SYMPOSIUM B

B: Materials, Integration, and Packaging Issues for High-Frequency Devices

December 1 - 3, 2003

Chairs

Yong S. Cho
Microcircuit Materials
DuPont Electronic Technologies
14 TW Alexander Dr.
Research Triangle Park, NC 27502
919-248-5160

Paul Muralt
Engineering Faculty
Swiss Federal Institute of Technology
Ceramics Lab
Lausanne, CH-1015 SWITZERLAND
41-21-693-4957

J-P. Maria
Dept. of Materials Science and Engineering
North Carolina State University
Research Bldg. One
1001 Capability Dr.
Raleigh, NC 27695
919-513-2843

Clive A. Randall
Pennsylvania State University
144 Materials Research Lab
University Park, PA 16802
814-863-1328

Christian Hoffmann
Microwave Ceramics/Modules
EPCOS OHG
Siemenstrasse 43
Deutschlandsberg, A-8530 AUSTRIA
43-3462-800-2585

Mareike Klee
Forschungslaboratorium Aachen
Philips GmbH
Weisshausstr. 2, D-52066 GERMANY
49-241-6003-324

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of the Materials Research Society
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* Invited paper

SESSION B1: LTCC
Chair: Clive A. Randall
Monday Morning, December 1, 2003
Room 201 (Hynes)

8:30 AM *B1.1
LTCC Material Systems for Automotive and RF applications. Christopher R Needes, Carl B. Wang, Kenneth W. Hang, Michael F. Barker, Patricia T. Ollivier, Yueli Wang, K. Manikantan Nair and Daniel I. Amey; DuPont Company, RTP, North Carolina.

The broadening portfolio of low-temperature cofired ceramic technology continues to strengthen its position as a relevant and competitive packaging option for RF and automotive circuit applications. Various platforms exist which, in combination with enablers such as photoformable and platable conductors, thin tapes, embedded high k dielectric and resistor materials, thermally-conductive metal vias and planes, allow the design and manufacture of circuits with a diversity of function. Furthermore, the routing flexibility that comes with an increased number of available planes, and the preservation of positional tolerance brought about by zero-shrink processes, allows design of smaller individual circuit sizes and substantially increases the practical area of the base substrate. These two factors have a profound impact on reducing circuit cost. This paper discusses the major materials systems behind the current tape platforms and the embedded passive materials. It also discusses conductor enhancements including photoformable, platable and thermally-conductive materials as well as real solutions to the thermal-cycled resistance of solder joints. Finally the concept and practice of zero-shrink processes are reviewed and examples of processes that can be used to achieve this are compared and contrasted.

9:00 AM *B1.2
Electronic Packaging with Low Temperature Co-fired Ceramics - Critical Processing Issues. Gary L Messing[1], Aravind Mohanram[2], David J Green[2] and Sang-Ho Lee[2]; [1]Center for Dielectric Studies, Materials Science and Engineering, Pennsylvania State University, University Park, Pennsylvania; [2]Pennsylvania State University, University Park, Pennsylvania.

Low temperature co-fired ceramics (LTCC) have opened numerous possibilities for miniaturization and the integration of passive components into a single electronic package. A number of companies have designed a suite of glass-based materials with uniquely low dielectric constant, loss tangent and a low temperature sintering range of 850-900oC. To date few design rules exist to guide the co-sintering of LTCC packages containing metallization and passive components. Differences in the sintering stain rate of the components lead to dimensional changes during sintering and consequently result in camber or warpage. Understanding and determining how the viscosity of the individual components changes during sintering is essential for designing the sintering process and tailoring materials to avoid such dimensional changes. Cyclic loading dilatometry (CLD) and isothermal CLD (ICLD) were used to determine the viscosities of commercial LTCC systems and components. The irregular changes in viscosity are shown to originate from the effects of temperature, density, filler concentration and crystallization. With this data we demonstrate both theoretically and with real time video of co-sintering systems, how viscosity differences lead to stress evolution, and thus, dimensional and shape changes during sintering. An important conclusion from this work is that a large viscosity difference results in constrained sintering. That is, the high viscosity component limits or constrains the sintering of the lower viscosity sintering component(s) to the axial direction only. Industry has recently introduced the concept of applying a surface mounted or embedded non-sintering layer to limit shrinkage in the lateral (x-y) axis to <1%. While the constraining layer is elastic, the viscous LTCC layer shows different sintering behavior based on its viscosity. We report on a series of theoretical and experimental analyzes to explain how constraining layers can be designed to yield camber-free packages of high dimensional tolerance.

9:30 AM *B1.3
Dielectric Materials Development for Low Temperature Co-fired Ceramics. Mike Lanagan, Elena Semouchkina and Clive Randall; Materials Research Institute, Penn State University, University Park, Pennsylvania.

With the rapid progress of wireless communication systems, the development of low temperature co-fired ceramics (LTCC) becomes more important for the passive components and packaging industry. In particular, LTCC for high frequency applications require dielectric materials with low loss and stable temperature coefficient of capacitance (TCC) as well as low sintering temperature that is compatible with low loss conductors such as silver (Ag) or copper (Cu). Ceramics with higher dielectric constant (k) than conventional LTCC, typically $5 < k < 10$, are required for further miniaturization of embedded capacitor components and resonators. Two candidate dielectric materials will be discussed for LTCC applications. Bi-based pyrochlores have low TCC values and dielectric constants in the 40 to 150 range. Prototype band-pass and low-pass filters have been fabricated by co-firing Bi-based pyrochlore ceramics with silver. A second material system, AgNbO3-AgTaO3 solid solution, has dielectric constant of 400 and low loss in the microwave frequency range. A low TCC capacitor structure was demonstrated by co-firing with silver electrodes. The microwave dielectric properties were characterized up to 20 GHz. Mixed dielectric structures are useful for microwave filters, antennas, and delay lines. A low dielectric constant matrix provides for high-speed interconnect and impedance matching. High dielectric constant materials are inserted into the low-k matrix for device miniaturization. The spatial distribution of high-k and low-k materials within a composite structure is optimized by a Finite-Difference-Time Domain (FDTD) computer model, which elucidates the electromagnetic wave propagation through the composite structure. The FDTD model provides the locations of electric field maxima within a dielectric structure and high-k materials are placed at these electric field maxima. In addition, frequency tunable structures are proposed which take advantage of placing high dielectric constant materials in the high electric field regions of an LTCC structure.

10:30 AM *B1.4
Wireless and RF Module Packaging using Low Loss Ceramic and Low Loss Organic Materials. James J Logothetis[1], Daniel I Amey[2] and Timothy P Mobley[2]; [1]Merrimac Industries Inc., West Caldwell, New Jersey; [2]DuPont Microcircuit Materials, Research Triangle Park, North Carolina.

High speed digital and high frequency wireless applications are resulting in the emergence of new interconnecting substrate and package materials to meet the needs for higher density, lower power, improved thermal conductivity, stable physical properties, environmental friendliness and lower cost. However, it can be difficult for any one material system to meet all of these demands. Both organic printed wiring and ceramic material solutions offer high-density packaging and interconnection with stable dimensional and electrical properties over a broad frequency range. Integrated passive components and functions in ceramic are in volume production *today* for wireless/RF and high-speed digital applications. Multi-Mix® is an organic technology based on etched copper conductors and PTFE composite dielectric layers that are fusion bonded to form homogeneous multilayer structures. The bonded layers may incorporate, resistors, thick metal heat-sink layers, via holes and vertical matched-impedance structures, passive circuit elements, and embedded semiconductor devices as well as LTCC modules. The multilayer, microwave integrated modules formed using this technology can be as small as 0.2 inches square, and multifunction modules as large as 16 x 22 inches. Green Tape™ LTCC (Low Temperature Cofired Ceramic) is a system consisting of glass ceramic dielectric compositions in a tape format and high conductivity via and conductor metalizations. The technology produces hermetic multi-layer interconnection structures (substrates, packages, modules) with very uniform and stable frequency and temperature dependent properties. A design approach combining the technologies offers the designer new options to meet the ever-increasing demands of high frequency packaging. This presentation will describe the basics of Multi-Mix® and Green Tape™ LTCC materials. The performance of a 25 GHz mixer design using a GaAs MMIC, a 943 Green Tape™ package with embedded capacitance on a multilayer laminate structure will be described demonstrating the tradeoffs, advantages and compatibility of the technologies.

11:00 AM B1.5
Design Guidelines for Co-firing LTCC Systems Based on Dynamic Viscous Behavior. Aravind Mohanram[1], Gary L Messing[2] and David J Green[3]; [1]Materials Science and Engineering, Penn State University, State College, Pennsylvania; [2]Penn State University, State College, Pennsylvania; [3]Penn State University, State College, Pennsylvania.

Low temperature co-fired ceramics (LTCC) technology is widely considered the packaging solution for future wireless applications. Commercially available LTCCs are of two types, ceramic-filled glasses and crystallizable glass systems. Constitutive models are available that predict their high temperature sintering (densification) and creep deformation behavior and these models require mechanical properties, such as viscosity, to be determined. Furthermore, in order to achieve optimum firing behavior by materials design, data on viscosity and understanding how it changes during firing is important. In this work, commercial LTCC systems, such as DuPont 951 Tape, Heraeus CT2000 and Ferro A6, have been characterized for their uniaxial viscosities using constant heating and isothermal cyclic loading dilatometry (CLD). A complex set of intrinsic and extrinsic factors influence viscosity and these are interdependent. The base glass composition and structure constitute the intrinsic factors. The extrinsic factors include porosity, temperature, volume fraction and size of ceramic fillers, glass crystallization, firing rate and percolation phenomena. These factors may lead to opposing behavior. For example, the viscosity decreases with temperature and increases with density. Further, for systems that undergo crystallization, the viscosity increases with decrease in the heating rate. The paper focuses on the interplay between intrinsic and extrinsic factors, as interpreted from chemical, mechanical and thermal analysis data, and how they affect the mechanical behavior of LTCC systems. Based on these analyses, guidelines for tailoring the sintering properties of LTCC systems are proposed.

11:15 AM B1.6
Material Issues of LTCC Fine Pitch CSP Design.
Megan M. Owens, Joseph W. Soucy, Thomas F. Marinis, Kevin A. Bruff and Henry G. Clausen; Electronics Packaging and Prototyping Division, The Charles Stark Draper Laboratory, Inc., Cambridge, Massachusetts.

LTCC substrates for fine pitch (1.0 mm and 0.8 mm) CSP applications have been designed, fabricated, and assembled. Two design approaches, enabling either custom design or rapid prototype capability, have been developed. The assembly process, including die mount, wire bond, glob top, and BGA solder ball attach, is described. The material and physical design interaction issues that emerged during development are discussed. The initial CSP design was conventional, with yellow gold (Au) vias and capture pads and solderable gold (PtPdAu) pads for solder ball attachment. Solder pad to capture pad misalignment was visible following solder pad firing. After solder ball attachment, electrical tests revealed opens. Investigation led to the following conclusions. As solder pad diameter decreased to accommodate the fine pitch design, the area allocated for the underlying via and capture pad became significant relative to the area of the solder pad. Misalignment that would have ordinarily been hidden under larger solder pads was then exposed. Even when the yellow gold of the capture pad was not visibly exposed, the smaller solder pad was still less of a barrier to solder leaching. Leaching was observed after solder ball attachment and subsequent reflow operations, yielding the electrical disconnects. Because solder pad size and location were critical to proper mating with existing test fixtures, solder pads were applied after co-firing in order to provide the best alignment relative to the CSP body. Following solder ball attachment, shear tests revealed consistent adhesion failure between the solder pads and the LTCC substrate. The next generation CSP design sought to reduce the solder leaching and to strengthen the adhesion of the solder pads to the substrate. To lessen leaching, the yellow gold capture pads were completely removed from the design and the first layer vias were made more robust, by using solderable, not yellow, gold. To increase adhesion between the solder pads and the substrate, the solder pads were made of a solderable gold metallization able to be co-fired with the LTCC layers. Evaluation of this design is also reported.

11:30 AM B1.7
Techniques for Assessing the Performance of Circuit Materials at Microwave and Millimeter-Wave Frequencies.
Charles E. Free, Advanced Technology Institute, University of Surrey, Surrey, United Kingdom.

As RF and microwave system applications move to ever-higher frequencies, the need for comprehensive characterization of circuit materials at these frequencies becomes a very significant issue. In particular, the circuit designer requires precise information on the dielectric constant and loss tangent of substrate materials. This paper will review the material measurement techniques that are currently available and discuss how techniques that are traditionally used at lower microwave frequencies can be extended to the millimeter-wave band. In particular, the paper will focus on the novel use of over-moded circular waveguide cavities for measuring the complex dielectric constant of materials at frequencies above 30GHz. Previously published work by the authors showed that the traditional perturbation measurement technique, in which a dielectric specimen is introduced into a resonant waveguide cavity, could be significantly simplified through the use of a slit in the waveguide walls through which to insert the specimen. Recent work has shown that this technique can be successfully employed at mm-wave frequencies using over-moded circular waveguide cavities. The diameter of the circular cavity used in the present work was 50mm and this overcame the problem of specimen preparation that results from using the necessarily small sized rectangular waveguide above 30GHz. The slit circular cavity has been particularly successful in measuring the performance of printed thick-film substrates. These materials are of particular current significance to the RF designer, both for single layer and multilayer circuits. Materials with loss tangents of the order of 0.007 were measured with an accuracy better than 4% at a frequency of 10GHz. For these samples the thickness of the printed layer was 50micron, with the layers were printed onto a 635micron thick supporting alumina substrate. Data will be presented to show how the performance of typical thick-film materials, including LTCC substrates, varies as
the frequency of operation is extended to the low millimeter-wave band.

SESSION B2: Tunable/High k Thin Films
Chair: Jon-Paul Maria
Monday Afternoon, December 1, 2003
Room 201 (Hynes)

1:30 PM *B2.1
Tunable Ferroelectrics For Microwave Applications: Can Materials Performance Meet Devices Needs? Alexander K. Tagantsev, Vladimir Cherman, Konstantin Astafiev, Venkatesh Janakiraman and Nava Setter; Ceramics Laboratory, EPFL Swiss Federal Institute of Technology, Lausanne.

Advances in electroceramic thin film technology enable the miniaturization and integration of a number of high frequency devices previously available only as discrete components. Among these are tunable microwave devices such as tunable phase shifters, filters, and delay lines. The potential cost reduction is one of the attractive advantages of these monolithic devices. Additional advantages are the potential superior performance at higher frequencies and the further miniaturization in comparison to the presently standard devices. Tunable materials technology (thin and thick films) is being currently elaborated in parallel to device development. Materials exhibiting high tunability, intermediate permittivity, low dielectric losses, and high stability during temperature variation and time are sought. The center of this paper is an analysis of the interrelations between these various properties. We summarize first the dielectric response of the ideal bulk ferroelectric (material without boundaries nor defects) and then discuss real ferroelectrics, modeling them as composite materials of various configurations. Then the dielectric response of ferroelectric thin films, in which size effects intervene, is analyzed. Theoretical results are compared with experimental results. Finally we enumerate key open questions in this field of growing commercial interests.

2:00 PM B2.2
In-plane Ferroelectricity in Strontium Titanate Thin Films.
Konstantin Astafiev[1], Vladimir Sherman[1], Alexander Tagantsev[1], Nava Setter[1], Peter Petrov[2], Tatyana Kaydanova[3] and David Ginley[3]; [1]Ceramics Laboratory, Swiss Federal Institute of Technology, Lausanne, Switzerland; [2]Centre of Physical Electronics and Materials, South Bank University, London, United Kingdom; [3]National Renewable Energy Laboratory, Golden, Colorado.

Strontium titanate ($SrTiO_3$) is a well known material which has been extensively studied for a long time. $SrTiO_3$ single crystals are a typical perovskite type incipient ferroelectric material which do not exhibit a paraelectric to ferroelectric phase transition down to 0K. However, as it has been shown recently, the ferroelectric phase in the $SrTiO_3$ material can be observed in the case of $SrTiO_3$ thin films deposited onto single crystal substrates. In this work we present results of the in-plane ferroelectricity investigations in $SrTiO_3$ thin films deposited onto MgO and $LaAlO_3$ substrates by a pulsed laser deposition technique. The appearance of the ferroelectric phase in $SrTiO_3$ thin films on $LaAlO_3$ substrates has been experimentally registered with the paraelectric to ferroelectric transition temperature in the range of 90-120K. The hysteresis loops have been monitored in a wide temperature range in the in-plane geometry of the $SrTiO_3$ thin film planar capacitors. The switching properties of $SrTiO_3$ thin films on $LaAlO_3$ substrate has been studied at low temperatures ($\sim$25K) and well saturated loops have been observed with very low coercive field ($<$5kV/cm). The presence of the imprint phenomenon has been also found at low temperatures for $SrTiO_3$ thin films on $LaAlO_3$ substrates. The obtained experimental data have been analyzed in terms of the Landau theory taking into account the room-temperature lattice mismatch of the $SrTiO_3$ thin film and substrates as well as the difference in their thermal expansion coefficients. It has been shown that the observed shift of the transition temperature in $SrTiO_3$ thin films on $LaAlO_3$ substrates can not be attributed to the effect of the film/substrate mechanical coupling. As a possible nature of the observed behavior one considers the non-stoichiometry of the film composition caused by the chemical contact of the film with the substrate and by the annealing procedure.

2:15 PM B2.3
Dielectric Properties of $Bi_{1.5}Zn_{1.0}Nb_{1.5}O_7$ Thin Films Deposited by RF Magnetron Sputtering. Jiwei Lu and Susanne Stemmer; Materials, University of California Santa Barbara, Santa

Barbara, California.

$Bi_{1.5}Zn_{1.0}Nb_{1.5}O_7$ (BZN) ceramics have relatively high dielectric constants of ~170 and dielectric loss tangents less than 4×10^{-4}. Thin BZN films show an electric field tunability of the dielectric constant [1]. This property makes these films interesting for tunable capacitors. We show that near-stoichiometric BZN films can be deposited by rf magnetron sputtering. An ex-situ furnace post-deposition annealing treatment was used to crystallize the films. X-ray diffraction detected cubic pyrochlore in films that were annealed above 400 °C and films were fully crystallized at 750 °C. Transmission electron microscopy (TEM) and electron diffraction were used to confirm the cubic pyrochlore structure of the grains. The dielectric constant and loss were measured using planar Si/SiO2/Pt/BZN/Pt and Al_2O_3/Pt/BZN/Pt capacitor structures, respectively. BZN films showed a permittivity of 180-220 at 1 MHz, and a loss tangent of less than ~ 5×10^{-4}. An electric field tunability (55%) of the permittivity is obtained at the maximum bias field of 2.4 MV/cm for films on platinized Al_2O_3. The dielectric constant and tunability of films on Si were greater than those of films of Al_2O_3. The frequency dependence of the dielectric properties (relative permittivity and dielectric loss) were characterized using frequencies up to 100 MHz and Al_2O_3/Pt/BZN/Pt planar capacitor structures. The permittivity was independent of the measurement frequency between 1kHz to 100 MHz. The loss tangent was frequency independent in the range of 1kHz to 1 MHz, and then increased with frequency. Measurements of capacitors employing different thicknesses of the Pt bottom electrodes showed that the Pt electrode dominates the loss tangent in this high frequency range. Despite deviations from the ideal stoichiometry, and complex microstructures, BZN film properties are very close to those of bulk ceramics, which is unusual for complex oxide thin films. These properties make BZN films very attractive candidates for integrated capacitor applications. [1] W. Ren, S. Trolier-McKinstry, C. A. Randall, and T. R. Shrout, J. Appl. Phys. 89, 767-774 (2001).

2:30 PM B2.4
Integration of Layered Cu-Based Electrode with $(Ba_xSr_{1-x})TiO_3$ Thin Films for Application to High Frequency Devices. Wei Fan[1,2], Bernd Kabius[1], Jon M Hiller[1], Sanjib Saha[1], John A Carlisle[1], Orlando Auciello[1], RPH Chang[2] and Ramamoorthy Ramesh[3]; [1]Materials Science Division, Argonne National Laboratory, Argonne, Illinois; [2]Department of Materials Science and Engineering, Northwestern University, Evanston, Illinois; [3]Department of Materials and Nuclear Engineering, University of Maryland, College Park, Maryland.

Copper (Cu) has recently been introduced as an interconnect material in sub-micron integrated circuit technology, due to its low resistivity and high electro- and stress-migration resistance. The main problems inhibiting its application as electrode material in high-dielectric constant (k) thin film based devices are the Cu oxidation and diffusion during the growth of the oxide layer at relatively high temperature in an oxygen-rich environment. To overcome the above problems, we have investigated the oxidation and diffusion resistance of heterostructured TiAl/Cu/Ta multilayers, which showed high electrical conductance and excellent thermal stability in oxygen environment up to 600 °C. Characterization of the layered structure using various analytical methods showed that two amorphous oxide layers were formed on both sides of the TiAl barrier after heating in oxygen, such that the oxide layer on the free surface of the TiAl layer correlates with a $TiAlO_x$ layer, while the oxide layer at the TiAl/Cu interface is an Al_2O_3-rich layer. This double amorphous barrier layer structure effectively prevents oxygen penetration towards the underlying Cu and Ta layers. Polycrystalline $(Ba_xSr_{1-x})TiO_3$ (BST) thin films were subsequently deposited on the Cu-based bottom electrode by RF magnetron sputtering to investigate the performance of BST/Cu-based capacitors for high-frequency devices. The thickness of the TiAl oxide layer and interface roughness play a critical role in the optimization of the electrical performance of the BST capacitors using Cu-based electrode. It was determined that low temperature (450 °C) BST deposition followed by rapid thermal annealing (RTA) at 700 °C in pure oxygen yield BST capacitors with Cu-based electrodes with good electrical properties for application to phase shifters and other high frequency devices. As a result, high permittivity (280), low dielectric loss (0.007), and low leakage current ($<2\times10^{-8}$ A/cm^2 at 100kV/cm) were achieved on the BST thin film capacitors using Cu-based electrodes. * This work was supported by the US Department of Energy, BES-Materials Sciences, under Contract W-13-109-ENG-38; and NSF-MRSEC under Grant #DMR 00-80008 (University of Maryland).

2:45 PM B2.5
Strain and Thickness Effects on the Microwave Properties of BST Thin Films. Jeffrey A. Bellotti[1], Koray Akdogan[2] and Ahmad Safari[2]; [1]Electronic Science and Technology Division, Naval Research Laboratory, Washington, District of Columbia; [2]Ceramic and Materials Engineering, Rutgers University, Piscataway, New Jersey.

Heteroepitaxial $Ba_{0.6}Sr_{0.4}TiO_3$ films were deposited on (100) $LaAlO_3$ and (100) MgO substrates by pulsed laser deposition in the thickness range of 22 nm to 1150 nm. The state of strain in the films as a function of thickness and substrate type was correlated with the microwave dielectric properties in the frequency range of 1 to 20 GHz. Films deposited on $LaAlO_3$ showed a compressive in-plane strain, which increased to -0.25% for the thinnest films, while films on MgO showed an increasing tensile in-plane strain with decreasing thickness, which reached a maximum of +0.35%. The tunability of each film series was distinctly different depending on both the direction and magnitude of the in-plane strain. Tensile strains were shown to be preferable to compressive strains for maintaining high tunability across a wide thickness range. A maximum tunability of ~65% was achieved for the thickest films in each series, while the thinnest films on MgO showed substantially higher tuning (30%) as compared to those on $LaAlO_3$ (3%). A region of maximum tunability was defined by the strain states of the films with the highest tunability in each film series, which was found to be in the range of 0 to +0.07% in-plane tensile strain. Finally, the temperature-dependent permittivity and tunability of several films on MgO were studied over the temperature range of 78 K to 328 K. Strain was shown to suppress the three phase transitions normally present over this temperature range, resulting in a single maximum in the permittivity, which was observed to shift towards higher temperatures and broaden with increasing in-plane tensile strain.

3:30 PM *B2.6
Progress in Ferroelectric Films for Tunable Filters.
Angus I Kingon[1], Brian Boyette[2], Jon-Paul Maria[1], Jin Zhang[1], Ali Tombak[2] and Amir Mortazawi[2]; [1]NCSU, Raleigh, North Carolina; [2]Department of Electrical Engineering, University of Michigan, East Lansing, Michigan.

Progress is currently being made in the development of voltage-tunable filters for use at RF and microwave frequencies. The filters are based upon ferroelectric (Ba,Sr)TiO3 (BST) thin films on glass or sapphire substrates. We we describe progress in three areas: 1) Issues relating to the losses, in particular the losses associated with the series resistance of the metallization, which becomes more problematic as frequency is increased. 2) Materials and integration issues, including the materials selection as it relates to required device performance, and practical issues of materials and device integration. 3) Advances in filter design, from simple Chebychev designs, to designs which provide reduced distortion as the pass-band is tuned. The performance of the filters are discussed, along with the outlook for commercialization.

4:00 PM B2.7
Chemical Soluton Deposition of Silver Tantalum Niobate, $AgTa_{0.5}Nb_{0.5}O_3$, Thin Films for Microwave Frequency Device Applications. Mustafa Burak Telli and Susan Trolier-McKinstry; Materials Science and Engineering, The Pennsylvania State University, University Park, Pennsylvania.

A chemical solution deposition method for preparing $Ag(Ta_{0.5}Nb_{0.5})O_3$ dielectric thin films on Pt/Ti/SiO2/Si substrates was developed using a 2-methoxyethanol-pyridine solvent system. Synthesis involved double alkoxide formation of tantalum and niobium ethoxides in 2-methoxyethanol and refluxing of this solution with silver nitrate dissolved in pyridine. Spin-coated substrates were pyrolized in air and crystallized in an oxygen environment. Crystallization in oxygen reduces the dielectric loss of the films relative to air-firing. Crystal structure analysis of the films using grazing angle XRD suggested that the films have a layered structure, with pseudocubic perovskite material at the surface and an unknown pyrochlore-like phase at the platinum - $Ag(Ta_{0.5}Nb_{0.5})O_3$ film interface. The effects of processing parameters on formation of the unknown phase were investigated, and heating rate and the existence of the low temperature heat treatment steps were found to be critical in determining the extent of perovskite phase. Preliminary electrical property characterization of $Ag(Ta_{0.5}Nb_{0.5})O_3$ composite films showed that the dielectric properties depended on the crystallization temperature. Mixed phase ~400 nm thick films measured at 10 KHz showed the max e1, 268, for 600 °C and the lowest tand, 0.0019 for crystallization temperatures of 750 °C. Two phase ~ 600 nm thick films had a temperature coefficient of capacitance (TCC) between − 650 and − 1800 ppm/ °C between 50 and 200 °C. tand ranged from 0.011 to 0.020 over the same temperature range. These materials may be promising medium permittivity dielectrics for integrated capacitors. Additional work on composition modifications will also be presented.

4:15 PM B2.8
Microstructures and Dielectric Properties of Ferroelectric $(Ba,Sr)TiO_3$ Thin Films On Vicinal (001) MgO Surfaces.

Chonglin Chen[1], Y. Lin[1], X. Chen[1], S. W. Liu[1], J. Horwitz[2], H. D. Wu[2], J. C. Jiang[3] and E. I. Meletis[3]; [1]Physics and TcSAM, University of Houston, Houston, Texas; [2]Naval Research Lab, Washington DC, District of Columbia; [3]Mechanical Engineering, Louisiana State University, Baton Rouge, Louisiana.

We have systematically investigated the epitaxial behavior, microstructures, and dielectric properties of ferroelectric (Ba,Sr)TiO$_3$ and Mn-doped (Ba,Sr)TiO$_3$ thin films on vicinal (001) MgO substrates grown by pulsed laser ablation. Microstructural studies from x-ray diffraction, rocking curve measurements, and electron microscopy reveal that the films have excellent epitaxial behavior with good single crystallinity and sharp interfacial structures and smooth surface morphology for the films grown on standard, 1$ô$ and 5$ô$ mis-cut (001) MgO surfaces. However, particle-like structures with rough surface morphology were found near the film surfaces for the films grown on 3$ô$ mis-cut (001) MgO substrates. Interdigital dielectric measurements indicate that dielectric tunability of 60% have been achieved at 2.0 GHz with very high dielectric constant of 1600 and low dielectric loss of 0.03 for the films grown on 1$ô$ and 5$ô$ mis-cut (001) MgO surfaces. However, only less that 40% of tunability can be obtained from the 3$ô$ mis-cut (001) MgO surfaces. The models of the surface-step-terrace induced the formations of conservative and nonconservative domain boundary structures have been developed to understand the microstructures-property relationship.

4:30 PM B2.9
Effect of Mn-doping on the Microwave Response of BST Thin Films. Jeffrey A. Bellotti, Steven W. Kirchoefer, Wontae Chang, Edward J. Cukauskas and Jeffrey M. Pond; Electronic Science and Technology Division, Naval Research Laboratory, Washington, District of Columbia.

Mn-doped $Ba_{0.5}Sr_{0.5}TiO_3$ films were grown on (100) MgO substrates by rf/magnetron sputtering using planar and off-axis deposition methods. Film thickness varied from 100 to 500 nm, with Mn doping levels in the range of 0.5 to 10 atomic%. Several different film morphologies were investigated, including polycrystalline and epitaxial, to determine the effect of the Mn dopant in each type of film structure. The film orientation and strain were studied with x-ray diffraction as a function of growth temperature up to 700 °C, and the surface roughness was investigated with scanning probe microscopy. X-ray photoelectron spectroscopy was used to determine the concentration and bonding states of Mn in the perovskite BST lattice. The microwave permittivity, tunability, and Q-factor were measured in the range of 1 to 20 GHz and correlated with the Mn dopant level and film morphology. In addition, the bonding state and valence of Mn will be discussed within the context of reducing the loss of the host material.

SESSION B3: Passives
Chairs: Yong Cho and Paul Muralt
Tuesday Morning, December 2, 2003
Room 201 (Hynes)

8:30 AM *B3.1
High-Q integrated RF passives and RF-MEMS on silicon. Joost van Beek[1], Marc van Delden[1], Patrick van Eerd[1], Margot van Grootel[1], Andre Jansman[1], Anton Kemmeren[1], Theo Rijks[1], Peter Steeneken[1], Mathieu Ulenaers[1], Arnold den Dekker[2], Pieter Lok[2], Nick Pulsford[2], Freek van Straten[2], Lenhard van Teeffelen[2], Jeroen de Coster[3], Robert Puers[3], Ingrid de Wolf[4] and Merlijn van Spengen[4]; [1]Philips Research, Eindhoven, Netherlands; [2]Philips Semiconductors, Nijmegen, Netherlands; [3]Katholieke Universiteit Leuven, Leuven, Belgium; [4]IMEC, Leuven, Belgium.

The PASSI technology platform is described for the integration of low-loss inductors, capacitors, and MEMS on high-ohmic Si substrates. Using this platform the board space area taken up by e.g. impedance matching circuits can be reduced by 50%. The losses of passives induced by the semi-conducting Si substrate can effectively be suppressed using a combination of surface amorphisation, e-beam irradiation, and the use of a poly-Si substrate. The incorporation of MEM tuneable capacitors and switches in high-Q inductor-capacitor networks is demonstrated.

9:00 AM B3.2
Cu-Compatible Ultra-High Permittivity Dielectrics for Embedded Passive Components. Jon Ihlefeld[1], Brian Laughlin[1], William Borland[2], Angus I. Kingon[1] and Jon-Paul Maria[1]; [1]Materials Science and Engineering, North Carolina State University, Raleigh, North Carolina; [2]DuPont iTechnologies, Research Triangle Park, North Carolina.

Barium titanate thin films have been prepared by chemical solution deposition on copper foils in the absence of chemical barrier layers. The final embodiment exhibits large randomly oriented $BaTiO_3$ grains and an equiaxed morphology. High resolution cross sectional microscopy shows no indication of interfacial phases. The $BaTiO_3$ films are sintered in a high temperature reductive atmosphere such that copper oxidation is avoided. Subsequent lower-temperature, higher oxygen pressure anneals are used to minimize oxygen point defects. Ultra-high permittivities are observed, with loss tangents under 2.5%. The $BaTiO_3$ phase exhibits pronounced ferroelectric switching and coercive field values near 20 kV/cm. Temperature dependent measurements indicate a ferroelectric transition near 100 °C with very diffuse character. Combining the approaches of the multilayer capacitor industry with traditional solution processed thin films has allowed pure barium titanate to be integrated with copper. The high sintering temperature - as compared to typical film processing - provides for large grained films and properties consistent with well-prepared ceramics. Integrating $BaTiO_3$ films on copper foil represents an important step towards high capacitance density embedded passive components.

9:15 AM B3.3
Design and Performance of Polymeric Ultra-thin Substrates for use in Embedded Capacitors: Comparison of unfilled and Filled Systems with Ferroelectric particles. John A Andresakis, Takuya Yamamoto, Pranabes Pramanick and Nick Biunno; Oak-Mitsui Technologies LLC, Hoosick Falls, New York.

As CPUs increase in performance, the number of passive components on the surface of the boards are increasing dramatically. To reduce the number of components, as well as improve the electrical performance (i.e. reduce inductance), designers are increasingly embedding capacitive layers in the Printed Circuit Board (PCB). The majority of the products in use today utilize reinforced epoxy laminates. These products are relatively easy to handle and provide good electrical performance, but a need exists for even better performance than a fiberglass reinforced product can produce. Other materials are being developed that are thinner (and thus increase capacitance and reduce inductance), but either have problems with dielectric breakdown strength, handling or only marginal improvements over the reinforced epoxy material. A need exists for an ultra-thin (less than 25 micron) material that not only provides improved electrical performance, but can be readily manufactured using standard PCB processing We will discuss the design criteria we used for developing our family of products, as well as the results. The design of the conductor (copper foil) has been determined to be as critical as the properties of the dielectric (polymer). Examination of the effect of loading the polymer with High Dk ferroelectric particles will also be examined. The products have been through both internal and external testing and are compared to existing and developing capacitor materials. We will describe the electrical as well as the processing characteristics in detail, and how these types of products can greatly improve performance of high-speed systems.

9:30 AM B3.4
Dielectric Performance Of PLZT Thin Films On Metal Foils For Advanced Embedded And Discreet Capacitors. Sanjib Saha[1], David Y. Kaufman[2], Stephen K Streiffer[1] and Dong Joo Kim[3]; [1]Materials Science Division, Argonne National Laboratory, Argonne, Illinois; [2]Energy Technology, Argonne National Lab, Argonne, Illinois; [3]Dept. of Mechanical Engineering, Auburn Univerisy, Auburn, Alabama.

PLZT thin film dielectrics on metal foils offer a viable means to achieve embedded and discreet capacitors with high volumetric efficiency and improved electrical performance. Chemical solution deposition has been used to fabricate PLZT thin films on Ni and Cu. To avoid parasitic interfacial reactions during high temperature processing in air, buffer layers were inserted between the PLZT and metal foil. Processing protocols for both the PLZT and buffer layer were developed to achieve capacitance densities as high as 1.4 $\mu F/cm^2$ with leakage current density below $1x10^{-6} Amp/cm^2$ at 350 kV/cm, for samples on Ni as the base metal. A thickness series of PLZT/buffer layer/metal foil capacitor structures was investigated to develop an understanding of scaling effects on capacitor performance, including leakage currents, dielectric breakdown, and temperature coefficient of capacitance. Strategies for utilizing this technology as embedded and discreet capacitors will be highlighted.

9:45 AM B3.5
High frequency loss mechanism in polymers filled with dielectric modifiers. Jan Obrzut[1], Aleksei Anopchenko[1] and Howard Wang[2]; [1]Polymers Division, NIST, Gaithersburg, Maryland; [2]Department of Materials Science and Engineering, Michigan Technological University, Houghton, Michigan.

The embedded capacitance power-ground planes made of typical dielectric materials exhibit undesirable multiple resonances, which limit the usable bandwidth to low frequencies. Novel embedded capacitance materials should exhibit not only high capacitance density but also should be capable of suppressing fluctuations in impedance by damping the resonance, especially at higher frequencies where discrete components are ineffective. High dielectric constant (high-k) organic-ceramic cpmposites have recently shown promise for embedded capacitance decoupling planes with desirable low impedance characteristics. In the case of organic hybrid materials, the loss mechanism is poorly understood. We analyzed the high frequency dielectric relaxation mechanism in high-k composite materials using film substrates made of low loss organic resin filled with ferroelectric ceramics and with single wall carbon nanotubes (SWNT). Small angle neutron scattering (SANS) was used to probe the dispersion of SWNTs in polymer matrices. We performed broadband permittivity measurements of high-k film substrates at frequencies of 100 Hz to about 10 GHz. In order to analyze the effect of the dielectric thickness, dielectric constant, loss and conductive loss on the impedance characteristics we used a High Frequency Structure Simulator to perform a full wave numerical analysis of several power planes. It was found that organic-ceramic composites exhibit an intrinsic high frequency relaxation behavior that gives rise to frequency dependent dielectric loss. The magnitude of the loss increases with increasing volume fraction of the ceramic component according to the conventional mixing-rule, while the dielectric loss-frequency spectrum follows the relaxation pattern of the organic resin. The highest frequency relaxation process dominates the overall loss characteristic. In the case of polymers modified with SWNTs, we observed that 2% of purified SWNTs, well dispersed within the polymer, increase the dielectric constant by 3 orders of magnitude, in apparent violation of the mixing-rule. The hybrid material appears to have preferential coupling within the dispersed phase. We believe that the manifestation of this particular nano-effect is associated with a characteristic length scale. The observed relaxation process and the corresponding relaxation strength may be attributed to restricted motions of charge carriers in SWNTs. The experimental data and numerical simulation indicate that the materials dielectric loss can play a significant role in suppressing the resonant behavior. The suppressing effect due to the dielectric loss can be larger than that caused by the conducting losses in typical copper cladding.

10:30 AM B3.6
Low Loss Ferrites for High Frequency Applications. M. Singh and S C Katyal; Physics, H.P.University, Shimla, India.

Magnesium-Manganese and Nickel Zinc ferrites of compositions $Mg_{0.9}$ $Mn_{0.1}$ Fe_2O_4 and $Ni_{0.7}Zn_{0.3}$ Fe_2O_4 were prepared by the citrate precursor method at temperature as low as 300 ^{o} C. This is much lower than those used in the conventional ceramic method for the prepration of ferrites ($\sim$ 1000 ^{o}c). The d.c. resistivity of the sintered specimens was observed to be $\sim 10^{9}$ Ω cm which is greater, by at least two orders of magnitude, the dielectric loss factor are about one order of magnitude lower than those obtained in the ferrites prepared by the conventional ceramic method. Due to high value of d.c resistivity and very low value of dielectric loss make these ferrites suitable for high frequency applications .The significance of citrate method lies,in preparing ferrites with better properties at reduced processing temperature.

10:45 AM B3.7
Noncentrosymmetric Inclusion of Magnetic V^{4+} Ion and Related Magneto-Induced Microwave Losses in Vanadium Doped Yttrium Aluminum Perovskite. Rakhim Rakhimov, Enrique Jackson and George Loutts; Center for Materials Research, Norfolk State University, Norfolk, Virginia.

Electron paramagnetic resonance investigation of vanadium doped yttrium aluminum perovskite ($YAlO_3$) reveals noncentrosymmetric inclusion of magnetic V^{4+} ion (electron configuration $3d^1$, electron spin S = 1/2) in octahedral aluminum site of the crystal. Four structurally nonequivalent VO_6 octahedra with different values of the g-factor and ^{51}V hyperfine interaction constant, and different spin-lattice relaxation rates are identified. We propose structural models of VO_6 octahedra, where V^{4+} ions are differently shifted from the center of the distorted octahedron and result in noncentrosymmetric position of the V^{4+} ion. We show that microwave losses, observed as an opposite-phase paramagnetic signal at zero magnetic field, is due to magneto-induced charge displacement in the noncentrosymmetric system. Sharp magneto-induced microwave absorption in this system is observed within low magnetic fields 0-1 mT, which makes vanadium doped $YAlO_3$ an attractive material for magnetic and microwave applications. This research was supported by the Virginia's Center for Innovative Technology (CIT) and Defense Advanced Research Projects Agency (DARPA) under CIT award No. ELC-02-006, and by the National Aeronautics and Space Administration under Faculty Awards for Research program (NASA/FAR), grant No. 1248732 administered by the California Institute of Technology, Jet Propulsion Laboratory.

11:00 AM B3.8
Passive Isolators Based on Barium Ferrite Sputtered Films.
Martine Le Berre[1], Stephane Capraro[2], Jean-Pierre Chatelon[2], Helene Joisten[3], Thomas Rouiller[2], Bernard Baillard[2], Daniel Barbier[1] and Jean-Jacques Rousseau[2]; [1]Lab. phys. Matiere, INSA Lyon, Villeurbanne, France; [2]DIOM, UJM, Saint-Etienne, France; [3]LETI, CEA, Grenoble, France.

Ferrites have magnetic properties suitable for electronic applications, especially in the microwave range (circulators and isolators). Hexagonal ferrite, such as barium ferrite (BaM), are of great interest for microwave device applications because of their large resistivity and high permeability at high frequencies. This contribution focusses on BaM films, 1 to 10 micron thick, which were deposited under optimized conditions by RF magnetron sputtering on alumina or silicon substrates. In order to crystallize the films that were amorphous after deposition, a post deposition annealing at 800 Celsius was implemented. All samples presented a good crystallization, a smooth surface and no cracks. The films were either randomly oriented or showed slight preferential orientations among the crystallographic planes (101), (200), (206), (102), (110) and (205) when the substrates were heated up to 400 Celsius during the deposition. Ba, Fe and O depth profiles obtained by Secondary Ion Mass Spectroscopy (SIMS) showed that the films had a good in-depth uniformity. The magnetic properties of BaM films determined by VSM, showed the optimized coercive force and the saturation magnetization reached 330 kA/m and about 500 mT respectively. These values are closed to that of the bulk BaM. Isolators were then realized using patterning of coplanar metallic lines with standard lift-off technique. The slots and the central width were set to 300 micron, gold was used for the lines. First results on transmission coefficients showed a non reciprocal effect, which reaches 3.3 dB/cm at 50 GHz. This proves that such a component behaves like an isolator in the 50 GHz band. Work is now under progress to vary the BaM film thickness as well as the isolator design.

SESSION B4: Resonators
Chairs: Christian Hoffmann and Paul Muralt
Tuesday Afternoon, December 2, 2003
Room 201 (Hynes)

1:30 PM *B4.1
Solidly-mounted Bulk Acoustic Wave Filters.
Hans-Peter Loebl[1], Christof Metzmacher[1] and Robert Milsom[2]; [1]Philips Research, Aachen, Germany; [2]Philips Research, Redhill, United Kingdom.

RF filters based on solidly-mounted thin-film bulk acoustic wave resonators (SBARs) are of interest for mobile and wireless applications due to their small size, rugged construction and potential for integration. These filters have been investigated in research over the last 20 years and attract now increasing attention due to progress of thin film techniques [1,2,3]. The SBAR configuration comprises piezoelectric layer, top and bottom electrode layers, an acoustic mirror (Bragg-reflector) with alternate quarter lambda layers of high and low mechanical impedance, and a substrate (typically silicon). Applying a rf signal to the electrodes excites the bulk acoustic wave (BAW) resonator to vibrate in its thickness extensional mode. The electrical impedance of the BAW resonator is low at its resonance frequency and high at its anti-resonance frequency. By combining BAW resonators e.g. electrically in ladder or lattice type structures, band-pass filters with very high selectivity and bandwidth up to 4% can be realised. Piezoelectric materials used for these filters include AlN and ZnO which grow both in the wurtzite structure and can be deposited by sputtering techniques. The paper covers growth and material aspects of thin piezoelectric AlN films, which have to be grown highly c-axis oriented on the electrode to show a high coupling coefficient. Filter and resonator results will be shown in the frequency range from 2 to 8 GHz. Modelling of BAW resonators and filter devices can be done very accurately within a combined 1-dimensional electro-acoustical model from Novotny and Benes [4,5]. Combining this model with electromagnetic modelling allows accurate prediction of the bulk acoustic wave resonator and filter performance. Limitations of this model will be discussed. [1] K.M. Lakin, G.R. Kline, K.T. McCarron, Development of miniature filters for wireless applications, IEEE Transactions on Microwave Theory a. Techniques, 43, 2933 (1995). [2] P.D. Bradley, SM, R. Ruby, A. Barfknecht, F. Geefay, C. Han, G. Gan, Y. Oshmyansky, A 5 mm x 5 mm x 1.37 mm Hermetic FBAR Duplexer for PCS Handsets with Wafer-Scale Packaging, 2002 IEEE Ultrasonics Symposium Munich, proceedings, p.907, 2002. [3] H.P. Loebl, C. Metzmacher, D.N. Peligrad, R. Mauczok, M. Klee, W. Brand, R.F. Milsom, P. Lok, F. van Straten, A. Tuinhout, J.W. Lobeek, Solidly Mounted Bulk Acoustic Wave Filters for the GHz Frequency Range, 2002 IEEE Ultrasonics

Symposium Munich, proceedings, p.897, 2002. [4] H. Nowotny, E. Benes, General one-dimensional treatment of the layered piezoelectric resonator with two electrodes, J. Acoust. Soc. Am., 82, 513 (1987). [5] R.F. Milsom, H.P. Loebl, D.N. Peligrad, J.W. Lobeek, A. Tuinhout, H.J. ten Dolle, Combined Acoustic Electromagnetic Simulation of Thin Film Bulk Acoustic Wave Filters, 2002 IEEE Ultrasonics Symposium Munich, proceedings, p.963, 2002.

2:00 PM B4.2
Investigation of Highly c-axis Oriented AlN Thin Film Re-growth. Fabrice Martin[1], Paul Muralt[1] and Marc-Alexandre Dubois[2]; [1]Ceramics Laboratory, Swiss Federal Institute of Technology EPFL, Lausanne, Switzerland; [2]RF microelectronics, CSEM, Neuchatel, Switzerland.

The growing needs for higher carrier frequencies in mobile telecommunications open exciting opportunities for Bulk Acoustic Wave (BAW) resonators and filters. Aluminum Nitride (AlN) is one of the most promising piezoelectric materials for the fabrication of filters with 1-2% bandwidth and low insertion loss up to 10GHz due to its high longitudinal acoustic velocity, good piezoelectric coupling coefficient, low stress, low temperature processing and compatibility with IC processing. For many applications, it would be desirable to dispose of several resonance frequencies on the same chip. The most economic way would be to interrupt growth and selectively re-grow on sites for lower frequency operation. Such a fabrication requires a screening and a lift-off procedure allowing the AlN re-growth to take place only where required. The properties of AlN films grown and re-grown in two successive and equal thicknesses have been studied by XRD, XPS, SEM, AFM and interferometry. It's been demonstrated that AlN layers with small rocking curve width and excellent piezo-electric coefficient can be fabricated in one continuous process. It will be showed that the use of a strongly alkaline developer solution (as to simulate photolithography developing process) actually etches down, increases the roughness and contaminates the surface of the AlN layer with oxides, hydroxides and hydrocarbons. As a consequence, the chemically pre-treated re-grown AlN layer exhibits reduced piezo-electric coefficient d33 and worse rocking curve width. The piezoelectric coefficient can be recovered by the use of RF plasma cleaning prior to the re-growth process.

2:15 PM B4.3
Critical Issues in Growth of Pulse Laser Deposited AlN films for MEMS and NEMS based RF Resonators. Shiva S Hullavarad[1], R D Vispute[1], John Koster[1], V N Kulkarni[1], T Venkatesan[1], A E Wickenden[2], L J Currano[2], A Herson[2], M Dubey[2], T Takacs[2] and J Pulskamp[2]; [1]Center for Superconductivity Research, University of Maryland, College Park, Maryland; [2]U.S. Army Research Laboratory, Adelphi, Maryland.

AlN exhibits strong piezo-electric properties suitable for RF resonator applications. In this work we report the growth of highly oriented AlN films for MEMS and NEMS resonator devices. A multiple flexural structure of Pt/SiO2/Si is used as a substrate and films are grown by pulse laser deposition technique at a pulse energy of ~2 J/cm2 with a repetition rate of 10Hz. The process is optimized for the growth of AlN on different thickness of underlying SiO2 thickness. The films are characterized by X-ray diffraction, and Rutherford Back Scattering techniques for crystalline quality and stoichiometry respectively. The interface analysis of underlying structures is analyzed in detail by RBS and oxygen content in the film is monitored by Resonant Oxygen Scattering technique. The morphology of AlN films is studied by scanning electron and atomic force microscopic techniques. For NEMS based resonators a thinner SiO2 acts as a flexural substrate layer. However, a critical oxide layer thickness appears to exist, below which rapid diffusion and breakdown of SiO2 layer is observed at growth temperatures >900C. The growth process of AlN for NEMS based resonators will be optimized.

3:00 PM *B4.4
Microwave Perovskites: Control of Order and Microstructure. Peter K Davies, Materials Science, University of Pennsylvania, Philadelphia, Pennsylvania.

With their ability to sustain an outstanding dielectric response in the microwave region and accommodate extensive chemical substitution, oxide perovskites are the most widely studied and technologically important family of microwave dielectrics. The highest quality factors are observed in systems such as $Ba(Zn_{1/3}Ta_{2/3})O_3$ in which the cations on the B-site adopt a "1:2" ordered arrangement of Zn and Ta. Through studies of their response to various chemical substitutions and different thermal treatments it is known that the properties of BZT and other related oxides are mediated by alterations in chemical order and by the volatilization of Zn at high temperature. This paper will focus on the development of new additives designed to enhance the stability of the cation order and reduce the sintering temperature to alleviate the problems associated with the volatilization of Zn. Examples will include new families of Li-based oxide perovskite dielectrics with both 1:2 and 1:3 ordered arrangements of cations on the B-sites. Results of studies aimed toward understanding the apparent size dependence of Q in resonator pucks prepared for 2GHz applications will also be presented.

3:30 PM *B4.5
Interpretation of Microwave Dielectric Properties of Pb-based Complex Perovskite Ceramics via Bond Valence and Far IR Reflectivity Spectra. Ki Hyun Yoon, Ceramic Engineering, Yonsei University, Seoul, South Korea.

Correlation between microwave dielectric properties and the dielectric polarizabilities related to the bond valences of A- and B-site ions in the Pb-based complex perovskite ceramics has been investigated. With the decrease of A-site bond valence, the dielectric constants were higher than those obtained from the dielectric additivity rule due to the rattling behavior of A-site ions. The temperature coefficient of the resonant frequency (TCF) depended strongly on the bond valences of the A- and B-sites, as well as the tolerance factor (t) in the perovskite structure. In the tilted region (t<1.0), the tilting of the oxygen octahedra increased and the TCF decreased because of the increasing bond valence of the B-site. Also, the dependence of TCF on the bond valence of the A-site was similar to its dependence on the tolerance factor (t). The Qf values were studied with the infrared reflectivity spectra from 50 to 4000 cm-1, which were calculated by Kramers-Kronig analysis and classical oscillator model.

4:00 PM B4.6
Structure and Dielectric Properties of New Lithium-Tungsten based Ordered Perovskites. Hui Wu and Peter K Davies; Department of Materials Science and Engineering, University of Pennsylvania, Philadelphia, Pennsylvania.

Cation order/disorder transitions in A[B(I)B(II)]O3 mixed-metal perovskites play a critical role in mediating the stability, crystal structure, and resultant dielectric response. Ordered perovskites such as Ba(Zn1/3Ta2/3)O3 (BZT) exhibit exceptionally high quality factors in the microwave region and are widely utilized as resonators in commercial wireless communications systems. While the properties of BZT and other closely related phases have been widely studied, many other potential ordered perovskite-forming stoichiometries have not been explored. This work has investigated new ordered lithium-tungsten based perovskite solid solutions. Examination of several stoichiometries revealed that the 1:2 ordered Li/W perovskites, A[(Li1/3W2/3]O3, cannot be stabilized. However, a series of new ordered phases with a mixture of Nb/Ta and W on the B(II) sites were obtained for compositions in the [AE2(1+x)/3La(1-2x)/3][Li1/3(Nb,Ta(1-x)Wx)2/3]O3 systems (AE = Sr and Ca). 1:2 ordered cubic perovskites were also discovered with mixtures of cations on both the B(I) and B(II) sites in the AE(Li1/4Nb3/4)O3 - AE(Li2/5W3/5)O3(AE = Ba, Sr, and Ca) solid solution systems. However, compared to the other known 1:2 ordered perovskite systems, this new series of ordered perovskites have an unusual type of 1:2 ordering due to their mixed cation occupancies on both B-sites. The structure, chemistry, and dielectric properties of these new phases will be presented and the role of W in affecting the formation of stable perovskites and the transformation between 1:2 and 1:1 ordered phases will be discussed.

4:15 PM B4.7
Theoretical and Experimental Investigation of Ba(Zn1/3Ta2/3)O3 Microwave Ceramics. Shaojun Liu[1,2], Hongxue Liu[1,2], Richard Taylor[3], Mark Van Schilfgaarde[1] and Nathan Newman[1,2]; [1]Chemical and Materials Engineering, Arizona State University, Tempe, Arizona; [2]Science and Engineering of Materials Program, Arizona State University, Tempe, Arizona; [3]School of Information and Electrical Engineering, University of Queensland, Brisbane, Queensland, Australia.

We have used advanced theoretical and experimental methods to explore the properties of Ba(Zn1/3Ta2/3)O3 (BZT) and related members of this perovskite family. Ab-initio electronic structure calculations give insight into the unusual properties of Ba(Cd1/3Ta2/3)O3, Ba(Zn1/3Ta2/3)O3 and their alloys. While BZT has a hexagonal Bravais lattice, the space group of Ba(Cd1/3Ta2/3)O3 is different from BZT's P321 as a result of a distortion of oxygen away from the symmetric position between the Ta and Cd ions. In both compounds, the conduction band maximum and valence band minimum are composed of mostly weakly itinerant Ta 5d-and Zn-3d/Cd-4d levels, respectively. The covalent nature of the directional d-electron bonding in these high-Z oxides plays an important role in producing a more rigid lattice with higher melting points and enhanced phonon energies.We have also extended traditional powder processing methods to produce complex shaped BZT doping Zr and Ni structures using ceramic injection molding(CIM).The microwave properties, electronic structure, and microstructure of conventional and CIM samples samples have been characterized.Conventional samples prepared with standard powder ceramic synthesis methods have an average dielectric constant(ϵ) of $\sim$30 , good microwave performance (Qxf>110,000), and a very low temperature coefficient of resonance frequency (τf $\sim$0.1). CIM samples have lower densities and exhibit an average dielectric constant(ϵ) of $\sim$20, good microwave performance with a Qxf of 63000, and a very low temperature coefficient of resonance frequency, τf, of $\sim$0.1. To achieve a high sintering density (>94%) in the CIM samples, elevated temperatures and long sintering times must be used. These results demonstrate that CIM is avaible technology for the development of complex-shaped microwave devices.

4:30 PM B4.8
Chemical Interactions During Processing of Multilayered Electronic Materials. Lawrence P. Cook, Winnie Wong-Ng and Julia Suh; Ceramics Division, NIST, Gaithersburg, Maryland.

Ceramics find many applications in microwave devices, where dielectric and other properties can be fine-tuned by controlling chemistry. While comprising a diverse group of materials, electronic ceramics in multilayer structures have in common the need for sintering at elevated temperatures (800°C and above) in order to achieve the desired structural integrity. At these temperatures, chemical reactions may occur at interfaces between dissimilar materials. Three principal types of interactions involve combinations of the metallization, the embedded passive ceramic devices, and the ceramic packaging material. To model the metal/embedded component interaction, we use as examples the systems AgO_x-Bi_2O_3-Nb_2O_5 and CuO_x-Bi_2O_3-Nb_2O_5. Similarly, the system BaO-SiO_2-TiO_2 allows us to treat an example of embedded component/packaging interaction. Finally, an example of metal/packaging interaction is found in the system CuO_x-CaO-SiO_2. By combining phase equilibrium data with thermodynamic properties, it is possible to develop models for interfacial interaction within each of these systems. Of special importance is the generation of chemical potential diagrams, which allow interpretation and prediction of interfacial reaction sequences. By fabricating bi-phasic interfaces and annealing, it is possible to follow experimentally the evolution of interfacial reaction zones. Such data can then be used iteratively as feedback for model development. The current status of ceramic interfacial reaction models will be discussed.

4:45 PM B4.9
Correlation between Ordering and Properties in Ni-based Microwave Perovskites. Niti Yongvanich[1], Peter K Davies[1] and Tyke Negas[2]; [1]Materials Science and Engineering, University of Pennsylvania, Philadelphia, Pennsylvania; [2]TCI Ceramics, Inc., Hagerstown, Maryland.

Ceramic materials for microwave applications are required to have high and temperature independent dielectric constants and low dielectric loss or high quality factors (Q). Complex perovskites with the general formula Ba(B/1/3B//2/3)O3 exhibit very high quality factors in the microwave region and are widely used in commercial applications. Previous investigations of Ba(Zn1/3Ta2/3)O3 (BZT) and other "1:2" perovskites have shown increasing degrees of cation order are associated with improvements in Q. However, the increase in Q can be mediated by the formation of domain structures where the order is confined to nanometer-sized domains. In this paper we investigate the evolution and growth of the 1:2 ordered domains with firing conditions in Ba(Ni/3Ta2/3)O3 (BNT). This nickel-based perovskite was selected to avoid complications associated with the excessive volatilization of Zn encountered in the more widely studied BZT system. BNT powders and pellets with various degrees of order were obtained by firing in air; the degree of order and variation in the lattice distortion accompanying the order were analyzed by XRD. At 1605 °C complete ordering of Ni and Ta in BNT powders is achieved after 32 hours; at higher temperatures small amounts of impurities are formed due to Ni-loss. The highest c/a ratio of 1.230 was obtained in powders annealed at 1605 °C for 48 hours. Studies of the ordering in dense ceramics revealed a clear difference in the growth rate of the ordered domains in powders and sintered pellets. This will be discussed together with the effect of the changes in lattice distortion and cation order on the microwave response.

SESSION B5: Poster Session
Chairs: Yong Cho and Paul Muralt
Tuesday Evening, December 2, 2003
8:00 PM
Exhibition Hall D (Hynes)

B5.1
Co-firing of low-K and middle-K dielectric layers in LTCC. Jae-Hwan Park, Jae-Gwan Park, Young-Jin Choi and Jung-Hyun Park; Div. of Materials, Korea Institute of Science and Technology, Seoul, Seoul, South Korea.

Low temperature Co-fired Ceramic (LTCC) technology is expected to become crucial for future microwave applications such as IC packaging radar, antennas, and wireless technologies. For realization of the highly integrated and multi-functioned LTCC module, it is required to integrate middle- and high- permittivity dielectric layers as well as low- K dielectric layers into one module by co-firing. In this study, we developed various low- K (5.5$\sim$7.0) and middle- K (22$\sim$60) dielectric systems the chemical compositions of which are design carefully considering the chemical and physical matching during co-firing. We will present about the thermal shrinkage, warpage, and delamination between the hetero- layers. The chemical and physical stabilities of the interfaces between low- K and middle- K layers will be described. Chemical reactions between the dielectric layers and Ag inner conductor will also be discussed.

B5.2
Sintering and Phase Change of BaTi4O9 Microwave Ceramics for LTCC RF module. Jae-Hwan Park[1], Young-Jin Choi[1,2], Sahn Nahm[2] and Jae-Gwan Park[1]; [1]Div. of Materials, Korea Institute of Science and Technology, Seoul, Seoul, South Korea; [2]Materials Science and Engineering, Korea University, Seoul, South Korea.

Effects of glass addition on the low-temperature sintering and microwave dielectric properties of BaTi4O9-based ceramics were studied to develop the materials for the functional substrate in low-temperature co-fired ceramics (LTCC). When 10 wt% of glass was added, sufficient densification was obtained and the relative density more than 98% was reached at the sintering temperature of 875oC. The microwave dielectric properties were k=32, Q*f=9000 GHz, and tf=10 ppm/oC. As the amount of glass increased, the phase changes from BaTi4O9 to Ti-rich phase was observed. When the BaTi4O9 ceramics was heat-treated at 950oC with borosilicate glasses, the composition changed completely to Ti-rich phases such as Ba2Ti9O20 or BaTi5O11 according to the glass content. The phase change seemed to be induced by the factor that glass absorbs Ba ions selectively than Ti ions.

B5.3
The Tunability of Bi-rich BZN Cubic Pyrochlore Thin Films by Reactive RF Sputtering. Donghyuk Back, Yoon Seop Lee, Young Pyo Hong, Joong Ho Moon and Kyung Hyun Ko; Material Science and Engineering, Ajou University, Suwon, South Korea.

$(Bi_{3x}Zn_{2-3x})(Zn_xNb_{2-x})O_7$ thin films (x=1/2 and 2/3) have potential great for tunable RF and microwave devices due to medium dielectric constant and low dielectric loss. The tunable dielectric properties of Bi-rich, $(Bi_{1.5}\ Zn_{0.5})(Zn_{0.5}\ Nb_{1.5})O_7$ thin films were investigated. To make Bi-rich cubic pyrochlore thin films, Bi_2O_3-ZnO-Nb_2O_5 orthorhombic pyrochlore ceramic targets were used in reactive RF magnetron sputtering process. Substrate heating was employed to improve surface morphology and tunability. As-deposited films were crystallized or amorphous state depending on substrate temperature. All films were annealed at 600°C$\sim$800°C for 3 hours in the air. There were no zinc niobate secondary phases in the films before and after post-annealing, while quite significant amount BZN thin films were found in sputtered using cubic pyrochlore ceramic targets, especially after post-annealing. It was found that Bi-rich BZN films have much larger tunability when as-deposited phase are amorphous. The maximum tunability 38% was obtained when substrate is heated to 350°C and composition of films is close to exact stoichiometric cubic BZN.

B5.4
Effects of Composition on the Voltage Tunable Dielectric Properties of Pyrochlore Bi-Ti-Zn-Nb-O Solid Solution Thin Films. Jin Young Kim, Dong-Wan Kim, Hyun Suk Jung and Kug Sun Hong; Materials Science and Engineering, Seoul National University, Seoul, South Korea.

Recently Bi-based pyrochlore thin films have been studied intensively because they attracted attention for use in voltage tunable devices due to their lower dielectric losses than those of existing tunable thin films such as $(Ba,Sr)TiO_3$ (BST). Structural and dielectric properties of $Bi_2Ti_2O_7$-$Zn_2Nb_2O_7$ solid solution thin films were investigated in this study since it was found that some chemical substitutions can enhance the dielectric properties of Bi-pyrochlore thin films. $(Bi_{2-x}Zn_x)(Nb_xTi_{2-x})O_7$ (BZNT, $0.05\leq x\leq 1.0$) pyrochlore thin films were prepared on platinized Si substrates using metalorganic deposition process. Broad ranges of solid solutions based on cubic $(Bi_{1.5}Zn_{0.5})(Zn_{0.5}Nb_{1.5})O_7$ were observed by chemical substitutions; i. e., $Bi^{3+} + Ti^{4+} = Zn^{2+} + Nb^{5+}$. Crystallization of BZNT thin films started below 600°C and completed at about 750°C. The crystal structure and dielectric characteristics of thin films were investigated using X-ray diffraction, FE-SEM, and LCR-meter. The dielectric constants of BZNT decreased with decreasing Bi and Ti content. The resultant solid solutions have dielectric constant in the range of 142-242. Room temperature capacitance-voltage measurements at 1 MHz demonstrated a tunability of 30%, with a zero bias tanδ of 0.005. The effect of residual stress on the dielectric properties and frequency relaxation behaviors were also discussed.

B5.5

Dielectric Properties of BaTiO3 Based Ceramics Sintered in Reducing Atmospheres Prepared from Nano Powders. Xiaohui Wang, Renzheng Chen, Hui Zhou and Longtu Li; Department of Materials Science and Engineering, Tsinghua University, Beijing, China.

With recent developments in electronics, the small-sizing of electronic parts has proceeded quickly and the desire to increase the capacity of monolithic ceramic capacitors (MLCC) has also become more and more remarkable. As a result, the requirements for thinning the thickness of the dielectric ceramic layer and more severe reliability requirement and temperature stability requirements have increased. As the thickness of the dielectric layer in the monolithic ceramic capacitor becomes as thin as 2μm, in order to meet the reliability requirement, the grain size of ceramic grains in each layer should be reduced to 200nm or less. Therefore, how to control the grain size cope with thinning the layer thickness is still a challenge. In this paper, high purity BaTiO3 (BT) nano powders with various grain sizes of 30~85nm synthesized by chemical method were used to fabricate BT-based MLCC ceramic materials. The effect of the initial grain sizes of BT nano powders on the phase structures, microstructures and dielectric properties of the ceramics were investigated. The BT based MLCC ceramics with average grain size less than 200nm were achieved after sintering below 1220oC in reducing atmospheres, showing high dielectric constant more than 2000, low dielectric loss less than 1%, which could satisfy the X7R characteristics prescribed by EIA standard. The inhomogeneous microstructure was also investigated by a transmission electron microscope (TEM) and energy disperse spectrum (EDS).

B5.6

Spectroscopic Ellipsometry of Model Multilayer Capacitors. Tanawadee - Dechakupt and Susan Trolier-McKinstry; Materials Research Institute, Pennsylvania State University, University Park, Pennsylvania.

Barium titanate based materials have been extensively used as the dielectric in multilayer ceramic capacitors (MLCCs). Recently, the palladium or palladium alloy inner electrode has been replaced by nickel for cost reduction. Using Ni electrodes, cofiring MLCCs must be performed in a reducing atmosphere ($P_{O2}<10^{-7}$ atm). However, the low oxygen pressure usually generates a large number of oxygen vacancies and electrons in barium titanate. Accumulation of oxygen vacancies near the cathode under applied electric field leads to insulation resistance (IR) degradation of MLCCs. While these difficulties can be ameliorated by post-firing oxidation steps, the kinetics of the re-oxidation of the barium titanate and the nickel surface are not fully understood. In this article, spectroscopic ellipsometry is used to observe the oxidation of a Ni surface in contact with barium titanate. Barium titanate thin films were prepared by a sol-gel method on sputtered Ni/Pt/Ti/SiO_2/Si substrates. The dielectric constant and loss of 270 nm thick barium titanate films are 310 and 0.03 at 1 KHz, respectively. The ellipsometric parameters i.e. Δ and ψ are measured from 300 to 750 nm and modeled to extract the depth profile of the samples. It is found that nickel oxide layer of ~40 nm in thickness develops when barium titanate film is crystallized at 700°C in air. The changes of depth profile and rate of nickel oxide buildup during the re-oxidation process will be presented.

B5.7

The Microstructures and Grain Boundary Segregation of Ceramic Barium Titanate Processed in Microwave Field. Hanxing Liu, State Key Laboratory of Advanced Technology for Materials Synthesis and Processing, wuhan university of technology, wuhan, hubei province, China.

The physics and chemistry of grain boundary influence great on the properties of perovskite ferroelectrics ceramic, such as impurity of BaTiO3,SrTiO3, PbZr1-xTixO3 producing interface effect: PTCR(Positive Temperature Coefficient Resistors), and IBLC(Internal Boundary Layer Capacitors) et. al. There are a lots of researcher focus their research on the topic about the segregation of BatiO3 ceramics. In the present paper, we paid more attention on the microstructure and boundary segregation of BaTiO3 ceramic which was sintered in conventional method and in microwave field. SEM, TEM + EDAX methods were employed to detected the microstructure and the element distribution near the boundary of ceramic BaTiO3. The results show the grain size and the element distribution near the grain boundary for the BaTiO3 sintered in microwave field were influenced by the impurities of acceptor, benefactor ,and SiO2 , Al2O3 et. al. because each of those impurities have a different interaction with the microwave field. The mechanism of the diffusions of different atoms in BaTiO3 ceramic were discussed detail based on the experimental results, and tried to explain the reason of the difference of segregation in conventional method and in microwave field.

B5.8

Crystallographic properties of ZnO/ZnO:Al thin film for FBAR. Min Jong Keum[1], Tae Yung Kang[1], In Hwan Son[2], Kabseog Kim[3], Daniel Park[3], JB Lee[3] and Kyung Hwan Kim[1]; [1]Electrical & Information Eng., Kyungwon Univ., Songnam, South Korea; [2]Electrical Eng., Shinsung College, Dangjin-gun, Chungnam, South Korea; [3]Electrical Eng., Shinsung College, Dallas, Texas.

Film bulk acoustic resonators have the advantages of small size and GHz range operation. In this study, ZnO thin films for Film Bulk Acoustic Resonator (FBAR) applications were prepared by FTS (Facing Target Sputtering) system. The FTS method enables to generate high density plasma and a high deposition rate at low working gas pressure about 1mTorr. In this study, in order improve the crystallographic properties of ZnO thin films were deposited on ZnO:Al(AZO) bottom electrode that have equal crystal structure of ZnO thin film. So we prepared the ZnO/ZnO:Al thin film with sputtering power, working pressure and substrate temperature. Thickness and c-axis preferred orientation of ZnO thin film and ZnO:Al bottom electrode were evaluated by α-step and XRD.

B5.9

Abstract Withdrawn

B5.10

Pulsed DC Reactive Magnetron Sputtering Of AlN Thin Films On High Frequency LTCC Substrates. Jung W Cho[1], Jerry J Cuomo[1], Yong S Cho[2] and Roupen L Keusseyan[2]; [1]Department of Materials Science and Engineering, North Carolina State University, Raleigh, North Carolina; [2]DuPont Electronic Technologies, Raleigh, North Carolina.

AlN thin films deposited on LTCC (Low Temperature Co-fired Ceramics) substrates were investigated with regard to their compatibility and property issues. The LTCC technology has been recognized as a key solution for RF and microwave frequency ceramic packaging, which particularly requires low dielectric losses. Surface deposition of high thermal conduction AlN thin films on LTCC is expected to improve heat dissipation in LTCC-based devices. Two commercially-available LTCC substrates, 951 and 943 LTCC tapes from DuPont, have been used in this work. Successful deposition of the AlN thin film was achieved by pulsed dc reactive magnetron sputtering using an Al metal target and a nitrogen gas. Thin film quality and properties were found to strongly depend on deposition condition and heat treatment. Different deposition temperatures above 700°C were used. For thermal conductivity, thermal diffusivity of the thin film was measured by the thermal mirage method. As a result, thermal conductivity of the AlN thin film on 951 LTCC was 26 W/mK, which is a substantial increase compared to the value (~ 3 W/mK) for the LTCC tapes. Microstructure and crystallinity of the aluminum nitride films were correlated to the resultant properties. FTIR and Raman spectroscopy were used to evaluate optical properties of the thin films.

B5.11

A New Dielectric Material System of $XLa(Mg_{1/2}Ti_{1/2})O3$-(1-X)$CaTiO_3$ at Microwave Frequency. Chen Yuan Bin, Huang Cheng Liang and Row Che Win; Department of Electrical Engineering, National Cheng Kung University, Tainan, Taiwan.

The dielectric properties and the microstructures of $xLa(Mg_{1/2}Ti_{1/2})O_3$-(1-x)$CaTiO_3$ ceramics with B_2O_3 additions (0.25wt%) prepared with conventional solid-state route have been investigated. Doping with B_2O_3 (0.25wt%) can effectively promote the densification and the dielectric properties of $xLa(Mg_{1/2}Ti_{1/2})O_3$-(1-x)$CaTiO_3$ ceramics. It is found that $xLa(Mg_{1/2}Ti_{1/2})O_3$-(1-x)$CaTiO_3$ ceramics can be sintered at 1400°C due to the liquid phase effect of B_2O_3 addition observed by Scanning Electronic Microscopy. At 1425°C, $0.5La(Mg_{1/2}$Ti1/2)O_3-0.5$CaTiO_3$ ceramics with 0.25 wt% B_2O_3 addition possesses a dielectric constant (ϵr) of 43, a Q×f value of 21114 (at 8GHz) and a temperature coefficients of resonant frequency (τf) of -8.94 ppm/°C. As an increasing the content of $La(Mg_{1/2}Ti_{1/2})O_3$, the highest Q×f value of 38200(GHz) could be achieved for X=0.7.

B5.12

Ordered Structures in the Ba(Cd1/3Ta2/3)O3 Perovskite Microwave Dielectrics: A High Resolution Electron Microscopy Study. Jian Sun[1], Shaojun Liu[2], Nathan Newman[2] and

David J. Smith[1]; [1]Center for Solid State Science, Arizona State University, Tempe, Arizona; [2]Chemical and Materials Engineering Department, Arizona State University, Tempe, Arizona.

Recently, first principles calculations have predicted unusual covalent bonding from the d-electrons in Ba(Cd1/3Ta2/3)O3 perovskite microwave dielectrics, which may play an important role in achieving both a high dielectric constant and low microwave loss in these materials. Experimental investigations also showed promising high frequency dielectric properties for Ba(Cd1/3Ta2/3)O3 dielectrics. It is well-known that the chemical ordering of cation and ordering-induced domain structure have a pronounced influence on the dielectric loss at high frequency for the peroskite microwave dielectrics, such as Ba(Zn1/3Ta2/3)O3 and so on. In this study, the ordered structures of the Ba(Cd1/3Ta2/3)O3 perovskites have been investigated systematically by selected area electron diffraction and high resolution transmission electron microscopy. The effect of sintering conditions and subsequent annealing on the ordered structure of the Ba(Cd1/3Ta2/3)O3 perovskite microwave dielectrics has also been studied. It has been shown that the strong superlattice reflections are visible at position of (h±1/3, k±1/3, l±1/3) along one ⟨111⟩ direction or at position of (h±1/3, k+1/3, l+1/3) along both ⟨111⟩ directions in samples, depending on the sintering aid and temperatures. Lattice images also indicated the 1:2 ordered structure of the samples. With these results of structural characterization of the materials, the relationship between dielectric properties and microstructure of Ba(Cd1/3Ta2/3)O3 perovskites will be discussed. It is anticipated that these investigations will shed new insights into the understanding of ordered structures and dielectric properties, which are critical in optimizing the dielectric response for high frequency applications of the Ba(Cd1/3Ta2/3)O3 provskite microwave dielectrics.

B5.13
Microwave Dielectric Properties of (1-x)CaTiO$_3$-xNd(Mg$_{1/2}$Ti$_{1/2}$)O$_3$ Ceramics System.
Chen Yuan Bin and Huang Cheng Liang; Department of Electrical Engineering, National Cheng Kung University, Tainan, Taiwan.

The microwave dielectric properties of (1-x)CaTiO$_3$-xNd(Mg$_{1/2}$Ti$_{1/2}$)O$_3$ ($0.1 \leq x \leq 1.0$) have been investigated. The system forms a solid solution throughout the entire compositional range. The dielectric constant decreases from 152 to 27 as x varies from 0.1 to 1.0. In the (1-x)CaTiO$_3$-xNd(Mg$_{1/2}$Ti$_{1/2}$)O$_3$ system, the microwave dielectric properties can be effectively controlled by varying the x value. At 1400°C, 0.1CaTiO$_3$-0.9Nd(Mg$_{1/2}$Ti$_{1/2}$)O$_3$ ceramics gives a dielectric constant er of 42 , a Qxf value of 35000 (GHz) and a τ_f value of -10 (ppm/°C).

B5.14
Microwave Dielectric Properties of LaScO$_3$-TiO$_2$ Materials.
Dokyun Kwon, Thomas R. Shrout and Michael T. Lanagan; Materials Research Institute, Pennsylvania State University, University Park, Pennsylvania.

From fundamental ionic polarizability concepts, LaScO$_3$ was projected as a candidate material as a microwave dielectric. Microwave dielectric properties of LaScO$_3$ were obtained as the dielectric constant (K) of 24, Q×f of 18,000 GHz, and the temperature coefficient of resonant frequency (TCF) of -69 ppm/°C. Solid solutions and polyphase assemblages were investigated in the LaScO$_3$-TiO$_2$ system as a function of TiO$_2$ content, and correlated with the microwave dielectric properties. Orthorhombic perovskite LaScO$_3$ transformed to tetragonal symmetry with Ti substitution on the B-site of LaScO$_3$ owing to the ionic radius difference between Sc^{3+} and Ti^{4+}. With this phase transition, the formation of A-site vacancies (V_{La}"') resulted in the precipitation of a La deficient secondary phase. The substitution of Ti also affected the dielectric properties. Dielectric constant increased and TCF became less negative with increased TiO$_2$ addition. However, the Q×f value decreased, due to the formation of the secondary phase. In case of 0.6LaScO$_3$-0.4TiO$_2$ composition, K of 40, Q×f of 6,000 GHz and nearly zero TCF were obtained.

B5.15
New Low-loss Hexagonal Perovskite Microwave Dielectrics.
Meganathan Thirumal and Peter k Davies; Materials science and Engineering, University of Pennsylvania, Philadelphia, Pennsylvania.

Cubic perovskites with the general formula A(B$^{1}{}_{1/3}$B$^{11}{}_{2/3}$)O$_3$ (A= Ba, Sr; B^1= Mg, Zn, Ni; B^{11}= Ta, Nb) have been widely studied for applications as dielectric resonators in wireless communication systems. Compared to the extensive studies of these systems, hexagonal perovskites - with ordered layers of face-sharing octahedra - have received relatively little attention. During investigations of the effect of Zn volatilization on the high Q Ba(Zn$_{1/3}$Ta$_{2/3}$)O$_3$ (BZT) system, we found that one of the resultant Zn-deficient impurity phases, Ba$_8$ZnTa$_6$O$_{24}$, also exhibits an excellent microwave response (ϵ = 30.5, Q.f = 62,000, τ_f = +36 ppm/ °C). This compound has a hexagonal perovskite structure that can also be stabilized by replacing Zn with other transition metal cations (e.g. Ni, Co). The Ni analog, Ba$_8$NiTa$_6$O$_{24}$, can be sintered at relatively low temperatures (1400 °C) and also has good dielectric properties ($\epsilon \sim 29$, Q.f = 51,000, τ_f = +22 ppm/ °C). Because the temperature coefficient of Ba$_8$NiTa$_6$O$_{24}$ is of opposite sign to that of its cubic perovskite counterpart Ba(Ni$_{1/3}$Ta$_{2/3}$)O$_3$ (ϵ = 23, Q.f = 50000, τ_f = -18 ppm/ °C), and because the two compounds form stable two-phase mixtures, the possibility of forming tuned τ_f = 0ppm/ °C with high Q Ba-Ni-Ta composites became apparent. The formation, sintering and dielectric properties of the Ba(Ni$_{1/3}$Ta$_{2/3}$)O$_3$ - Ba$_8$NiTa$_6$O$_{24}$ composites will also be presented.

B5.16
Rapid Prototype Fabrication of Custom Chip Scale Packages.
Megan M. Owens, Joseph W. Soucy, Thomas F. Marinis and Henry G. Clausen; Electronics Packaging and Prototyping Division, The Charles Stark Draper Laboratory, Inc., Cambridge, Massachusetts.

Many new electronic systems require very high-density packaging to meet system volume and weight constraints. The Chip Scale Package (CSP) is often used to meet this need. However, the limited commercial availability of die in CSP form frequently drives system designers to pursue custom CSP fabrication. Long lead times and manufacturers' reluctance to run small batches typically limit the use of custom CSPs to high volume applications. This paper presents an approach for the rapid prototype of Low Temperature Co-fired Ceramic (LTCC) CSPs. Integral to the approach is the concept of using a small family of generic substrate designs to build a large variety of CSPs. The generic substrates may be fabricated and kept on hand until a CSP application need arises. When it does, a 12-to-16-week industry-typical lead time does not apply; the CSP may be fabricated rapidly, on site. Fabrication consists of simply mounting, wire bonding, and encapsulating the die, populating the solder ball pads, and singulating the packages. The lead time may be slashed from several months to just a few days. The family of substrate designs will be described. The substrates, with gold-based interconnects, have standard JEDEC Ball Grid Array (BGA) footprints of either 0.8 mm or 1.0 mm pitch. Substrates have a top surface metallization scheme of either a large central die bond pad surrounded by a number of peripheral bond sites for wire bonds, or a blanket metallization layer that may be patterned, via photolithography, to accommodate a specific application at the time of need. The die pad design is used for CSPs with a single die, while the blanket metallization design is patterned for hybrid or multi-die applications. The design approach, substrate fabrication, custom photopatterning and gold etch, and assembly processes will be presented.

B5.17
Effect of Mn Dopant on the Electromagnetic Properties of NiCuZn Ferrite Prepared by a Citrate Precursor Method.
Xiaohui Wang, Weiguo Qu, Tonghao Liu and Longtu Li; Department of Materials Science and Engineering, Tsinghua University, Beijing, China.

NiCuZn ferrite has been long used as one of the most important soft magnetic medium materials in surface mounting electronic devices such as MLCIs for its high permeability. Many methods have been used to enhance the performance of NiCuZn ferrite so as to optimize the performance and also minimize the size and weight of these devices. In this paper, nano-sized NiCuZn ferrite powders with the composition of (Ni0.15Cu0.2Zn0.65O)(Fe2-xMnxO3+0.5x)0.992, (X=0.05,0.10,0.15,0.25,0.30,0.35,0.40) were prepared using a citrate precursor method. Samples made of nano-sized powders were sintered using a two-stage method at a temperature around 890 degree. The effect of Mn content on the resonance frequency and initial permeability was investigated. The microstructures of the sintered ceramics were observed and analyzed by SEM. The experiment results indicate that the introduction of Mn into NiCuZn ferrite has a great influence on its electromagnetic properties. The initial permeability of NiCuZn ferrite increases greatly with a small amount of Mn addition firstly, and then further increase of Mn content leads to a slight increase in the initial permeability but a considerable decrease in the resonance frequency. By changing the content of Mn addition, the useful frequency dependence of initial permeability could be adjusted in a range of frequency from several hundreds of KHz to several MHz. To achieve NiCuZn ferrite with promising initial permeability as well as resonance frequency, a proper amount of Mn should be introduced into it.

B5.18
Tape casting of M type hexaferrite particles. Denis Autissier, Nicolas Dechambre, Laurence Longuet and Hubert Pascard; Materials, CEA, Monts, France.

The M type hexaferrite BaFe12O19 has very strong uniaxial anisotropy, due to the hexagonal crystalline structure. Substituting x(Co2+,Ti4+) cations for 2x Fe cations changes the anisotropy that becomes planar for x=1.2. This property allows high values of magnetic permeability, but to derive some benefit from, all grains of the ceramic have to be aligned with the c axis of the hexagonal cell perpendicular to the surface of the object. Static magnetic permeabilities of tape cast samples are compared with those of a reference material, prepared by slip casting under magnetic field. Powders are prepared through a classical ceramic way : stoechiometric weighting, mixing with iron balls, calcining at 1150C. Rheological optimization of the slurry has been carried out. Tapes are cast (350 micro m thick), dried under rotating magnetic field (0.05 T) and cut in 25 mm disc. 40 of them are uniaxially pressed under vacuum and sintered (1270C). The comparison between samples dried with and without magnetic field shows it is required. High values of permittivity are observed, reflecting the presence of divalent iron. Wear of iron balls induces an iron excess, responsible for electrical conductivity. Samples with iron under stoechiometry (1 to 6pc), combined with oxygen sintering are elaborated. The reference static permeability is obtained. Measurement of permeability vs temperature has been carried out in order to understand the role of divalent iron.

B5.19

Hyperfrequency magnetoelastic effects in Y3-xTbxFe5O12 garnets. Denis Autissier, Virginie Grimal, Laurence Longuet and Hubert Pascard; Materials, CEA, Monts, France.

Hyperfrequency magnetoelastic effects are very important in the field of microwave applications of ferrites : the application of a stress, due to the device processing can change the materials properties. Our approach in this paper is to study the effects of stresses on the magnetic permeability in the range 0.01 GHz to 6 GHz. To this end we have studied Y3-xTbxFe5O12 garnets (x between 0 and 1). In this family, the magnetostriction coefficient increases from negative values for x=0 to positive one for x=1. Samples are prepared through a classical ceramic way. Precursor oxides are weighted, mixed with iron balls, calcined at temperatures between 1100 and 1250 C. Powders are characterized (XRD, SEM, magnetization...). Cylindrical samples are uniaxially pressed (300 MPa) and sintered in oxygen at 1500 C during 15 hours. Densities are closed to the theoretical density. The microstructures are homogeneous, with a 20 micro m grain size. Static determination of the sign of the magnetostriction coefficient is carried out using hysteresis measurement under stress. Dynamic permeabilities are measured with APC7 standard samples, between 0.01 and 6 GHz combined with the application of a stress between 0 and 17 MPa in the axis of the torus. The variations of the permeability versus stress are presented for materials with positive, negative or null magnetostriction coefficients. A proposition of interpretation of the magnetic comportment of the materials will be suggested.

B5.20

Process Control Feedback Problems for High Frequency And High Power SiC Based Devices. Kevin W. Kirchner and Ken A Jones; Micro-Devices Branch, Army Research Laboratory, Adelphi, Maryland.

Because of many favorable intrinsic material properties including the ability to handle high power and operate at high temperatures, SiC is being investigated and developed for use in high frequency and high power devices. Analytical techniques that provide feedback to the material growers and device manufactures are needed in order to mature this material system. One of the principal analytical tools used for this feedback is x-ray diffraction (XRD). Although XRD is itself well established, use of this analytical tool with SiC can produce some unusual results because SiC wafers often have a mosaic structure. This paper will address the confusing or even incorrect information a grower might receive when he has x-ray analysis done of his SiC based prototype. For example, by adjusting the spot size of the x-ray beam impinging on his sample, one can move a long way towards controlling the common problem of obtaining multiple peaks in the x-ray rocking curve analysis of the sample. These overlapping peaks are hard to analyze in critical respects (position and width) necessary for the x-ray analysis to produce meaningful results. Other steps that will be discussed that can also help clarify the information from the x-ray analysis include adjustments to: the slit configuration, beam conditioning, and output display scales. The information in this paper is meant as an overview for a grower or a device person to help them be in a better position to get the feedback they need for their material and device development.

B5.21

Effect of substitution in La3Ga5SiO14 crystals on their growth and piezoelectric properties for the high temperature sensor applications. Il Hyung Jung and Keun Ho Auh; Ceramic Processing Research Center, Seoul, South Korea.

The rapid growth of electronic technologies requires the development of new piezoelectric materials that have smaller in size, larger in piezoelectricity and temperature stability. For designing piezoelectric devices, langasite (LGS, La3Ga5SiO14) which represented as Ca3Ga2Ge4O14 (CGG) type crystals has new piezoelectric properties, which exhibit intermediate properties between those of quartz and lithium tantalate. We have therefore investigated the influence of substitution in each site on their growth and piezoelectricity. In this study, we will report the relation of substitution and piezoelectric properties for the high temperature applications. For this purpose, La3Ta0.5Ga5.5O14 (LTG), Sr3NbGa3Si2O14 (SNGS), Sr3TaGa3Si2O14 (STGS), Ca3NbGa3Si2O14 (CNGS) and Ca3TaGa3Si2O14 (CTGS), La3-x BaxTa 0.5+x/2 Ga5.5-x/2O14 (LBTG) and La3Ta0.5Ga5.5-x AlxO14 (LTGA) single crystals are grown and investigated.

SESSION B6: Integration and Devices
Chair: Mareike Klee
Wednesday Morning, December 3, 2003
Room 201 (Hynes)

8:30 AM *B6.1

High Frequency, High Density Interconnect Using AC Coupling. Paul D Franzon[1], Stephen Mick[1], John Wilson[1], Lei Luo[1], Karthik Chandrasakhar[1], Angus Kingon[2], Salvatore Bonafede[3], Chad Statler[3] and Richard LaBennett[3]; [1]ECE, NC State University, Raleigh, North Carolina; [2]MSE, NC State University, Raleigh, North Carolina; [3]MCNC-RDI, Research Triangle Park, North Carolina.

Introduction Achieving high-density connectivity with conventional I/O schemes presents a number of difficulties. All these schemes have, at their root, the concept of using a mechanical connection for signal transmission. To achieve reliable connections, the mechanical connection must be sufficiently compliant to withstand thermal cycling. Achieving a tight pitch, while maintaining compliancy is very difficult, as it usually results in a tall, thin, and thus relatively fragile and difficult-to-make mechanical structure. In addition, high density interconnect connections require greater smoothness and flatness of the surfaces being mated, often increasing their cost. Transmission of digital (and many analog) signals do not require the DC and low frequency components. Thus the signals can be transmitted through series capacitors and transformers, no mechanical connection is needed. Previous efforts to explore capacitive coupling have shown success but did not address issues such as how to connect power and ground. An approach has been identified that solves this, and other, problems with AC coupling. Half capacitors, or spiral inductors, are fabricated on the chip and the opposing chip or package surface. The chip side is covered with a thin overglass, to prevent accidental shorting. DC connections are provided through a dense field of conventional solder bumps. The bumps are buried either in the package or in the redistribution layer on the chip. This geometry brings the opposing half capacitors or spirals into close and controlled proximity. Single-sided, partial and full differential can all be supported, with the normal tradeoffs. Inductive coupling provides the interesting potential for creating a differential circuit with only one pad per I/O. This scheme has a number of advantages over the mechanical alternatives, including excellent compliance, good tolerance to temperature changes etc. It also permits high-speed signaling with excellent signal integrity. The basic feasibility of the solder bumps and buried solder balls have been demonstrated. Performance and Materials Issues The main factors that determine the performance limits of ACCI are as follows: - Capacitive Coupling. The main issue is the series capacitance. Our models and experiments use a glass-air combination. Obviously a high-K dielectric underfill would be very desirable. Such a material would have to offer stress relief properties, and be compatible with IC processing, as it also replaces the overglass. - Inductive coupling. To a first order signal integrity is dominated by the coupling coefficient, k. $k > 0.9$ is desired. We are investigating high permeability materials that suit these planar structures and enhance coupling. Other important parameters are turns-ratio, and the frequency response as determined by parasistics.

9:00 AM B6.2

Characterization Of Mechanical Properties Of A Au/Sn Solder Ball To Au/Pt/Pd Pad Attachments.
Kevin Anthony Bruff[1,2], Thomas Marinis[2], Joseph Soucy[2], Megan Owens[2], Cosme Furlong[1] and Ryszard Pryputniewicz[1]; [1]Mechanical Engineering, Worcester Polytechnic Institute, Worcester, Massachusetts; [2]Electronics Packaging and Prototyping, Draper Laboratory, Cambridge, Massachusetts.

High-density interconnections, ruggedness, as well as surface mount compliant technology utilizing ball grid arrays (BGAs) is a viable Microsystems packaging option. A significant factor in BGA package reliability is the integrity of the attachment of the solder ball to the substrate via the constitutive layers constructed during the fabrication process. There is a need to develop both qualitative and quantitative methods for determining solder ball attachment reliability as well as performance. This paper presents fatigue testing of BGA packages to simulate real-time periodic loading conditions, which was performed to characterize adhesion of the solder ball attachments. The surface mount BGA sample was attached to the circuit board to construct the test vehicle and was loaded via a tensile testing machine, which applied a transverse loading effect along a single direction. The failure mechanism was determined by metallurgical analysis. Mechanical testing incorporated cyclic loading and data logging. Results obtained provided information regarding grain boundary distortion before and after the application of loading. Scanning electron microscopy was employed to deliver qualitative information regarding dislocations and grain size changes. Data on the grain size changes were utilized to understand structural changes undergone during loading cycles. Finite element modeling was utilized to perform parametric simulations in order to develop an understanding of the stresses and strains affects due to cyclic loading. If a microstructure evolves during the loading then the material may exhibit a measurable change in its ability to withstand cyclic loads, such as those due to vibrations encountered during normal operating conditions.

9:15 AM B6.3
High-Density, Low-loss MOS Decoupling Capacitors Integrated in a GSM Power Amplifier. Fred Roozeboom[1], Anton L. Kemmeren[1], Jan F. Verhoeven[1], Eric van den Heuvel[1], H. Kretschman[1] and Tomas Fric[2]; [1]Philips Research, 5656 AA Eindhoven, Netherlands; [2]Philips Semiconductors, 6534 AE Nijmegen, Netherlands.

High-density MOS capacitors, made from dry-etched macroporous silicon, have been fabricated with ~ 25 nF/mm^2 specific capacitance on 150-mm highly doped (~ 1-5 mOhm.cm) Si-wafers, containing arrays of macropores with 3.5 um pitch and ~ 1.5 um diameter. The dry-etching process used was the *Bosch* process where in a time-multiplexed way ~25 um deep pores are anisotropically etched by alternatively introducing SF_6/O_2 etching gas and C_4F_8 passivation gas into the plasma. The macroporous Si-wafers thus obtained served as high-surface substrate for the capacitor structure. MOS capacitors were fabricated from these dry-etched wafers by fully MOS-compatible processing (e.g, thermal oxidation, LPCVD of silicon nitride, silicon oxide and in situ doped polycrystalline-Si, etc.). Wafers were fabricated with a ~ 0.7 um poly-Si/ ~2 um Al top electrode [1] and dielectric stacks showing 7-10 MV/cm electrical breakdown field and leakage < 1 nA/mm^2 @ 20 V. The processed wafers were thinned to 380 um and sawn into dies. Typically an ESR < 50 mOhm; and an ESL < 20 pH as well as resonance frequencies were found for ~ 40 nF capacitors as measured by transmission measurements (~ 0.1 - 13 GHz) on these dies in a 50 Ohm microstrip line geometry, cf. Table 1. The table shows the low-loss factors of the MOS capacitors vs. SMD capacitors. 40 nF dies were mounted by wire bonding on Al_2O_3 or laminate substrate as supply-line decoupling capacitors in complete GSM power amplifier test modules. The signal stability for these modules was measured (~ 0.1 - 1 GHz)and compared to identical test modules containing conventional SMD ceramic capacitors. In both configurations the output spectra were very noisy with SMD capacitors (oscillations around 248 MHz and 655 MHz up to - 40 dBm at 50 Ohm termination and many more oscillations up to - 15 dBm at 1:8.5 mismatch), and very smooth and stable with the MOS decoupling capacitors (smooth spectra with transmission remaining below the - 60 dBm specification). These measurements showed superior decoupling by the MOS capacitors, thus improving the stability of power-amplifier modules by replacing conventional SMD technology. This makes these MOS capacitors very suitable for integrated decoupling purposes, e.g. supply-line decoupling in RF wireless communication and analog and mixed-signal systems. 1. F. Roozeboom, R. Elfrink, T.G.S.M. Rijks, J. Verhoeven, A. Kemmeren and J. van den Meerakker, -Int. J. Microcircuits and Electronic Packaging, 24 (2001) 182-196 Table 1. Electrical data extracted from transmission measurements by LCR-modelling for MOS capacitors in dry-etched porous Si and a conventional SMD 0402 ceramic capacitor.

9:30 AM B6.4
Metal Silicide with Adjustable Workfunction as Metal Gate Electrode. Daniel Pham, Billy Nguyen, Gabriel Gebara and Larry Larson; International Sematech, Austin, Texas.

In this paper, we present a study of metal silicide as a possible candidate for dual-metal gate electrode technology. The silicide films are formed by rapid thermal annealing of metals such as cobalt or titanium with pre-doped polycrystalline silicon. High K HfO2 dielectric was used in the experiment. The film properties are investigated in term of chemical and thermal stability, inter-diffusion and work-function. The work-function was extracted from C-V measurements on MOS capacitors. The use of silicide films presents multiple advantages: (1) Tuning of work-function achievable by choice of metal and/or doping the polysilicon before silicidation process, (2) Conservation of dielectric integrity, (3) Full compatibility with CMOS process and good thermal stability of metal silicide, (4) Eliminating the polysilicon gate depletion, boron penetration and increased gate resistance. In our study, Ti and Co silicide gate capacitors were fabricated on n-type and p-type substrates. The polysilicon film was implanted with either phosphorous or boron before the silicidation. Capacitance-voltage characteristics performed relatively well for all conditions. The work-function was extracted using two or three dielectric thicknesses and plotting flatband voltage (Vfb) vs. EOT. The slope of the Vfb vs. EOT plot leads to the value of fixed charge in the gate dielectric while the intercept results in the value of the metal-semiconductor work-function difference, fms. Knowing the substrate doping, the work-function of the metal was extracted. In our study, we found that the metal- semiconductor work-function difference of TiSi on n-type and p-type substrate can be separated by 0.55eV and very symmetrical around mid-gap. Results of CoSi cases are also very promising.

9:45 AM B6.5
High Electron Mobility SiGe/Si Transistor Structures on Sapphire Substrates. Samuel A. Alterovitz[1], Carl H Mueller[2] and Edward T Croke[3]; [1]NASA Glenn Research Center, Cleveland, Ohio; [2]Analex Corporation, Cleveland, Ohio; [3]HRL Laboratories LLC, Malibu, California.

SiGe/Si field effect transistors (FETs) are now being developed for high frequency applications. However, the substrate normally used is Si, which causes large losses in the passive elements required for a complete high frequency circuit. Because of its high electrical resistivity, sapphire is an almost perfect substrate for high frequency passive components, and integration of these two components is highly desirable. However, to our knowledge no reports of SiGe/Si n-type FET structures grown on sapphire have been reported. In the present study, high mobility n-type SiGe/Si FET transistor structures have been fabricated by MBE on sapphire substrates using strained 10 nm thick silicon channels. The strained Si channels were sandwiched between Si0.7Ge0.3 layers, which, in turn, were deposited on Si0.7Ge0.3 virtual substrates and graded SiGe buffer layers. The electrons in the strained Si channels were obtained using two methods: modulation doping of the top Si0.7Ge0.3 layer using a delta-doped Sb technique, and phosphorus ion implantation followed by post-annealing. The phosphorous ions were preferentially located in the Si channel at a peak concentration of approximately 1x10E+18 cm-3. The highest room temperature electron mobilities measured were 1380 cm2/V-sec at a carrier density of 1.8x10E+12 cm-2 for the Sb delta-doped sample, and 900 cm2/V-sec at a carrier density of 1.3x10E+12 cm-2 for the phosphorous ion implanted sample. A systematic study of the ion implanted samples showed that the electron concentration appears to be the key factor that determines mobility, with the highest mobility observed for electron densities in the 1 - 2x10E+12 cm-2 range. Measurements at low temperatures show a large increase in the mobility in some delta doped samples. Mobility above 13,000 was measured at LHe temperatures accompanied by Shubnikov de Haas oscillations, showing the existence of a 2DEG and excellent confinement of the electrons in the channel.

10:30 AM *B6.6
RF-MEMS: Materials and Technology, Integration and Packaging. Harrie A. C. Tilmans, IMEC v.z.w., Leuven, Belgium.

Wireless communication is showing an explosive growth of emerging consumer and military applications of radio frequency (RF), microwave, and millimeter-wave circuits and systems. Future personal (hand-held) and ground communications systems as well as communications satellites necessitate the use of highly integrated RF front-ends, featuring small size, low weight, high performance and low cost. Continuing chip scaling has contributed to the extent that off-chip, bulky passive RF components, like high-Q inductors, ceramic and SAW filters, varactor diodes and discrete PIN diode switches, have become limiting. Micro-machining or MEMS technology is now rapidly emerging as an enabling technology to yield a new generation of high-performance RF-MEMS passives to replace these off-chip passives in wireless communication (sub)systems. This paper presents the progress in RF-MEMS device and package development, thereby addressing relevant technology and materials issues. MEMS devices, unlike ICs, contain movable fragile parts that must be packaged in a clean and stable environment. So-called 0-level packaging of the RF-MEMS device is described, creating an on-wafer device scale enclosure around the MEMS device, carried out during wafer processing, prior to die singulation. The 0-level package must be strong, equipped with electrical RF signal feedthroughs and be (near-)hermetic. The individual 0-level assemblies can next be mounted in a low-cost plastic molded 1-level package, e.g., a BGA package, or in a (more expensive) ceramic package. Alternatively, the assembly can be handled as a chip scale package (CSP) and directly joint to a printed microwave wiring board. The paper concludes in stipulating how integration of RF-MEMS passives with other passives (as inductors, LC filters, SAW devices) and active circuitry (RFICs) can lead to so-called "RF-MEMS system-in-a-package (RF-MEMS-SiP)" modules. The evolution of the RF-MEMS-SiP technology is illustrated using IMEC's microwave multi-layer thin film MCM-D technology which today already serves as a technology platform for RF-SiP.

11:00 AM B6.7
Photodefinable Metal Oxide Dielectrics: A Novel Method for Fabricating Low Cost RF Capacitive MEMS Switches. Sean J. Barstow[1], Augustin Jeyakumar[1], Guoan Wang[2], John Papapolymerou[2] and Clifford Lee Henderson[1]; [1]School of Chemical Engineering, Georgia Institute of Technology, Atlanta, Georgia; [2]School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, Georgia.

Low-cost MEMS switches are prime candidates to replace conventional GaAs FET and p-i-n diode switches used in RF and microwave communication systems due to their low insertion loss, good isolation, linear characteristics, and low power consumption. Various capacitive RF micromechanical switches made from a variety of metals have been reported in the literature for use in applications including phase shifters, reconfigurable filters, and tuners. The structure of these capacitive switches generally consists of a lower electrode, thin dielectric layer, and moveable membrane. Several studies have shown the importance of the dielectric layer in both switch performance and reliability. In most MEMS switches reported so far, this dielectric layer is typically silicon nitride deposited with PECVD or HDICP CVD techniques. Taking into account the higher costs and limitations associated with using CVD and sputtering techniques for switch fabrication, there is a need for lower cost fabrication methods, particularly in the area of dielectric deposition and patterning. This paper presents a novel method for depositing the patterned dielectric layers required for capacitive MEMS switches. In this process, a photosensitive metal-organic precursor solution is used to coat the substrate and form a precursor thin film. Upon UV exposure, the organic ligands of the precursor molecules are cleaved which results in the formation of an amorphous metal oxide in the exposed areas. The remaining unexposed precursor material may be subsequently washed away using a developer solvent. Thus, the photosensitivity of these materials allows one to selectively deposit metal oxide structures without requiring the deposition of blanket oxides via sputtering or other means and it eliminates the need for subtractive plasma or wet etching. This paper discusses recent progress in developing novel photopatterned oxide materials including physical and electrical characterization of the oxides and results from the use of these materials in MEMS microwave switches.

11:15 AM B6.8
Characterization of Au80/Sn20 solder for MEMS packaging applications. Ryszard J. Pryputniewicz[1], Thomas F Marinis[2], Joseph W Soucy[2], Adam R Klempner[1], Peter Hefti[1] and Cosme Furlong[1]; [1]Mechanical Engineering, Worcester Polytechnic Institute, Worcester, Massachusetts; [2]Draper Laboratory, Cambridge, Massachusetts.

Effective development of packaging for MEMS is based on use of solder for bonding dice to substrates. During bonding, solder is subjected to creep because of its exposure to high temperatures of the processes involved. Unless creep can be controlled during these processes, the dice and/or substrates, bonded by the solder, may fracture, destroying the package. In order to develop procedures to control solder creep, we are using analytical, computational, and experimental solutions (ACES) methodology to determine optimum set of parameters, characterizing a bonding process, that will minimize effects that creep has on dice and substrates used a given MEMS packaging application. More specifically, we experimentally determine creep characteristics of Au80/Sn20 solder as functions of temperature and stress. Then, we use these characteristics to computationally determine the effects that solder may have on the components it bonds and we measure these effects using optoelectronic laser interferometric microscope (OELIM) methodology. The OELIM methodology provides deformation data with submicron spatial resolution and nanometer measurement accuracy in full-field-of-view in near real-time on samples subjected to specific test conditions. Correlation between OELIM data and computationally determined effects is made subject to uncertainty limits. These limits are analytically determined using phenomenological relationships, based on equations governing the bonding process, which are solved for specific values of independent parameters comprising them. The solutions also include determination of contributions that uncertainties in individual independent parameters have on the overall uncertainty in creep and use of these contributions to efficiently control creep, as will be illustrated with representative examples.

11:30 AM B6.9
Integrated Phased Array Antenna/Solar Cell System for Flexible Access Communications. Eric B Clark[1], Carl H Mueller[2], AnnaMaria T Pal[1], David M Wilt[1], Richard E Lee[1] and Felix A Miranda[1]; [1]NASA Glenn Research Center, Cleveland, Ohio; [2]Analex Corporation, Cleveland, Ohio.

This paper describes recent efforts to integrate advanced solar cells with printed planar antennas. Several previous attempts have been reported in the literature, but this effort is unique in several ways. It uses Gallium Arsenide (GaAs) multijunction solar cell technology. The solar cells and antennas will be integrated onto a common GaAs substrate. When fully implemented, the Integrated Antenna/Solar Array Cell will be capable of dynamic beam steering. In addition, this program targets X-band (8 to 12 GHz) and higher frequencies, as compared to the 2.2 to 2.9 GHz arrays targeted by other organizations. These higher operating frequencies enable wider communication bandwidths and thus higher data transfer rates. The first phase of the effort involves the development of 2 x 2 cm^2 GaAs Monolithically Integrated Module (MIM) solar cells on one side of the substrate, with integrated patch antennas on the opposite side of the substrate. Subsequent work will involve the design and development of devices having the GaAs MIMs and phased array antennas on the same side of the substrate. Results from the phase one efforts will be presented.

11:45 AM B6.10
Degradation in PHEMTs: Origin and Relation to Device Structure. Tamara Baksht[1], Sana Solodky[1], Alexandr Khramtsov[2], Mark Leibovich[3], Isai Ortenberg[1], Gregory Bunin[3], Shlomo Hava[2] and Yoram Shapira[1]; [1]Department of Electrical Engineering - Physical Electronics, Tel Aviv University, Tel Aviv, Israel; [2]Department of Elect.&Comp. Engineering, Ben-Gurion University of the Negev, Beer Sheva, Israel; [3]Gal-El (MMIC), Ashdod, Israel.

ΔThe AlGaAs/InGaAs/GaAs pseudomorphic high electron mobility transistors (PHEMTs) are the technology of choice for a number of high frequency applications. Power applications of electronic components at high frequencies require very stable performance. Therefore, any changes of a device DC and RF parameters during normal operation conditions, i.e., performance degradation, make the device unacceptable for several applications. To eliminate the causes of degradation in PHEMTs it is vital to determine its mechanisms. The aims of this research are a) to determine the physical mechanism of degradation and b) to reveal the correlation between PHEMT degradation and its physical structure and geometry. The degradation could be parameterized in terms of a permanent shift of the main PHEMT figures of merit: threshold voltage (ΔV_T), maximum transconductance value (Δgm_{max}), small-signal gain (ΔMAG), and threshold frequency (Δf_T). Measurements of more than 250 PHEMTs with different geometries have been performed. An empirical model, relating degradation parameters and device structure, has been developed. The recess width (Wr) and the gate-to-drain distance (L_{GD}) are the key lateral parameters. The results show an unambiguous relation between degradation and impact ionization. Generation of hot holes, following impact ionization in the InGaAs channel, results in parasitic charge accumulation and is responsible for PHEMT degradation. Variations of PHEMT geometry and doping level impact the electric field distribution in the device and therefore tune the degradation.

SESSION B7: Materials, Packaging and Processing
Chairs: Yong Cho and Christian Hoffmann
Wednesday Afternoon, December 3, 2003
Room 201 (Hynes)

1:30 PM B7.1
GaAs Backside Via holes Process Optimisation, Targeting high yield and Manufacturability. Irit Hallakoun[1,3], Lina Karasik[1,2], Joseph Kaplun[1], Gregory Bunin[1], Dov Sherman[2] and Yoram Shapira[3]; [1]Gal-El (MMIC), Ashdod, Israel; [2]Technion Institute, Haifa, Israel; [3]Tel-Aviv University, Tel-Aviv, Israel.

GaAs backside through-wafer via-hole processing is known to be a "yield killer" step. It includes both etching the via-hole itself and metal deposition into the "blind" hole. A common problem is an electrical disconnection between front and back side. The electrical contact is achieved by depositing a few microns thick gold layer on the backside and inside the via-hole that ends with gold stop layer at the front side. This is done by sputtering a thin gold seed layer, followed by the electrodeposition of a thicker layer from a solution containing gold ions. A discontinuation of the gold layer on the sidewall of the via-hole may be caused by a number of reasons such as pillars (whiskers) inside the via, or insufficient cover of the gold sputtered layer followed by inappropriate plating conditions We have investigated the integration of the etching process with this of the electroplating to achieve maximal yield and design to manufacturability. This is done by eliminating the pillars inside the via-holes to enable good metal coverage, and replacing the chemical component, which supplies the gold ions into the plating solution. We have compared the behavior of a potassium gold cyanide complex based solution, and a gold sulfite complex. We found out that discontinuities in the seed layer can be filled with gold, despite of the lack of electrical contact, choosing the right combination of process parameters and plating solution. DOE of different plasma conditions was performed in order to optimize pretreatment procedure before gold electroplating. Influence of different electroplating parameters on seed layer stress and adhesion was investigated. In order to integrate the backside process with the following soldering process we have implemented an additional step of thin Ti layer deposition only into the hole. Visual inspection method was developed for verifying that Ti barrier layer prevents penetration of solder into the via holes.

1:45 PM B7.2
Microstructural Evolution of Cu/Ta/GaAs Multilayers with Thermal Annealing. Chang-You Chen, Wei-Cheng Wu, Cheng-Shih Lee, Edward Yi Chang and Li Chang; Department of Materials Science and Engineering, National Chiao Tung University, Hsinchu, Taiwan.

For GaAs integrated circuits, copper metallization has the following advantages over traditionally used gold metallization: lower resistivity, higher thermal conductivity, and lower cost. Since copper diffuses very fast into GaAs and acts as a deep acceptor for GaAs, this causes degradation of electrical property of GaAs devices, so a diffusion barrier is required. Sputtered tantalum film can effectively prevent the interaction of copper and GaAs after annealing up to 500°C.[1] We extend the previous work and characterize the microstructural evolutions of Cu/Ta/GaAs with thermal annealing treatments. The failure mechanism after high temperature treatment is also presented. In this study, copper metallization for GaAs is evaluated by using Cu/Ta/GaAs multilayers for its thermal stability. A thin Ta layer of 30 nm thickness is sputtered on the GaAs substrate as the diffusion barrier. After Cu metallization, the samples are annealed at temperatures ranging from 400 to 600°C for 30 minutes in argon atmosphere. Sheet resistances of the samples are measured by four-point probe to survey the overall reaction involving copper. XRD and AES are used for the analysis of the phases of the reaction products and the interdiffusion of the elements across the interfaces, respectively. Microstructural characterization is carried out by using cross-sectional TEM with electron diffraction for phase identification, and EDS for microanalysis of chemical compositions. HRTEM is used to observe the lattice image of selected areas at atomic scale, and the Fast Fourier transformation of the lattice images is used to identify the crystal structure pattern of the corresponding areas. As can be judged from the results of sheet resistance, XRD, AES and TEM, the Cu/Ta films on GaAs are stable up to 500°C. The sheet resistance remains almost unchanged after 400 and 500°C annealing as compared with that of the as-deposited structure. However, the sheet resistance increases slightly upon annealing at 550°C and increases drastically after 600°C annealing. The results of the XRD and AES studies show that the phases and the distributions of the elements in the deposited films remain almost unchanged after 500°C annealing. However, annealing at higher temperatures results in severe changes of phases and severe redistribution of all the elements in the multilayer. It is seen from the TEM analysis that after 550°C annealing, the interfacial mixing of Ta with GaAs substrate occurs, resulting in the formation of $TaGa_2$ and $TaAs_2$ at the Ta/GaAs interface, and the diffusion of both Ga and As through the Ta layer into Cu layer occurs, forming the Cu_3Ga and Cu_3As phases at the Cu/Ta interface. After 600°C annealing, the reaction of GaAs with Ta and Cu forms TaAs and Cu_3Ga as a result of Cu migration and interfacial instability after thermal annealing. 1 C. Y. Chen, L. Chang, E. Y. Chang, S. H. Chen and D. F, Chang, Appl Phys Lett. 77, 3367(2000).

2:00 PM B7.3
Abstract Withdrawn

2:15 PM B7.4
Fabrication of III-V optoelectronic devices from an epitaxial film bonded to Si by BCB. Alex Katsnelson, Vadim Tokranov, Michael Yakimov, Matthew Lamberti and Serge Oktyabrsky; SNSNE, SUNY Albany, Albany, New York.

Chip-level optical interconnects involve high frequency photoemitters and photodetectors integrated with electronics on a Si substrate, and are considered as a possible solution to substitute wires in off-chip I/O's to improve latency, speed and power characteristics. A method for hybrid integration of III-V optoelectronic components on Si platform was proposed and realized. Simulations of thermal behavior and mechanical stresses of this integration scheme were performed using finite element analysis, which revealed adequate heat dissipation. Simulations show that this bonding protocol allows reduction of overheating and mechanical stress thats enhances the optoelectronic device performance and increases reliability. A reversed VCSEL structure was grown homoepitaxialy by molecular beam epitaxy and used for manufacturing of the test devices on Si platform. The structure was bonded to Si using BCB (Cyclotene™). The substrate was completely removed by selective wet etching down to an AlAs etch stop layer embedded into the structure. An AlAs layer was removed in hydrochloric acid to open surface of the top distributed Bragg reflector. The array of the devices was fabricated using wet etching and two-level metallization. Lateral wet oxidation was employed to form VCSEL apertures for current and optical confinement. Electro-luminescence spectrum, I-V and P-T characteristics were measured and compared with a reference homoepitaxial structure and the results of the simulations. It was found that FWHM of the electroluminescence line is 0.6 nm and the serial resistance of fabricated devices is 170Ω. Measured thermal impedance was found to be about two times higher than that for the devices on a host GaAs wafer.

2:30 PM B7.5
Influence of Bottom Electrode Material on Electrical Characteristics of Integrated Amorphous Tantalum Oxide Metal-Insulator-Metal Capacitors for System-on-Chip Applications. Satyavolu S. Papa Rao, Asad M. Haider, Lindsey H. Hall, Gaddi Haase, James S. Martin, Jinyoung Kim, Edmund Burke, M. Grant Albrecht and Kelly J. Taylor; Silicon Technology Development, Texas Instruments, Inc., Dallas, Texas.

A planar metal-insulator-metal (MIM) capacitor using a high dielectric-constant material, integrated into the metal levels is a good candidate for decoupling and analog capacitors at the 90 nm node. We have integrated a single-mask tantalum oxide (TaO) MIM capacitor at the first metal-level directly on tungsten contacts. The integration scheme we used is compatible with a construction on copper vias like would occur for an upper metal level integration of the MIM capacitor. TaO was deposited by metal-organic chemical-vapor-deposition at 400°C. The electrodes were deposited by physical vapor deposition and the entire MIM-capacitor built directly on tungsten contacts. Plasma etch and wet-etch processes were used to define the MIM capacitor structure. The top electrode metal was TiN. The performance of the bottom electrode is critical to the success of the MIM capacitor and is the focus of this report. We compared TiN to TaN as possible bottom electrode materials since both materials are compatible with our copper damascene integration scheme. We saw that TiN (and TiAlN) has a 10x lower current leakage and 15% higher capacitance density than TaN, making it our material of choice for the MIM capacitor bottom electrode. Subsequent processing of the planar MIM-capacitor causes more degradation of both TiN and TaN-based capacitors. Our observations are consistent with oxidation of the bottom electrode due to the oxidizing ambient of the TaO deposition and anneal. In addition, it was shown that Cu diffusion is successfully inhibited with a hybrid TaN/TiN stack. We successfully built an amorphous TaO single-mask MIM capacitor with capacitance density of 10 $fF/\mu m^2$ and leakage current-density $<1x10^{-4} A/cm^2$ at 2V with TiN bottom and top electrodes.

2:45 PM B7.6
Improvement of Tantalum Pentoxide Metal-Insulator-Metal Capacitors For SiGe RF-BiCMOS Technology. Hongjiang Sun, Ka Man Lau, Eyup Aksen and Nancy Bell; Philips Semiconductors, Hopewell Junction, New York.

Intensive improvement activities were made for the fully integrated Metal-Insulator-Metal (MIM) capacitors ($>5fF/\mu m^2$) used in the advanced SiGe RF BiCMOS technology. MIM capacitor is composed of two metal plates separated by amorphous Tantalum pentoxide (Ta_2O_5) with a high dielectric constant of 23 ~ 28, depending upon process. The fabrication requires only one additional mask to integrate the Ta_2O_5 MIM capacitor into existing technology. Achieved improvements include not only a lower leakage density but also a better voltage linearity at 27^0 C ~ 150^0 C temperature range, a lower temperature dependency at − 6V to +V bias range. Voltage coefficients VC1 and VC2, measured at 27^0 C, are 187 ppm/V and 26 ppm/V^2, respectively, and temperature coefficient TC1 of capacitance is 94 ppm/^{0}C. The leakage current density varies from $4.9x10^{-7}$ A/cm^2 at 27^0 C to $1.9x10^{-4}$ A/cm^2 at 125^0 C with a breakdown voltage of 20 V. To increase capacitance density meanwhile keeping the leakage lower, an ozone treatment after tantalum pentoxide film deposition has been investigated. A capacitance density as high as 10.3 $fF/\mu m^2$ has been achieved with a leakage density one order lower than standard process. The fact that the extracted dielectric constant increased from 28 to 32 as well as the change of the voltage and temperature coefficients clearly indicated that the ozone treatment changed the intrinsic property of the tantalum pentoxide film as well as the surface condition. The need for such high-k materials is derived from the cost of telecommunications products and the reduction of the circuit area available for passive structures.

3:30 PM B7.7
Fluid Dynamic Assembly of Semiconductor Blocks for Heterogeneous Integration. Ikuo Soga, Yutaka Ohno, Shigeru Kishimoto, Koichi Maezawa and Takashi Mizutani; Nagoya University, Nagoya, Japan.

Recently, heterogeneous integration (HI) technology is attracting much attention. It enables us to integrate devices made of various materials, for example, high-performance InP HEMTs and SAW filters. One of the most promising techniques for HI is the fluidic self-assembly (FSA) proposed by J. S. Smith et al. In the FSA technology, small device blocks separated from its substrate are scattered on the tilted host-substrate placed in fluid, then they slide and fall into recesses on the substrate. Here, we propose a new approach to FSA, using fluid dynamic effect. In this technique, special structures are made on the top-side of blocks. With these structures the blocks are forced to move with a specific direction by fluid dynamic effect. This technique, we call it here as a fluid dynamic assembly (FDA), is advantageous to control faces and direction of the supplied blocks, and to increase assembly yield when the thickness and size of the block shrink. By designing appropriate structures on the blocks, we can supply thin blocks to the host substrate with a top-side-up geometry. To confirm the possibility of the method, we carried out experiments for simple disk-shaped GaAs blocks with 50 um-diameter and 4 um-thickness. The structures on the blocks were made of polyimide because it can be removed easily after assembly. We investigated the effect of the shape and thickness of the polyimide sturucture on the assembly process. We first carried out numerical simulations and it was found that the ring-type structure having thickness of large than 5 um is effective to control faces of the supplied blocks. This prediction is confirmed by the experiment that the blocks were arranged more than 95% with top-side-up geometry using the ring-shaped polyimide structure.

3:45 PM B7.8
Laser Drilling to IC and Passive Components used in RF Multi-Chip Modules. Caroline Kondoleon, Thomas Marinis and David Hagerstrom; Electronics Packaging and Prototyping, Charles Stark Draper Laboratory, Cambridge, Massachusetts.

Monolithic RF chips first multi-chip modules (MCM) have been fabricated by laminating Kapton film on top of IC chips and passive circuit components, which attached to a substrate carrier. The components are electrically connected by drilling vias through the Kapton to their I/O pads, followed by thin film metal deposition and patterning. A Q-switched YAG laser, operating at a wavelength of 354 nm, a repetition rate of 8 kHz, and an average power of 100 mW is used to drill the vias. It is critically important that damage to the chip pad metallization and underlying structure be avoided during via drilling. Experience has shown that the process window for via drilling is highly dependent upon the metallization and morphology of the I/O pads. Gold films, which are typically used on capacitor, resistor, and inductor elements, are most susceptible to ablation and damage to the underlying structure. Copper films, over laid with 2000 angstroms of titanium, are extremely robust with respect to laser damage. This metallization is used to make interconnections within the RF modules. The performance of thin film aluminum pads, which are typically used on IC chip I/O, is intermediate between these other two metallizations and exhibits the greatest sensitivity to pad morphology. This paper catalogs the type and extent of damage that is observed on various component I/O pads and develops a model to help interpret the experimental results and screen candidate components for use in this MCM fabrication process.

4:00 PM B7.9
Study of Dislocation Mobility in 4H-SiC by X-ray Topography and Transmission Electron Microscopy. Hosni Idrissi[1], Maryse Lancin[1], Joel Douin[2], Gabrielle Regula[1] and Bernard Pichaud[1]; [1]TECSEN, Faculty Sciences, Marseille, France; [2]LEM, CNRS-ONERA, Paris, France.

Dislocations in SiC are being widely studied because of their harmful influence on electrical properties. Concerning the dislocation dynamics, information were obtained from plasticity experiments followed by transmission electron microscopy (TEM) observations. Such an approach shows that partial dislocations with silicon core have a higher mobility than those with a carbon core but there is still some contradiction with calculations. Because the mobility was never directly measured for perfect or partial dislocations whatever the core, we are developing such studies by using X-Ray transmission Topography (XRT), chemical etching and TEM. This work consists in introducing well controlled dislocations and observing their movement as a function of stress and temperature. In as grown (0001) oriented 4H-SiC, large and heterogeneous dislocations and micro-pipes densities were detected. In as-grown (11-20) oriented 4H-SiC, screw dislocations normal to the basal plane, basal dislocations and very few micro-pipes were observed. This sample was selected because of its better crystallographic perfection and its most suitable orientation for deformation. In (11-20) rectangular samples, dislocations were introduced by scratching the surface, bending at room temperature in cantilever mode and annealing between 823 K and 1323 K in the stressed state. The stress along the sample length was measured by determining the local radius of curvature. XRT observations reveal straight lines parallel to the basal plane with asymmetric distribution as compared to the scratch position. These lines correspond to elongated half loops consisting of two short emerging segments and one very long segment parallel to the surface and located close to the neutral plane at half the thickness of the sample. The Burger's vector and the dislocation core was determined by TEM. The development of the long half loops is controlled by the movement of the emerging segments and the observed asymmetry derives from the different mobility of these segments. Considering all the possible surface sources at the origin of the half loops we can explain the asymmetry by the differences in nucleation and glide ability of the different partial dislocation involved in compression mode.

4:15 PM B7.10
Remote Plasma−Enhanced Atomic Layer Deposition (PEALD) of TiN Using TDMAT With NH_3 Plasma. Do Youl Kim, Ju Youn Kim and Hyeongtag Jeon; Division of materials science and engineering, Hanyang University, Seoul, South Korea.

Titanium nitride (TiN) has been most widely used as a diffusion barrier in ultra large scale integrated (ULSI) devices because of its very low bulk resistivity, high melting point, good chemical and thermal stability, impermeability to Si diffusion and excellent adhesion to silicon and silicon dioxide films. As the device dimension has been shrinking down continuously, TiN films deposited by sputtering and chemical vapor deposition have faced the serious problems of high impurities, poor step coverage and conformality. To improve these problems, we constructed the down stream type remote plasma ALD system and tried to deposit TiN film with this system. In this study, TiN films were deposited under various conditions such as the plasma power, plasma exposure time, process pressure and temperature. The efficiency of plasma treatment was systematically evaluated to optimize the processing conditions. The characteristics of TiN films were analyzed using Auger electron spectroscopy (AES), X−ray photoelectron spectroscopy (XPS), Rutherford backscattering spectrometer (RBS), cross−sectional transmission electron microscope (XTEM), field emission scanning electron microscopy (FESEM), and four−point probe method. TiN films deposited by using tetrakis−dimethyl−amino−titanium (TDMAT) with ammonia (NH_3) plasma showed low resistivity and low impurity contents compared to the other deposition methods. In this study we will present the characteristics of TiN films deposited by remote PEALD method using metal organic precursor with ammonia (NH_3) plasma.

4:30 PM B7.11
Surface Oxide Evolution on Al-Si Bond Wires. Wentao Qin[1], Ray Doyle[1], Scharr Tom[2], Mahesh Shah[2], Mike Kottke[1], Gordon Chen[1] and David Theodore[1]; [1]Process and Materials Characterization Lab, Motorola, Tempe, Arizona; [2]Radio Frequency & Digital Signal Processing, Motorola, Tempe, Arizona.

Al-Si wires are often used to make contact to bondpads of semiconductor chips and devices. During operation in certain types of devices the wires typically reach relatively high temperatures. Under such situations, if extensive oxidation occurred, wire resistance could increase which would have a negative effect on reliability. It is of interest therefore to understand the oxidation behavior of the bond wires particularly under situations of elevated temperatures. In the current study, Al-Si wires were characterized as received, and after thermal annealing at 240 C and 300 C. The surface oxides were found to evolve from a single-layer oxide to a double-layer oxide with varying chemistry. Oxide thicknesses were substantially lower than the minimum skin depth for high frequency applications, even after 3000 hours of annealing.