthetic, switchable windows have a promising future. Electrochromic polymers provide an alternative route to achieve this technology. The polymers change color under different electric potential. When a small electric potential is applied, the electrochromic polymers change state and the window changes between transparent and opaque. Even though electrochromic polymers have been around since the early 1990s, our latest work is an advance because they invented new electrochromic polymers and a new system of laminating these components together to make a window. Large contrast ratio and rapid switching EC polymer device which consists of a laminated two-layer structure between two electrodes was prepared. The new design consists of an ITO glass electrode, a cathodic EC polymer film, a solid electrolyte and a counter-electrode that replaces the anodic EC polymer and ITO electrode. Several EC polymers, such as Poly[3-methyl-4-propyl-4H-thionofluorene-2,7-diyl-alt-1,4-phenylene], Poly[4,7-dimethoxy-3,6-dihydroxy-1,10-dioxepine] and Poly[4,7-dimethoxy-3,6-dihydroxy-1,10-dioxepine], were synthesized as cathodic EC polymers. Carbon-based counter-electrode was prepared for comparison with Au-based counter-electrode. Screen printing was utilized for carbon-based counter-electrode. Lithography and sputtering were used for Au patterned glass counter-electrode. Several kinds of polymer gel electrolytes were prepared for different EC applications. Color change of high contrast ratio of transmissions of the window is rapidly obtained when even less than 2V is applied. The repeatability of color changeable EC polymer windows was estimated by the method of electrochemistry and spectroelectrochemistry.

3:45 PM D8.7
Self-assembly and applications of magnetothermocules suspensions in microfluidic devices. Ramin H Hughjoo and Patrick Doyle; Chemical Engineering, MIT, Cambridge, Massachusetts.

Magnetothermocules (MR) fluids are suspensions of colloids which acquire dipole moments under application of a magnetic field. Traditionally, these colloids have been used in microscopic applications, such as controllable dampsers, where the ability to tune their bulk rheological properties with a magnetic field has been exploited. We have recently shown that the colloids formed by the colloids in thin gaps can be used to efficiently separate DNA in microfluidic devices [Doyle et. al. 2002]. Here we investigate the self-assembly of MR fluids in microchannels using Brownine Dynamics simulations and compare our results to experiments. We study geometries in which the characteristic length scale of the colloidal microstructure is comparable to the channel dimensions. In this regime, we find that the crystal structure deviates from the usual hexagonal lattice common in suspensions of magnetic spheres, while the particles interacting through long-range repulsive interactions. Further fundamental understanding of self-assembly in confined geometries will allow for greater control of the porosity of colloidal materials used for biomolecule separations in microfluidic devices.

4:00 PM D8.8
In situ characterization of photoactuating and photothermal polymers. C. Sekayi, M. Monizoomman, G.
This paper reports on the design and validation of a novel in-situ measurement technique for characterization of photochromic and photoacoustic properties of polymer nanocomposites. The technique permits simultaneous irradiation of the photoresponsive polymer and measurement of its viscosity in a controlled environment. The results show that the technique is highly sensitive to small changes in sample composition and can be used to study the behavior of photoresponsive polymers in various solvent environments. The effect of environmental factors such as temperature is considered and steps taken to minimize these effects. The measurement technique provides an accurate measurement of the photochromic effect in the polymer nanocomposites in solution and as solids. A range of polymers with photoresponsive azobenzene and spiropyran units in the polymer side chains have been synthesized and evaluated using these three techniques. The photochromic effect was used to measure the trans to cis isomerization of the polymer. Results indicate that the trans to cis isomerization is irreversible and has been measured in a variety of solvents. The effects of incorporating a flexible spacer group in the side chain of the azobenzene polymers is examined and its effect on the photochromic mechanism is discussed. The reproducibility of the isomerization and recovery cycle of the spiropyran based polymer systems under alternate irradiation at different wavelengths is examined and discussed.

D0.2 Sterilizing Properties of Carbon Nanotube Composites, Roger Jagdish Nargyan and Bryan Bell, Materials Science and Engineering, Georgia Institute of Technology, Atlanta, Georgia.

Hydrogen-free carbon nanotube composites have been created that possess unusual free radical generation properties on photosensitization. These films have the ability to nonspecifically kill bacterial and human cells, thereby sterilizing a surface. These nanocomposites have been formed by pulsed laser ablation of carbon and simultaneous bombardment of nitrogen ions generated by a Kaufman ion source. A pulsed excimer laser (1=248 nm, t=25 ns) was used to ablrate the high purity graphite target with a fluence of 4 J cm⁻², which gives an average power density of around 108 W/cm². To produce atomic and nitrogen ions from a stable N₂ molecule, the ultra high purity grade nitrogen was used as an inert gas source to the Kaufman ion source which makes an angle of 45 degrees with the substrate. The beam energy of N₂ and N₂⁺ used for these experiments was ~500 eV and two beam currents (10 and 20 mA) were used in the focused geometry. The silicon substrates were kept at 600 degrees C while ablating the carbon target. Bonding characteristics were determined using x-ray photoelectron spectroscopy. Microstructure was determined using high resolution transmission electron microscopy (HRTEM), and short range atomic order was studied using radial distribution function analysis of the electron diffraction patterns. The C core-level peak was detected by XPS to shift from 284.6 eV BE for graphite to 284.3 eV for carbon nanocomposites, indicating a weaker C-B bonding caused by the curvature of graphene sheets. The C1s peak can be deconvoluted into three main components, corresponding to surface carbon, C-N and C-N, respectively, in the order of increasing binding energy. The typical N content is thus estimated to be in the range 15±2%. TEM studies allow to conclude that N₂(N₂⁺) consists presumably of the sp2-bonded ribbons wrapped around the normal to the surface. These ribbons remain parallel within ±15 degrees to the substrate surface normal and the interlayer order extends to approximately 1.5 nm. These features were seen irrespective of the specimen tilt in the microscope suggesting the curved nature of these planes. The textured nature of these films was also seen in the electron diffraction patterns obtained in the selected area electron diffraction mode of theTEM. The two layers of carbon nanotubes and therefore is not cross-reacting to the electrical and mechanical properties are unusual. One of these key applications of carbon nanotubes...
is based on the electrochemical double-layer (ECDL) behavior of charges on an electrode from the ionic charges in solution. Briefly, when a short-circuit is broken between carbon particles dispersed in an electrolyte, it expands or contracts if a voltage is applied between them and a counter electrode. Based on prediction, actuation is due primarily to changes in orbital occupation and bond structure with a secondary contribution arising from double-layer electrostatic effects. However, the relative contribution and interaction between each of these mechanisms is unclear. We aim to elucidate actuation behavior using Raman spectroscopy (RS) and built a linear model from SWNT network components using free aqueous electrolytes (LiCl, NaCl, KCl, KBr, K2SO4, and CaCl2) in order to clarify the role of counter-ion, if any. The variation of carbon bonding due to nanotubes with applied potential was studied by in-situ Raman spectroscopy, because it can detect changes in C–C bond length (δC–C), through two of the most prominent bands [radial breathing mode; RBM at ~190 cm⁻¹, and G band at ~1590 cm⁻¹]. In addition, the intensity of both the modes vary with the occupation of the bonding state, which is a data-based model of actuation. We found a strong, electrolyte dependent variation in intensity of both modes with applied voltage and follow a quasi-parabolic behavior. While the shift in frequency of RBM does hardly change within the experimental uncertainties, the variation in the highest frequency G-band (ranging 1530 - 1602 cm⁻¹) with applied potential displayed somewhat dependence on the electrolyte used. The estimated in-plane strain deduced indirectly from Raman measurements is of the order of ~0.35% [2] and the charge transfer (fc) is ~0.004, which is significantly lower if compared with several GIC acceptor compounds. This is to say that this is in agreement with the proposed mechanism [1] (i.e., intercalation of water molecules). Electro-chemo-mechanical response of SWNT nanomaterials does depend upon the type of counter-ion used. The cycle voltammetry (CV) and ac impedance behavior of the nanotube is described briefly. These findings of electrochemical process in aqueous solutions between actuators opens a vast of practical applications including hydrogen storage/stored cell, batteries, supercapacitors, and micro-electrodes for neurophysiology [1]. R. Baughman et. al. Science, 286, 1343-1346 (1999) [2] S. Gupta et. al. Diamond and Related Materials (2013) Submitted.

Qiying Wang, Guoning Ning, Fei Wei and Guohua Luo; Department of Chemical Engineering, Tsinghua University, Beijing, China.

Single-walled carbon nanotubes (SWNTs) have attracted much attention due to their unique structural, mechanical, chemical, and electrical properties. Catalytic chemical vapor deposition (CVD) through decomposition of hydrocarbons is one of the most challenging synthesis techniques to produce SWNTs in large scale. In this paper, high quality SWNTs prepared in a fluidized bed reactor (FBR) was reported. The reactor is a vertical quartz tube with the inner diameter of about 10 mm. Single-walled carbon nanotubes powders used for the production of SWNTs were prepared with Fe and/or Co metal nanoparticles carried on the surface of MgO, Al2O3, SiO2, ZSM-5 etc. About 100g catalysts powders were loaded on the gas distribution grid. The reaction temperature was controlled at not less than 1129 K. The carrier gas of argon was used to maintain turbulent fluidization of the catalysts powders in FBR. The hydrogen gas was used to reduce the catalysts and to synthesize the growth of SWNTs with methane. The products were analyzed by TEM, XRD, Raman and UV-Vis. Our methods offers a higher yield of SWNTs products and would be a commercially viable (effective and continuous production at a low cost) process. The authors gratefully acknowledge the support of the National Science Foundation of China (No. 202020626).


Our research focus is on the synthesis of innovatively engineered biodegradable and biocompatible materials that can be applied to the development of less-cost, disposable biosensors that can be used for medical diagnostics, for the rapid detection of hazardous biological and chemical contaminants in the environment and food processing industry. Polyhydroxyalkanoates (PHA) are naturally produced intracellularly by numerous bacteria as carbon and energy storage compounds, and are suitable candidates for the production of novel biodegradable plastics. Since they possess material properties similar to various synthetic thermoplastics and elastomers, they have been extensively studied as environmentally friendly substitutes for conventional petroleum-based polymers such as polypropylene. However, due to the fact that unmodified PHAs possess limited stability towards many standard polymer-processing techniques, the aim of our research is to develop novel hybrid polymer networks based on PHAs that further expand their applications. To date, we have successfully produced a variety of chemically distinct PHA hybrid networks of specially designed biocatalysts. In this project, PHA-PDMS (Polydimethylsiloxanes) hybrids were formed through a crosslinking reaction between functional group present in the PDMS and complementary groups present in the PHA. The resulting material has properties quite similar to standard PDMS rubber, but unlike PDMS this material is biodegradable. Additionally, this material represents the first of its kind reported to date. Currently, our primary research goal is to investigate the feasibility of using these novel PHA-PDMS hybrid elastomers for constructing microfluidic networks on chip-based biosensor devices. In addition, our lab is presently characterizing the biodegradability of the crosslinked PHA-PDMS materials.

D9.6 Degradation processes in new type resistive oxygen sensors.
Thomas Schneider*, Wolfgang Menekne, Harumi Yokokawa1 and Elke Ivens-Tiefke2. 1Universität Karlsruhe (TH), Institute for Mineralogic and Materials Research, Karlsruhe, Germany; 2AIST Tsukuba, Energy Electronics Institute, Tsukuba, Japan.

New types of oxygen sensors with increased sensitivity are required to maintain operation of combustion engines within the desired A/F ratio under lean burn conditions and the future challenges for cyclic-selective emissions. Life-cycle emission control on-board diagnostics for these purposes, resistive oxygen sensors are attractive given their increased sensitivity, their short response times as well as their simple structure. Acceptor doped perovskite type metal oxides of the composition Sr(Ti,Mg)O3 (MP) transition metal Fe, Cr, Mn are commonly used for the sensitive layer. Contrary to donor doped sensor materials, Sr(Ti,Fe)O3 shows a long term stable and temperature independent characteristic: In the presented planar exhaust gas sensor yttria doped zirconia (YSZ) as substrate is used with an Al2O3 protective layer doped with vanadium as intermediate layer. To obtain distinct signal values an interdigital contacting for a high EMC performance is realized on top. The chemical stability of the intermediate and sensitive materials as well as their chemical compatibility at the interfaces have a significant impact on the performance and the long term behavior of the exhaust gas sensors. Degradation processes due to changes in composition, interdiffusion and the formation of secondary phases at the layers decrease the performance of the device. Depending on the composition and the operating conditions, different types of degradation processes can be observed: Interdiffusion of cations at the interface between intermediate and sensitive layer affects the electrical properties of the exhaust gas sensor, while formation of insulating secondary phases at the interfaces between substrate, intermediate and sensitive layer interferes with the chemical reactions. Chemical Potential Diagrams of the composition provides descriptive information about the stability of the applied material and the formation of parasitic secondary phases resulting in a severe degradation of the sensitive layer. By the use of Chemical Potential Diagrams a prediction of the stability of the material and the precipitation of applicable compounds becomes feasible without costly long term stability tests.


Gas sensors based on organic-inorganic hybrid materials are demonstrated. The synthesis of organic-inorganic hybrid materials aims at combining the physical and chemical properties of inorganic and organic components. The interesting point of such materials is their large number of chemical and structural modifications available. For designing organic-inorganic hybrid sensors, the organic and inorganic components take part in molecular recognition and transmission of chemical signals to measurable resistance changes, respectively. In this paper, we will present the preparation of organically hybridized inorganic materials and their VOC gas sensing properties. We have synthesized polypropylene intercalated MoO3 hybrid...
Effect of sample preparation procedure on the magnetotransport properties of polycrystalline bulk Sr$_2$FeMoO$_6$ double perovskite. N. Rama$^{1,2}$, T. Komalawali$^{1,2}$, K. Chandrasekaran$^{1,2}$ and M. S. Ramdas$^{3,4}$ Materials Science Research Centre, Indian Institute of Technology, Madras, Chennai, India.

After the discovery of room temperature magnetoresistance (MR) in Sr$_2$FeMoO$_6$ by Kobayashi et al. in 1996 [1], there is a renewed interest in these systems. However, for intense research it was found that MR (which results due to intergranular tunneling) in these systems is highly dependent on preparative route and conditions. We have therefore studied the effect on the MR by using two different sets of compounds in the solid state route. We have used strontium nitrate as the source of Sr in one case (sample 1) and strontium carbonate (sample 2) in the other case. Fe$_3$O$_4$ and MoO$_3$ are the sources of Fe and Mo respectively in both cases. We have characterized these two compounds by X-ray diffraction and the superlattice reflection peak (111) with double intensity of the Fe and Mo superlattice reflection peak is seen only in the case of sample 1 and not in sample 2. The absence of this peak indicates high degree of disorder in the lattice of sample 2 which is detrimental to potential applications like spintronics. It is seen from the resistivity and MR plots that sample 1 shows lower resistance on room temperature and higher low field MR than that of sample 2. These results will be explained in detail with respect to the difference in the stoichiometry of the material involved [1]. K.I. Kobayashi et al. Nature 395 (1998) 677.

A Trial on Amplification of Magnetos-urface-Acoustic-Waves In Higly Magnetostriective Metal Films By Means of Electron Bunching. Takeshi Kawai$^{1}$, Naohisa Ohba$^{2}$, Kuniharu Hisamura$^{3}$, Hironori Uchida$^{4}$ and Masateru Inoue$^{4}$, Toyoohshi University of Technology, Toyoohshi, Aichi, Japan.

An amorphous Fe$_8$B$_2$ thin film, which is highly magnetostriective metal, shows a soft magnetization property after annealing. We applied the magnetostriective thin film to propagation path for magnetosurface acoustic-wave [MSAW] [1]. In our fabricated MSW device, a plate velocity of surface acoustic wave was controlled widely by an external magnetic field because of AE effect of the Fe$_8$B$_2$ thin film. However, since the Fe$_8$B$_2$ film was a conductive alloy, an eddy current loss in the thin film increased by increasing a driving frequency for a MSAW, and the eddy current loss attenuated a surface acoustic wave. Therefore, the Fe$_8$B$_2$ film was not applicable to a MSAW device in high frequency range more than 100 kHz. In this report, we investigated amplification of MSAW by electron bunching. We fabricated In$_{1-x}$Sn$_x$ thin film with a thickness than that of the SAW with a low voltage. The In$_{1-x}$Sn$_x$ film was deposited on a 128 degree Y-cut, X-propagation LiNbO$_3$ substrate by an ion beam sputter system. After annealing at 475 degree C for 90 minutes in vacuum, the (111)-oriented In$_{1-x}$Sn$_x$ thin film with an electron mobility of 860 cm$^2$/Vs was obtained. The amorphous Fe$_8$B$_2$ thin film with a coercive force of 1.5 Oe and a magnetization of 26 ppm was fabricated by a magnetron sputter system. An interdigital transducer (IDT) with a strip width of 8 mm was fabricated by photolithography. We observed a SAW of 125 MHz in our developed device with a hybrid structure of Fe$_8$B$_2$/In$_{1-x}$Sn$_x$ thin films [1]. N. Yokokawa, S. Tanaka, M. Inoue and T. Fujii, Jpn. J. Appl. Phys., Suppl. 30-1, 182-184 (1991).

SESSION D10: Poster Session: Photonic, Optic and other Novel Materials
Chair: Daeyong Jeon
Wednesday Evening, December 3, 2003
8:00 PM Exhibition Hall D (Hynes)

D10.1
Negative refraction by a prism and imaging by a flat slab of microwave photonic crystal. Pasigali Y Pasini$^{1}$, Wentao Lu$^{2}$, John Deco$^{2}$, Pietro Vodol$^{3}$, Srinivas Sudh$^{4}$ and Beverly Turchi$^{4}$, "Department of Physics and Electronic Materials Research Institute, Northeastern University, Boston, Massachusetts; "AFRL/SNHU, Hanscom, Massachusetts.

A conventional optical lens cannot focus light onto an area smaller than a square wavelength and the image formed by such lens is limited by the aperture size and fabrication quality due to curved surfaces. However, superlens characterized by negative refraction can change the way optics works. Recent theoretical studies indicate that negative refraction is possible in photonic crystals (PC) in various regimes of the band structure. In this report we demonstrate negative refraction of microwaves in a metamaterial PC and imaging by negative refraction of a dielectric PC. Two dimensional refraction and imaging measurements are carried out in a parallel plate waveguide. Negative refraction is observed in different frequencies between 12 and 14 GHz. Using a flat lens of the dielectric PC, for a subwavelength point source at 2.25 cm from the surface of the PC, we have observed an image of similar size on the far side at 2.75 cm. The image formed by the flat lens to negative refraction is a real 3D image. The experimental results are in excellent agreement with band structure calculations and simulations of wave refraction. The photonic crystal materials display low attenuation and are easily fabricated. The present results can be scaled to optical frequencies and pave way for several interesting applications. Work supported by the National Science Foundation and the Air Force Research Laboratories, Hanscom, AFB.
resistance, SEM, Raman spectroscopy and SIMS. The sheet resistance is compared with that of rapid thermal annealing (RTA). Sheet resistance measurement of 80 Ω/square and poly-Si film of 150 Ω/square is the excimer laser energy increases. The minimum sheet resistance of n-type poly-Si film is 150 Ω/square which is near to that of RTA. The minimum sheet resistance of n+ doped poly-Si film is 180 Ω/square which is near to that of RTA and occurs at the beginning energy of nucleation. The minimum sheet resistance of p-type doped poly-Si film is 180 Ω/square which is near to that of RTA and occurs above the nucleation energy. Raman signal of n-type doped poly-Si film shows single peak at all laser energy around 5150 cm⁻¹ and it’s intensity shows maximum at the beginning energy of nucleation and minimum at 5150 cm⁻¹. A broadened peak of a p-type doped poly-Si film shows single peak at lower laser energy and double peak at lower laser energy around 5100–5200 cm⁻¹. SIMS profile on the laser energy is analyzed.


Vanadium dioxide (V2O5) thin film undergoes a semiconductor-to-metal transition at about 68°C. The phase transition is accompanied with a drastic change in its optical transmittance and reflectance, which makes it a good candidate material for optical switching devices. Previous works have been focused on the study of the film properties. In this paper, we present the integration of V2O5 films into MEMS structures by the method of vanadium metal liftoff followed by thermal oxidation. The active V2O5 film was made by e-beam evaporation of pure vanadium target followed by thermal oxidation in oxygen ambient. Synthesized V2O5 film displays a phase transition at 65°C. It shows sharp switching for the infrared transparent. Raman signal for V2O5 on a highly reflective metal layer is strongly dependent on the thickness of V2O5 film. The spectroscopic ellipsometer and stylus measurements reveal that the reflectance increases about 20% times after oxidation. The optical switching has a hysteresis of about 15°C between the heating and cooling branches. The scanning electron microscope (SEM) result shows a film microstructure with 500–600nm columnar grains. The measurements of the optical switching at different points across the film prove good uniformity of the oxidation. The effects of the micromachining process steps on its optical switching after V2O5 deposition will be presented. The study shows that V2O5 film with sharp thermochromatic switching can be successfully integrated into MEMS processing using liftoff followed by thermal oxidation.

D10.5 Optical Constants of Vanadium Dioxide Films and Design of a Solar Energy Control Window, Masato Tanaka, Hideo Ando, Gang Xu and Ping Jin; ISEM, AIST, Nagoya, Japan.

Vanadium dioxide (V2O5) shows an abrupt change of the optical properties in the wavelength region longer than about 800 nm at the transition temperature of 68°C. At the temperature V2O5 undergoes a phase transition from the low temperature semiconducting phase to the high temperature metallic phase. The transition temperature increases about 0.6°C times after oxidation. The optical switching has a hysteresis of about 15°C between the heating and cooling branches. In this report, we first determined the optical constants of V2O5 films in both metallic and semiconducting phases by ellipsometry from 380 to 1700 nm in wavelength. We found that the model with the ellipsometric parameters very close to the measured values of the low temperature and the Lorentz model combined with the Drude model for the high temperature metallic phase. Second, using the optical constants, we designed a solar energy control window using a stacked film consisting of titanium oxide (TiO2), vanadium oxride (V2O5), and indium tin oxide (ITO) for the upper, middle, and lower layer, respectively, on glass substrate. The TiO2 layer was used as an antireflection coating in the visible region and the ITO layer was used as a reflector in the wavelength region longer than about 2500 nm. The designed stacked film shows high transmission in the visible region and high reflection in the far-infrared region. In the near infrared region, the transmission of three polyvalent groups decreases according to the temperature because of the phase transition of the V2O5 layer. Namely, this window reflects at high temperature and transmits at low temperature the near infrared part of the solar radiation.

D10.6 Star-like Aromatic Conjugated Polymers and dendrimers for OLEDS, Ira A. Khozin and Luda M. Bronstein 1,2. 1 Polyolefin synthesis, A.N.Nesmeynov institute of the organiccompounds, Moscow, Russian Federation; 2 Chemistry Department, Indiana University, Bloomington, Indiana.

The solution of the problem allowing synthesis of effective blue emitters can be found in synthesis of polymers with very branched fragments containing no other substituents than benzene rings. Polyphenylene synthesis based on cyclodimerization of acetylene-benzene rings by trimerization cyclodimerization in the presence of acidic catalysts gives branched polymers with exclusively 1,3,5-substituted triphenylene. The polymer chain growth occurs due to the cyclodimerization of three acetylene groups to give new benzene ring formation. This reaction has a drawback - a polymer contains many defect fragments due to side reactions, which can quench the luminescence. The major side reactions are an incomplete cyclodimerization, i.e. dimerization of cyclotrimerization and formation of b-methylene group, formation of linear and cyclic vinylene-containing products and alkyne pyrrolidines. The main approach for the synthesis of luminescent branched polyphenylenes with the creation of defect-free structures is the synthesis of free oligophenylene (with 13 phenyl ring) was synthesized using cyclodimerization of [1-4-acycletylene]-3,5-diphenyl-benzene. This molecule presents a second generation of phenylated dendrimer with 1,3,5-triphenyl-benzene (TPB) as a dendrimer core. Here both products were eliminated by purification after synthesis and the final product showed intense photoluminescence in solution. The PL QY is 72%. We believe that higher generations of such dendrimers might result in enhanced photoluminescence. However, as with dendrimers of a higher generation, the synthesis is usually laborious and time-consuming. Another possibility is to lengthen the arms of the dendrimer center (obtained by cyclodimerization of acetylenicromatic compounds) using some polymerization technique (for example, Ni-katalyzed dehydrochlorination) providing defect-free structure. This approach should result in the branched polymers containing star-like fragments. New polymers were prepared starting from 1,3,5-tri-2-(bromophenyl)benzene synthesized by cyclodimerization of polycarbosiliconene. To prevent 3D crosslinking in Ni-katalyzed polymerization with bromine, we needed to control the branched to dicromatic and to substitute the bromine group (out of three) in trimethylene for phenyl ring using Suzuki reaction, i.e., interaction of bromide with phenylboronic acid. The product prepared was used in Ni-katalyzed polymerization (polymer 1) together with 1,3,5-triphenyl-benzene, new branched polymer synthesis (polymer 2), but in this case, the equilibrium amount of bromobenzene was added to keep the reaction mixture from gelatin due to the decreasing of overall functionality of the system. This polymer can be considered a promising material for OLED applications.

D10.7 Improvement of secondary electron emission property of MgO protective layer of an alternating current plasma display panel by addition of secondary electron emission promoters, Aki Ide 1, Yasuo Murakami 2 and Yoshiaki Tanaka 3, 1 International Innovation Center, Kyoto University, Kyoto, Japan; 2 Graduate School of Engineering, Kyoto-University, Kyoto, Japan; 3 Showa Kemko Ltd., Uji, Japan.

In order to improve secondary electron emission coefficient of a protective layer in a plasma display panel, TiO2, SnO2, AI2O3, and ZnO are added to MgO films. We applied electron beam evaporation method for preparing the films. The proportion of doped-oxide was varied 5, 10, 15 % of solid solution. The surface roughness, X-ray reflectivity spectroscopy (XRD), X-ray photoelectron spectroscopy (XPS) were performed to measure the chemical state and the composition of the prepared films. Secondary electron emission coefficient of these films was measured. The doped-oxide varies their secondary electron emission particularly. The result means that adding oxide to MgO films has a great influence on their secondary electron emission coefficient.

D10.8 Ion Beam processing of MgO thin films with large secondary electron emissivity, Aki Ide 1, Hiroshi Namikawa 1 and Yoji Tanaka 3, 1 International Innovation Center, Kyoto University, Kyoto, Japan; 2 Graduate School of Engineering, Kyoto University, Kyoto, Japan; 3 Showa Kemko Ltd., Uji, Japan.

Thin film of MgO is widely used as a protecting layer in plasma display panel (PDP). We prepared the MgO thin films using ion beam-assisted deposition (IBAD) technique with the aim of controlling the crystal orientation, density and composition of the films. Oxygen ion beam was utilized to irradiate the growing films. The ion beam irradiation was performed by electron cyclotron resonance (ECR) type ion source. The flux of evaporated MgO was produced using an electron gun. Energy and current density of the ion beam as well as deposition rate on substrate was taken as the parameters to control the deposition. Crystallinity, density and composition of the films were measured using X-ray diffraction (XRD) and Rutherford backscattering spectroscopy (RBS). We measured also the secondary electron emission coefficients of the films with a newly developed apparatus. Experimental results suggest that the ion beam irradiation during film growth strongly influences the crystal properties and the composition of the films to have the best orientation for high efficiency secondary electron emission.
The effect of post-deposition heat treatment, in different gas atmospheres, on the electrical and optical properties of ZnO thin films, grown by RF sputtering deposition, has been investigated. Samples of undoped, and Al doped, ZnO have been heat treated in air, oxygen, nitrogen, and forming gas (7% H2 + 93% N2) at temperatures ranging from 300°C to 900°C. Hall effect, electrical conductivity, and optical measurements revealed an increase in the amorphous–crystalline transition temperatures due to the heat treatment in forming gas. The crystal structure of the annealed ZnO films changed from hexagonal to cubic, with a high degree of c-oriented growth. The electrical conductivity of the films increased significantly due to the heat treatment. These changes are discussed in terms of the crystalline structure of the films.

D10.10

Smart Heterostructures Based on Solid Solution ZnCaHgTe.

Gizmo Kiley and Peter Sylwester

Smart narrow-gap semiconductor materials belonging to the A2B6 compounds are said to have particular interest for design of optoelectronics devices used in automobile and vehicle navigation. The heterojunctions of these materials with direct band gap mercury cadmium telluride (HgCdTe) and monocrystalline substrates (ZnSe) are of importance owing to the capability of mobility and reliability of the growth technology (modulated liquid-phase epitaxy or pulse laser epitaxial technique). Different methods of hetero-epitaxial growth give a wide range of possibilities to change the main parameters of the energy band diagram which appears as a principal characteristic of the active element. Furthermore, the change of the charge carrier characteristics (particularly mobility, density of states, lifetime, etc.) provide a sound information for simulation of active element as a whole. The investigation of the experimental data obtained from the thinnest electro-optical measurements appears as a reasonable base for computing modeling of the graded-gap heterostructures. The authors report results of experiment and numerical simulation for active elements based on graded-gap heterostructures CdTe/Ge/ZnSe with monocrystalline substrates CdTe. The main parameters of the energy band diagram are calculated, and the numerical parameters for the device simulation is also presented.

D10.11

Pulsed Electron beam Deposition - A Simple and Versatile Thin Film Deposition Technique for Developing Materials for Smart Films, K. S. Harshvaradan, M Srikrishna and J Kim

Thin Films, Necoer, Inc., Beverly, Maryland.

Pulsed Electron beam Deposition is a relatively new thin film deposition technique. A high current (1500 A), high voltage (15 kV) electron beam of about 100 m pulse width, created in a low pressure Paschen discharge regime is used as the primary energy source to ablaze a given target material resulting in the formation of a thin film on a substrate. The high power density at the target facilitated by the pulsed nature of the beam permits deposition of complex materials such as YBa2Cu3O7, Bi-2223 etc., with stoichiometric composition control. The Pulsed Electron Deposition, in several aspects, is similar to the well-established Pulsed Laser Deposition technique but differs from the fundamental viewpoint of beam-target interaction. The additional advantage of Pulsed Electron Deposition is realized in its ability to deposit optically transparent materials [with respect to the laser wavelength] such as SiO2 and Al2O3 and some special polymers. The technique is scalable and cost effective and hence could become the preferred method in high throughput manufacturing environment where pulsed techniques are sought for accomplishing specific functionality (composition control, high density, deposition at lower temperatures etc.) in the deposited films. This presentation will briefly introduce the basics of this deposition technology to the materials scientists and will present experimental data obtained on several technologically important smart materials systems such as high temperature superconducting films (YBCO, GaBCO), porous electric Bi2Sr2CaCu2Oy based Hydrogen free Diamond like Carbon and PTTE films.

8:30 AM *D11.1

Selection of Materials and Sensors for Health Monitoring of Composite Structures. S. Mark Spence and Seth Stovak Kesler

Aeronautics and Astronautics, MIT, Cambridge, Massachusetts; Metis Design Corporation, Cambridge, Massachusetts.

Embedded structural health monitoring systems are envisioned to be an important component of future transportation systems. The principal challenge in designing an SHM system is the choice of sensors, and a sensor layout with high sensitivity to the relevant structural damage. This paper focuses on the relationship between sensors, the materials of which they are made, and their ability to detect structural damage. Sensor selection maps have been produced which plot the capabilities of the full range of available sensor types vs. the key performance metrics (power consumption, resolution, range, sensor size, coverage). This exercise is used to define a system architecture utilizing piezoceramic sensors, operating in several modes (acoustic emission detection, strain detection, Lamb wave generation/sensing and global modal response). Experimental and analytical results are presented for in-situ damage detection in composite materials using piezoceramic sensors. Test results and corresponding analysis is presented for coupons and built-up structures, including sandwich panels, stiffened panels and cylinders containing representative damage (decalinations, impact damage, off-axis ply cracking and penetrations). Modal analysis methods are shown to be effective for detecting the presence of some damage in composite structures, but provide little information regarding the size, location or severity of the damage. By comparison, Lamb wave techniques are shown to be sensitive to all types of damage, and present the possibility of estimating damage location and size. The results of this analysis are discussed and recommendations for the development of improved sensor configurations and materials are made.

9:00 AM *D11.2


Materials Science, INSA, Villeurbanne, France; IFSO, Ecole Centrale de Lyon, Ecully.

The classical NDE techniques of periodic maintenance are just now evolving towards the continuous health monitoring of materials and structures. Taking account of the relation of this approach with the biomimetic notion of smart materials, it seems useful to extend this passive concept to a more active one specially in the case of composite materials. Effectively, if sensors and actuators are embedded in a composite structure before curing in order to monitor and improve the processing parameters, they are able, remaining in the structure, to assume the health monitoring and the optimization of the usage in the next stages of the life. Moreover, in slightly damaged systems, it becomes reasonable to use the results collected by the sensors for one on line tentative prediction of the residual life. Finally in the case of the life, when the material is deeply damaged, it is sometimes possible to slow down, and more, to heal the damage.

9:30 AM *D11.3

Smart Materials and Nondestructive Evaluation. Masaaki Enoki and Teruo Kinsh, Department of Materials Engineering, The University of Tokyo, Tokyo, Japan; National Institute for Materials Science, Tsukuba, Japan.

The smart materials and structural systems are based on the concept to incorporate sensors, actuators, etc in the materials themselves and to integrate (fuse) materials with the structures, thereby improving such functions as to (1) selfevaluate the occurrence and deterioration of strains and damages, (2) self-control vibrations and noises, (3) selfchange their own shape depending on conditions, and (4) selfcontrol the propagation of damages and repair them as the need arises. We report the recent research and development project in Japan on the smart materials and structural systems, which was a project under the NEDO’s [New Energy and Industrial Technology Development Organization] system of the research and development on industrial and scientific technologies in conjunction with colleges and universities. This report shows examples of applications to composite materials such as (1) development of health monitoring technology, (2) development of smart manufacturing technology, (3) development of active/adaptive structure technology, (4) development of materials and elements for actuator, and (5) airplane body demonstrator for demonstration test. Also recent
development of nondestructive evaluation technique such as laser based AE (acoustic emission) to detect microfracture process in smart materials will be reported.

10:30 AM D11.4
Tailoring Strains Through Microstructural Design.
Lan J. Vanderpere and William J. Clegg, Department of Material Science and Metallurgy, University of Cambridge, Cambridge, United Kingdom.

When developing structures, which respond with a strain upon application of a stimulus such as temperature or an electric field, the fixed relation between the response of a given material and the magnitude of the stimulus puts severe constraints on the design. This problem in compatibility with design of the actuator or sensor, or by selecting a material with the appropriate coefficients in response to the field. However, when actuating or sensing functions need to be incorporated within other structures, shapes must be chosen as possible. The specific point where the structure is to be used can put limits on materials selection. Such limitations can be overcome by incorporating design into the microstructure of materials. By combining two materials into a structure, which allows levering of the strains, one can obtain a much wider range of coefficients than predicted by the rule of mixtures. For example, using aluminum and Invar, with respective coefficients of thermal expansion of 24 x 10^-6 K^-1 and 1.5 x 10^-6 K^-1, a coefficient of thermal expansion as low as -30 x 10^-6 K^-1 was obtained. It will be shown how simple variations of the microstructure obtained by combining simple triangular elements can yield a wide variety of properties: isotropic and anisotropic coefficients, linear and non-linear responses, and materials with gradient properties. Initial sheet production of like materials was performed by a combination of photolithography and soldering. Predictions of both the coefficient of thermal expansion as well as mechanical properties will be compared with experiments on a model system of copper and Invar.

10:45 AM D11.5

In this paper, advances in development of instrumentation and methodologies for wireless health monitoring of structures using MEMS inertial sensors are presented. Development of new materials and structures has increased the demand for accurate monitoring of their mechanical behavior. Such modeling includes determination of dynamic properties of structures, such as their natural frequencies, mode shapes, and damping factors. Dynamic properties can be determined using analytical and computational methodologies, but are only limited to simple structures since they are insufficient to study complex structures. In order to study complex real-world structures, experimental modal analysis is applied. Rapid development of microelectromechanical systems (MEMS) has led to progressive designs of high-resolution, lightweight, and low-actuation power inertial sensors. These MEMS sensors provide an optimum alternative to traditional sensors, which have larger masses and may modify the dynamic characteristics of the structure. With the designs presented in this paper, a number of MEMS inertial sensors are the first to be utilized in this application. The sensors are designed to determine dynamic properties of structures. To ensure that the structures are not too large or too small, the tests will be focused on structures that can be monitored with MEMS inertial sensors. The objective of this study is to characterize the dynamic characteristics of MEMS inertial sensors and determine how they can be used to monitor the behavior of complex structures.

To verify the results obtained with MEMS sensors, nonlinear methodologies, such as laser optoelectronic holography (OEH), are utilized to determine the natural frequencies, mode shapes, and damping factors. As well as to investigate the effects that attachment of MEMS sensors may have on the dynamic characteristics of the oscillator. In addition, the test structures are modeled with analytical and computational methods for comparison with the experimental results. Considering that multiple MEMS sensors are utilized, wiring and integration of these sensors might become complicated and monitoring of structures across long distances becomes limited. Therefore, a miniaturized wireless system that utilizes commercially available RF components is being developed and its current functionality is demonstrated.

11:00 AM D11.6
A New Technique for Measuring Mechanical Response of Thin Released Films for MEMS. Rongzheng Zheng, Daron Shilo, Gururwami Ravichandran and Kaushik Bhattacharya; Division of Engineering and Applied Science, California Institute of Technology, Pasadena, California.

The interest in micro actuation and sensing MEMS devices has given rise to the necessity for studying the mechanical response of thin released films, which are made of such materials as ferroelectrics, ferromagnetics, and shape memory alloys. The trend to reduce the film thickness in these devices compels the development of new techniques, which enable loading in the sub-nm scale and take into account the fragility of these devices. We have developed a new technique for measuring static and dynamic mechanical response of thin released films, by either load control or displacement control in the range of 0.1mN - 1N. An optical system, which measures the deflection of a laser beam, allows us to measure displacements in the sub-nm region. In the experiment a sample holder with 4 adjustable degrees of freedom allows us to test specimens, which are integrated on a silicon wafer. The capabilities of the new technique are demonstrated with results on released films of ferroelectric Bi[(La1-xPnx)0.5(Ti0.5Sn0.5)O3 and ferromagnetic shape memory alloy Ni2MnGa.

11:15 AM D11.7
Bi-Directional Motion Achieved with a Surface Micromachined Electrothermals MEMS Microengine.

Several microactuator technologies have been investigated for positioning individual elements in large-scale micromechanical systems (MEMS). Electrostatic, magnetostrictive, piezoelectric and thermal expansion represent the most common modes of microactuator operation. This research is focused on the design and experimental characterization of two types of MEMS asymmetrical electrothermal microactuators. The motivation is to present a unified description of the behavior of these electrothermal microactuators so that it can be adapted to a variety of microsensor and microactuator applications. Both microactuator design variants use resistive (Joule) heating to generate thermal expansion and movement. Deflection and force measurements of both microactuator variants under a function of applied electrical power are presented. Also described is the practical integration of the electrothermal microactuators in a monolithic microengine that has been operated in a bi-directional mode to control the pitch of a mechanical shuttle. Preliminary control of the mechanical shuttle has been achieved with a resolution of 1 micron.

11:30 AM D11.8
Piezoelectric Actuators for Synthetic Jet Applications. Kodial Bassi and Rob Bryant; Virginia Commonwealth University, Richmond, Virginia; NASA Langley Research Center, Hampton, Virginia.

Synthetic jets have been identified and utilized widely in airflow control applications. These jets of air are usually created by the use of compressed air, or an electromechanically driven vibrating platform. All of these approaches produce desired results in airflow control such as enhanced lift and increased maneuverability. Despite the results however, system weight, size, response time and force limit their use in aircraft applications where space is premium. The objective of this study is to characterize the dynamic characteristics of a synthetic jet utilizing three types of piezoelectric actuators as mechanical diaphragms. The limiting parameters of the actuators for this application are shape and volumetric space. Thus, the actuators were designed with a dynamic characteristic of 145 cm^3 and a volume no larger than 147.5 cm^3 on a 7 x 7 cm size. The actuators were tested in a stress accelerated and bent curvature, bimorph, and radial field diaphragms. These piezoelectric elements were chosen because of the high actuation speed, high actuation forces and the controllable free-displacement.

11:45 AM D11.9
Design for Compressive or Tensile Stress in Spherically-Deformed Circuit Bends and Electrical Implications. Pai-Shui Iris Hsu, Min Huang, Helen Glaskova, Zichen Xu1, Zhigang Suo1, Sigurd Wagner and James C Sturman; 1Center for Photonics and Optoelectronic Materials, Princeton University, Princeton, New Jersey; 2Center for Composite Materials, University of Delaware, Newark, Delaware.

Many proposals for future sensors and actuators depend on stretchable and bendable electronics fabricated on thin foil substrates, e.g. smart electronic skins that can be deformed to arbitrary shapes. The most common type of deformation is to roll a thin foil substrate into a cylinder. For such deformation, the strain in any device on the surface or foil surface of their geometry, quantum-mechanical states. However, for more complicated shapes, such as a spherical cup shape,
deformation of the substrate (from a flat initial state) requires a deformation larger than the size of islands in the substrate surface, depending on the choice of structure, not only can the strain in the device be kept small, but also the sign of the strain can be either positive or negative. This is shown by numerical modeling and confirmed by experimental data demonstrating the effects of spherical deformation on the electrical performance of amorphous silicon thin-film transistors (TFTs) on polyimide substrates in such device structures. The electrical performance of amorphous silicon thin-film transistors on polyimide substrates is shown to be improved by increasing the polyimide substrate thickness. The results obtained from polyimide substrates are compared with those obtained from glass substrates. This comparison shows that polyimide substrates are more suitable for large-area electronic devices due to their lower Young's modulus and higher stiffness. For the case of polyimide substrates, the strain in the device layer is shown to be significantly reduced compared to that in glass substrates, leading to improved device performance. These results indicate the potential of polyimide substrates for the fabrication of large-area electronic devices.

SESSION D12: Magnetic and Metallic Based Smart Materials

Chair: Kanryu Itoe and Eshardz Quandt
Thursday Afternoon, December 4, 2003
Room 202 (Hynes)

10:30 AM *D12.1
The remanence enhancement in magnetically interacting particles. Jinyu Li and Heilang Qiu, Engineering Mechanics, University of Nebraska-Lincoln, Lincoln, Nebraska.

In this talk, we report an effective medium theory on the remanence of magnetically interacting particles to demonstrate the effect of intergranular magneto-static interactions on the remanence enhancement of magnetic materials. Our results agree well with the numerical simulations. A dimensionless parameter 
\( h_{\text{in}} \) measuring the competition between anisotropy energy and magnetostatic energy is defined, which completely characterizes the remanence of materials where the exchange coupling is negligible. Three distinct regimes were observed: 
\( h_{\text{in}} < 0.1 \) for hard magnets, where anisotropy energy dominates and little remanence enhancement is observed; 
\( 0.1 < h_{\text{in}} < 1 \) for intermediate magnets where up to 50% remanence enhancement is observed due to the intergranular magnetic anisotropy energy; and 
\( h_{\text{in}} > 0.1 \) for soft magnets, where the dominance of magnetic anisotropy energy leads to much reduced remanence in the materials.

2:00 PM D12.2
Refractive Magnetic-Field-Induced Deformation And Magneto-Mechanical Fatigue Of Ni-Mn-Ga Ferromagnetic Martensites. Peter Mueller1, Valodyr A.Clermenko1 and Germain Kosotov1;
1ETH Zurich, Zurich, Switzerland; 2Institute of Magnetism, Kiev, Ukraine.

Magnetoplasticity, i.e., the magnetic-field-induced deformation of ferromagnetic shape-memory alloys, and its inverse effect, i.e., the deformation-induced change of magnetization, can be used for building actuators and sensors. When magnetic-field-induced strains - and more recently magnetic-field-induced stresses - have been studied intensively since 1996, information about the reproducibility and long-time stability of these properties is very limited. In this study, cyclic magneto-mechanical experiments were performed with Ni-Mn-Ga alloys exhibiting tetragonal to monoclinic phase transition. The length of the samples was measured in a magnetic field, and the magnetic-field-induced strain was evaluated as a function of the number of field cycles. More than 10^7 cycles were applied. Depending on thermo-mechanical history and the martensite structure, the deformation of the field-induced strain varies dramatically. For 7-folded orthogonal martensite, the field-induced strain can increase during cycling to 0.5% for 5-folded tetragonal martensite, while the strain can increase up to 2% for 5-folded tetragonal martensite. In 7-folded tetragonal martensite, the field-induced strain in orthorhombic martensite, the field-induced strain increases from 0.5% up to 3% for 7-folded tetragonal martensite. The different magneto-mechanical long-term stability result from differences in crystal symmetry. For tetragonal martensite with uniaxial magnetic anisotropy, there is only one preferred martensite domain (out of three) for a given field direction. Therefore, there is a

2:15 PM D12.3
Magnetization Process Associated with Rearrangement of Magnetic-Variants in Iron Based Ferromagnetic Shape Memory Alloys. Takashi Fukuda1, Tatsunori Sakamoto1, Tomoyuki Tera1, Tomoyuki Kakeshita1 and Koji Ishida2; 1Department of Materials Science and Engineering, Graduate School of Engineering, Osaka University, Suita, Osaka, Japan; 2Department of Superconductivity Engineering, Graduate School of Engineering, University of Tokyo, Bunkyo-ku, Tokyo, Japan.

Fe-31.2Pd(21%), Fe-31Pd and Fe-31Pd are ferromagnetic shape memory alloys whose transformation temperature is around 230 and 85 K, respectively. Both features exhibit a large magnetic field-induced strain (MFS) in association with rearrangement of martensite variants. Especially, concerning the Fe-Pd, a part of MFS recover spontaneously in the field remanence process. In this presentation, we show the magnetization process of Fe-31.2Pd and Fe-31Pd, and discuss the mechanism of MFS. The magnetization curves measured on the martensite state of these alloys exhibit a hysteresis between field applying and removing processes, whose area corresponds to the energy dissipated during the rearrangement of variants. The area features on the characteristics of MFS. In case a large MFS appears in the field applying process but does not recover in the field remanence process, the area is in the order of 10^3 J/m^2. This is the same order as that has been reported for Ni-Mn-Ga alloys. On the other hand, in case the MFS induced by the magnetic field recovers spontaneously in the field remanence process, the area is in the order of 10^3 J/m^2. The universal magnetocrystalline anisotropy constant is evaluated from their magnetization curves, and it is about 15 J/m^2 for Fe-31.2Pd and 77 K, and is about 350 J/m^2 for Fe-31Pd at 4 K. These values are the same order as that of Ni-Mn-Ga alloys, supporting the macroscopic explanation of MFS in ferromagnetic shape memory alloys that the MFS is caused by the magnetic field energy difference between adjacent variants under a magnetic field.

2:30 PM D12.4
Microstructure and Magnetostatic Distortion of Rapid Solidified Fe-Ga System Alloys. S. H. Kim, Y. P. Park, T. S. Oh, T. Osakab, and K. Okumari; 1Tokai University, Hiratsuka, Japan; 2Hiroshima University, Higashi, Japan; 3Graduate School of Engineering, Tohoku University, Sendai, Japan; 4Materials and Nuclear Engineering, University of Maryland, College Park, Maryland.

It was reported that melt-spinning, rapid solidified Fe-Ga ribbon sample exhibited large magnetostriction and good ductility as compared with conventional bulk sample. In order to relieve the large magnetostriction in Fe-Ga ribbon sample, the correlation between magnetostriction and the crystal grain morphology has been investigated characterized by X-ray diffraction and transmission electron microscopy. It is shown that the large magnetostriction is caused by the presence of considerable large internal stresses in as-ribbon sample as well as the remanent stress in the ribbon. The following conclusion was obtained. 1. Fe-Ga rapidly solidified ribbons consist of many low angle grain boundaries and strong texture. 2. Texture is formed in near [110], and that is concentrated by short-time heat treatment. 3. Largest magnetostriction occurs in short-time heat treated Fe-15%Ga ribbon. That result is obtained from both internal stresses and strains oriented parallel to [110]. Bulky Fe-Ga actuator/preform materials have been developed by combining the used rapid-solidified ribbons with spark plasma sintering methods. The features of Fe-15%Ga ribbon, the origin of intrinsic stresses, and the methods to relieve the intrinsic stresses are described. The present study was performed by J. A. Clark, J. B. Reycastle, M. W. Fogle, T. A. L. Gleason, D. Schlegel, IEEE Trans. Magn. 36 (2000) 2, 2, T. Ishigaki, C. Sun, T. Okumari, JIM 66 (2002) 901-904 (in Japanese).

2:45 PM D12.5
Magnetostatic Field-Structured Composites. James E. Martin1, Robert A. Anderson2 and Gerald Gallay3,1; 11122, Sweden National Labs, Albuquerque, New Mexico; 2Physics, Dominican University, River Forest, Illinois.

Field-structured magnetic particle composites are an important new class of materials that have great potential as both sensors and actuators. These materials are synthesized by suspending magnetic particles in a polymeric resin, subjecting these to magnetic fields while the resin polymerizes. If a simple uniaxial magnetic field is used,
the particles will form chains, yielding composites whose magnetic susceptibility is enhanced along a single direction. A biaxial magnetic field, component of a polycrystalline composite, can be used to enhance the magnetic properties of the composite. The magnetic field is parallel to the direction of the chain. The magnetic properties of the composite are enhanced along the direction of the chain.

2:30 PM D12.6 Development of Stress Sensors Based on Magnetostatic Tunneling Juncions, Markus Loehndorf, Stefan Kupulig, Manfred Buchegger, 1Joachim Wecker and Eckhard Quandt; 2Cesce, Center of Advanced European Studies and Research, Bonn, Germany; 3Ceramic Technology, Siemens AG, Erlangen, Germany.

Micromachined highly sensitive strain sensors are presented. The sensors are based on magnetic tunneling junctions (MTJs) incorporating magnetostatic free layers. Ultra-thin, nearly zero-magnetostatic soft magnetic materials are chosen as free layer, in order to avoid interaction caused by stress or strain. In this study, however, we have intentionally used highly magnetostatic materials and alloys as free layers to fact showing the governing strain sensitivity. Results for magnetostatic Fe50Co50 materials or amorphous CoCr or Fe-based alloys serving as sensing (or free) layers are discussed in view of possible applications. In addition, MTJ-based sensor devices have been prepared upon polymer substrates. As a result, MTJ with magnetostatic free layers show gauge factors on the order of 600 which are a factor of 3 better than silicon based strain sensors.

4:40 PM D12.7 High frequency devices with integrated magnetoelastic materials, Michael Frommberger and Eckhard Quandt; smart materials, cesce, Bonn, Germany.

A wireless mechanical stress sensor based on thin films showing the inverse magnetostatic effect will be presented. The magnetostatric films are incorporated in the inductance L of an electrical LC resonator [1,2]. The magnetic field from the film is measured using inductive sensors for wireless measurements of mechanical quantities such as stress or force on rotating or hidden objects. The operating frequencies can be up to several GHz limited by the ferromagnetic resonance frequency of the used materials. We have fabricated a stress sensor based on soft magnetic magnetostatic FeCoBi thin films which has been fabricated and characterized. In a bending test jig, the sensor shows a high sensitivity exceeding most commercial available strain gauge elements. This sensor can be used in a wide range of different applications of wireless measurements of mechanical values. Besides the optimization of the sensor layout with regard to the desired frequency range future research efforts will also focus on improving the different sensor parameters and the continuation of high frequency magnetic material development suitable for those applications. Our current efforts in material design and process development will be presented and their benefits will be discussed.

8:30 AM D12.3 Ferromagnetic Shape Memory Alloys: Recent Advances, R. C. O’Handley1, S. M. Allen1, S. P. Henry2, M. Marion3, M. Richards, J. Fuchsmaier1, B. Peterson1, D. Bono1, J. K. Hurung1, D. I. Piel1, J-X J Lin1,3, Robin Ives1, Ryan Wages3, Catherine Jenkins1 and Keli Griffin1; 1Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts; 2Department of Electrical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Ferromagnetic shape memory alloys (FSMAs), most notably those based on Ni-Mn-Ga, have received considerable attention because of the remarkable 6 to 9% field-induced strains they have exhibited at room temperature in magnetic fields of order 0.5 T. The stress above which the field-induced strain in FSMAs is blocked is currently 2 to 4 MPa. This is to be compared to blocking stresses of over 100 MPa and several tens of MPa for piezoelectric and magnetostrictive materials. Recent progress in understanding and using these materials will be reviewed. Ni-Mn-Ga samples that show relatively easy twin boundary motion near room temperature fall in a narrow composition range that includes both tetragonal and orthorhombic martensites. FSMa samples measuring several mm on edge show a bandwidth of approximately 1 to 10 GHz for continuous wave excitation or pulse excitation, respectively. Application of submillisecond field pulses of amplitude greater than the anisotropy field (about 0.6 T) do not induce greater strain, but only increase the stress at which full strain is achieved. While the curves of strain versus alternating field amplitude appear smooth, studies of individual twin boundary motions show them to be highly irregular.

Because actuator applications seem appropriate for Ni-Mn-Ga FSMAs given the large values of $d_{15}$ and $d_{33}$, significant efforts have been aimed at developing small samples, valves and underwater transducers. The large equal values of $d_{15}$ and $d_{33}$ in Ni-Mn-Ga suggest sensor applications, but there is no published work directed toward these goals. The large hysteresis associated with twin boundary motion has been exploited to demonstrate superior vibration suppression in Ni-Mn-Ga-loaded composites compared to Teflon-loaded polymers.

SESSION D13: Materials and Devices for Smart Systems
Chair: Yasumoto Fujaya and Eckhard Quandt; Friday, December 6, 2003; Room 202 (Hyne's)

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9:00 AM D13.2 Fundamental Investigation Of Ferromagnetic Shape Memory Alloys - In - Situ Study Of Temperature Dependent Magnetic And Thermo-Elastic Correlated Behavior. Matthew R. Sullivan¹, Daniel A. Ayres¹, Steven Pizziotta¹, Ashali A. Shah¹, G. H. Wilo¹ and Hanqiang Qian². ¹Martin Physics and Materials Science, University of California, Los Angeles, USA; ²School of Aeronautics and Astronautics, University of Delaware, Newark, Delaware, USA. This work was supported by the Department of Energy, Office of Basic Energy Science, and monitored by DOE Grant No. DE-FC03-01ER45990.

Ferromagnetic shape memory alloys (SMAs) belong to a class of complex correlated systems whose physical properties depend on interaction across two or more energy regimes - magnetic and thermodynamic. In the case of ferromagnetic SMAs, this talk will focus on results obtained from experiments in which the microstructural, structural, domain dynamics and thermodynamic properties of these alloys were measured and observed in situ and at the same time. The simultaneous study of these properties has provided a fundamental understanding of some key issues that govern the properties of these alloys. The talk will focus on results obtained from oriented single crystals of Ni-Mn-Ga and Fe-Pt. Some key results include formation and dynamics of magnetic vortices at the parent (martensite) product (martensite) phases, which provides clear evidence that the length scales of magnetic domains are a function of the lattice parameters of the martensite phase. Additional clear evidence is found of a series of magnetic and structural transformations, as well as precursors just above the martensite transformation temperature. Finally, from a practical viewpoint, these results directly pinpoint the origin of high coercivity, as an issue of practical concern as high loads and high temperatures are needed for low switching fields and coercivity. This work was supported by DOE Grant No. DE-FC03-01ER45990, Office of Basic Energy Science, and this support is gratefully acknowledged.

9:30 AM D13.3 Synthesis And Characterization of Sputtered Fe-Pt Based Alloy Thin Films. Jun-Young Park¹, T. Mihalasoglu¹, S. P. Wang² and K. Inoue¹ ¹Institute of Materials Engineering, National Taiwan Ocean University, Keelung 202, Taiwan; ²Department of Physics, Amity University, Noida-201307, India. This work was supported by the National Natural Science Foundation of China (Grant No. 50671076) and the Ministry of Education of China. A new approach to develop high-performance magnetic Fe-Pt alloy thin films, which is important for many high-technology electronics and magnetic devices. The Fe-Pt alloy thin films are prepared by the MBE technique on silicon wafer substrates. The deposited films are annealed between 400 and 800 °C in order to transform the soft magnetic FePt phase to the hard magnetic FePt phase. The effects of film composition and annealing temperature on the magnetic structure and magnetic properties of Fe-Pt alloy thin films are investigated in detail. X-ray diffraction studies on annealed Fe-Pt thin films revealed the presence of a single and FePt phase, and the structural properties of Fe-Pt were determined. The microstructure analysis of the Fe-Pt thin films was performed using high-resolution transmission electron microscopy (HRTEM) and energy-dispersive X-ray spectroscopy (EDS). The structural properties and magnetic properties of the Fe-Pt thin films were investigated using a vibrating sample magnetometer (VSM) and a superconducting quantum interference device magnetometer (SQUID). The magnetic properties and structural properties of the Fe-Pt thin films were found to be dependent on the composition and annealing temperature. The Fe-Pt thin films show high magnetic saturation and excellent magnetic stability, which makes them suitable for magnetic data storage applications.

10:00 AM D13.5 Thermal Analysis And X-Ray Diffraction Study Of Ferromagnetic Fe-Pt-Pd-Based Shape Memory Alloys. Guowei Sun¹, Yuning Yang², Reid Jonassen³, Seung-oung Bae¹, Shozo Inoue⁴, Kimmo Murań⁵, Keiji Koteraśn⁶, Soo-jong Jeong⁶, Kyosuo Mizuči⁷ and Kenjiro Inoue⁸. ¹Fukushi Central University, Fukushiii, Japan; ²Materials Science and Engineering, Chosun University, Kwangju, South Korea; ³Materials Science and Engineering, University of Washington, Seattle, Washington; ⁴Mechanical and Intelligent Engineering, Himeji Institute of Technology, Himeji, Hyogo, Japan; ⁵Kobe Material Testing Lab. Co., Hiyogo-ku, Kobe, Japan; ⁶Korean Electric and Magnetic Devices Group, Korean Electrotechnology Research Institute, Changwon, South Korea; ⁷Osaka Municipal Technical Research Institute, Osaka, Japan.

Ferromagnetic shape memory alloys have received considerable attention in the past several years due to their potential in applications such as high-performance magnetic actuators. However, the development of magnetic shape memory alloys has been limited by the presence of magnetic domains. In this study, we investigated the effects of Fe-Pt-Pd alloys on the magnetic and shape memory properties of Ni-Mn-Ga and Fe-Pt-Pd alloys. The magnetic properties of Ni-Mn-Ga and Fe-Pt-Pd alloys were studied using magnetic force microscopy and x-ray diffraction. The magnetic properties and shape memory properties of the alloys were found to be dependent on the composition and annealing temperature. The Ni-Mn-Ga and Fe-Pt-Pd alloys show high magnetic saturation and excellent magnetic stability, which makes them suitable for magnetic data storage applications. The magnetic properties and structural properties of the Ni-Mn-Ga and Fe-Pt-Pd alloys were found to be dependent on the composition and annealing temperature. The Ni-Mn-Ga and Fe-Pt-Pd alloys show high magnetic saturation and excellent magnetic stability, which makes them suitable for magnetic data storage applications.
without magnetic field. The compound compositions used were around 70.25% Mg, 25% Zn, and 4.75% S, where the transition occurred near room temperature. It was found that triggering stress is lowered when deformed under constant magnetic field at temperatures below M_s, while such stress is little affected when deformed at temperatures above M_s. In the former case the compound could be deformed repeatedly without failure, showing ductile behavior, whereas in the latter it failed after several cycles of deformation. The ductile and brittle behavior appears associated with the readiness of reorientation of martensite variants. Magnetic field effect on stress was also investigated under constant stress and it was found that there is a threshold stress, above which magnetic-field-induced strain increases linearly with magnetic field when deformed at temperatures near M_s. This magnetic-field-induced stress-assisted strain is irreversible at the experimental conditions used.

11:00 AM DI3.7
Coupled Magneto-Mechanical Modeling of Ferromagnetic Particle Reinforced Composites, Linh Sun and H.M. Yin; University of Iowa, Iowa City, Iowa.

The objective of this work is to investigate effective magneto-mechanical behavior of composites containing aligned ferromagnetic particles. We first solve the local magnetic field, magnetic force and elastic field for pair-wise interacting magnetic particles embedded in the infinite domain subject to applied magnetic and mechanical loads. We further derive the effective (homogenized) magnetoelastic properties and effective magnetostriiction of the composites. For magnetoreological elastomer, the configuration of the microstructure changes when a magnetic field is applied, leading to the magnetic loading due to the small elastomer's stiffness, so the local magnetic field and elastic field are fully coupled. This model accounts for the coupled magneto-elastic interaction and pair-wise interaction between particles. We find that the effective properties of the composite can be expressed in terms of effective magnetic permeability and effective elastic modulus. The effective permeability and effective elastic modulus depend on the distribution of magnetic field, the applied magnetic field, the applied mechanical load, the magnetic alignment of magnetic field, and the magnetic alignment distribution of the particles.

SESSION DI4: Sensor Materials and Devices Chair: Yasutami Furuta and Minoru Taya Friday Afternoon, December 5, 2003
Room 203 (Hynes)

1:30 PM DI4.1
Piezoelectric Properties of Ceramic Strain Gages with Controlled Nanoporosity, Otto J. Gregory and Yao You; Chemical Engineering, University of Rhode Island, Kingston, Rhode Island.

A ceramic strain gage based on reactively sputtered indium-tin-oxide (ITO) thin films is being developed to monitor the structural integrity of components employed in advanced aerospace propulsion systems that operate at temperatures in excess of 1500°C. Electrical and chemical stability is particularly critical in these harsh environments, since these ceramic strain gages must survive tens of hours of strain testing at elevated temperatures. SEM images of the surfaces of these strain gages after high-temperature exposure revealed a partially sintered microstructure consisting of a continuous network of nanosized ITO particles with well-defined necks. Electrical conduction across the surfaces of these continuous ITO particles resulted in a very stable and large piezoelectric response at temperatures as high as 1575°C. It appeared that densification of the ITO particles was retarded during high-temperature exposure with nitrogen playing a key role in stabilizing the nanoporosity. To prepare this nanoporous ITO, sputtered ITO films were subjected to a post deposition anneal at 700°C in nitrogen and subsequently exposed to high temperature. Based on these preliminary results, ITO strain sensors were reactively sputtered in various nitrogen/oxygen/argon environments. SEM and AFM indicated that although the microstructures of these nitrogen-sputtered films were similar in appearance to those produced by a post deposition anneal in nitrogen, the average pore size and particle size were an order of magnitude smaller. It appears that nitrogen was metastabally retained in the individual ITO grains during sputtering and diffused out of the bulk grains at elevated temperature, eventually becoming trapped at grain boundaries and triple junctions. Under these conditions, sintering and densification of the ITO particles containing these nitrogen-rich grain boundaries was retarded and a contiguous network of nanosized ITO particles was established. Static strain testing of the nitrogen-sputtered ITO strain sensors indicated that a similarly stable and responsive strain gage could be fabricated using this approach. The high-temperature-piezoelectric behavior of ITO strain gauges prepared with controlled nanoporosity is presented within and the potential impact on other types of ceramic sensors will be discussed.

2:00 PM DI4.2
Development of a New Design of Immunosensor for the Rapid Detection of Pathogens, Eric Carnes and Etkin Wilkins; Chemical and Nuclear Engineering, University of New Mexico, Albuquerque, New Mexico.

A portable, flow-through amperometric immunosensor system utilizing a newly designed immunosensor has been developed for the detection of pathogens. A sandwich scheme of immunosensor involving two stages of immunosorption was employed using Bacterioides as an immobilized in an agarose gel. E. coli antibodies were immobilized on Torgy carbon paper to create a disposable immunofiltration membrane. Detection of the bacteria was achieved by the horseradish peroxidase-labeled antibodies, which, when coupled with a substrate of hydrogen peroxide and sodium iodide, were measured amperometrically at a potential of +0.15 V. The immunosensor is highly sensitive and selective. Its use in a disposable immunofiltration membrane that also functions as an immobilized enzyme, which enhances the rate of the immunoreaction due to the high surface to volume ratio of the solid to liquid phases.
230 PM D14.5 Accelerated Reliability Test inputs in analyzing the device response of MgZnO based UV Detector, Shrin S Hullurand1, Ishiro Takewah1, Tirimulah Venkatesam1, Ratnakur Vispute5, and Sharad Yadav1,2; Center for Superconductivity Research, University of Maryland, College Park, Maryland; 3Blue Wave Semiconductors, Inc, Columbia, Maryland.

Ultraviolet (UV) light sensors is an essential component of UV light detection and monitoring required in a variety of commercial applications such as medical imaging, radiation detection of materials, fire detection, lithography, data storage as well as for defense applications. MgZnO is found and shown to exhibit immense potential in this area as a tunable UV sensor due to its desirable optical and electrical properties. In this work, we present the fabrication of MgZnO based Metal Semiconductor-Metal (MSM) UV sensor and address its stability issues. MgZnO is grown by pulse laser deposition (PLD) on three different substrates viz., glass, quartz and sapphire. X-ray diffraction and Raman scattering measurement are performed to study the crystallographic and the optical nature of the films. Standard photolithographic and lift off techniques are used to define MSM patterns on the device quality MgZnO films. Photo-response of the device is monitored by photomultiplier and lock-in-amplifier combination set up. Device stability and performance is examined under accelerated conditions of prolonged UV exposure.

245 PM D14.6 a large grain polycrystalline silicon film for resistive bolometer, Tae-Sik Kim and Hee Chul Lee, EE & CS, KAIST, DAEGUN, South Korea.

Bolometers, uncooled IR detector, based on vanadium oxide (VOx) and amorphous silicon (a-Si) films have been studied all over the world for a long time. These films have large temperature coefficient of resistivity [TCR] of -3%/K, however, their reproducible properties and dioxide form without some hysteresis. Although the fabrication process for bolometer made with a-Si film is CMSO compatible and its TCR value is around -2.2%/K for a resistivity of 80kΩ, a-Si films exhibit large 1/f noise, thereby yielding a decrease of detectivity. In this paper, we have investigated large grain polycrystalline films for such resistive materials of bolometers as alternative to a-Si. These a-Si films are much more stable material than VOx and a-Si films and CMSO technology can be used to fabricate polycrystalline-based bolometers. In comparing with a small grain polycrystalline film, a large grain polycrystalline film has properties as follows: First, the TCR of the film theoretically increases in proportion to the increase of the grain size of the film. Second, we can obtain a polycrystalline film with fewer grain boundary defects, which lead to a decrease of the 1/f noise of the film. Last, the large grain polycrystalline film shows less dependence of resistivity on the variation of the doping concentration; therefore, it is easy to obtain required resistivity in the film. The achieved average grain size was as large as 1670nm using a seed selection through ion channelling technique. Its resistance at 150°C and cdc20 K is calculated as high as 2.46%/K for a resistivity of 310kΩ and to be about 1.75x10^10/cm^2, respectively. The 1/f noise parameter, was calculated to be 1.53x10^-6. From the above results, the estimated detectivity was found to reach up to 5x10^13cmHz^1/2/W.

3:30 PM D14.7 Self-Assembled Membranes Based on Humic Acid for Controlled Detection of Glucose in Implantable Biosensors, Ritesh Tiwari1, Siddhesh D Paw1, Dinne J Burgess2, Usaqur Jain3, and Eros Panagiotakopoulos1; 1Nanostructures Optoelectronic Laboratory, Department of Chemistry, Polymer Program, Institute of Material Science, University of Connecticut, Storrs, Connecticut; 2Department of Pharmaceutical Sciences, University of Connecticut, Storrs, Connecticut; 3Department of Electrical and Systems Engineering, University of Connecticut, Storrs, Connecticut.

Implantable biosensors are an important way to continuously monitor blood glucose levels. However, their potential applications remain unexplored due to the negative tissue responses such as biofouling, inflammation, tissue fibrosis, and calcification generated by the implantation of such devices thus leading to device malfunctioning and eventually failure. We report here on development of a semi-permeable membrane, which can prolong the life of glucose sensors, while preventing related failures. Our group has previously shown that the layer-by-layer self-assembly of humic acid (HAs), a naturally occurring biopolymer, with ferric ions can provide for the timely growth of a biocompatible, calcification resistant film, over the previously employed Nafion® based membranes. Modified sensors based on glutaraldehyde stabilized glucose oxidase were modified with a varying number of self-assembled layers. For this, the pH was carefully monitored to import the desired control over the thickness and permeability of HAs/FexOy films. This enabled us to overcome the previous impediment over enzyme deactivation due to the acidic nature of Fe(III) ions and obtain long-lived glucose sensors while maintaining current linearity over physiological and pathogenic glucose levels. Furthermore, we are currently working towards fabricating a miniaturized, CMOS-based sensor which would be completely autonomous and can be integrated subcutaneously to eliminate the presence of an open wound for feed-through electrodes. Acknowledgements: Department of Defense, US Army Medical Research. Grant # DAAD17-02-1-0713.

3:45 PM D14.8 Merging Micro- and Nano-Technologies: Advanced Gas Sensors for an Intelligent Air Quality Monitoring Network, Marie-Isabelle Baron1 and Ihab Meflah2; 1SPECT'S UMR CNRS 6088, University of Limoges, Limoges, France; 2CERAMEC R&D, Limoges, France.

The growing concern worldwide about the consequences of urban pollution on public health has generated an increasing demand for outdoor air quality monitoring. In the framework of two European projects, we have proposed a new concept for cost-effective outdoor air quality monitoring based on a dense network of mobile microsensors. These microsensors mounted on GPS-tracked public transportation vehicles wirelessly communicate with a central computer via the GSM network and are equipped with advanced semiconductor chemical sensors in order to decrease both the cost and the size of the system. The development of our advanced chemical sensors benefited from three major research directions: 1) use of semiconductor nanoparticles in the screen-printing fabrication technology; 2) development of micro- and nano-layer deposition technique for further increase of gas sensor sensitivity; 3) control and tailoring of surface chemistry of nanoparticles. We present here some of our consolidated results concerning the characteristics of the nanosized particles and their response to gas sensing. As well as by various methods such as XRD, TEM, FTIR, and electrical measurements. We explain how our prototype devices which are capable of detecting O3 and NO2 concentrations down to 20ppb and 50ppb respectively, and CO concentrations down to 3ppm in air, can be used as sensing elements in an intelligent air quality monitoring network. The SMOGLESS and INTARNET projects were financially supported by the European Community (contracts No. BRPR-CT96-0092, and IST-1 2015).


Sensing gas molecules is critical to environmental monitoring, control of chemical processes, saving energy, and safety in life. Gas sensors using semiconducting metal oxides such as tin oxide has been used practically as home gas leakage monitors. Such the sensors working by change mechanism due to the decreasing of semiconductor activity of this principle. The lack of gas selectivity, e.g. between CO and H2 gases, has been regarded as a problem to be solved. The improvement of selectivity requires a careful study of the surface reactions at the origin of the gas detection mechanisms. Here we demonstrate gas sensors based on SnO2 films hybridized to organic component with hydroxyl or amino groups. Upon exposure to CO gas, the electrical resistance of the sensor increases (K-increasing response), whereas other interfering gases such as H2 and CH4 gases cause the decreasing in the sensor resistance due to the ordinary combustion mechanism. The SnO2 films hybridized to organic component without hydroxyl or amino groups do not show the K-increasing response to CO gas. Interaction between the hydroxyl or amino groups of the organic component and SnO2 surface could be affected by CO gas, which works as switching to change the sensor resistance. We expect that our approach can provide highly selective gas sensors.


Organic electronic devices have enormous potential for various applications due to their chemical and electronic similarity, mechanical flexibility, processability, and low cost. In this talk, we will discuss the field effects in the organic electronic materials and their applications for gas and bio-sensor applications. Pentacene thin film transistors with 100 μm channel lengths were fabricated on Si substrates with 300 nm SiO2 as the gate dielectric. Our studies show that the characteristics of these transistors are sensitive to the relative humidity of the surrounding atmosphere. Their sensitivity was found to depend on the thickness of the
pentacene film. The origin of the humidity effects in a change of pentacene film mobility. We will also discuss an unusual field effect in conducting polymer poly(ethylene dioxythiophenoxy)-poly(vinylenesulfone) (PEDOT-PSS) and the application of these transistors in DNA sensing. The advantages of the PEDOT-PSS devices include high sensitivity and low gate voltage.

4:30 PM D14.11

Metal-containing diamond-like carbon-silicon nanocomposite films as temperature sensors. Toshikazu Takagi1, Alexei Borisov2, Takahito Takeshita1 and Mikhail Shchipanov3. 1Institute of Fluid Science, Tohoku University, Katahira 3-2-1, Aoba-ku, Sendai, Japan; 2Moscow State University, Moscow, 119992, Russian Federation; 3Moscow Power Engineering Institute, Moscow, 105835, Russian Federation.

The transition metal-containing diamond-like carbon-silicon nanocomposites are characterized by the stability to the aggressive environments and possess attractive mechanical properties, such as high hardness and wear resistance, low friction. The variation of the metal concentration allows to change the conductivity of the nanocomposites in the wide range. The possibility of the application of metal-containing diamond-like carbon-silicon nanocomposite films as advanced temperature sensors with controlled temperature response was studied. W- and Nb-containing diamond-like carbon-silicon nanocomposite films were deposited onto dielectric polycrystalline substrates by PECVD of silicones vapours in DC stimulated discharge and DC magnetron co-sputtering of metal target. The RF bias voltage was applied to the substrate holder during deposition of the films. It was shown that the conductivity of diamond-like carbon-silicon nanocomposite films containing both W and Nb decreases with temperature and follows the power law dependence. The decrease of metal concentration leads to rather sharp increase of the power exponent in the range from 0.3 to 0.7. Such temperature dependence of the conductivity corresponds to the electron transport mechanism being described by the inelastic electron tunnelling between metal nanoclusters dispersed in an insulating carbon-silicon matrix with high degree of disorder. The absolute value of the dimensionless sensitivity defined as dS/dT, where S is the conductivity and T is temperature, demonstrates the dependence on the temperature close to the linear one in the investigated temperature range and increases from 0.12 to 1 with metal concentration. The experimental data obtained show the principal possibility of the fabrication of the wide temperature range thermometers, which retain their functionality under extreme environmental conditions.

4:45 PM D14.12


Reactions between crystalline Si surfaces and chemical species that lead to modification of the Si surface barrier offer an exciting opportunity for chemical sensing [1]. In order to explore this concept, high quality Si wafers were exposed at room temperature to aqueous solutions of inorganic acids and bases, and then the surface potential was measured in a non-contact, non-destructive fashion using the Surface Photovoltage (SPV) [2]. The SPV signal was obtained by illuminating the Si surface with monochromatic light (wavelength > Si bandgap) and it was measured with a transparent, conducting electrode placed above the Si surface. The change of the surface potential barrier was clearly related to the type of chemical species and their concentration. It was also dependent on the Si orientation and the microscopic topography of the Si surface. In addition, the SPV signal was dependent on the wafer cleaning process that preceded the experiment. Relatively small changes in the concentration of chemical species, especially within the low concentration range, caused large changes of the SPV signal, demonstrating high sensitivity. Repeated cycles of acid and base exposure showed that the surface reactions were reversible and that the SPV signal cycled between the base-specific and acid-specific values, thus showing that the sensing device can be reused many times. In order to further enhance the SPV signal, the Si surface was intentionally terminated with a layer of selected organic or inorganic molecules. This termination had two purposes: it provided stable surface termination, and it offered the possibility of selective binding of only specific molecules. Preliminary results indicate that proper choice of the binding layer can make the SPV chemical sensing highly selective with respect to a large number of chemical species. The simplicity of the SPV measurement setup indicates that SPV-based chemical sensors can be easily miniaturized and cheaply produced in a compact form [1]. J.M. Burik; Chem.Rev.102, 1271 (2002). [2] K Naunak, T.I.Kamins, J Electrochem.Soc. 146, 292 (1999).