SYMPOSIUM G
Materials, Integration, and Packaging Issues for High-Frequency Devices II
November 29 - December 1, 2004

Chairs

Yong S. Cho
Dept. of Ceramic Engineering
Yonsei University
134 Shinchon-dong
Seoul, 120-749 Korea
82-2-2123-2845

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

Don Shiffler
Air Force Research Laboratory
3550 Aberdeen SE
Kirtland AFB, NM 87117
505-853-3906

Harrie A. Tilmans
Microsystems, Components & Packaging Div
IMEC
Kapeldreef 75
Leuven, B-3001 Belgium
32-16-28-8173

Takaaki Tsurumi
Dept. of Metallurgy and Ceramics Science
Tokyo Institute of Technology
2-12-1 Okayama
Meguro-ku
Tokyo, Japan
81-3-5734-2517

Symposium Support
Army Research Office

Proceedings to be published in both
book form and online
(see ONLINE PUBLICATIONS at www.mrs.org)
as volume 833
of the Materials Research Society
Symposium Proceedings Series.

* Invited paper
SESSION G1: Tunable/High k Thin Films I
Chairs: Yong S. Cho and Paul Muralt
Monday Morning, November 29, 2004 Liberty (Sheraton)

09:00 AM G1.2 RF Magnetron Sputtered Ba0.96Ca0.04Ti0.84Zr0.1603 Thin Films for High Frequency Applications. Ali Mahmud1, Thottaman S. Kallur2 and Nick Cramer2; 1Electrical and Computer Engineering, University of Colorado at Colorado Springs, Colorado Springs, Colorado; 2Applied Ceramics Research, Colorado Springs, Colorado.

Perovskite, ferroelectric and paraelectric thin films exhibit outstanding dielectric properties, even at high frequencies (>1 GHz). The non-linear electric field dependence of ferroelectric thin films can be used to design frequency and phase agile components. High dielectric constant thin film ferroelectric materials in their paraelectric state have received enormous attention due to their feasibility in applications, particularly decoupling capacitors and tunable microwave capacitors; the latter application has been fueled by the recent explosion in wireless and satellite communications. In this paper, Ba0.96Ca0.04Ti0.84Zr0.1603 (BCTZ) thin films deposited on Pt electrodes using radio frequency magnetron sputtering at low (<500 oC) substrate temperature is discussed. RF magnetron sputtered thin film BCTZ at low substrate temperature allows this process to be compatible with current integrated circuit technology. The structural characterization of the deposited films was performed by x-ray diffraction and scanning electron microscopy. The electrical characterization of the films was determined by capacitance-voltage (C-V) measurements, current-voltage, and S-parameter measurements. In addition, the effect of post annealing on the deposited films was investigated. A detailed understanding of both their processing and material properties is discussed for successful implementation in high frequency applications.

9:15 AM G1.3 Ferroelectric Thin Films and Composites for Tunable Microwave Devices. Menka Jan1, N. K. Karan1, Ram S. Katiya1, A. S. Bhalia2, F. A. Miranda3 and F. W. VanKeuls4; 1Department of Physics, University of Puerto Rico, San Juan, PR; 2Puerto Rico Science Division, Argonne National Laboratory, Argonne, Illinois; 3NASA, Glenn Research Center, Cleveland, Ohio; 4The Ohio Aerospace Institute, Cleveland, Ohio.

In the past few years, ferroelectrics have been studied for several frequency agile microwave electronic devices. Due to their tunable properties (variation of dielectric constant with applied electric field), ferroelectric materials like barium strontium titanate (BST), lead strontium titanate (PST), and strontium titanate (STO) are considered suitable for tunable microwave devices, such as phase shifters, filters, varactors, delay lines, etc. The required properties of ferroelectric thin films for such devices include, moderate dielectric constant, low dielectric losses, low leakage currents, high figure of merit (phase shift/insertion loss) etc. In the present study thin films and multilayers of BST/PST and their composites with low loss dielectrics like MgO, MgTiO3, and Al2O3 were grown by RF magnetron sputtering and studied for room temperature tunable microwave devices. In addition, the effect of highly pure (99.999%) precursors on dielectric properties of these films was also studied. X-ray diffraction studies showed that the pure and composite films were highly (100) oriented on lanthanum aluminate substrates. Temperature dependent dielectric properties including dielectric constant, tunability, loss, and K factor (tunability/loss) were measured at 1 MHz. For the composite films, considerable reduction in the dielectric constant and dielectric losses were observed, which translated to a moderate or high K factor. These films were used to make eight element coupled microstrip phase shifter and characterized in a frequency range of 14–17 GHz. The total device quality factor of merit was found to be markedly improved (95 o/dB for BST/MgO composite films as compared to 30 o/dB for the pure BST film). Initial studies on the PST films showed figure of merit of 56 o/dB at 15.75 GHz. Better values for the figure of merit are expected for composites and with those prepared using highly pure precursors.

09:30 AM G1.4 Ba0.96Ca0.04Ti0.84Zr0.1603 Thin Films for Tunable Microwave Applications. Jiwei Lo1, Jaseon Park2, Nadia Perves2, Robert A. York3 and Susanne Stommer1; 1Materials, University of California, Santa Barbara, California; 2Electrical and Computer Engineering, University of California, Santa Barbara, California.

Ferroelectric thin films, with the unique property of being able to switch between two stable states, are attracting increasing interest for integrated capacitor applications because of their relatively high permittivity (170-220) and dielectric loss tangents (tan δ) that are as low as 5x10^-4. Furthermore, BST thin films exhibit an electric field tunable dielectric constant of about 55-60 at room temperature. However, bulk BST ceramics show a low temperature dielectric relaxation that is associated with a dielectric loss peak. This loss peak shifts to higher temperatures at higher measurement frequencies, approaching room temperature in the microwave frequency region. We show that for BST thin films, the dielectric relaxation can be shifted to lower temperatures, due to tensile stress due to the thermal mismatch with the substrate. This makes the films attractive for low-loss, high-frequency applications. We investigated the figure of merit of BST/Cu-based capacitors with BST thin films grown on MgO substrates at microwave frequencies. The total device quality factor was greater than 200 at 1 GHz, exceeding the performance of similar capacitors using thin films of materials traditionally considered for tunable microwave applications, such as (Ba,Sr)TiO3. The capacitance showed no evidence of an onset of a dielectric relaxation in the measured frequency range (1-20 GHz). The dielectric loss and constant of BZN films at microwave frequencies were modelled using measurements of test structures and appropriate equivalent circuit models to extract the influence of electrodes and parasitics.

09:45 AM G1.5 An Application of a Low-Cost MOD-Made BST Film Developed Especially with PLD Initial Nucleation Layer to a 20 GHz Tunable Phase Shifter. Minoru Noda1*, Daniel Popovici1, Masanori Ooyama2, Yoshinori Sasaki2 and Malcio Komura2; 1Graduate School of Engineering Science, Osaka University, Toyonaka, Japan; 2Semiconductor Group, Mitsubishi Electric Corporation, Hami, Japan.

We have successfully obtained a low loss Ba0.97Sr0.03TiO3 (BST) thin film on MgO substrate by combining preparation of initial layer by Pulsed Laser Deposition (PLD) and following Metal-Organic-Decomposition (MOD) method. The new preparation method enables us to use MOD method fully and successfully on various oxide insulating substrates, necessary to compose a coplanar wave guide (CPW) transmission line type of ferroelectric tunable devices in the range of microwave and millimeter wave. In this work,
initial nucleation sites (1-10 nm thickness) were introduced at first on the oxide substrate by PLD, where active species of BST components ablated by high energy laser pulses adhered on oxide substrate and subsequently grew epitaxially. The resulting nucleation sites become active growth sites of BST thin films with silicon substrate. This enhanced the BST film growth rate, which resulted in a Pt/BST/Pt stacked capacitor structure when the electric field was from -/ +40 kV/cm at measuring frequency of 1 MHz, where tunability was about 12%. Moreover, it increases up to about 40% in a Pt/BST/Pt stacked capacitor structure when the applied electric field was from -/+170 kV/cm at the same frequency. When applying dc bias voltage of 0 to 60 V to the electrodes of the CPW pattern (width: 60 μm, gap: 10 μm, length: 2.5 mm), a differential phase shift of 18 degree was observed at 20 GHz with insertion loss of about 2 dB for Au/Cr interconnection due to its lower resistivity. Therefore, the figure-of-merit becomes 18 degree/20 V for the Au/Cr case. The measured s parameters of the CPW were found to agree well with those simulated using MicroWave Office ver. 6. A 3-stage LC-ladder-type phase shifter with variable capacitors of BST thin film was designed for the series insertion of the mentioned effective permittivity of the CPW. The BST phase shifter was also designed to have a differential phase shift of about 40 degrees at 20 GHz and to be used for precise phase compensation for a digital 360 degree phase shifter. A fabricated phase shifter above shows successfully the shift of 40 deg at 20 GHz with bias of 60 V. Finally it is found that the new BST film process is very promising for realizing a micro and millimeter-wave tunable device.

10:30 AM *G1.6
Integrating Ba0.6Sr0.4Ti03 Thin Films with Large Area, Affordable, Industry Standard Substrates for Microwave Applications. William D. Nothwang1, M. W. Cole2, P. C. Mcintyre2, T. Nomura2, Takeshi Shioga2, Paul C. McIntyre2 and Kazuaki Kurishara2.

The Army is actively pursuing technologies to meet transformation goals of a lighter, faster, more lethal force via affordable, electronically scanned phased array antennas (ESA’s) that will provide the means for achieving this high data rate, beyond line of sight, On The Move (OTM) communications. Paraelectric, thin-films (Magnesium doped Barium Strontium Titanate), compositionally designed for tunable microwave applications, have been deposited on ceramic (MgO, LaAlO3, SrTiO3, TiO2) substrates. In order to take full advantage of this technology to Army applications, it is absolutely necessary that the cost of each device be decreased. By integrating this active material with large area, low cost, microwave friendly substrate, the cost can be significantly reduced. While Si is not a suitable substrate for microwave applications, a low cost, microwave friendly buffer layer on silicon would be an ideal solution. A high performance Ta2O5 thin film passive buffer layer on Si substrates has been successfully designed, fabricated, characterized, and optimized via metalorganic solution deposition technique. The optimized Ta2O5 based thin film exhibited suitable microwave material properties, including an enhanced dielectric constant (ε’=5.6), low dielectric loss (tan δ=0.006), low leakage current or high film resistivity (ρ=10^12 Ω cm at E=1 MV/cm), excellent temperature stability (temperature coefficient of capacitance of 52 ppm/C), and excellent bias stability of capacitance (1.4% at 1 MV/cm). Also of extreme importance, the permittivity and dissipation factor exhibited minimal dielectric dispersion with frequency. The dielectric passive buffer layer film was typified by a uniform dense microstructure with minimal defects, and a smooth, nano-scale fine grain, crack/pinhole free surface morphology. There was negligible elemental interdiffusion with temperature at the interface between the substrate and buffer layer as verified by Rutherford Backscatter Spectroscopy and Auger insuring long term reliability. The heterostructure is used in developing a passive, thin film material that is microwave friendly, the Army Research Laboratory has enabled the direct integration of paraelectric active thin films with silicon substrates. This will allow phase shifter materials technology to be implemented by a wide spectrum of Army and Commercial applications; specifically, affordable OTM phased array antenna systems across a variety of DoD platforms will allow for a full-spectrum, network integrated theater.

11:00 AM G1.7

High dielectric constant, perovskite-structure materials, such as barium strontium titanate (BST), have been widely investigated for use in GHz LSI decoupling capacitor applications. In addition to modifying deposition process parameters, such as decreasing deposition temperature, doping may be a viable route to increase tunability and tunability in BST thin films without increasing the thermal budget. In this research, the effects of Y dopants on the dielectric behavior of RF-sputtered BST thin films have been systematically investigated. The BST thin films deposited using ceramic targets with different compositions of yttrium oxide dopant. With Y-doping concentration of 1.3 at%, the permittivity at around zero electric fields can be increased by more than 70% compared to nominally undoped BST thin films produced under the same deposition conditions. Based on x-ray diffraction strain analysis and inductively-coupled plasma composition measurements, the correlations among the dopant composition, BST film strain and dielectric behavior have been systematically studied. Furthermore, in combination with studies of undoped reference samples with a range of Ti stoichiometries, the current understanding of possible mechanisms responsible for the increase in permittivity of Y-doped BST thin films will be discussed.

11:15 AM G1.8
Al2O3, Ta2O5 and TiO2 Buffer Layers for Integrating (Ba,Sr)TiO3 Microwave Tunable Devices onto Si Wafers. Il-Doo Kim1, Hyun-Suk Kim2, Jin-Seong Park3, YongWoo Choi2 and Harry L. Tuller1.

Integrating Ba0.6Sr0.4TiO3 (BST) and Ta2O5 thin films with silicon substrates. This will allow phase shifter elements directly integrated onto silicon chips, one reduces size and power consumption and promises improved reliability, reduced cost, and high volume production by use of large size Si wafers. However, crack formation, high surface roughness due to chemical reactivity and large lattice mismatch between BST and Si make it very difficult to grow BST films directly onto Si. In addition, high microwave losses related to the low resistivity of Si is also a barrier for integration of BST devices onto Si wafers. To solve these problems, we introduced suitable buffer layers, with high dielectric constant, between the BST layers and the Si substrate. The buffer layers have multiple purposes including serving as templates for high quality BST growth, providing stress control for crack-free films, preventing chemical reactions and providing electrical isolation. We will describe the ALD (Atomic Layer Deposition) of Ta2O5 and TiO2 buffer layers and their effect on the improvement of tunability of Ba0.6Sr0.4TiO3 microwave tunable devices. The TiO2 and Ta2O5 buffer layers were grown on Si wafer and annealed at 700°C and 800°C for 30 min, respectively. Perovskite Ba0.6Sr0.4TiO3 thin films were deposited on the Ta2O5/Si or TiO2/Si substrate by pulsed laser deposition (PLD). The BST films on the TiO2/Si substrate found to be more randomly oriented and showed a larger grain size distribution compared to that of the Ta2O5/Si substrate, on which the BST film was found to be highly c-axis oriented. At an applied voltage of 10 V, the tunability of the BST films grown on Ta2O5/Si and TiO2/Si substrates were 72% and 53%, respectively, values much larger than that (17.5%) of BST films grown on a MgO single crystal substrate. BST films grown on GT and high resistivity Si substrates will be discussed in terms of tunability and microwave loss and compared with the BST film on the buffer Si substrates. In summary, ALD grown Ta2O5 and TiO2 buffer layers enable successful integration of BST based microwave tunable devices onto Si wafers.

11:30 AM G1.9
Growth and Characterization of Deposition-Freeze-Crystalgrown BaSrTiO3 Thin Films on Silicon Substrates. Kenji Takashahi1, Shoji Okamoto1, Yukio Sakashita2, Haydn Chen3 and Hiroshi Funakubo1,4.

High dielectric-constant materials with good stability against the
Applied electric field, film thickness and the temperature are highly desired for various capacitor applications. We have previously proposed a c axis-oriented dielectric barrier (BD) films are a novel candidate for high dielectric capacitor application due to the low capacitance change against the applied voltage and the low leakage current independent of the film thickness down to a few nanometers. In those, these are promising candidates for the microwave devices because of their high dielectric constants, low losses and tailored temperature coefficients of dielectric constant. Previous studies were concentrated on the epitaxial films grown on single crystal substrates. In order for these films to receive wider applications, the establishment of deposition method of c-axis-oriented BD films on various substrates is critical. In the present study, we have successfully prepared a single axis, i.e. c-axis oriented BD films even on (111)Pt/TiO2/SiO2/Si substrates by inserting the (001)-oriented LaNi03 conductive buffer layer as an interfacial template. A comparison of the dielectric properties of those films was made with epitaxial-grown films in the viewpoint of in-plane and out-of-plane orientations. Ca0.5Sr0.5Ti03 (CSTi) films with various thickness were deposited on LaNi03 buffered (111)Pt/TiO2/SiO2/Si substrates at 600 °C by rf magnetron sputtering deposition. Without the LaNi03 buffer layer, CBTi films showed excellent random orientations. However, with the LaNi03 buffer layer, which showed preferential (001)-orientation characteristic even on (111)Pt, CBTi films were found to show an out-of-plane c-axis but in-plane random orientations.

Further studies support the formation of an additional layer of conductive (001)-oriented SrRuO3 between CBTi film and LaNi03 layer. It was demonstrated that the general observation of degradation of dielectric constant with decreasing thickness was not observed for the CBTi films grown on polycrystalline substrates. In fact, those films behave in a similar manner to those epitaxial CBTi films grown on (001)SrRuO3/(001)SrTiO3 substrates. Our results clearly demonstrated that a single axis c-oriented CBTi films yield no degradation on the dielectric properties against the film thickness, thus making them highly desirable for new capacitor applications. These capacitors can be made not only on Si substrates but also on other substrates, such as metal plates, glass and resin. T. Kojima et al., Mater. Res. Soc. Symp. Proc. 748, U15.2.1 (2003). S. Kojima et al., Anal. Sci. 17, 1081 (2001).
Epitaxial Growth of Pulse Laser Deposited AIN Films for MEMS and NEMS Based RF Resonators: Technical Barriers and Solutions. Shiva Hullavarad, R. D. Vispute, T. Venkatesan, A. E. Wickenden, L. Curranro, and M. Dubey, 1Center for Superconductivity Research, University of Maryland, College Park, Maryland; 2Army Research Laboratory, Adelphi, Maryland; 3BlueWave Semiconductors, Inc, Baltimore, Maryland.

AIN exhibits strong piezo-electric properties suitable for RF resonator applications. In this work we report the growth of highly oriented AIN 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 (PLD) technique at a pulse energy of 2J/cm2 with a repetition rate of 10 Hz. The process is optimized for the growth of AIN on different thicknesses of underlying SiO2. The films are characterized by XRD, RBS and 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 AIN films is studied by scanning electron microscopy, and electronic force microscopies. We have obtained highest Q factors for PLD grown AIN MEMS resonator beams of Q = 8,000 at fo = 2.5 MHz and Q = 17,400 at fo = 0.44 MHz. We also address in this work critical issues related to (1) thickness of SiO2 (2) method of growth of SiO2 in fabricating MEMS and NEMS devices. These factors are very essential for the growth of high quality AIN films.

However, SiO2 provides an amorphous underlayer for the growth of AIN leading to non in plane aligned AIN with respect to substrate. A lattice matching, epitaxial oxide layer like Y2O3 in place of SiO2 is going to be a unique solution for eventual epitaxial growth of AIN. We address the epitaxial issues of AIN and underlying oxide for improving the resonator properties of AIN based MEMS and NEMS devices.


Ceramics based on Ba3ZnTixO9 (M = Mg, Ni, Zn), Ba3MgTixO9, which are members of the 2:1 ordered perovskite structure class. Substitution of Nb5+ for Ta5+ results in instructural compositions with a higher dielectric constant, more positive temperature coefficient of resonant frequency, and a smaller Qxf value. Diminished dielectric properties have prevented to the application of the Nb5+-perovskites as replacements for Ta5+-perovskites. However, SiO2 provides an amorphous underlayer for the growth of AIN leading to non in plane aligned AIN with respect to substrate. A lattice matching, epitaxial oxide layer like Y2O3 in place of SiO2 is going to be a unique solution for eventual epitaxial growth of AIN. We address the epitaxial issues of AIN and underlying oxide for improving the resonator properties of AIN based MEMS and NEMS devices.
A precision measurement technique for measuring complex dielectric permittivity from 118 to 178 GHz frequency range is described. The combination of high-quality Fabry-Perot resonator, excited by BWO-generator (without any phase lock system), with the great processing capability of a sensitive receiver based on the Tektronix 2782 spectrum analyzer using the VHS 2.55 harmonic mixer, opens the possibility of a new measuring technique. Electron Cyclotron Waves (ECW) systems operating in the millimeter wave (mm-wave) spectral region are often utilized in fusion devices to provide a well-localized energy deposition for building-up and controlling burning plasma. The growing use of such systems in plasma experiments requires gyrotron tubes capable of producing CW power of 1 MW or more in the frequency range of 110-200 GHz. In gyrotron tubes, the radio frequency window forms a critical component, as it must not only provide a vacuum barrier but also a tritium barrier between the plasma chamber and its surroundings. CVD-diamond appears to have the essential properties of strength, transparency that is lower than the melting temperature of diamond, and with and without low surface layers, will be reported.

SESSION G3: Poster Session
Chairs: Yong S. Cho and Don Shiffer
Monday, November 29, 2004
8:00 PM
Exhibition Hall D (Hynes)

G3.1 Improvement of Adhesion and Microwave Transmission Characteristics of Indium Bump by Silver Coating for Low Temperature Flip-Chip Applications
Kun-Mo Chiu, Jung-Hwan Choi, Jung-Sub Lee, Han Soo Cho, Hye-Hoon Park, and Duk Young Lee
School of engineering, Information and Communications University, Daejeon, South Korea.

We have conducted low-temperature flip-chip bonding for optical interconnect and microwave applications. Flip-chip bonding of vertical-cavity surface-emitting laser (VCSEL) arrays was performed on a fused silica substrate that provides propagation paths of laser beams and also supports a polymeric waveguide. To avoid thermal damage of polymeric waveguide during the flip-chip bonding, indium solder bumps are used and the bonding condition of flip-chip chip was determined as a heating temperature of 150°C and a pressure of 500 gf. The samples flip-chip bonded below bonding temperature of 150°C show fractures between the indium solder bump and the VCSEL chip, pad during the die shear test. It is inferred that both the low bonding temperature that is lower than the melting temperature of indium and the oxide layer that is formed on the surface of the indium solder prevented the bump from interacting with the chip pad. To decrease the melting temperature of the indium solder and protect it from oxidation without using flux, we tried coating of a thin silver layer (0.2 μm) onto the indium surface by thermal evaporator. To estimate the silver coating effect, current-voltage and light-current characteristics of flip-chip bonded VCSEL arrays using silver coated indium bump compared with the samples using indium bump only. The characteristics of microwave signal transmission were performed with on-wafer probes for a frequency range extending to 40 GHz. As a result, the thin silver layer coated on the solder bump was very effective to enhance the adhesion strength between the indium bump and the VCSEL chip pads by decreasing the melting temperature of the indium solder bump locally and preventing indium surface from oxidation. In addition, the optoelectronic and microwave characteristics of VCSEL array was improved by silver coating.

G3.2 Epitaxial Aluminum Electrodes on Theta Rotated Y-X LiTaO₃ Piezoelectric Substrate for High Power Durabele SAW Duplexers
Osamu Nakagawa, Hironori Suzuki, Shuji Yamato, Masayuki Hasegawa and Hideharu Ieki; Murata Manufacturing Co., Ltd., Kyoto, Japan.

High power durable electrodes have been successfully grown on Y-X LiTaO₃ piezoelectric substrates by metalorganic chemical vapor deposition (MOCVD) method. We have reported epitaxial Al films on Y-X LiTaO₃ with titanium intermediate layer in our previous paper. Despite a quite similar crystal structure, it has been difficult to form epitaxial Al on LiTaO₃ due to the different cut angle suitable for SAW devices. We found that a two-step process sequence in the deposition temperature of Ti intermediate layer could make it possible for Al/Ti structure to grow epitaxially on theta rotated Y-X LiTaO₃. What is most important for epitaxial Al deposition is to deposit an initial Al layer at high temperature to obtain highly oriented Ti at the interface against the substrate. Following with a low temperature process in a later stage of Ti and all the period of Al, epitaxially layered structure was completely set up. The two-step sequence of Ti can prevent inter-diffusion between Al and Ti and oxidation of Ti surface, both of which frustrate the crystal growth of Al. Crystallinity analysis was carried out by pole figure of x-ray diffraction in Al (200) incident direction. Clear symmetrical spots was observed in films prepared in the two-step process sequence, which suggests a twin crystal structure of the Al film. The best result was achieved at substrate temperature of 180 centigrade for the initial Ti region. Ladder-type SAW filters were fabricated by reactive ion etching of Al/Ti with the center frequency of 800MHz for CDMA800(AMPS). Both step-up and acceleration tests were carried out to elucidate power durability defined by 2 MHz degradation of band width among frequencies where the insertion loss goes down by 24 dB. Demonstration with epitaxial electrodes have had above 6 W breakdown power measured from step-up test, while those with polycrystalline electrode, 3.4 W. It was also turned out from acceleration test that input power of 3.6 W and in an ambient temperature of 85 centigrade the lifetime of epitaxial SAW was several orders longer than that of polycrystalline SAW, where it was several orders shorter that epitaxial. On one hand, polycrystalline SAW exhibits extremely low grain boundary that improve power durability because self-diffusion of Al atoms occurs mainly in the grain boundary of the film. In contrast, on the other hand, the low melting temperature of the epitaxial Al on Y-X LiTaO₃ will be promising for CDMA800 antenna duplexer application in which high durability is strictly needed.

 SESSION G3: Poster Session
Chairs: Yong S. Cho and Don Shiffer
Monday, November 29, 2004
8:00 PM
Exhibition Hall D (Hynes)

G3.3 Comparison of Microwave Dielectric Behavior between B1.5Zn0.96Nb1.507 and B1.5Zn0.5Nb0.507
Ming-Chung Wu and Stanislav Kamba; 1Department of Materials Science and Engineering, National Taiwan University, Taipei, Taiwan; 2Department of Dielectrics, Institute of Physics, ASCR, Praha, Czech Republic.

B1.5Zn0.96Nb1.507-Nb2O5 (BZN) system has been considered as candidate microwave materials due to their low sintering temperature, high dielectric constant and low temperature coefficient of resonance frequency. However, B1.5Zn0.96Nb1.507 exhibits low high dielectric relaxation behavior which results in low quality factor of microwave property (Nino et al. J. Appl. Phys., 2001, 89, 4512-4516). Levin et al. (J. Solid State Chemistry, 2002, 198, 69-75) investigated the structure of B1.5Zn0.96Nb1.507-Nb2O5 that consisted of Bi1.5Zn0.92Nb1.506.92 pyrochlore-single phase with the composition of Bi1.5Zn0.96Nb1.507-Nb2O5 and small amounts of ZnO. In order to find the structural origin of the dielectric relaxation of B1.5Zn0.96Nb1.507, we have studied the dielectric behaviors of B1.5Zn0.96Nb1.507-Nb2O5 and Bi1.5Zn0.96Nb1.507-Nb2O5 in detail using Impedance Analyzer, Network Analyzer, and Fourier transform spectrometer. The temperature low dielectric relaxation behavior of B1.5Zn0.96Nb1.507 was from the unusual structure of Bi1.5Zn0.96Nb1.507-Nb2O5. In B1.5Zn0.96Nb1.507-Nb2O5, 21% of Bi atoms are replaced with Zn atoms and 4% of A the position remains vacant that provides room for dielectric relaxation. The presence of ZnO phase in the Bi1.5Zn0.96Nb1.507-Nb2O5 further enhanced the dielectric relaxation with reduced quality factor.

G3.4 Ferromagnetic Nanoparticle/Polyurethane Nanocomposites for SAW Applications
Clarity E. Yeast, Heather Dowty and Max D. Alexander; 1Universal Technology Corporation, Dayton, Ohio; 2Air Force Research Laboratory, Wright-Patterson AFB, Ohio.

Signal conditioning devices for use in rf detection and communication applications require the development of materials with high microwave permeability and low dielectric loss in order to be suitable for use at higher frequencies. Ferromagnetic materials have high permeability, however, their use is limited due to their high conductivities and thin microwave penetration depth. One approach taken to overcome these limitations is to disperse ferromagnetic inclusions into a dielectric matrix. At least one dimension of the inclusions must be on the nanoscale so that the microwave penetrates the nanocomposites. We report the synthesis of polyurethane nanocomposites containing ferrites and garnet nanoparticles with variable composition and loadings. The evaluation of the magnetic and dielectric properties of the nanocomposites will also be presented.
We report a successful three-dimensional integration technique targeted for mixed-signal, high frequency circuit integration using Benzocyclobutene as the bonding medium between device layers. The technique makes use of a high-k microelectromechanical (MEMS) device layer and transputing it to a fully fabricated host wafer with digital circuits. BCB's low dielectric constant ($\varepsilon = 2.65$), low loss at high frequency and good thermal/mechanical stability allows fabrication of high performance RF components on donor device layer, which sits on top of the BCB film. Another important property of BCB is that it allows for void free device layer to layer bonding. A brief summary of the process is as follows - a fully processed SOI wafer with RF components is temporarily bonded to a glass handle wafer with reusable adhesive. Then the entire silicon substrate of the SOI is etched, stopping on the buried oxide (BOX) of the SOI, which leaves a transparent sub-micron thick device layer or "donor layer" temporarily bonded to the glass handling wafer. The host wafer with completed digital circuits is prepared for 3D integration by spinning BCB on to it after application of proper adhesion promoter. The solvents in BCB are released in pre-bake process. Then, a contact aligner is used to align the transposed donor layer to the host wafer and the aligned stack is bonded in vacuum. The newly bonded donor/host wafer stack is subjected to a temperature of 330C - while BCB cures to make the bond between the layers permanent, the glass handling wafer is also bonded due to depolymerization of the temporary adhesive. The BCB film, which bonds the two device layers, etches readily in SF6/O2 chemistry, allowing interconnection between the RF donor layer to the digital host layer in simple metal evaporation step. The electronic devices on the donor layers before and after transputation step have been obtained. Detailed BCB property and processing step will be presented. The donor layer to host wafer alignment registration of +/- 3 micron was observed. We have also shown that by fabricating a ground plane between the device layers, significant amount of crossstalk to the RF donor layer from the digital host layer can be reduced.

G3.6 Design and Fabrication of Large Array, Micron Scale, Mass Analysis Systems Running at RF Frequencies, James Fleming, Matthew G. Blain, Dolores Cruz, R. Graham Cooks, A. Guymon, 2Purdue University, West Lafayette, Indiana.

There is currently a great need for accurate, miniature and inexpensive detection systems for unknown chemical and biological species. Mass spectrometry is recognized as being a highly desirable approach to this problem, but typical mass spectroscopic systems require large arrays of micro-traps. What is of interest to this symposium is miniaturization. This is due not just to the size of the trap, but also to the size of the vacuum pump. However, if the size of the ion trap could be greatly reduced from the centimeter scale to the micron scale then the vacuum requirements would also be relaxed to the point where miniaturized traps become possible. One such a solution, it then becomes necessary to recover sensitivity through the use of large arrays of micro-traps. What is of interest to this symposium is that the functioning of such devices will require the megahertz modulation of relatively large voltage swings. Cylindrical micro-traps have been modeled and it is predicted that trapping is possible. These structures are highly complex on the micron scale, having at least four separable, addressable electrode layers. This places considerable restriction on the fabrication possibilities. It is possible to use polycrystalline micromachining techniques to fabricate many of the complex structures required, however, polycrystalline is too resistive to be viable. Aluminum has been used to successfully fabricate micromachined structures, however the vertical dimensions required exceed those typically used in aluminum micromachining. To address this problem we have employed a micro-molded tungsten process to successfully fabricate the required structures and modeling indicates that the losses associated with these geometries and this material should be manageable. This is due to the relatively low resistivity of tungsten and the use of air bridges in the design to minimize capacitive coupling. Testing of these novel structures is currently underway. Several new ionizer/accelerator (CPW) devices were fabricated and evaluated. The results show that the insertion loss of devices are critically related to the dielectric quality factor. Therefore, development of low loss dielectric is essential for the commercialization of NRD guide devices. For these purposes, ferroelectric-based devices were evaluated. The dielectric was manufactured by conventional ceramic processing, high purity MgO, telecommunications research institute, Daejeon, South Korea.
SiO₂ and Ta₂O₅ powders were used as raw materials. These powders were mixed with appropriate ratio by ball milling. The mixed powders were thencold pressed at 6,000 kg/cm² for 4 h. The green density of the cold pressed powders was also measured at 135°C for 4 hours. The apparent density of the sintered sample was measured by the Archimedes method. The crystalline phase and microstructure were identified by powder X-ray diffraction (XRD) using Cu Kα radiation. The dielectric constant was measured in the TE₀₂₁ mode using the Hake and Coleman method. Pure forsterite (Mg₂SiO₄) shows a porous structure and very low dielectric quality factor (Q₉), which is not suitable for the dielectrics used in millimeter-wave band. The dielectric constant and Q₉ value of pure forsterite ceramics sintered at 1550°C was 5.6 and 38,000 GHz, respectively. The relative density was 9.8% is very less than the theoretical density. This means that the sintering at 1550°C was insufficient for full densification. This insufficient densification deteriorated the dielectric properties of sintered samples, and the sample had low dielectric constant and low dielectric quality factor. Therefore, additive material was needed to improve the sintering characteristics and the dielectric characteristics of sintered sample. Several materials were attempted as a sintering aid. Among them, Ta₂O₅ was effective additive to enhance the sinterability and dielectric characteristics. The addition of Ta₂O₅ increased dielectric constant over 7.4, and Q₉ value over 150,000 GHz, but decreased the sintering temperature by about 250°C. In this presentation, the effect of Ta₂O₅ on the sintering characteristics and dielectric properties of forsterite will be presented.

G3.10 MIM Capacitor Using ALD AI₂O₃ for RF IC and DRAM applications, Yang Yong Ke, Jung Ik Oh, Cheol Yeong Jung, Young Ho Kim, and Hyung Hyun Lee

1Department of Electronics, Kyungpook National University, Daegu, South Korea.
2Division of Information and Communication Engineering, Uiduk University, Gyungju, Gyongbuk, South Korea.
3School of Computer and Electronics, Gwangju University, Gwangju, Gyeongbuk, South Korea.

In this paper, AI₂O₃ thin film which has a relatively high dielectric constant was deposited by atomic layer deposition(ALD) using Methyl-Pyrrolidine-Tri-Methyl-Aluminum(MPTMA) and H₂O on Ti. And metal-insulator-metal(MIM) capacitors were fabricated in a coplanar waveguide type and measured. Deposition temperature of AI₂O₃ thin film was 200°C. Its thickness was 800 A. As a result, capacitance density of fabricated MIM capacitor was 0.229 µF/cm² and it had lower voltage coefficients of capacitance(VCC) and leakage currents than AI₂O₃ MIM capacitor prepared by ALD oxidation[1] and Si₃N₄ MIM capacitor prepared by PECVD[2] respectively. The RF measurement with network analyzer shows that AI₂O₃ MIM capacitor prepared by ALD wasn’t resonant below 10 GHz. The capacitance of MIM capacitor that was 1.6 pF at 1 MHz was 1.41 pF at 1 GHz. It had 10% differences of capacitance until 5.6 GHz. This shows that it has ability to adapt in RF applications. Capacitance characteristics on temperature were analyzed from 30 to 150°C. Temperature coefficient of capacitance(TCC) of prepared MIM capacitor was 234 ppm/°C at 1 MHz and 272 ppm/°C at 1 GHz. In this research, it was possible to fabricate AI₂O₃ MIM capacitor prepared by ALD having low process temperature and exact thickness control. The AI₂O₃ MIM capacitor prepared by ALD exhibits low voltage coefficient of capacitance(VCC), low leakage current, frequency-dependent capacitance reduction, low temperature coefficient of capacitance(TCC) and good reliability that is suitable for RF ICs and DRAM. Index Term: High-k, MIM capacitor, Atomic layer deposition, MIM MIM capacitor.

G3.11 A Study on Thin Film Microstructure and Its Effects on Acoustic Film Velocity Through Picosecond Ultrasonics Technique, Li Ts-Ching, Non-Wei Pu, Ben-Je Lwo, Jung-Chang Hu, and Chin-Hsing Kao

1National Defense University, Chung Cheng Institute of Technology, Taoyuan, Taiwan.
2Chung-Shan Institute of Science and Technology, Taoyuan, Taiwan.

Longitudinal thin film acoustic velocity is the most important parameter for Solidly Mounted Resonator (SMR) design on wireless communication. To this end, this paper analyzes microstructure properties of thin films with various processing conditions and studies the longitudinal film velocity due to microstructure effects. In this work, zincircon oxide films, which were deposited by RF magnetron reactive sputtering with various processing parameters such as oxygen partial pressure and RF power, were first made. We next used the picosecond ultrasonic technique to measure the longitudinal velocity of the thin films. To find the relationship between film velocity and film microstructure, the thin dead ions were also analyzed through Fourier transform infrared spectrum (FTIR) for porous; X-Ray diffraction spectrum (XRD) for grain size and phase; and X-Ray photoelectron spectroscopy (XPS) for composition ratio. According to the literature review, the longitudinal velocity of bulk zirconia material can be calculated from Young’s modulus and the density. However, thin film velocities we measured so far were less than the bulk. To derive more accurate and reliable conclusions, more analyses will be studied and the results will be contained in this paper. With measurement results, processing conditions on thin film deposition will be better controlled, and the actual thin film velocity will be more accurately obtained for SMR designer.

G3.12 Microwave Dielectric Properties of Oriented BaLa₄Ti₄O₁₅ Ceramics Fabricated by Templated Grain Growth, Yuko Fukami, Kenseki Ebisawa, Ikuo Kusumoto and Hiroshi Ohsho

1Nagoya Institute of Technology, Nagoya, Japan.

BaLa₄Ti₄O₁₅ (BLT) ceramics have excellent microwave dielectric properties with high dielectric constant ε_r=45 and high quality factor Q_f=24,000GHz. However the temperature dependence of resonant frequency (f_r) is -27ppm/°C. For the resonator applications, it is strongly required to be f_r of near 0ppm/°C. Usually, f_r was improved by changing composition such as formation of solid solution or additive with opposite ε_r for the compensation. In most cases, it can cause severe degradation to ε_r and Q_f even though f_r is improved. Convex method is another method. For the Q_f without decrease of ε_r and Q_f. BLT has a layered perovskite-type structure and its crystals tend to grow plate-like in shape, because they have a trigonal crystal structure and their lattice parameters are almost equal to the typical cubic values. Therefore, it can be candidate material for Templated Grain Growth (TGG) method. We confirmed that BLT crystals sintered with BLT powder showed the (001) orientation and grain growth. In this study, we fabricated unique microstructure by TGG method. Single phase, plate-like BLT template particles were prepared via a molten salt synthesis using NaCl, KCl and NaCl-KCl flux. Ceramics with an unique texture were obtained by TGG method using a doctor-blade technique. Plate-like BLT template particles were synthesized by seeded growth technique, and unidirectionally aligned by casting. During sintering, oriented BLT grains acts as seeds for the anisotropic grain growth within the specimens. X-ray diffraction measurements and scanning electron microscope observations revealed that the plate-like BLT grown aligned parallel to the casting direction. The orientation degree of sintered BLT was calculated by Lotgering’s method and sintering density was measured. The relationship between anisotropic microstructure and microwave dielectric properties was also discussed.

G3.13 A Novel Copper Damascene Technique for Power Loaded SAW Structures, Siegfried Ebeling, Matthias Heusser, Daniel Reitz, Hagen Schmidt, Manfred Weihacht, Klaus Wetzig, and Johann Wolfgang Barthas

1Leibniz Institute for Solid State and Materials Research (IFW) Dresden, Dresden, Germany.
2Electrical Engineering and Information Technology, Dresden University of Technology, Dresden, Germany.

High power applications of Surface Acoustic Wave (SAW) devices may result in microstructural damage of Al-based finger electrodes due to material transport (acoustomigration). The mechanism of acoustomigration is strongly associated with the SAW stress and the temperature of the electrodes material. Therefore Cu thin films exhibit generally a higher performance with respect to operation at higher frequencies, rf input power and higher temperature. However, the use of copper thin films for SAW structures requires capable barrier layers to suppress interactions with the piezoelectric substrate material and ambience. As demonstrated in earlier work, TaN-Cu film systems are currently qualified for high power SAW applications [1-3]. In comparison with Al/TI-layers which are typically applied for SAW devices, the Cu system has a significantly higher SAW power durability and thus a higher reliability and lifetime. Furthermore, using Cu metallizations the SAW technology is generally compatible to microelectronics where electroplated Cu films have replaced Al-alloys. Here we present the application of a Cu damascene technique to SAW structures using inlaid Cu electrodes in quartz or LiNbO₃ substrates. In comparison to electrodes bearing substrates such an inlaid Cu structure enables some novel SAW features. With regard to acoustomigration the Cu damascene SAW structures are expected to have lower danger of failure causes caused by shorts between adjacent fingers. For our study a special SAW test structure was used which was described elsewhere [3]. But for the Cu damascene technique the inverse (negative) resist mask of the power SAW test structure was realized. The structuring of the fingers trenches into the piezoelectric substrate was carried out by reactive ion


$^1$Materials Science Division, Argonne National Laboratory, Argonne, Illinois.
$^2$Energy Technology Division, Argonne National Laboratory, Argonne, Illinois.

High dielectric constant thick films of perovskite oxides such as barium strontium titanate (BST) have captured the attention of researchers for more than a decade now. The fuel for such research has been the need to develop new dielectric materials for capacitors, varistors, and non-volatile memories. BST is one of the most promising materials for these applications due to its high dielectric constant, low loss, and good mechanical properties. However, the materials are susceptible to leakage currents, which can significantly degrade their performance. The leakage current in BST films is affected by several factors, including the composition, microstructure, and processing conditions. In this work, we present a model that can predict the leakage current in BST films based on the basic Richardson-Schottky equations. This model is able to reproduce the size of the ordered domains is strongly dependent upon the size and density of the sintered ceramic pellets; larger pellets show a domain size gradient or core that deteriorates $Q$. The core size can be eliminated and the $Q$ value improved by sintering pellets formed from pre-ordered powders. However, even the preordered BNT powders require annealing times of at least 32 hours at 1500 °C to reach a large domain, fully ordered state and they do not sinter to a high density as their partially ordered counterparts. In an attempt to overcome the slow ordering kinetics of BNT, we have examined the effect of small concentrations of B-site vacancies on the core size. The vacancies can be introduced through the formation of ordering induced domain boundaries. Through investigations conducted on BNT(Ta,Nb)O$_3$ (BNT) we have found that the core size is strongly dependent on the vacancy concentration. The effect of the vacancy formation on the kinetics of the ordering reactions, domain sizes, and microwave dielectric properties will be discussed.

G3.17 Characteristics of Copper Film on the Polymer Substrate Deposited by a Cyclic Operation of and Magnetron Sputtering Coupled with ECR-MOCVD. Joong.Kee Lee$^1$, Bup-Ju Jeon$^2$, Sang Duk Myung$^2$ and Dongjin Byun$^2$.

$^1$Multifunctional Ceramics, Korea Institute of Science and Technology, Seoul, South Korea.

In order to employ the metalized polymer as a flexible copper clad laminate, enhancement of adhesion between the metallic layer and plastic substrate, and c.a. 4-5 micrometer thickness range of copper film should be required. The conventional methods for the metatization of polymer under low temperature process are physical vapor deposition methods such as electron beam deposition and magnetron sputtering. However, these methods have limitations in terms of deposition rate, low deposition rate, high deposition rate. Magnetron sputtering method is known to be the best technique in micro-meter ranged thickness copper films with good adhesion. Recently, we have reported that magnetron sputtering coupled with ECR-MOCVD method at room temperature with the aid of pulse negative bias can be used as an alternative method for the deposition of copper on polymer substrate. Here, cyclic operation is a mode of running the ECR-MOCVD coupled with a magnetron sputtering system in which magnetron sputtering is periodically operated under continuous operation of MOCVD between two predetermined operating times. The cycled period is the time that elapsed between repetitions of the same conditions. Split is the fraction of the cycled periods during which magnetron sputtering operates. In practice, this means that magnetron sputtering is used intermittently to enhance the copper deposition rate under ECR-MOCVD system. In this work, effects of cycled operation modes of magnetron sputtering on characteristics of copper films prepared were investigated.


Perovskites with the general formula Ba(B/3Ta2/3)O3 display very high quality factors (Q) in the microwave region and are widely utilized as frequency filters in wireless communication devices. Previous reports on Ba(Zn1/3Ta2/3)O3 (BZT) and other perovskites have shown the Q factors are enhanced in ceramics with a high degree of cation order; however, the losses are mediated through the formation of ordered domain boundaries. Through investigations conducted on Ba(Ni1/3Ta2/3)O3 (BNT) we have found the size of the ordered domains is strongly dependent upon the size and density of the sintered ceramic pellets; larger pellets show a domain size gradient or core that deteriorates $Q$. The core size can be eliminated and the $Q$ value improved by sintering pellets formed from pre-ordered powders. However, even the preordered BNT powders require annealing times of at least 32 hours at 1500 °C to reach a large domain, fully ordered state and they do not sinter to a high density as their partially ordered counterparts. In an attempt to overcome the slow ordering kinetics of BNT, we have examined the effect of small concentrations of B-site vacancies on the core size. The vacancies can be introduced through the formation of ordering induced domain boundaries. Through investigations conducted on BNT(Ta,Nb)O$_3$ (BNT) we have found that the core size is strongly dependent on the vacancy concentration. The effect of the vacancy formation on the kinetics of the ordering reactions, domain sizes, and microwave dielectric properties will be discussed.
Similarly we will demonstrate low loss frequency range from 0.3-1.2 THz. Laser pulses from a mode locked for tuning the THz wave at room temperature by applying voltage films. Moreover among these thin films, the BSTO thin film show the structures. Gold of 0.4mm with Ti adhesion layer of 20nm is same thickness as the Au layer, so is the adhesion layer. With similar applications in THz frequency domain. The rapid extractions [3] can be done with rigorous equivalent circuit models to Tuning THz Wave by Ferroelectric Thin Films. Kenta Kotani, obtain Q-factor, inductance and resistance as a function of frequency. We have found inductance and Q factor improvement up to 15GHz development in the generation and detection techniques of THz waves during last decade made it feasible to apply this frequency technology. Therefore, the focus of this work has been the application to tunable microwave devices and high-density dynamic random access memories. These thin films can also be utilizes for microwave filters prepared on these low embodiments. The thin film sample was mounted on a fixed emitter/detector. The thin film sample holder. THz waveforms after transmission through thin film before and after applying voltage bias to interdigital electrodes have been measured in time domain at room temperature. The samples were adjusted to the position so that THz wave could pass through the area which is covered with the interdigital electrodes. We have observed a slight change in time delay and amplitude of the transmitted THz wave form. The intensity of the peak of the waveform increases within bicycle in phase by applying the bias voltage. Our experimental result demonstrates that these thin films can be used for future frequency agile THz devices.

**G3.23 Compositions from the BST and PZT Solid Solution Families Deposited on Low Cost Substrates. Jon-Paul Murray, Department of MS&E, North Carolina State University, Raleigh, North Carolina.**

The integration of high permittivity dielectric materials in high volume application has been a long sought after goal pursued by numerous researchers since the mid-1980’s. Appreciation of this goal has been slower than anticipated for a variety of reasons, perhaps most importantly, the incredible complexity of ferroelectric materials under challenging physical, electrical, and mechanical boundary conditions. An additional reason for the slow rate of progress has been associated with the high cost of integration imparted by an expensive complement of electrode materials and the complicated process flows for deposition and patterning. In this presentation we discuss current efforts at NCSU to develop methods for preparing device quality ferroelectric thin film processes that address both cost and complexity issues. We will focus on compositions from the BST and PZT solid solution families deposited on low cost substrates like base metal foils. These films are targeted towards embedded capacitors, however, numerous high volume applications can be envisaged. The materials challenges associated with this work are centered upon achieving process compatibility as it pertains to thermal expansion, chemical reactivity, and interface formation. In all cases, the necessary pathways to success involve careful maintenance of the process flows. Our processes for chemical solution deposition of BT on Cu will be discussed, with specific attention to the achievement of permittivity values in excess of 3000 in film thicknesses less than 0.6 μm. Similarly we will demonstrate low loss dielectric can be prepared on copper by sputtering, with dielectric quality factors in excess of 300 in the absence of any chemical barrier layers. Finally, we will show recent results for tunable microwave filters prepared on these low embodiments.

**SESSION G4: Passives**

**Chair: Don Shiffer and Harris A. C. Tlimas**

**Tuesday Morning, November 30, 2004**

**Liberty (Sheraton)**

**8:30 AM **

**G4.1 Embedding Ceramic Thick-Film Capacitors into Printed Wiring Boards. William Borland, Marc Doyle, Lynne Delli, Olga Renovales and Digtarja Majumdar, DuPont Electronics, Research Triangle Park, North Carolina.**

Embedding passives into printed wiring boards have numerous advantages that show up in different segments of the market. For example, the ability to locate decoupling capacitors within a couple hundred microns of semiconductor I/Os greatly improves response time and signal integrity leading to product performance improvements. One crucial need, however, is high capacitance density. High capacitance density can be achieved by using ceramic technology. Therefore, the focus of this work has been the development of ceramic thick-film capacitor technology that can be used to bury high capacitance density components within an organic substrate. This allows high value decoupling capacitors to be buried for chip packaging or related applications in spaces available within any layer of the substrate. The dielectric paste is based on doped barium titanate composition and works together with a cofired copper electrode paste. The capacitor system is designed to be printed on the copper foil in the locations desired in the circuit and fired in nitrogen at 900 °C degree to form the ceramic components. Following this, the foil is laminated, component face down, to the organic laminate using standard prepreg and the inner layer etched to reveal the components in an organic matrix. The system has a dielectric constant of approximately 4000 and achieves a capacitance density of 1.5 nF/mm². In the following sections, some process issues are discussed and test data for electrical performance and reliability are presented.
In the development of thin film integrated passive components, a combination of low processing temperatures, and the ability to prepare a range of compositions spanning different permittivities and temperature dependences is desirable. This paper reviews recent approaches to these ends in the difficult case of low processing temperatures in all cases, it has been found that chemical solution deposition nickel-zinc ferrite can be crystallized below 400°C by pulsed laser annealing. The resulting films on Pt-coated Si substrates have dielectric constants of 178, loss tangents below 1%, and temperature coefficients of capacitance of -285 ppm/°C. Deposition on Ni-coated kapton substrates has also been demonstrated. For intermediate permittivities, the silver tantalate niobate (ATN) system provides permittivities from 50 – 400, coupled with reasonable Q’s in the microwave for some compositions. A chemical solution deposition route was developed for ATN. It is difficult to prepare single phase perovskite films on Pt-coated substrates, but epitaxial perovskite films were achieved on SrBa03/LaAlO3 substrates. With permittivities comparable to those of bulk materials. Finally, the development of high permittivity, lead-free, dielectric films will be discussed.

11:30 AM G4.6 Optimization of Passive Isolator Based On Barium Ferrite Sputtered Films. Martine Le Berre1, Stephane Capraro1, Jean-Pierre Chatelon2, Thomas Roulleau2, Bernard Hayard2, Daniel Barbier1 and Jean-Jacques Rousseau1. LPM, INSA Lyon, France. Barium ferrite is widely used as passive isolator, either as bulk material, or as magnetic screen in superconducting applications. However, the microwave properties of barium ferrite and its mixture with other magnetic materials have been extensively studied in recent years. In this study, we used the mixture of barium ferrite with other magnetic materials (BaFe12O19 and BaM) to improve the microwave properties of barium ferrite, such as high microwave loss, high magnetic blocking field, and high permeability. The mixture of barium ferrite with other magnetic materials was deposited using RF magnetron sputtering. The microwave properties of the mixture of barium ferrite with other magnetic materials were measured using a coaxial transmission line and a vector network analyzer. The results showed that the microwave properties of the mixture of barium ferrite with other magnetic materials were improved compared to those of barium ferrite. The addition of other magnetic materials to barium ferrite improved the microwave properties of barium ferrite, such as high microwave loss, high magnetic blocking field, and high permeability. The mixture of barium ferrite with other magnetic materials can be used as passive isolators in superconducting applications.
and the substrate. As standard design, the CPW were deposited on the top of the magnetic film. For this design, transmission coefficients showed a non-reciprocal effect, which increased insertion losses. When the magnetic film is buried in the CPW, the isolation effect is increased and insertion losses decrease in comparison to the standard design. Moreover, in this case the isolation effect increased with the conductor thickness as the interaction between the magnetic film and the metal increases.

**SESSION G5: Tunable/High k Thin Films II**
Tuesday Afternoon, November 30, 2004
Liberty (Sheraton)

**1:30 PM  G5.1 Recent Advances in Microwave Applications of Thin Ferroelectric Films at the NASA Glenn Research Center.** Robert R. Romanofsky, Fred W. Van Keuls and Matthew D. Valerio. Antenna, Microwave and Optical Systems Branch, NASA Glenn Research Center, Cleveland, Ohio; Ohio Aerospace Institute, Brookpark, Ohio.

We report on recent developments in microwave applications and understanding of ferroelectric TOS films with particular emphasis on focused on developing low loss, wide band phase shifters from X-band (8.4 GHz) to Ka-Band (26.5 GHz) for scanning reflectarray antennas. We have demonstrated a hybrid device at X-band that produces in excess of 300 degrees of phase shift with less than 3-dB insertion loss and greater than 10% bandwidth. Novel planar transmission line designs and results at Ka-band will be presented. The effects of mild (000 rad Si) proton radiation on device performance will be discussed. Preliminary results on optical phase shifters will be included. Prospects for mm-wave devices to 110 GHz, in the context of loss tangent and tuning, will be presented based on experimental measurements.

**2:00 PM  G5.2 Stroboscopic X-Ray Diffraction Measurements of a Sub-μm Domain Dynamics in Ferroelectric Films.** Emili Zolotoyabko, John Quintana, David J. Towner, B. H. Hoerman, and B.W. Wessels. Microelectronics and Materials Science Branch, NASA Glenn Research Center, Cleveland, Ohio; Ohio Aerospace Institute, Brookpark, Ohio; University of South Florida, Tampa, Florida; University of Cambridge, Cambridge, England; Technion, Haifa, Israel.

Ferroelectric thin films have promising applications for random access memories and electro-optic devices. Domain dynamics is the major factor, which determines the speed of device operation. In this study, the pulsed synchrotron radiation at Argonne National Laboratory was used to stroboscopically measure the structural response of ferroelectric films subjected to a high-frequency electric field, which is expected to stimulate domain movements. For this purpose, electric pulses with frequency 6.517 MHz from a synchrotron bunch clock generator were passed through a programmable delay unit (the minimal step was 18 ps) and delivered to the sample at frequencies on the order of 100 kHz which generated a sinusoidal signal of multiple frequencies, which was synchronized (phase-locked) with the x-ray bursts coming to the sample position and, after amplification, applied to the ferroelectric film. We show that stroboscopic measurements of lattice parameters at different delay times make domain dynamics visible and allow us to obtain spectral characteristics of domain motions [1,2]. Samples in this study were 200 nm thick BaTiO3 films epitaxially grown by metal-organic chemical vapor deposition on a 5000-A thick SrRuO3 layer on Pt/TiO2/SiO2/Si. Epitaxial crystalline SrRuO3 has been found useful as electrode due to its structural compatibility with the ferroelectric material for applications in tunable microwave devices like filters, phase shifters and resonators due to its high dielectric constant and large dependence of dielectric permittivity on the applied electric field. High tunability and low dielectric loss are desired for tunable microwave devices. The bottom electrode in parallel plate capacitor configuration is particularly challenging, since it should have high oxidation resistant at high growth temperature and high conductivity. Though platinum is the most desirable metal electrode, hillock formation was observed after the deposition of BST thin film on Pt/TiO2/SiO2/Si. Epitaxial crystalline SrRuO3 has been found useful as electrode due to its structural compatibility with SrTiO3/SrRuO3 superlattice although both SrRuO3 and SrTiO3 showed paraelectricity in nature. It seemed that the anisotropic lattice distortion induced by the lattice mismatch was the origin of the physical properties.

**3:00 PM  G5.3 Dielectric and Optical Properties of Perovskite-Type Artificial Superlattices.** Takahiro Higaki, Sonjoon Nam, Hirofumi Kakemoto, Satoshi Yusa, Kaisei Saito and Takaaki Tsurumi. Tokyo Institute of Technology, Tokyo, Japan; Bruker AXS K.K., Yokohama, Japan.

BaTiO3/SrTiO3 artificial superlattices with the perovskite-type structure exhibit some interesting experimental results, although physical properties of the artificial superlattices have not been clearly understood yet. To elucidate the origin of some unique properties observed in the superlattices, it is required to study the relationship between the structure and the material properties using various type artificial superlattices. In this study, we fabricated BaTiO3/SrTiO3, BaTiO3/SrZrO3 and SrZrO3/SrTiO3 artificial superlattices on SrTiO3 substrates by the molecular beam epitaxy process. The stacking periodicity was varied from 1 unit cell to 40 unit cells, and the total thickness was fixed at 80 unit cells of the primitive perovskite lattice. Structures of the superlattices are analyzed by reflection high-energy electron diffraction, normal x-ray scan mode x-ray diffraction, and the reciprocal space mapping measurement. The refractive indexes of the superlattices were measured by a rotating-analyzer type spectroscopic ellipsometer in the wavelength range from 350-850 nm. The complex admittance of the superlattices with interdigital electrodes were measured using an impedance analyzer at frequencies from 1 kHz to 110 MHz, and change vs. voltage (Q-V) hysteresis curves were obtained. It was clarified that the dielectric permittivity and the refractive index changed by the superlattice periodicity and those of 10-periodic superlattice was larger than those of other specimens. In the case of the SrZrO3/SrTiO3 system, a clear hysteresis curve was observed on 10-periodic superlattice, suggesting that the ferroelectricity was induced into the superlattices although both SrZrO3 and SrTiO3 showed paraelectricity in nature. It seemed that the anisotropic lattice distortion induced by the lattice mismatch was the origin of the physical properties.

**3:15 PM  G5.5 Dielectric Polarisation and Relaxor-Type Behaviour in Sr1-xMnxTiO3 Ceramics.** Alexander Tisch, Paula Maria Vilarinho and Andrei Khoklin. Ceramics and Glass Eng., University of Aveiro, Aveiro, Portugal.
Strontium titanate (ST) is a quantum paraelectric/incipient ferroelectric. High dielectric tunability of ST is useful for high-frequency applications, where the frequency can be shifted by moderate dc electric field. Pure ST does not exhibit ferroelectricity at temperatures as low as 0.035 K. There are several ways to induce the ferroelectric anomaly in ST by (i) application of electric field [1], (ii) application of uniaxial stress [2], (iii) isotope substitution of O anion [3], and (iv) substitution of Sr cation [4]. Namely, it has been shown that substitution of Sr for isovalent Ca, Ba and Pb induces a ferroelectric phase transition in SrTiO3. Dielectric tunability can be adjusted with varying Mn content and the effects of Mn were obtained also by nonisovalent substitution of Sr for rare-earth ions and Bi. In this work, the effect of Mn substitution on the ferroelectric behaviour of ST ceramics is reported. Sr1-xMnxTiO3 (x < 0.02) ceramics were grown by conventional solid-state method. Room temperature x-ray diffraction results indicated that all the samples are single cubic perovskite phase, and transmission electron microscopy (TEM) coupled with energy dispersive spectroscopy (EDS) analysis confirmed the incorporation of Mn into ST grains and the absence of any second crystalline phase until x < 0.02. Ferroelectric relaxor behaviour was found in Sr1-xMnxTiO3 ceramics. For x = 0.005-0.02, radio frequency dielectric measurements showed a maximum at 30-65 K, dependent on frequency and amount of Mn. The observation of hysteretic behaviour in the P vs E curves confirmed ferroelectricity of the low temperature phase and supported the ferroelectric relaxor-type evolution in Sr1-xMnxTiO3. The existence of ferroelectric and relaxor behaviour was attributed to a ferroelectric domain state induced by random fields. P. A. Fleury, J. F. Scott, and J. M. Worlock: Phys. Rev. Lett. 21, 16 (1968). 2. H. U. Wite and T. Sakudo: Phys. Rev. 1961 (1966). 3. M. Ito, N. Kinoshita, Y. Oikawa, T. Y. Goto, Y. J. Shih, T. Nakahara, Phys. Rev. Lett. 88, 147 (1999). 4. V. V. Lemanov, Ferroelectrics 226, 133 (1999).

3:30 PM G5.6

BST 60/40 paraelectric thin films with <110> texture were deposited on <100> NdGaO3 substrates by pulsed-laser deposition (PLD) and measured of their temperature dependent dielectric properties in the THz frequencies. BTO and BSTO thin films of thickness about 1.0 μm and STO thin film of thickness 650 nm were deposited on MgO substrate. The dielectric and optical properties of thin films have been studied by THz time domain spectroscopy (THz-TDS) in the frequency range from 0.7 THz to 1.5 THz. Each thin film sample was mounted on the cold finger of a closed cycle cryo-cooler that facilitates the measurement in the temperature range from 20 K to 250 K. The sample was cooled down to minimum temperature (20 K) and THz waveforms after transmission through thin films substrate have been measured in time domain at various temperatures in warming run. Both real and imaginary parts of the dielectric constant of the thin films have been evaluated from measured waveforms. The temperature dependence of the dielectric constant can be fitted to a simple mechanical model that mainly corresponds to their phase transitions. At low temperatures, the measured frequency dispersion of the dielectric constant of STO thin film shows Lorentzian oscillator behavior, while BTO and BSTO thin films show almost linear frequency dispersion. The dielectric constant of BSTO shows a marked increase in temperature and saturates near 60 K in the frequency range 0.7 THz, while for BTO thin film at the same frequency, it starts decreasing in temperature and saturates near 60 K in the frequency range 0.7 THz. The dielectric constant of BTO shows almost linear frequency dependence in the entire temperature range with a bump near 0.7 THz and shows a small peak near 1 THz.

3:45 PM G5.7
Microstructure-property relationships of SrTiO3 thin films on epitaxial Pt electrodes for tunable microwave devices. Jiewen Lu, Sean Keane, Steffen Schmidt, Dmitri O. Klenov, Lia Bregante and Susanne Stember; Materials, University of California, Santa Barbara, California.

SrTiO3 is a prototype, incipient ferroelectric with the perovskite structure. At low temperatures, SrTiO3 shows a nonlineal, electric field tunable dielectric constant, which is of interest for tunable microwave devices. Dielectric tunability of SrTiO3 thin films on metal electrodes typically are polycrystalline or textured. The dielectric tunability can be adjusted with varying Mn content and the effects of Mn were obtained also by nonisovalent substitution of Sr for rare-earth ions and Bi. In this work, the effect of Mn substitution on the ferroelectric behaviour of ST ceramics is reported. Sr1-xMnxTiO3 (x < 0.02) ceramics were grown by conventional solid-state method. Room temperature x-ray diffraction results indicated that all the samples are single cubic perovskite phase, and transmission electron microscopy (TEM) coupled with energy dispersive spectroscopy (EDS) analysis confirmed the incorporation of Mn into ST grains and the absence of any second crystalline phase until x < 0.02. Ferroelectric relaxor behaviour was found in Sr1-xMnxTiO3 ceramics. For x = 0.005-0.02, radio frequency dielectric measurements showed a maximum at 30-65 K, dependent on frequency and amount of Mn. The observation of hysteretic behaviour in the P vs E curves confirmed ferroelectricity of the low temperature phase and supported the ferroelectric relaxor-type evolution in Sr1-xMnxTiO3. The existence of ferroelectric and relaxor behaviour was attributed to a ferroelectric domain state induced by random fields. P. A. Fleury, J. F. Scott, and J. M. Worlock: Phys. Rev. Lett. 21, 16 (1968). 2. H. U. Wite and T. Sakudo: Phys. Rev. 1961 (1966). 3. M. Ito, N. Kinoshita, Y. Oikawa, T. Y. Goto, Y. J. Shih, T. Nakahara, Phys. Rev. Lett. 88, 147 (1999). 4. V. V. Lemanov, Ferroelectrics 226, 133 (1999).

4:00 PM G5.8
THz Time-Domain Spectroscopy of Ferroelectric Thin Films. Muki Misra, Keita Kobayashi, Iwasawa Masahiro and Masayoshi Tanouchi; Research Center for Nonlinear Photonics, Osaka University, Suita, Osaka, Japan.

Ferroelectric thin films such as SrTiO3 and BiSTO have been very popular due to their very high dielectric constant and electrical tunability. Ferroelectric thin films offer a promising technology for electrically tunable frequency-agile devices. The ferroelectric properties of SrTiO3 (STO), BiSTO (BTO) and Bi2Sr2Ti2O9 (BSTO) thin films have been extensively studied for their application to microwave tunable filters, matching networks, phased array antennas and high-density dynamic random access memory. Recent developments in the technology of the low-loss, tunable THz frequency spectrum is of great interest for the development of new generation THz devices for various applications. These thin films are a strong candidate for application to THz devices due to their high electro-optic coefficient, high dielectric constant and tunability. The dielectric and optical response of these thin films differ significantly from that of the single crystal and strongly depends on the quality of thin film and therefore a systematic study of high quality thin films of these ferroelectric materials is required in THz frequency spectrum.

4:15 PM G5.9
A High K Nanocomposite for High Density Chip-to-Packaging Interconnections. Taeyun Kim, Jayesh Nath, John Wilson, Stephen McCue, Paul D. Franson, Michael B. Steer and Angus I. Kingon; Materials Science and Engineering, North Carolina State University, Raleigh, North Carolina, Electrical and Computer Engineering, North Carolina State University, Raleigh, North Carolina.

Increasing chip functionality demands a high density interconnect technology. One of the most commonly used interconnect technology uses a direct, contacting path for every input/output connection. This limits achievable density in pin and ball grid arrays and creates rework and compliance problems in very-high-density solder bump arrays. AC-coupled interconnects is a very promising technology for achieving high-density interconnects while simultaneously providing a simple mechanical interface. In this technology buried solder bumps enable DC power and ground connections, and capacitors spaced across the same surface serves as the capacitively coupled interconnect for high frequency signals. Most implementations of the AC-coupled interconnect concept requires that the chip and the substrate be...
brought into close proximity (2-5 μm) to achieve the required capacitance for effective coupling. This requirement poses significant manufacturing challenges to meet the required reliability. This results in increased complexity, yield losses, and increased yield losses associated with such small dimensions. Hence there is a need for a high dielectric constant material that can achieve higher capacitance densities and relax the proximity requirements between the chip and the substrate. Such a material can also provide stress relief and thus improve the overall reliability of the interconnects. In this work the development of a high K nanocomposite and its high frequency characterization has been presented. The dielectric properties and mechanical reliability of the composite were evaluated for dielectric underfill in high frequency AC coupled interconnects. Bisphenol-A epoxy and a photosensitive epoxy were utilized for polymer matrix materials. 260 nm BaTiO3 nano-powder was used for modulating of dielectric properties of underfill. Thermal behavior of underfill was evaluated by TGA and DSC, respectively. Dielectric properties were evaluated with ceramic loading and curing temperature. Mechanical reliability testing of underfill was performed on anodic solder bumped Si substrates by tensile adhesion test as well as aging the part under 85/85 environment. The electrical properties were measured from 45 MHz up to 26.5 GHz.  Because of the same requirements for high density, high frequency interconnects. A floating parallel plate capacitor structure was used to extract the capacitance and quality factor of the capacitor over the frequencies of interest. The dielectric constant was found to be in the range of 33-40 and the Q factor of the capacitor was found to be 31 at 26.5 GHz. The high K nanocomposite shows relatively high dielectric constant compared to materials currently used (usually air or SiO2) in capacitively coupled interconnects for chip-to-package communication. The loss was also found to be tolerable up to a frequency of 26.5 GHz and this should allow signaling well into the multi-gigabits range.

4:30 PM G5.10
Preparation of Nanocomposite Microwave Dielectric Films Using Aerosol Deposition Method and Their Dielectric Properties. Song-Min Nam1,2,3, Naoko Morii1,4, Mihoko Momotani1,5, Hirofumi Kakemoto1, Satoshi Wada1, Jun Acedo2 and Tatsuki Tsukuda1,2,1Tokyo Institute of Technology, Tokyo, Japan; 2AIST, Tsukuba, Japan.

In recent years, development of mobile electronic devices, such as cellular phones, portable gaming devices and digital-assisted notebooks has been rapidly progressed so that microwave dielectric materials have been greatly paid attention to for filters, resonators, antennas operating at the microwave frequency ranges. For instance, perovskite composite microwave dielectric films fabricated by the Aerosol Deposition Method (ADM) which enables ceramic films with nanometer crystallite size to be grown at room temperature. Because the ADM is low temperature fabrication technology in nature, nano composite films with different temperature coefficients of the permittivity are expected. In the case of barium titanate films prepared by the ADM, their temperature coefficients of the permittivity are expected. In the case of barium titanate films prepared by the ADM, their temperature coefficients of the permittivity showed positive as we expected, even though their permittivity was much lower than that of bulk barium titanate. We will discuss the dielectric properties of the nano composite microwave dielectric films fabricated by the ADM using the barium-, strontium-, calcium-based perovskite materials.

4:45 PM G5.11
Abstract Withdrawn
structures for these MEMS devices. This paper presents an update concerning the novel methods we have recently developed for depositing thin metal-dielectric-membrane stacks on capacitive MEMS switches. Thus far, we have achieved consistent results with several materials. Our results show that the use of thick metal oxide veneers in the exposed areas of the device structures may be a key to developing high-Q capacitive RF MEMS microwave switches.


Gennium Corporation, Burlington, Ontario, Canada; 1Electrical and Computer Engineering, University of Waterloo, Waterloo, Ontario, Canada.

The growth of the wireless industry over the past ten years has created a need for good quality passive components, and in particular high-Q inductors. There has been a large amount of work aimed at improving the quality factors of inductors on silicon and ceramic substrates. KAIST and other research groups have explored MEMS techniques, releasing the inductor coil to create an air gap between the coil and underpass, on silicon [1]. Typically the inductor coil has been separated by a 50 to 70 nm thick dielectric oxide (e.g. perovskites) without the need for etching processes or high temperatures by using a combination of the photodefined metal-organic systems and subsequent temperature hydrothermal treatment. This paper will discuss our recent results in this area including physical and electrical characterization of the patterned dielectric oxide results and use of these materials in capacitive RF MEMS microwave switches.

10:45 AM G6.6 High-Density, Low-loss MOS Decoupling Capacitors for integration with an RF Transceiver in a System-in-Package. Fred Roosbeoom 1, Anton Kemmeren 2, Jan F. Verhoeven 1, Eric van den Heuvel 1, Johan Klootwijk 1, David Cherrie 2, Francesco L. Coradini 1, Serge Bardys 2, Pascual Ph. de Meeûl 2, and Toon T。n 2.

1Philips Research Labs, WAGO2, Prof. Holstlaan 4, 5656 AA Eindhoven, Netherlands; 2Philips Semiconductors, 2 Rue de la Girafe, F-14079 Caen, France; 3Philips Semiconductors, Gerstweg 2, 8534 AE Nijmegen, Netherlands.

Recently the first high integrated cellular RF transceiver systems were launched using Philips’ new silicon-based System-in-Package (SiP) technology. This new technology utilizes back-end silicon processing to integrate passive components (particularly high-density capacitors) onto a silicon substrate that then acts as a carrier for active dies. A radio transceiver IC can be flip-chip mounted onto the passive silicon substrate, thus minimizing interconnect parasitics and footprint area [1]. This sub-assembly is then flipped back into a standard leadframe package. The passive die is made in the so-called Philips Interconnect Connecting Substrate (PICS) technology developed to integrate passive components such as high-Q inductors, resistors, accurate MIM capacitors and, in particular high-density (25 nF/mm²) MOS capacitors for decoupling and filtering. These capacitors are MOS ‘trench’ capacitors fabricated in macro-porous arrays that are dry-etched in silicon with pores of 1.5 µm diameter and up to 30 µm depth [2]. Capacitors with 30 nm ONO dielectric and poly-Si/Al top electrodes showed superior dielectric breakdown voltage (30 V typical) and very low leakage current density at 1 nA/mm² @ 22 V [3]. On die-level the MOS capacitors integrated in RF power amplifiers showed superior signal stability compared to identical test devices with discrete ceramic capacitors. This proved that these capacitors are very efficient in RF power supply decoupling and can be integrated with microwave subsystems in one package at low cost. A next step in the miniaturization is the use of so-called high-k oxides (HfO2, etc.), where we already have realized capacitance densities in excess of 100 nF/mm² [4].

11:15 AM G6.7 Direct Integration of AlGaAs/GaAs HEMT’s on Ceramic Substrates for Super-Hybrid Microwave ICs using Fluidic Self-Assembly. Ikuo Soga, Shoji Hayashi, Yutaka Ohno, Shigeru
Recently, heterogeneous integration (HI) technology has been attracting much attention. It enables us to integrate devices made of various materials, for example, optical devices, high-performance InP HEMTs, and silicon chips. One of the most promising concepts for HI is the fluidic self-assembly (FSA) proposed by J. S. Smith et al. In the FSA technology, small device blocks separated from their substrates (epitaxial lift-off) are scattered on the tilted host substrate placed in fluid, then they slide and fall into recesses on the substrate. This technique has various advantages compared to heterogeneous epitaxial growth and wafer bonding. For example, this method is applicable to non-crystalline substrate materials, such as ceramics. In addition to this, the FSA process is very cost-effective due to the excellent efficiency of the material use, because the device blocks can be fabricated densely all over the guest wafer. We apply this technique to direct integration of HEMTs on ceramic substrates. Here, the device blocks are fabricated in a single growth on a GaAs wafer. First, the HEMTs were fabricated on epitaxial layers grown on GaAs substrate. Next, the HEMT blocks were separated from the substrate by selective etching of the buried sacrificial layer (AlAs). The size of the device blocks, which have two fingers of 50-urn gate width, was 87x57 um2. Then, the device blocks were arranged on the ceramic substrate using FSA. Finally, the process has been completed by a wafer planarization and metal evaporation for wiring and pads. It has been demonstrated that the good FET characteristics were obtained even after FSA process.

Multilayer ceramic technology offers a cost-effective and versatile approach to design and manufacture high performance and high reliability, three-dimensional (3D) microelectronic packages. Multilayer technology, high Q passive components in a separate wafer (semiconductor is not required), high-performance analog-to-digital (A/D) converters and a RF transceiver IC in a second wafer, and a digital processing IC in a third wafer are bonded together with an adhesive, thins the top wafer in a three-step process and provides vertical interconnects with a copper damascene process. With this 3D technology, memory-only wafers can also be incorporated in the 3D system if needed. The technology is applicable to smart wireless terminals, millimeter phased array radars, and smart imagers. The presentation of this technology and application will include direct integration and simulation results, and a comparison with system-on-a-chip (SoC) and system-in-a-package (SIP) approaches.
Our analysis of the dielectric properties showed that the cubic fluorite solid solution of Bi$_2$O$_3$ and Nb$_2$O$_5$ exhibits a permittivity that is high enough for it to have the potential for use in LTCC technology (90). Unfortunately, the dielectric losses too high and the temperature coefficient of resonant frequency is too negative for this kind of application. As well as this cubic solid solution, another tetragonal, fluorite-based modification was reported to appear in the same composition range (25 mol% of Nb$_2$O$_5$). It is evident from the literature that the conditions for the formation of this tetragonal phase are not understood and, therefore, neither a synthesis of the single-phase tetragonal ceramics nor their properties have been reported. We have investigated the nature of the cubic-to-tetragonal phase transition in order to determine the conditions for the synthesis. Our studies showed that the change in the crystal system is induced by a superstructural ordering. The order-disorder transition starts as homogeneous nucleation and is associated with the transformation from an incommensurate to a commensurate state. The order-disorder transition temperature was determined to increase with an increase in the Nb$_2$O$_5$ concentration. Studies of the influence of the order on the dielectric properties of Bi$_2$O$_3$ - Nb$_2$O$_5$ solid solutions show that the ordering reduces the dielectric losses and reverses the sign of the temperature coefficient of resonant frequency. The permittivity remains around 90. The temperature range over which the ordered tetragonal modification is stable coincides with the sintering temperatures of LTCC modules, and that opens up the possibility of using it in this technology.

For high performance microelectronics and MEMS package, ceramics-based package are preferred over plastics. Low temperature co-fired ceramic (LTCC) technology is under study for microwave applications. In this study, B2O3 and glass are employed to reduce the sintering temperature of Bi$_2$(Nd$_{0.8}$Sm$_{0.2}$)$_2$Ti$_4$O$_{12}$ dielectric. Thick-film capacitors with Bi(Nd$_{0.8}$Sm$_{0.2}$)$_2$Ti$_4$O$_{12}$ dielectric doped with low glass and/or low melting point oxide are prepared. The electrical properties and microstructure of the capacitors are correlated. The electrode/dielectric interfaces are observed. In this paper, the sintering behavior, phase evolution, interface reactions, and microwave dielectric properties are investigated. The microstructure of the electrode/dielectric interface has been investigated using scanning and transmission electron microscopy (SEM and TEM), and its correlation to the overall impedance has also been discussed.

opportunities and Needs for Ceramic Materials in Wireless Communications. Terrell A. Vanderah, Ceramics Division, NIST, Gaithersburg, Maryland.

Ceramic materials have critical enabling functions in both the high-power (e.g. base station infrastructure) and low-power (end-user devices) arenas of wireless technology. Attempts to predict future needs must be tempered with the economic uncertainties faced by the communications industry. Materials needed to enable and optimize next-generation applications will depend on the economic success of emerging approaches. One example is 3G telecommunications, which may require drastic infrastructural changes. What is certain is that wireless communications are here to stay and have markedly transformed society. An attempt will be made to describe generic technical needs – both near and long term – shaping the demands for new and/or improved ceramics, processes, and materials.

Evolution of Dielectric Permittivity of Barium Titanate Fine Powders. Tatsuki Tsurumi, Tatsuki Sekine, Takuya Hoshina, Hirofumi Kakemoto and Satoshi Wada; Dept. of Metallurgy and Ceramic Science, Tokyo Institute of Technology, Tokyo, Japan.

Barium titanate fine powders are being used for a raw material of microelectromechanical systems fabrication (MEMS) and for a filler in polymer composites for the embedded film capacitors. Selection of powders with a high permittivity is extremely important to achieve high performance in such devices. However, there is no effective method to evaluate dielectric properties of powders at present; therefore, the quality of powders has been evaluated after making devices, which markedly reduces the efficiency of the development. In this study, we have first proposed a reliable method to evaluate dielectric permittivity of powder itself. Our method uses a slurry as a sample of dielectric measurement and a finite element method to evaluate the permittivity of powder from that of slurry. Various barium titanate powders were supplied from manufacturing companies. Barium titanate powders were dispersed in a solvent of propylene carbonate using a ball mill and the dielectric permittivity of the slurry was measured at 20 MHz with a liquid measuring cell. The permittivity of the powder depended on its particle size, tetragonality and density. A statistical method was employed to explain the change in permittivity with these parameters.


Abstract Polycrystalline alumina (Al2O3) and aluminum nitride (AIN) have been used widely as high reliability substrate materials for electronic device packaging because of their superior strength and excellent electrical and thermomechanical properties. Recently, polycrystalline AI2O3 and AIN have been proposed and tested for high temperature electronic device packaging applications intended for operation at temperatures up to 500°C. Therefore, the dielectric properties of these materials, including dielectric constants and effective bulk conductivities, at elevated temperatures are of interest, especially for RF applications. This article reports temperature dependent dielectric properties of polycrystalline 96% AI2O3 and AIN substrates from room temperature to 500°C measured by AC impedance at 120 Hz, 1KHz, 10KHz, and 100 KHz. The dielectric constant of 96% AI2O3 was measured 9.5 at room temperature at all four frequencies. At 500°C, the dielectric constant was 2.27 times of the room temperature at 120Hz, and was 1.11 times that at room temperature at 100KHz. At 120Hz, the effective bulk conductivity of 96% AI2O3 increased by four orders to 1.41E-7 S/m from 23°C to 500°C, but at 100KHz, it increased by only one order to 2.91E-6 S/m from room temperature to 500°C. The relative dielectric constant of AIN increased from 8.95 at room temperature to 5344.6 at 500°C, but at 100KHz it increased from 8.72 at room temperature to 115.0 at 500°C. The effective bulk conductivity of AIN demonstrated negative temperature coefficient from 23 to 50°C at all four frequencies. At 500°C, the bulk conductivity increased by a factor of 3.3E4 from the 50°C value of 2.65E-10 S/m at 120Hz, and increased by a factor of 1.1E4 from the 50°C value of 8.9E-8 S/m at 100KHz. The temperature and frequency dependency on the quality factor and loss angle measurements will be discussed.


By combining ion track technology with ordinary low-resolution PCB lithography it is possible to cost effective create slits in high aspect ratios or bunches of submicron connector wires at a cost of 10 dollars per square inch at each via. We are investigating using the technology with novel integrated PCB devices in two different flexible polyimide based foils (Expandex and Kapton HN), using the ultra high density track to create angle tracks in the surrounding material that create through-holes. The basic principle is to superimpose angles with the surrounding material that create through-holes. The basic principle is to superimpose laser track to create through-holes. The basic principle is to superimpose laser track to create through-holes. The basic principle is to superimpose laser track to create through-holes.
overall physical properties. Typically, the latent track that has undergone pyrolysis has a width of 10 nm, and is etched with selectivity from a few hundreds to a thousand times faster than the surrounding bulk. Hence, nearly cylindrical pores are created in the selective etch process. When the pores are etched for long they will start to merge together and finally a fully opened via is created. This process can be stopped at any moment, giving the desired porosity in the vias. Combining via connectors and submicron wires obtained by this way with lithographically patterned metal interconnectors on the foil, the above-mentioned devices are demonstrated.

4:45 PM G7.8
High Frequency Copper Migration Phenomena in Stress-Induced Phosphorus Mold Epoxy: an Electrochemical, Materials, and Package Model Analysis.
Surasit Chongpaiboonpatana,1,2 and Frank G. Shi;1 Chemical Engineering and Materials Science, University of California, Irvine, California; 2Worldwide Manufacturing, Conexant (Mindspeed) Corp., Newport Beach, California.

The new paradigm shift in the back-end packaging and assembly industry is demanding environmentally friendly bleeding-edge materials. Accordingly, many Pb-free and Green (non-Halogen) materials are introduced to be incorporated into existing package varieties. Based on RoHS and EIA initiatives, the conversion of assembly materials into 100% non-hazardous components must be completed before the year 2006. Several previous studies have reviewed the implementation capability of different material combinations. However, they rarely address in detail the failure mode mechanism using these newly developed materials and seldom provide extensive failure analysis on the package model level. Furthermore, the challenges of higher product performance and package reliability requirements on any new chemistry and developed formulation are not fully examined. One new Pb-free/Green chemistry that causes significant industry concern is the P (Phosphorus) flame retardant particle for the epoxy mold compound. This P particle supports the UL flammability requirements and eliminates the use of hazardous Br (Bromine) and Sb (Antimony) based materials in the package component. But the presence of P produces a new failure mechanism of product leakage and/or short issues under specific operating conditions. Consequently, this study aims to develop a package level model and an understanding on the stress-induced Cu migration phenomena when the P particulates are present. The research is based on the electrochemical and failure mode analysis using active and high-frequency Si device designed for a large form factor package. First, the mold epoxy with embedded P particles is processed through JEDEC specified assembly and undergoes reliability stressings at the package qualification level. The various types of stressings and reliability conditions are exercised using TC, HTS, and biased-HAST with preconditionings to identify the mechanism of Cu migration when it is induced by the P particulates. Then, a detailed failure analysis on active modules is examined using SEM, EDX, continuity tests, fine-focused X-ray, and extensive parallel backlapping sequences to reveal the Cu migration path and its underlying mechanism. The study finds that Cu migration is induced by the stressed formation of phosphoric acid during specific biased and moisture related module applications, and its extension follows a non-coplanar pattern through the epoxy matrix. This research concludes with potential strategies for improvement, application-related modifications, and a detailed migration model obtained by comparing the analyzed failure mode mechanism, material properties, and electrochemically derived concept.