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

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

8:30 AM G1.1
Science and Technology of Dielectric Materials and Films: Integration for High-Frequency Devices, Orlando Arcedillo, Wei Fan, Bernard Kung and Sreejy Sabharwal, Science Division, Argonne National Laboratory, Argonne, Illinois.

The science and technology of complex oxide thin films and materials integration strategies for application to high-frequency devices (HFD) will be reviewed in light of recent research that provided unique insights into fundamental and applied processes relevant to these devices, as revealed by using a variety of complimentary in situ and ex situ characterization techniques. In particular, we will discuss the synthesis of BaxSr1-xTiO3 (BST) thin films and the integration of different electrode materials for application to the fabrication of capacitors for high-frequency devices such as phase array antennas. We will discuss the extensive studies performed to understand the effect of interfaces on the dielectric properties of the capacitors and the strategies developed to optimize those properties. This was achieved using a unique integrated ion beam sputter-deposition (IBSD) in situ mass spectroscopy of recoil ions (MSRI) / X-ray photoelectron spectroscopy (XPS) system developed by our group for in situ studies of film growth and interface processes, and ex situ high-resolution HRTEM. MSRI provides valuable information about species on the surface of thin films, while XPS yields information on the chemical environment at the atomic scale; HRTEM provides atomic scale information on the microstructure and composition of films and interfacial layers. We will specifically discuss research focused on developing diffusion barrier layers to integrate Cu as the electrode layer for BST capacitors. A reliable oxygen diffusion barrier is needed for integration of Cu electrodes with high-K dielectric oxide layers, since the dielectric layer of such capacitors is generally grown in an oxygen environment at relatively high temperature. For this purpose, we have investigated the integration of Ti-Al alloy layers as diffusion barriers in heterostructured Ti-Al/Cu/Ti multilayers, which exhibited exceptional thermal stability and outstanding electrical conductivity. These Ti-Al/Cu/Ti multilayered films were subsequently deposited on the Cu-based bottom electrode by RF magnetron sputtering to investigate the performance of BST/Cu-based capacitors for high-frequency devices. We demonstrated that the first review with good electrical properties that open the way for BST-based capacitors with low-loss high-conductivity electrodes for the development of high frequencies devices. Outlook for future research will also be discussed.

This work was supported by the U.S. Department of Energy, BES-Materials Sciences, under Contract W-31-109-ENG-38.

9:00 AM G1.2
RF Magnetron Sputtered Ba0.96Ca0.04Ti0.84Zr0.16O3 Thin Films for High Frequency Applications, Al Mahmud, Thottam S. Kailas and Nick Cramer, 1 Electrical and Computer Engineering, University of Colorado at Colorado Springs, Colorado Springs, Colorado; 2 Applied 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 influenced by the recent explosion in wireless and satellite communications. In this paper, Ba0.96Ca0.04Ti0.84Zr0.16O3 (BCTZ) thin films deposited on Pt electrodes using radio frequency magnetron sputtering at low (<550 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), 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 successfull implementation in high frequency applications.

9:15 AM G1.3
Ferroelectric Thin Films and Composites for Tunable Microwave Devices, Menko Jan, 1 N. K. Karan, Sam S. Katiyara, A. S. Bhalla, F. A. Miranda and F. W. VanKeuls, 1 Department of Physics, University of Puerto Rico, San Juan, PR; 2 Puerto Rico.

We have successfully obtained a low loss BaxSr1-xTiO3 (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,
Moreover, it increases up to 12% dielectric loss in a Pt/BST/Pt stacked capacitor structure when the electrodes of the CPW pattern (width:60 μm, length:2.5 mm) are designed for achieving this high data rate, beyond line of sight, On The Move. For the interdigitated capacitors with finger spacing of 10 μm, dielectric loss was found to be as low as 0.002 to 0.004 when applied surface electric field was from -/+40 to +/−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 to +/−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 degrees was obtained at 20 GHz with insertion loss of about -2 dB for Au/Cr interconnection due to its lower resistivity. Therefore, the figure-of-merit became higher degree/DB for the Au/Cr case. The measured S parameters of the CPW were found to agree well with those simulated by MicroWave Office ver.6. A 3-stage LC-ladder-type phase shifter with variable capacitances was designed [21] by setting the values 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 applied 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 Ba0.6Sr0.4TiO3 Thin Films with Large Area, Affordable, Industry Standard Substrates for Microwave Application. William D. Nothwang1, M. W. Cole1, P. C. Mcintyre1,4, & John D. Barney2, Kenji Nomura2, Takashi Shiga2, Paul C. McIntyre1 and Kazuaki Kuribara5; 1Materials Science and Engineering, Stanford University, Stanford, California; 2Fujitsu Laboratories Ltd., Atsugi, Japan.

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 increasing deposition temperature, doping with Al may be used to improve self-pair 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. Thin BST 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 concentration, 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, TiO2 Buffer Layers for Integrating (Ba,Sr)TiO3 Microwave Tunable Devices onto Si Wafers. Il-Doo Kim1, Hyun-Suk Kim1, Jin-Seong Park9, YongWoo Choi1 and Harry L. Tuller1; 1Department of Materials Science and Engineering, MIT, Cambridge, Massachusetts; 2Department of Materials Science and Engineering, KAIST, Daejeon, South Korea; 3Department of Chemistry and Chemical Biology, Harvard University, Cambridge, Massachusetts; 4Microsystem Technology Laboratory, MIT, Cambridge, Massachusetts.

The Army is pursuing technologies to meet transformation goals of a lighter, faster, more lethal force via affordable, electronically scanned phased array antenna (ESA's) that will provide the means for achieving this high data rate, beyond line of sight, On The Move (OTM) communications. Paraelectric, active thin films (Magnesium doped Barium Strontium Titanate), compositionally designed for tunable microwave applications, have been deposited on ceramic (MgO, LaAlO3, SrTiO3), high resistivity (Al2O3) substrates in order to pursue 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 decreased. 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 metallorganic solution deposition technique. The optimized Ta2O5 based thin film exhibits excellent microwave material properties, including an enhanced dielectric constant (ε* = 146), low dielectric loss (tan δ = 0.006), low leakage current or high film resistivity (γ = 1017 Ω-cm at E=1 MV/cm), excellent temperature stability (temperature coefficient of capacitance of 52 ppm/C), and excellent bias stability of capacitance (0.1% 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 heterostructures developed using 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 phased array antennas to be implemented by a wide spectrum of Army and Commercial applications; specifically, affordable OTM phased array systems across a variety of DoD platforms will allow for a full-spectrum, network integrated theater.
applied electric field, film thickness and the temperature are highly desired for various capacitor applications. We have previously proposed that c-axis-oriented dielectric thin films (BLC) 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 20 nm with the smooth surface[1]. In addition, these are promising candidates for the microwave devices because of their high dielectric constants, low losses and tailored temperature coefficients of dielectric constant. However, 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 BLC films on various substrates is critical. In the present study, we have successfully prepared a single layer, i.e. c-axis oriented BLC films even on the (111)Pt/TiO2/SiO2/Si substrates by inserting the (001)-oriented LaNiO3 buffer layer as an interfacial template. A comparison of the dielectric properties of these films was made with epitaxial-grown films in the viewpoint of in-plane and out-of-plane orientations. Ca0.5Bi4Ti4O15 (CBTi) films with various thickness were deposited on LaNiO3 buffered (111)Pt/TiO2/SiO2/Si substrate at 600°C by rf magnetron sputtering deposition. Without the LaNiO3 buffer layer, CBTi films showed random orientations. However, with the LaNiO3 buffer layer, which showed prominent (001)-orientation characteristic even on (111)Pt, CBTi films were found to show an out-of-plane c-axis but in-plane random orientations. Furthermore, adding a second layer of conductive (001)-oriented SrRuO3 between CBTi film and LaNiO3 layer. It was demonstrated that the general observation of degradation of dielectric constant with decreasing thickness was significantly improved by these CBTi films on all 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 of the dielectric properties against the film thickness, thus, making them highly desirable for new capacitor application. These capacitors can be made not only on Si substrates but also on other substrates, such as metal plates, glass and resin. 1) T. Kojima et al., Mater. Res. Soc. Symp. Proc. 748, U15.2.1(2003). 2) S. Kojima et al., Anal. Sci. 17, 1004(2001).

4:15 AM G1.10
AC Loss Modeling in Ba0.9Sr0.1TiO3 Using Dielectric Relaxation, Nadia K. Parvey1, Jovi Lu2, Susanne Stömer3 and Robert A. York5, 1Electrical and Computer Engineering, University of California, Santa Barbara, California; 2Materials Department, University of California, Santa Barbara, California.

Universal relaxation refers to behavior where a material's complex dielectric susceptibility is observed to follow a decreasing power law over multiple decades in frequency [1]. This behavior is observed in a variety of different materials including CBTi, Bi4Sr2Ti2O9, Al2O3, TiO2, HfO2 and SiO2 [2][3]. It appears to be a property of extrinsic disorder rather than an intrinsic material property [4][5]. The susceptibility shows an n-th power frequency dependence, where 0 < n < 1. For a lossless material, n = 1. A direct consequence of this power law is that if the real component of the material's complex susceptibility obeys a power law, no, so must the imaginary component. While many materials have been observed to obey Curie-von Schweidler behavior, corresponding to n = 1, little attention has been focused on the corresponding loss predictions using the universal relaxation model. Even when little relaxation is observed — when n is very close to 1 — the model can still accurately predict loss. The ability to calculate losses from capacitance data may be advantageous in situations where the direct measurement of Q-factors is difficult, such as network analyzer measurements of low-loss films. Reflection-type measurements of high-Q reactive loads performed with network analyzers are less accurate than measuring bridge losses with impedance analyzers. However, auto-balancing bridge measurements are limited to below 110 MHz. Provided that parasitic electrode inductances at high frequencies can be accounted for, this technique offers an accurate way to indirectly measure film loss through capacitance measurements. In Ba0.9Sr0.1TiO3, we have successfully used power-law capacitance data to predict Q-factor values. Table 1 shows a comparison between 1 MHz Q-factors calculated and measured using an impedance analyzer. The calculated values are consistently equal to or slightly higher than measured values, consistent with the expected small contribution of series electrode resistance to measured Q-factors as 1 MHz. [1][2][3][4][5][6]

2:00 PM G2.2
Pulsed DC Sputtered Aluminum Nitride: A Novel Approach for the Control of Stress and c-Axis Orientation, Philippe Soussan1, Kathy O'Donnell2, Wanling Pan1, Jan D'Haeza, Geert Vanhoyland1, Eric Beyne2 and Harrie A. C. Timmans3, 1Microsystems , components and packaging, IMEC, Heverlee, Belgium; 2Next systems, Billerica, Massachusetts; 3IMOMEC, IMEC, Daejeon, Belgium; 4Institute for Material research, Limburgs Universitair centrum, Daejeon, Belgium.

For application in high frequency devices like film bulk acoustic resonators (FBARs) thin-film piezoelectric aluminum nitride (AIN) must display perfect c-axis orientation (along with a high piezoelectricity) and a low residual film stress. Recently, significant improvements were reported on the deposition of AIN films [1]. This combination and despite its economical interest, deposition processes on Aluminum remain challenging because the AIN film deposited on it presents poorer properties [2]. This paper reports on a novel low temperature sputter deposition process yielding high crystalline orientation on Al comparable to Pt. The study focuses on the importance of the initial film growth step on both stress and crystalline orientation. The AIN layer is deposited using Pulsed DC (250 kHz, 90% duty cycle) magnetron reactive sputtering (93% N2, 7% Ar) using an AI target. The substrates are 150nm Si wafers coated with an aluminum thin film. The thickness of the AIN films is about 2.5µm with a uniformity across the wafer of 0.4%. The films have been deposited in 4 passes of 0.625µm each to avoid overheating of the substrate. An interesting additional factor is the fact that for each pass the deposition conditions may be different. The influence of the RF substrate bias (0, 80 and 120V, integrated value from power) and argon pre-sputtering (present or not) of the aluminum have been investigated. The gas flow, plasma pressure and power were kept constant. Full Width at Half Maximum of the rocking curve of the (002) plane is used to quantify crystallinity of layers and wafer bow measurements are used to quantify the stress of the films. The films grown on an aluminum layer with 0V bias exhibit a FWHM rocking curve angle of 2.8° but displayed cracks due to a large tensile stress, exceeding 1.1GPa. For the films having their first layer deposited using an DC bias of 80V, the stress is lower and the FWHM is 1.8°. For the film deposited using a DC bias of 120V, the stress is the largest and the FWHM is 1.3°. It was found that the stress is proportional to the rocking curve angle of the remaining 3 layers showed only a small dependence on the substrate bias during deposition. For the films deposited using a DC bias of 120V, the magnitude of the argon pre-sputtering on the first layer is vital. There was a change from compressive w/o pre-sputtering towards tensile stress with pre-sputtering. It can be concluded that, within a certain range, the deposition parameters during the initial film growth are driving
The properties of the total film. A possible explanation for this drasting dependence is the difference in the seed layer. Lattice mismatching (in the pattern of polycrystalline crystal structure of AIN), inertness to nitrogen, activation of the surface, are known to have an impact on the quality of the film. With this method, it was possible to deposit AIN layers on AI with a FWHM rocking curve of 2.45° at a lowness of 1.1% towards a suitable route to the kinetics of the B-site ordering reaction. For example, in a composition containing 1 mole Ba3Sb2O9 the ordering phase is stable up to 1141°C; this substitution also reduces the sintering temperature by as much as 56°C. The ceramic sintering of these solid solutions is some of the lowest dielectric losses recorded for niobate perovskites dielectrics with Qf > 110,000 at 8 GHz. The role of B-site vacancies and W on the sintering, microstructure and stabilization of the cation ordering will be discussed together with the correlations between the phase stability and microwave dielectric properties.

**2:45 PM G2.6**
Microwave Dielectric Properties and Crystal Chemistry of Ba3Nb2-xSbxO9 (M = Mg, Ni, Zn), Michael Wayne Lufaso1, Steve M. Bell2 and Elizabeth A. Hopkins3, 1Ceramics Division, National Institute of Standards and Technology, Gaithersburg, Maryland; 2TCI Ceramics, Hagerstown, Maryland.

Exceptional microwave dielectric properties are exhibited by Ba3ZnTa2O9 and Ba3MgTa2O9, which are members of the of 2:1 ordered perovskite structure class. Substitution of Nb5+ for Ta5+ results in the B-site cation. Dielectric constants, temperature coefficients of resonant frequency, and Qxf are presented versus Nb5+ substitution.

**3:00 PM G2.4**
Microwave Materials with High Q and Low Dielectric Constant for Wireless Communications. Hidetsu Ohkato, Material Science and Engineering, Nagoya Institute of Technology, Nagoya, Japan.

The wireless communications have been tremendously developed in recent ubiquitous age. The utilizable region for the frequency expands to millimeterwave, because of shortage of the region. The high frequencies would be expected for ultra high speed LAN, ETS and car anti-collision system on the intelligent transport system (ITS) and so on. In this paper, microwave dielectric materials have been developed for higher frequencies. The frequency of AIN is high due to the high dielectric constant, but the dielectric loss is high. Therefore, the dielectric loss should be compensated by the partial replacement of Nb by W, increases the microwave dielectric properties. A possible explanation for this drasting dependence is the difference in the seed layer. Lattice mismatching (in the pattern of polycrystalline crystal structure of AIN), inertness to nitrogen, activation of the surface, are known to have an impact on the quality of the film. With this method, it was possible to deposit AIN layers on AI with a FWHM rocking curve of 2.45° at a lowness of 1.1% towards a suitable route to the kinetics of the B-site ordering reaction. For example, in a composition containing 1 mole Ba3Sb2O9 the ordering phase is stable up to 1141°C; this substitution also reduces the sintering temperature by as much as 56°C. The ceramic sintering of these solid solutions is some of the lowest dielectric losses recorded for niobate perovskites dielectrics with Qf > 110,000 at 8 GHz. The role of B-site vacancies and W on the sintering, microstructure and stabilization of the cation ordering will be discussed together with the correlations between the phase stability and microwave dielectric properties.

**3:00 PM G2.5**

Ceramics based on Ba(Zn1/3Nb2/3)O3 (BZN) have been extensively investigated for application as microwave dielectric resonators in wireless communications systems. Because the B-site ordering of BZN is extremely low (less than 6% at 1150°C) less than 6% towards a suitable route to the kinetics of the B-site ordering reaction. For example, in a composition containing 1 mole Ba3Sb2O9 the ordering phase is stable up to 1141°C; this substitution also reduces the sintering temperature by as much as 56°C. The ceramic sintering of these solid solutions is some of the lowest dielectric losses recorded for niobate perovskites dielectrics with Qf > 110,000 at 8 GHz. The role of B-site vacancies and W on the sintering, microstructure and stabilization of the cation ordering will be discussed together with the correlations between the phase stability and microwave dielectric properties.

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**4:00 PM G2.7**

The rapid development of communication technologies, especially mobile communication systems, is facilitated by miniaturization of devices. Integrated decoupling capacitors and microwave resonators are of interest for such systems. Dielectric materials for these applications must possess medium or high dielectric constants, high temperature coefficients of capacitance (TCCs) and low loss tangent values. For this purpose, bismuth zinc niobate (BZN) thin films with different composition have been studied, and it has been demonstrated that B1-xZnxSnO3 and B1-xZnxTaO3 films deposited by metalorganic decomposition (MOD) methods have many of the required electrical properties[1, 2, 3]. However, typically, the annealing temperature must be higher than 650 °C to get well crystallized BZN films, which makes integration with polymeric substrates problematic. To reduce the annealing temperature, pulse laser annealing (PLA) was employed using a defocused 248 nm laser beam. Well crystallized B1-xZnxSnO3 and B1-xZnxTaO3 films have been successfully obtained by PLA with a laser energy density of 34 mJ/cm2 and substrate temperatures around 400 °C. Electrical measurements showed that the PLA B1-xZnxSnO3 and B1-xZnxTaO3 films (laser energy of 34 mJ/cm2 and a substrate temperature of 400 °C) have a relative permittivity of 178, with low loss tangents and a TCC of -285 ppm/°C. The dielectric constant of the PLA B1-xZnxSnO3 and B1-xZnxTaO3 films decreased with bias field, while the loss tangent changed very little. The dielectric constant decreased 5% under a bias of 675 kV/cm; a higher tunability is expected when higher bias is applied to the samples. The dielectric properties of the PLA B1-xZnxSnO3 and B1-xZnxTaO3 films annealed at 400 °C are comparable to those of RTA B1-xZnxSnO3 and B1-xZnxTaO3 films annealed at 650 °C. The low annealing temperature makes PLA a unique solution for eventual epitaxial growth of AIN. We have also addressed the epitaxial issues of AIN and underlying oxide for improving the properties of the total film. A possible explanation for this drasting dependence is the difference in the seed layer. Lattice mismatching (in the pattern of polycrystalline crystal structure of AIN), inertness to nitrogen, activation of the surface, are known to have an impact on the quality of the film. With this method, it was possible to deposit AIN layers on AI with a FWHM rocking curve of 2.45° at a lowness of 1.1% towards a suitable route to the kinetics of the B-site ordering reaction. For example, in a composition containing 1 mole Ba3Sb2O9 the ordering phase is stable up to 1141°C; this substitution also reduces the sintering temperature by as much as 56°C. The ceramic sintering of these solid solutions is some of the lowest dielectric losses recorded for niobate perovskites dielectrics with Qf > 110,000 at 8 GHz. The role of B-site vacancies and W on the sintering, microstructure and stabilization of the cation ordering will be discussed together with the correlations between the phase stability and microwave dielectric properties.

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A precision deposition technique for measuring complex dielectric properties in the 118 to 178 GHz frequency range is presented. 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 2780 spectrum analyzer (using the Y-factor 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, and the capability to be machined as a substrate allowing the use of megawatt output windows for gyrotrons.

In addition, the optoelectronic and microwave characteristics of microwave materials 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, and the capability to be machined as a substrate allowing the use of megawatt output windows for gyrotrons.

SESSION G3: Poster Session
Charis: Yong S. Cho and Don Shiller
Monday Evening, 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 Chu1, Jung-Hwan Choi2, Jung-Sub Lee3, Han Seo Cho2, Hye-Soon Park4 and Duk Young Lee4, 1Science and Engineering, Korea Advanced Institute of Science and Technology, Daejeon, South Korea; 2School 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 provided guidance paths for the laser beams and also supports a polymeric waveguide. To avoid thermal damage of polymeric waveguide during the flip-chip bonding, indium solder bumps were used and the bonding condition of flip-chip was determined as a heating temperature of 130°C and a pressure of 500 gfs. 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 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 Electrodess on Theta Rotated Y-X LiTaO3 Piezoelectric Substrate for High Power Durable SAW Duplexer. Otsnu Nakagawa1, Hironori Suzuki, Shuji Yamato, Masayuki Hasegawa and Hidehuru Ieki; Murata Manufacturing Co., Ltd., Kyoto, Japan.

High power durable electrodes have been successfully grown on Y-X LiTaO3 piezoelectric substrate adopting AlN films. We have reported epitaxial Al films on Y-X LiTaO3 with titanium intermediate layer in our previous paper1. Despite a quite similar crystal structure, it has been difficult to form epitaxial Al on LiTaO3 due to the different cut 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 growth is to deposit an initial layer of Al at high temperature to obtain highly oriented Ti at the interface against the substrate. Following 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 process sequence of Ti can prevent inter-diffusion between Al and Ti and oxidation of Ti surface, both of which will make the crystal growth of Al. Crystallinity analysis was carried out by x-ray diffraction in Al (200) incident direction. Clear crystalline peaks were obtained in films prepared by 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 2dB. Demonstration with epitaxial AlN 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 at input power of 3.0 W and in an ambient temperature of 50°C that these results obtained by the two-step process sequence, which suggests a twin crystal structure of the Al film.
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 used is a simple scale integrations process. It involves only a single step. The electrical measurements of devices on the donor layer before bonding, before temporary bonding to a glass wafer with releasable 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 transferred 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 330°C - while BCB cures to make the bond between the layers permanent, the glass bonding wafer is relaxed 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 electrical devices on the donor layer before and after transtionation step have been observed. Detailed BCB process and property planning will be presented. The donor layer to host wafer alignment registration of +/- 3 micron was observed. We have also shown that by fabricating ground plane between the device layers, significant amount of crosstalk to the RF donor layer from the digital host layer can be reduced.

There is currently a great need for accurate, miniaturized 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 are expensive and require special skill. Hence, the use of mass spectrometry is not just limited to the laboratory, 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 miniaturization becomes a more feasible 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 separate, addressable electrode layers. This places considerable restrictions on the fabrication possibilities. It is possible to use polysilicon microetching techniques to fabricate many of the complex structures required, however, polysilicon is too resistive to be viable. Aluminum has been used to successfully fabricate micro-electromechanical systems, however the vertical dimensions required here exceed those typically used in aluminum microetching. 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 the material used 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. Sandia is a multiprogram laboratory operated by Sandia National Laboratories, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.
SiO2, and TazO5 powders were used as raw materials. These powders were mixed with appropriate ratio by ball milling. The mixed powders were calcined at 1200°C for 4 hours. The calcined powders were then sintered at 1500°C for 4 hours. The apparent density of the sintered specimen was measured by the Archimedes method. The crystalline phase and microstructure were identified by powder X-ray diffraction analysis. The dielectric constant was measured in the TE011 mode using the Hakki and Coleman method. Pure forsterite (Mg2SiO4) displays a porous morphology and very low dielectric quality factor (Qf), which is not suitable for the dielectric used in the millimeter-wave band. The dielectric constant and Qf value of pure forsterite ceramics sintered at 1550°C was 5.6 and 380 GHz, respectively. The relative density was 98.6% ± 0.01%. This shows that the sintering temperature of 1550°C was sufficient 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 properties and enhance the dielectric characteristics of sintered sample. Several materials were attempted as a sintering aid. Among them, TazO5 was effective additive to enhance the sinterability and dielectric characteristics. The addition of TazO5 increased dielectric constant over 7.4 and Qf value over 150,000 GHz, but decreased the sintering temperature by about 250°C. In this presentation, the effect of TazO5 on the sintering characteristics and dielectric properties of forsterite will be presented.

G3.10 MIM Capacitor Using ALD Al2O3 for RF IC and DRAM applications, Sung Yong Ko1, Jung Ik Oh1, Cheol Yeong Jung2, Young Ho Bae1, Young Chul Jung1, Yong Hyun Lee1, 1Dept. of Informatics and Media Engineering, Kyungpook National University, Daegu, South Korea; 2School of Computer and Electronics, Gyeongsang University, Gyeongbuk, South Korea.

In this paper, Al2O3 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 Al2O3 thin film was 250°C. Thickness of Al2O3 capacitor was 500Å. As a result, capacitance density of fabricated MIM capacitor was 0.229 pF/μm2 and it had lower voltage coefficients of capacitance (VCC) and leakage currents than Al2O3 MIM capacitor prepared by Al oxidation [1] and Si3N4 MIM capacitor prepared by PECVD [2] respectively. The RF measurement with network analyzer shows that Al2O3 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 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 224 ppm/K at 1 MHz and was 722 ppm/K at 1 GHz. In this research, it was possible to fabricate Al2O3 MIM capacitor prepared by ALD having low process temperature and exact thickness control. The Al2O3 MIM capacitor prepared by ALD exhibits lower voltage coefficient of capacitance (VCC), lower leakage current, frequency-dependent capacitance reduction, low temperature coefficient of capacitance (TCC) and good reliability that is suitable for RF ICs and DRAM. In this paper, high-k MIM capacitor, Atomic Layer Deposition, Al2O3 Reference [1] S. B. Chen, C. H. Lai, Albert Chin, J. C. Hsieh and J. Liu, "High-Density MIM Capacitors Using Al2O3 and AuTiOX Dielectrics," IEEE Electron Device Lett., Vol. 23, No. 4, pp. 185-187, 2002 [2] Jeffrey A. Babcock, Scott G. Bislter, Angela Puno, Christoph Durrer, Philipp Steimann, Reinier Jumperz and Badih El-Karch. "Analog Characteristics of Metal-Insulator-Metal Capacitors Using PECVD Nitride Dielectrics," IEEE Electron Device Letters, Vol. 22, No. 5, pp. 230-292, 2001.

G3.14 Modelling Leakage Current in (Ba,Sr)TiO₃ Films. Sanjib Saha¹, Stephen K. Strafford¹ and David Y. Kaufman²
¹Materials Science Division, Argonne National Laboratory, Argonne, Illinois; ²Energy Technology Division, Argonne National Laboratory, Argonne, Illinois.

High dielectric constant thin 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 increased demand from industry for better-performing dielectrics, to replace traditional ones. While such materials are already being integrated into various devices, a complete understanding of electronic properties is still elusive. A crucial part of this understanding centers on the leakage behaviour of these BST films. Previously several authors have modelled the leakage current of BST thin films based on Richardson-Schottky and Fowler-Nordheim mechanisms. These models have generally been in good agreement with experimental observations of the leakage currents. Following in particular the Baniecki [1] approach, we have modelled the variation of potential, electric field and local permittivity in Pt/BST/Pt heterostructures, also incorporating field-dependent dielectric behavior as described by phenomenological Landau-Ginzburg-Devonshire theory. This gives a working model that can quantitatively estimate the local permittivity of the films as a function of its thickness and with variations in temperature and applied electric field. Corrections arising from extrinsic interfacial effects such as the surface-dead-layer model and the Thomas-Fermi screening effect for metallic electrodes have also been incorporated into our simulation. Distinguishable leakage currents were used to determine the leakage characteristics of BST thin films using basic Richardson-Schottky equations. This model is able to reproduce the experimentally observed positive temperature-coefficient of resistance (PTCR) behaviour found in BST films. The impact of changing the thickness of the BST film and the thickness effect on the PTCR behaviour will be highlighted. Comparison of these results with experimental observations will be shown for films grown using MOCVD. [1] J. D. Baniecki et al. J. Appl. Phys. 89, 2878 (2001).

G3.15 Abstract Withdrawn

G3.16 Middle-permittivity LTCC dielectric compositions with adjustable temperature coefficient. Jae-Hoon Park, Young-Jin Choi, Jong-Ho Park, Multifunctional Ceramics, Korea Institute of Science and Technology, Seoul, South Korea.

Middle-permittivity LTCC dielectric compositions with adjustable temperature coefficient have been studied based on CaZrO₂-CaTiO₃. To lower the densification temperature from 1450°C to less than 900°C, a series of lithium-borosilicate glass system was designed and added to CaZrO₂-CaTiO₃ system. As the tcf of glass frit and CaZrO₃ are slightly negative (-0.2-0.5%/°C) and that of CaTiO₃ is significantly positive, zero tcf could be realized by mixing an appropriate amount of CaTiO₃ (10-20wt%) with CaZrO₃. Microstructural, physical properties, and microwave dielectric properties were measured as a function of the compositional ratio of CaZrO₃-CaTiO₃. Nearly zero tcf together with acceptable microwave quality factor were obtained at the composition of CaZrO₃-CaTiO₃ frit=70:30 15%Pt.

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 Lee¹, Bup-Ju Jeon², Sang Duk Myung³ and Dongjin Byun³
¹Eco-Nano Research Center, KIST, Seoul, South Korea; ²Department of Material Science & Engineering, Korea University, Seoul, South Korea.

In order to employ the metallized polymer as a flexible copper clad laminate, enhancement of adhesion between the metallic layer and plastic substrate, and c.a. 4-5 micron thick copper layer thickness of copper film should be required. The conventional methods for the metallization of polymer under low temperature process are physical coating methods such as sputtering and plasma coating. Magnetron sputtering method is convenient to operate and get high deposition rate. However, it has a limitation of thickness of metallic layer caused by poor adhesion. Recently, we found that metallic conductivity films (MOCVD) could be formed at room temperature when a pulse negative voltage is applied to the near of the polymer substrate. The high efficiency in exciting the reactants under ECR plasma coupled with negative voltage from a DC bias allows the deposition of Cu films at room temperature with excellent adhesion. We have reported before that metallized polymer with good adhesion could be prepared by MOCVD method at room temperature with the aid of pulse negative DC bias near the substrate. However, the deposition rate of copper film was very low compared with that of magnetron. In this work, cyclic operation of magnetron sputtering couple with ECR-MOCVD was tried in order to obtain the micro-meter ranged thickness copper films with good adhesion on the 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 elapses 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 coppper films prepared were investigated.


Complex perovskites with the general formula Ba(B₁/₃BII₂/₃)O₃ display very high quality factors (Q) in the microwave region and are widely utilized as frequency control devices. Previous reports on Ba(Zn₁/₃Ti₂/₃)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 induced 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 coring that deteriorates Q. The coring effect 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 as high a 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 Nb₂O₅ on the B-site, and the formation of Nb²⁺ vacancies in the Nb₂O₅ rich B-site, and ordering of BNT powders and ceramic pellets. Structure studies reveal that BNT can accommodate 3% Ni vacancies on the B-site, with a corresponding concentration of oxygen vacancies. The effect of the vacancy formation on the kinetics of the ordering reactions, domain sizes and microwave dielectric properties will be discussed.

G3.19 The effect of annealing for dielectric properties of Ti doped K(Ta,Nb)O₃ thin film using PLD. Hyeong-Jun Bu¹, Jennifer Sigman¹, L. A. Boanter² and David P. Norton³

K(Ta,Nb)O₃ (KTN) has been widely studied for optical wave guides and tunable microwave applications due to its non-linear properties. For tunable microwave applications, high tunability, and low dielectric losses under small operational bias are required. In this study, epitaxial KTN films with 52% Nb and 48% Ta, films with 3% Ti were investigated. Titanium (+4) substitution on the Nb/Ta site should reduce dielectric losses of KTN:Ti film by introducing an acceptor state. This acceptor state traps electrons due to oxygen vacancies that form during the film growth. KTN:Ti films were grown using pulsed laser deposition, and then annealed at different temperatures in oxygen ambient. The crystallinity, and surface morphology of KTN:Ti film were investigated using x-ray diffraction, and atomic force microscopy. The dielectric properties of Ti doped KTN films measured for unannealed and annealed films will be reported. Tunability and dielectric loss of as-deposited KTN:Ti film were determined to be 10% and 0.6134, respectively. For films annealed at 1000°C and 1050°C, the dielectric loss decreased but with a decrease in tunability as well.

G3.20 Abstract Withdrawn
Similarly we will demonstrate low loss frequency range from 0.3-1.2 THz. Laser pulses from a mode locked Ti:sapphire laser of pulse width 100 fs and repetition rate 82 MHz was used to trigger/gate dipole type LT-GaAs photoconductive switch electric detector. The thin film sample was mounted on a 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 the forward phase by applying the bias voltage. Our experiment 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. Jen-Paul Maria, 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 recent efforts at NCSU to develop methods for preparing device quality ferroelectric thin film processes that offer significant 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 ferroelectric thin 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 0.0 μm. Similarly we will demonstrate low loss tunable dielectrics 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.

G3.22

Ferroelectric thin films of SrTiO3 (STO), BaTiO3 (BTO) and Ba0.6Sr0.4TiO3 (BSTO) have been exploited for their application to tunable microwave devices and high-density dynamic random access memories. These thin films can also be utilized for similar applications in THz frequency domain. The rapid developments in the generation and detection techniques of THz waves during last decade made it feasible to apply this frequency domain for various kinds of applications and therefore it requires a variety of devices such as reliable frequency tunable, phase and time delay components at this frequency range. The high quality epitaxial BTO, STO and BSTO thin films were grown on the MgO substrates by pulsed laser deposition. We have studied their properties in the frequency range from 100 GHz to 1.5 THz in the temperature range from 29 K to 300 K for fixed time domain spectroscopy method. After the measurement of THz time domain spectroscopy, the interdigital electrodes of Ti and Pt were sputtered fabricated by standard photo lift-off technique on these thin films to measure their dielectric properties at room temperature. The real and imaginary parts of the dielectric constant of the thin film have been measured from room temperature to 29 K in the cooling process. The STO and BSTO thin films show their characteristic phase transitions at respectively 185 K and 195 K. The loss tangent of these thin films at room temperature is of the order of 10-2 indicating a high quality of thin films. Moreover among these thin films, the BSTO thin film show the maximum change in the value of dielectric constant with the applied voltage bias at room temperature, therefore we choose BSTO thin film for tuning the THz waves at room temperature by applying voltage bias to the interdigital electrodes fabricated on the BSTO thin film. The tuning of THz waveforms by BSTO thin film has been studied by pump-probe THz time domain spectroscopy (THz-TDS) setup in the frequency range from 0.3-1.2 THz. Laser pulses from a mode locked Ti:sapphire laser of pulse width 100 fs and repetition rate 82 MHz was used to trigger/gate dipole type LT-GaAs photoconductive switch electric detector. The thin film sample was mounted on a 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 the forward phase by applying the bias voltage. Our experiment result demonstrates that these thin films can be used for future frequency agile THz devices.
Dielectric Thin Films for Integrated Passive Components.

Saoirse O'Farrell, Jian-Gong Cheng, Mustafa Hanif, Teli and Hajime Nagata, Materials Science and Engineering, Penn State, University Park, Pennsylvania.

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 towards these ends and highlights some difficulties in achieving low processing temperatures in all cases, it has been found that chemical solution deposition bismuth zinc niobate 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 -2.85 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 to 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 SrRuO3/LaAlO3, with permittivities comparable to those of bulk materials. Finally, the development of high permittivity, lead-free, dielectric films will be discussed.

Scaling Effects in PLZT/Ni Film-on-Foil Capacitors For Embedded and Discrete Capacitors. David Y. Kaufman1, Sanjib Saha2 and Stephen K. Streiffer2, Energy Technology Division, Argonne National Laboratory, Argonne, Illinois; 2Materials Science Division, Argonne national Laboratory, Argonne, Illinois.

PLZT thin films on metal foils are promising elements for high-k embedded passives and high volumetric efficiency discreet devices. The effects of increasing PLZT thickness on the dielectric and electrical properties were examined with the intent of sustaining higher voltages in film-on-foil capacitors. A thickness series of PLZT thin films from 0.7 to 3.5 microns were deposited on Ni and NiO by chemical solution deposition (CSD). Increasing the PLZT thickness increased the apparent dielectric constant due to diminishing influences of a parasitic capacitance at the PLZT/Ni interface. Microstructural aspects of the interfacial reactions will be shown. To remove the influence of interfacial effects a LaNiO3 buffer layer was inserted between the PLZT and Ni foil. Capacitance densities as high as 1.5 microfarads per square centimeter could then be achieved. The high materials uniformity and density afforded by CSD enabled breakdown fields as high as 1.8 MV/cm to be maintained even in relatively thick films (440 V across a 2.4 micron PLZT film). The leakage current behavior and temperature response of the dielectric properties as a function of PLZT thickness, with and without a LaNiO3 buffer layer, will be presented. Application of this technology in both embedded passives and discreet devices will be highlighted.

Materials Issues in Epitaxial Ferrite Thin Films for Microwave Applications. Yuri Suzuki1, Yayo Hikamur1, Rajesh V. Chopdekar1, Darren Dals2 and Guohan Hu1, Materials Science and Engineering, UC Berkeley, Berkeley, California; 1Materials Science and Engineering, Cornell University, Ithaca, New York; 2Hitachi Global Storage Technologies, San Jose, California.

Ferrites constitute a class of materials that has been recognized to have significant potential in applications ranging from millimeter wave integrated circuitry to magnetic recording. In particular, epitaxial ferrite films have provided not only technological promise for the incorporation of magnetically tailored thin film materials in a variety of applications, but also understanding of the structure-property relationships in this family of materials. From a more material perspective, epitaxial ferrite films have provided a model system in which, for example, the effects of perpendicular exchange coupling, modified superexchange interactions and nearly ideal exchange coupling have been observed. In this talk, we will focus on examples displaying these phenomena and functionality in epitaxial ferrite thin films. You will also learn about other various parameters on the device performances: the magnetic thickness, the positioning of the magnetic field (whether buried in the CPW or under the CPW), the CPW metallic thickness Microwave device engineers continually seek materials advances to improve performance of magnetic components at reduced size and cost, wherever possible; needle-like devices are adopted in preference to bulky waveguide structures. For the past decade, the goals have also included the deposition of thick-film ferrites of spinel, garnet, or hexagonal crystal structures for microwave integration with semiconductor, such as Si and GaAs [1]. More recently the prospects of using more-refractory SiC have attracted increased attention and a renewal of interest in previous work. In radar and communications applications, the nonreciprocal properties of ferrites are essential in systems requiring the action of phase shifters, circulators, and isolators [1]. The introduction of superconducting circuits has led to the development of very low-loss phase shifters and circulators [2]. Recent demonstrations of high-speed operation by controlling the state of magnetization at very low magnetic fields has led to the development of high-speed, high-Q tunable filters [3]. In this paper, design issues of four classes of microwave device are reviewed: (1) self-biased microstrip circulars with normal or in-plane magnetic bias, (2) microstrip tunable filters, (3) low-loss microstrip phase shifters, and (4) high-power quasi-optical millimeter-wave circuits that include self-bias options. [1] J. D. Adam, L. E. Davis, G. F. Dionne, E. F. Schloemann, and S. N. Sittrer, IEEE Trans. Microwave Theory Tech. 42, 1361 (1994); [2] D. E. Oates, and G. F. Dionne, IEEE Trans. Appl. Supercond. 9, 4176 (1999).


Materials with high microwave permeability are of practical importance for many applications, such as magnetic sensors, tunable microwave filters, magneto-dipole antennas, etc. These materials are typically composites filled with ferromagnetic metal or alloy inclusions. The usage of composites instead of bulk material allows to diminish conductivity losses and to improve the microwave performance. The largest value of the microwave permeability can be achieved with planar situated flat particles with in-plane magnetic anisotropy and can be estimated with Acher's formula \( (\mu-1)\mu_{res}=\frac{2}{(\mu_{res}+1)-2\mu_{res}^2} \), where the static permeability \( \mu_{res} \), the resonance frequency, and the saturation magnetization Ms of the ferromagnet, and \( \gamma \approx 2.8 \text{ GHz/Oe} \). The presentation reports a technology development and investigation of microwave properties of composites filled with planar magnetic particles. The samples under study are regular composite structures comprising circular spots of iron films of sub-millimetre diameter. The samples are fabricated by chemical etching of multilayer metal-dielectric laminates produced on flexible polymer substrate by the RF magnetron sputtering. The developed technology permits us to produce the films with desirable frequency dependence of magnetic permeability. The permeability is measured by a coaxial measuring cell in the frequency range of 0.1 to 10 GHz [2]. The measurements were also conducted with the permanent external magnetic of up to 500 Oe. The results are discussed in terms of effective magnetic properties of the manufactured composites.

Optimization of Passive Isolator Based On Barium Ferrite Sputtered Films. Martine LeBerre1, Stephane Caprar1, Jean-Pierre Chatelon2, Thomas Rouiller2, Bernard Bayard2, Daniel Barbier3 and Jean-Jacques Rousseau2, LPM, INSA Lyon, 2LPM, INSyA Lyon, Villeurbanne, France; 3DIOM, Universite JeanMonnet, Saint-Etienne, France.

Ferrite materials have magnetic properties suitable for electronic applications, especially in the microwave range (circulators and isolators). Hexagonal ferrite, such as barium ferrite (BaFe12O19 or BaM), which have a large resistivity and high permeability at high frequencies are of great interest for microwave device applications. This contribution deals with BaM films, 1 to 30 microns thick, fabricated under optimized conditions by RF magnetron sputtering. The films were then crystallized using a 800°C thermal annealing under air. Isolators were then realized using patterning of coplanar wave guides with a developed lift-off technique. The isolation of the samples was over 20 dB, which was set to 300 mK, gold was used for the lines. We evaluated the influence of various parameters on the device performances: the magnetic film thickness, the positioning of the magnetic field (whether buried in the CPW or under the CPW), the CPW metallic thickness.
Recent Advances in Microwave Applications of Thin Ferroelectric Films at the NASA Glenn Research Center. 
Robert R. Romankofsky, Fred W. van Keuls and Matthew D. Valerio.

We report on recent developments in microwave applications and understanding of the (100) BaTiO₃ films. Our results have 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 (400 rad/s) 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.

Stroboscopic X-Ray Diffraction Measurements of a Subdomain Dynamic in Ferroelectric Films. 
Emili Zolotoyabko, John Quintana, David J. Towner and Bruce Wessels. 

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 X-ray source at Argonne National Laboratory was used to stroboscopically measure the structural response of ferroelectric films subjected to a high-frequency electric field, which is necessary 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 film. High frequency electric field generated a sinuous-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 500 μm thick SrRuO₃ substrates. An external electric field was applied through gold interdigital electrodes with a 5-micron spacing between fingers deposited on top of the films. This design allowed us to drastically reduce the sample capacitance and, correspondingly, the response time of electrical circuit [1]. We measured the shapes of the 2θ/BaTiO₃ diffraction profiles in the Laue (transmission) scattering geometry, as a function of the delay time, in order to follow modifications of the in-plane lattice parameter parallel to the applied electric field. The time dependences of lattice parameter measured in the frequency range between 25 MHz and 1.3 GHz demonstrated both periodicity and attenuation features related to domain dynamics. Two order of magnitude reduction in the attenuation time (i.e. remarkable increase in damping) was found with increasing electric field frequency.

The effects in tunability and loss tangent with SrRuO₃ as the metal oxide electrode in ferroelectric capacitors for microwave applications. 
Sriraj Manavalan, Ashok Kumar and Thomas Weller. 

Barium Strontium Titanate (BST) thin film is shown as a promising 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 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 ferroelectric material. SrRuO₃ was deposited using pulsed laser deposition (PLD) and film deposited at 600°C was highly crystalline. Ba₀.₈Sr₀.₂TiO₃ thin films were grown by PLD. SrRuO₃ deposited on top of the BST films was patterned using lithography technique in order to make the top electrode. The electrical measurements were achieved in the parallel plate capacitor configuration with SrRuO₃ as the top and bottom electrode. The microstructural and phase analysis of the BST films were performed using X-ray diffraction (XRD) method. XRD results show that the BST (100) peak is the most intense. The diffraction patterns are attributed to cubic (perovskite) crystal system. The analysis of surface morphology is done using atomic force and scanning electron microscopy. Results of structural and surface analysis, tunability and loss tangent as a function of deposition temperature, oxygen pressure and annealing temperature will be discussed. The optimization of tunability and dielectric loss of pulsed laser deposited BST thin films with Pt as the bottom electrode with different deposition conditions has been performed and the tunability of 3.11 and loss tangent of 0.0121 was achieved at 0.41–0.5 GHz. The effects in tunability and loss tangent with SrRuO₃ as the electrodes will be analyzed and compared with Platinum electrodes.
Ferroelectric. High dielectric tunability of ST is useful for high-frequency membranes, where the dielectric response 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 an external stress [3]; (ii) isostructural transformation of O anion [4], and (iii) substitution of Sr by rare-earth ions [4]. Namely, it has been shown that substitution of Sr for isovalent Cs, Ba, and Pb induces a ferroelectric phase transition in SrTiO$_3$. Dielectric transistors with thin films of SrTiO$_3$ in combination with random magnetic elements were obtained also by nonvalent substitution of Sr for rare-earth ions and Bi. In this work, the effect of Mn substitution on the dielectric behavior of ST ceramics is reported. Sr$_{1-x}$Mn$_x$TiO$_3$ (x ≤ 0.02) ceramics were investigated by conventional metal-insulator-semiconductor (MIS) structures and 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 substitution into SrTiO$_3$. TEM studies of the changes in Pt electrode microstructures after annealing. At room temperature, SrTiO$_3$ films on heat-treated Pt electrodes showed near intrinsic microstructure on the dielectric properties. This research was supported by DOE office of Basic Energy Sciences (# DE-FG03-02ER45994).

Dispersive ferroelectric materials such as SrTiO$_3$ and BaTiO$_3$ have been very popular due to their high dielectric constant and electrical tunability. Ferroelectric thin films offer a promising technology for electrically tunable frequency-agile devices. The ferroelectric properties of SrTiO$_3$ (STO), BaTiO$_3$ (BTO) and BaxSr$_{1-x}$TiO$_3$ (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 memories. Recent developments in the THz frequency spectrum are 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 dielectric constant, low loss, and dielectric 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. We have grown very high quality STO, BTO, and BSTO thin films by pulsed laser deposition (PLD) and measured their temperature dependent dielectric properties in the THz frequency range. 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 to 1.5 THz. The sample was cooled down to minimum temperature (20 K) and THz time domain spectroscopy was used 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 waves 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 remains almost constant in most temperature transitions that mainly corresponds to their phase transitions. At low temperatures, the measured frequency dispersion of the dielectric constant of STO thin film show Lorentzian oscillator behavior and softening of TO$_1$ phonon modes takes place with decrease in temperature and saturates near 60 K at the frequency of 0.7 THz. The dielectric constant of BTO shows almost linear frequency dependence in the entire temperature range with a bump near frequency around 0.45 THz diminishing with increase in temperature. The Real part of dielectric constant of BSTO thin film decreases from 100 GHz to 1.1 THz and shows a small peak at 1.1 THz and afterwards it increase with the increase in frequency.

Increasing chip functionality demands a high density interconnect technology. One of the most commonly used interconnect technology used in most of the electronic systems is the Direct, contacting path. This limits achievable density in pin and ball grid arrays and creates a rework and compliance issues in high-density solder bump arrays. AC-coupled interconnects are a 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. Multiple implementations of the AC-coupled interconnect concept requires that the chip and the substrate be...
I"m) fabrication technology in nature, nano composite films with different evaluated for dielectric underfill in high frequency AC coupled capacitance and quality factor of the capacitor over the frequencies of operating at the microwave frequency ranges. For instance, perovskite communications. The loss was also found to be tolerable up to a cellular phones, personal digital assistants and notebook computers of barium titanate films prepared by the ADM, their temperature on eutectic 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 to evaluate its suitability for use in 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 35-40 and the Q factor of the capacitors was found to be 3 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 communications. Dielectric loss was also found to be tolerable up to a frequency of 26.5 GHz and this should allow signaling well into the multi-gigahertz range.

4:30 PM G5.10

In recent years, development of mobile electronic devices, such as cellular phones, PDAs, and digital assistants, 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 ceramics with high permittivity, low dielectric loss and low temperature coefficient of the permittivity will be promising materials. Especially, the control of temperature coefficient of the permittivity will be a very important factor in microwave dielectrics because changes in dielectric permittivity caused by external environments are critical for the high frequency applications. Generally, barium- and strontium- based perovskites show positive and negative temperature coefficient of the permittivity, respectively, around room temperature. In this study, we focused on barium-strontium-, calcium- based perovskite system as dielectric materials. If nano composite films can be fabricated at low temperature using the perovskite materials with different temperature coefficients of the permittivity, we can expect to control their temperature coefficients of the permittivity. So, we focused on 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 showed positive as we expected, 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

SESSION G6: MEMS & Integration
Chairs: Fred Rooszeboom and Harrie A. C. Timmans
Wednesday, December 1, 2004
Liberty (Sheraton)

8:30 AM *G6.1
MEMS SiGe Technologies for RF and MillimeterWave Communications. Augustin Jeyakumar, David Dubuc, Katia Gremier and Patrick Pons; LAAS-CNRS, Toulouse, France.

The information age is leading to a tremendous increase of the number of wireless applications devoted to personal and mobile communications, satellite communications, automotive applications, health monitoring. This revolution has given rise to a spectrum overcrowding and a need for the future terminal to feature advanced performance in terms of noise and linearity and more functionalities as reconfigurability and adaptability. In this context, the conventional approach that is used for microwave IC is the SiGe HBT cmos technology. This technology has a lot of limitations and the future architecture will have to involve both the MEMS technologies with SiGe technologies in order to assess the concept of smart systems. Different approach can be considered. The above IC approach where using silicon based ICs are plugged to realized the desired functions. For each approach, it is important to assess the compatibility of the process with the integrated circuits. It will be presented the technological processes that have been developed to address all the approaches described and some demonstrators will be given to validate the concept. More precisely, low insertion loss filter in the 24 GHz will be presented followed by original antenna architecture surrounding the integrated circuits. A switch technology that have IC compatible will be presented.

Finally, a bank of SiGe VCO will be presented allowing to synthesize signal from 2 GHz to 30 GHz that is a key component for reconfigurable front end. a full 24 GHz MEMS based transceiver will be presented illustrating the benefit of the MEMS SiGe concept.

9:00 AM G6.2

Flexible substrates have advantages of light weight and improved resistance to impact damage, making them suitable for portable devices. There is a general interest in integrating active and passive electronic, electromechanical and photonic devices onto flexible substrates. A critical barrier towards realizing flexible systems is the high process temperatures normally associated with the fabrication of inorganic electronic and optoelectronic devices. In order to solve this problem, we begin by fabricating the systems on rigid substrates followed by transfer to a flexible substrate. We utilize a laser transfer method in which films of interest are deposited by PVD onto high temperature durable transfer layers such as Lao.5Sr0.5CoO3 (LSCO) and Lao.5Pb2-O.5CoO3 (LPFO) films which in turn are deposited onto transparent substrates such as MgO and Quartz. For fabricating photonic and microwave devices, BaTiO3 (BT) and (Ba,Sr)TiO3 (BST) films were grown on a LSCO/MgO, Quartz substrate. The sample was attached to a flexible substrate such as ployimide. The BT and BST films on the transfer layer were separated from the rigid substrate by Kir-senner laser ablation (266 nm, 150 mJ) which passes through the transparent substrate and is absorbed by the transfer layer. Laser transfer was performed with various laser energy intensities (100 mJ 400 mJ) and repetition rates (1 Hz 50 Hz). The characteristics of BaTiO3 waveguide and BST microwave tunable devices, prepared on flexible substrates, are discussed.

9:15 AM G6.3
Photonic Enable Mixed Oxide Dielectrics II: Direct Fabrication of Patterned High-k Dielectrics for Low Cost RF Capacitive MEMS Switches. Clifford L. Henderson, Paul J. Roman, Augustin Jeyakumar, Abimbola Balogun, John Papapolymerous and Guoan Wang, School of Chemical & Biomolecular Engineering, Georgia Institute of Technology, Atlanta, Georgia; School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, Georgia.

Low-cost MEMS switches are prime candidates to replace conventional GaAs FET and p-i-n diode switches used in RF and microwave communication systems due to their low insertion loss, good linearity, linear characteristics, and high power density. Various capacitive RF microelectromechanical switches made with a variety of metals have been reported in the literature for use in applications including phase shifters, reconfigurable filters, and tuners. The trend of these capacitive switches generally consists of a lower electrode, thin dielectric layer, and moveable membrane. Several studies have shown the importance of the dielectric layer in both switch performance and reliability. In most MEMS switches reported so far this dielectric layer is typically silicon nitride deposited with PECVD or HDICP CVD techniques. Taking into account the higher costs and limitations associated with using CVD and sputtering techniques for switch fabrication, and the relatively poor dielectric properties of SiN, there is a need for low-cost fabrication methods that can be used to produce higher dielectric constant oxide.
structures for these MEMS devices. This paper presents an update concerning the novel methods we have recently developed for depositing the required dielectric layers necessary for capacitive MEMS switches. In this process, a photosensitive metal-organic precursor solution is used to coat the substrate and form a precursor thin film. Upon UV exposure, the organic ligands of the precursor molecules are removed, resulting in the formation of a porous metal oxide in the exposed areas. The remaining unexposed precursor material may be subsequently washed away using a developer solvent. Thus, the photosensitivity of these materials allows one to selectively deposit microscopic structures with predefined geometries. In our recent switch performance experiments and perhaps enhance reliability, we have been interested in developing methods to likewise deposit higher dielectric constant crystalline oxides for such applications. We have succeeded in developing a photosensitive metal organic dielectric process for producing high dielectric materials (e.g. perovskites) without the need for etching processes or high temperatures by using a combination of the photo-definable metal-organic systems and subsequent low temperature hydrothermal treatment. This paper will discuss our recent results in this area including physical and electrical characterization of the patterned crystalline oxides and results from the use of these materials in capacitive RF MEMS microwave switches.

9:30 AM *G6.4 Novel High-Q Suspended Inductors on Alumina Ceramic Substrates. Issa Woodarz1,2, Paul Woon3, Mirece Capucan3, Ivo Koutsky3,4, Dr. Selvakumar3 and Andrew Cervin-Lawry3
1Gennum Corporation, Burlington, Ontario, Canada; 2Electrical 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 (Si) and ceramic substrates. KAIST and other research groups have explored a MEMS technique, 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 10 μm air gap and has been processed using a thick photoresist and resistive etching. In this present work, suspended inductor coils have been fabricated and characterized on an alumina ceramic substrate [2]. The gap used was only 1 μm and this was enough to increase the self-resonance frequency by up to 4GHz after release. The inductor coils were created in 610μm thick electroplated gold and the underpass in an aluminum layer. A sacrificial LPCVD oxide layer was used as the released dielectric. In the present study a range of inductance from 1 to 30nH was explored before and after release. The Q factors achieved in this work range from 40 to 70 in the 2 to 10 GHz range, which are some of the best Q factors reported for planar inductors on alumina ceramic [3]. In addition, since the architecture allowed the use of three metal layers, released transformers were also fabricated. They showed promising high frequency performance, which also will be presented. Minimum insertion loss was achieved of 2dB at 2GHz [4]. The above described process is simple, precise, and manufacturable with the ability to extend the useful range of inductors to higher frequencies (1-10 GHz). [1] J.-B. Yoon et al., “CMOS-Compatible Surface Micromachined Suspended-Spiral Inductors for Multi-GHz Silicon RF ICs,” IEEE Electron Device Lett., vol. 23, pp. 591-593, Oct. 2002. [2] A. Cervin Lawry et al., “Development of a Miniature Bluetooth Module for Manufacturability using a System-in-Package Approach,” Ceramic Interconnect Technology. Next Generation, Proceedings of the Society of Photo-Optical Instrumentation Engineers (SPIE), vol. 5231, pp. 7-11, 2003.

10:15 AM *G6.5 Communications and Sensor Technology and Systems at Millimeter Wave Frequencies. Jussi Toivonen, MilliLab, VTT, Espoo, Finland.

Millimeter wave technology, which covers the frequency range from 30 to 300 GHz of the electromagnetic spectrum, has experienced a strong development period during the last decade. Submillimeter wave spectrum, in frequency above 300 GHz, has also become more mature but does still lack significant commercial applications. Excluding recent imaging systems, practically all submm-wave applications are related to scientific or earth observation applications. Millimeter wave areas on the other hand has several commercial applications and the technology, especially up to 100 GHz, is very similar to conventional microwave technology. Millimeter wave applications include radio links at different bands up to 60 GHz, automotive radars at 77 GHz, Wireless Local Area Networks (WLAN), and radar and autonomous vehicle detection around 94 GHz. The development of monolithic microwave integrated circuits (MMIC) has been the main factor for the breakthrough of microwave and millimetre wave technology. However, these circuits are produced to a great extent through the use of gallium arsenide technology, which has been used up to 100 GHz. The development of silicon-on-insulator (SOI) technology, which makes use of the deep SiGe HBT Bipolar Transistors (HBT) have a cut-off frequency of 300 GHz. It can be seen that the SiGe technology will become a major competitor for GaAs in the microwave semiconductor market, because of lower cost and better power consumption. From the reliability and yield point-of-view SiGe has also an advantage, because nowadays SiGe foundries are running on higher volumes than GaAs foundries. However, GaAs technology continues to have a well established position in power amplifiers and switching applications. Recently there has been an increasing interest in using CMOS and Low Temperature Co-fired Ceramic (LTCC) technology for RF and microwave components. Smart antennas have emerged as a key technology for third and higher generations of wireless communication systems because they add a new, spatial dimension to the currently used time, frequency, and code multiple access technologies. They offer an excellent and relatively inexpensive opportunity of increasing system capacity, number of users served, and quality of service. Smart antennas have an immediate impact on the efficient use of the spectrum, and also on the potential physiological impact on humans. This presentation describes millimeter and submillimeter wave applications for telecommunication and sensor systems with emphasis on specific needs and challenges related to materials.

10:45 AM *G6.6 High-Density, Low-loss MOS Decoupling Capacitors for integration with an RF Transceiver in a System-in-Package. Fred Roozeboom1, Anton Kemmeren1, Jan F. Verhoeven1, Eric van den Heuvel2, Johan Klootwijk2, David Chevrier2, Francois Le Corre2, Serge Bardys2, Piash Chakraborty2 and Tom Cauwenberghs1
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, 9534 AE Nijmegen, Netherlands.

Recently the first highly integrated cellular RF transceiver systems were based on using Philips' new silicon-based System-in-Package (SiSiP) 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 PICS (Passive Integration Connecting Substrate) 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 macroe 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 electrode showed superior dielectric breakdown voltage (30 V typical) and very low leakage current density of 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 proves 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]. References 1. P. Philips 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, 9534 AE Nijmegen, Netherlands.

11:15 AM *G6.7 Direct Integration of AlGaAs/GaAs HEMTs on Ceramic Substrates for Super-Hybrid Microwave ICs using Fluidic Self-Assembly. Ikuo Soga, Shoji Hayashi, Yutaka Ohno, Shigeru
Kishimoto, Koichi Maszawa and Takashi Mizutani; Nagoya University, Nagoya, Japan.

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 Si CMOS circuits, onto various substrates. One of the most promising techniques for HI is the fluidic self-assembly (FSA) proposed by J. S. Smith et al. In the FSA technology, small device blocks separated from their substrate (epitaxial lift-off) are scattered on the tilted hot 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 efficient quality of the material use, because the device blocks can be fabricated densely all over the substrate. We apply this technique to direct integration of HEMTs on ceramic substrates. Here, the device blocks are fabricated on a part of the HEMT wafer (without pads), the size of which is as small as a few tens of microns. This technology, we call it here the super hybrid integration technology, takes advantage of both monolithic and hybrid microelectronics. A large parasitic inductance and capacitance due to the wiring between devices and ceramic substrate can be eliminated, because the standard planar-wiring process can be applied to the device blocks, which are arranged in the recesses with an accuracy of less than a few microns. Therefore, the ceramic substrate can be regarded as a large chip for a MMIC. Furthermore, the cost of the circuit should be much lowered because the expensive semiconductor area used as the substrate is minimized. This paper discusses the process performance of the AlGaAs/GaAs HEMTs integrated on an AlN ceramic. First, the HEMTs were fabricated on epitaxial layers grown on GaN substrate. Next, the HEMT blocks were separated from the substrate by selective etching of the buried sacrificial layer (AlGaN). The size of the device blocks, which have two fingers of 50-um gate width, was 87x57 um2. Then, the device blocks were arranged on the ceramic substrate using FSA. Finally, the process has been completed by the AlN planarization and metal evaporation for wiring and pads. It has been demonstrated that the good FET characteristics were obtained even after FSA process.

11:30 AM G6.8
Die-on-Wafer and Wafer-Level Three-Dimensional (3D) Integration of Heterogeneous IC Technologies for RF-Microcircuits-Millimeter Applications, Jian-Qiang Lu, Siddharth Deyaram, Annie Y. Zeng, Ken Rose and Ronald J. Gutmann; Center for Integrated Electronics, Rensselaer Polytechnic Institute, Troy, New York.

Three-dimensional (3D) integration of heterogeneous IC technologies using through-die micron-sized vias is an attractive technology for high-performance RF-microcircuit applications, especially where high manufacturing quantities are anticipated. This 3D integration technology requires die-to-wafer or wafer-to-wafer alignment, bonding-lamination and vertical inter-chip interconnection. A wafer-level technology platform is described, which bonds fully-processed, aligned wafers using a micron-thick dielectric adhesive, thinning in a through-die manner (AlSi). This technology provides vertical interconnects with a copper damascene process. With this 3D 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 can be stacked and vertically interconnected through short inter-chip vias. Memory-only wafers can also be incorporated in the 3D system if needed. The technology is applicable to microprocessors, wireless terminals, multimeter phased array radars, and smart imagers. The presentation of this 3D heterogeneous integration approach will include design and simulation results, and a comparison with system-on-a-chip (SoC) and system-in-a-packaging (SiP) approaches.

11:45 AM G6.9

It has been demonstrated that micro-mechanical resonators have high quality factors making them good alternatives to conventional RF filters for system-on-chip applications for mobile communications. One of the major challenges of optimizing this approach is the integration of MEMS with CMOS circuitry. Fabrication processes of suspended structures like micro-mechanical resonators rely on extensive RF release etch of sacrificial SOI2 to release polysilicon structures. The use of silicon nitride makes it easier to integrate SOI-based MEMS circuits utilizing SiO2 shallow trench isolation (STI) in close proximity to MEMS structures. One possible approach to overcome this problem is to use silicon nitride as the isolation material for shallow trench isolation instead of SiO2. Silicon nitride-silicon interface, however, has very high interface defect density leading to significantly high concentration of interface fixed charges. Interface fixed charges on the silicon sidewalls of the active areas of the MOSFETs lead to lower threshold voltage of the surface, leading to very high levels of drain to source and drain to substrate leakage currents. One possible way of reducing the leakage currents is to increase the substrate doping levels, which in return will increase the threshold voltage of the devices significantly. Another alternative would be to control all the relevant surfaces of the MOSFET with an additional gate surrounding the active area of the device. We have demonstrated excellent transistor characteristics by suppressing the peripheral leakage currents in silicon nitride isolated MOSFETs by employing an independently controlled side-gate, surrounding the active area of the devices. The surrounding side-gate, with the application of a negative bias for nMOSFET, increases the threshold voltage of the Si-STI interface by shifting the drain-to-source leakage current. The negative potential on the side gate also keeps the p-type body of the device in accumulation, significantly reducing the Si-STI interface defect-assisted-peripheral-leakage components of the drain-to-substrate leakage of the p+ junction. Our Nitride STI process is done by depositing thin silicon nitride, and n+ in-situ-doped polysilicon after the active area definition and etch. The polysilicon is patterned around the active areas with a lead to a contact area. STI process is completed by depositing thin silicon nitride and a thick layer of low stress nitride and chemical mechanical polishing of the wafers. Side-gated nMOSFET fabricated with the nitride STI process show high gateto-source current (Igss > 0.9mA/um, very good sub-threshold slope of 80mV/dec, very minimal short channel effects; DIBL=21mV/V, and drain-to-source leakage below 5x10^-14 A, leading to Imax/Imin >3x10^6, for Leff=0.22um , Woffs=20 um for channel doping of 1x10^19/cm3 and allow integration with micro-mechanical resonant structures.

SESSION G7: Ceramic Materials and Packaging
Chairs: Yong S. Cho and Takasaki Tsurumi
Wednesday Afternoon, December 1, 2004
Liberty (Sherriton)

1:30 PM G7.1
Science-Based Processing Technology For LTCC Microelectronic Packaging, Kevin Ewasik, Christopher DiAntonio and Markus Reiterer; Sandia National Laboratories, Albuquerque, New Mexico.

Multilayer ceramic technology offers a cost-effective and versatile approach to design and manufacture high performance and high reliability, three-dimensional (3D) microelectronic packages. However, the close technological challenge in the development of functionally different materials into a 3D multilayer package. In particular, reproducible manufacturing of reliable multilayer ceramic packages requires processing control of the assembly processes. The experience and trial-and-error are typically used to design and develop manufacturing processes for multilayer ceramic microelectronic packages; however an empirical engineering approach has limited application to new, more complex products. Manufacturing reproducibility and control can be achieved with statistical process control (SPC); however, this technology has limited application in the design and development of new processes for new products. Process control is required to design and manufacture high performance and high reliability multilayer microelectronic packages. Process control can be achieved through a combination of practical and science-based understanding. Science-based understanding is developed through materials and process control of the assembly processes. Together, science-based understanding and practical expertise can be applied to systematically develop more cost effective and more robust manufacturing processes. This paper focuses on master curve theory and its application to LTCC microelectronics packaging. Master curve theory, which utilizes analytical models based on fundamental theory, has practical application in the multilayer packaging industry to better understand and control the firing process (i.e., binder burnout and sintering). For process control, master curve theory in the form of the master decomposition curve (MDC) and the master sintering curve (MSC) have successfully been applied to predict and control binder burnout and sintering of LTCC dielectric tape, respectively. MSC theory has also been applied to assess lot-to-lot materials consistency and green process control/reproductibility in manufacturing. MSC theory has also been applied to assess process sensitivity. This science-based technology offers significant potential to improve the processing of multilayer microelectronic ceramic packages with improved dimensional control. Sandia National Laboratories is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of Energy.

193
starts as homogeneous nucleation and is associated with the same composition range (25 mol% of Nb).

Unfortunately, the dielectric loses too high a 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 NbO).

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 super-structural 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 NbO concentration. Studies of the influence of the ordering on the dielectric properties of Bi2O3-Nb2O5 solutions show that the ordering reduces the dielectric losses and reverses the sign of the temperature coefficient of resonant frequency. The permittivity remains around 96. 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.

Microstructure and electrical properties of thick-film capacitor with low temperature fired Bi(Nd2-xSmx)Ti4O12 dielectrics. Li-Chun Chang and Bi-Shan Chung, National Chiao Tung University, Hsinchu, Taiwan.

For high performance microelectronics and MEMS package, ceramics-based package are preferred over plastics. Low temperature co-fired ceramic (LTCC) technology is most valuable in microwave applications. In this study, Bi2O3 and glass are employed to reduce the sintering temperature of Bi2O3 (around 550C) to room temperature at 120Hz. The electric constant of 96% Al2O3 was measured 9.5 at room temperature at 120Hz, and was 1.11 times that at room temperature at 100kHz. At 120Hz, the effective bulk conductivity of 96% Al2O3 increased by four orders to 1.41E-7 S/m from 23C to 500C, but at 100kHz, it increased only one order to 2.35E-6 S/m from room temperature to 500C. The relative dielectric constant of Al2O3 increased from 8.95 at room temperature to 5344.6 at 500C at 120Hz, but at 100kHz it increased from 8.72 at room temperature to 115.0 at 500C. The effective bulk conductivity of Al2O3 demonstrated negative temperature coefficient from 23 to 50C at all frequencies. At 500C, the bulk conductivity increased by a factor of 3.3E4 from the 50C value of 2.65E-10 S/m at 120Hz, and increased by a factor of 1.1E4 from the 50C value of 8.95E-8 S/m at 100kHz. The temperature and frequency dependences on the 96% Al2O3 will be discussed.
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.
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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.