SYMPOSIUM H
Materials Issues for Tunable RF and Microwave Devices III
April 2 – 3, 2002

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Proceedings to be published in both book form and online
(see ONLINE PUBLICATIONS at www.mrs.org)
as Volume 720
of the Materials Research Society
Symposium Proceedings Series

*Invited paper
SESSION 1: BST FILMS AND APPLICATIONS
Chairs: James S. Horwitz and Xiaoning Xi
Monday Morning, April 2, 2002
Salon 3/4 (Marriott)

8:30 AM *H1.3
SCIENCE AND TECHNOLOGY OF BARIUM STRONTIUM TITANATE THIN FILMS AND THEIR INTEGRATION INTO HIGH FREQUENCY TUNABLE DEVICES. D. D. Y. Kaufman, C. S. Lee, J. S. Speck, University of California Santa Barbara, Santa Barbara, CA.

We have performed extensive work in the last three years on the synthesis and characterization of [Ba,Sr]2TiO4, BST-type films and their integration into devices for microwave application. High frequency tunable devices require the synthesis of BST films with high tunability as well as low dielectric and substrate losses. A review of our work will be presented including the properties of the films and how they can be used in various devices.

9:00 AM *H1.5
DIRECT WRITE PROCESSING FOR TUNABLE MICROWAVE DEVICES. Tanya Rivkin, Calvin Curtis, Alex Medzner, John Perkins, Jeff Allman and David Ginley, National Renewable Energy Laboratory, Golden, CO.

We report on the development of a new direct write technique for producing high-quality BST thin films using an atomic force microscope (AFM) to create the films. This technique allows for the creation of complex geometries with high aspect ratios, which is important for creating tunable devices.
production of BST that gives very low losses (tan d as low as 0.002-0.004) in thin film materials, while retaining large [ΔC/ C >500%] tunability. In operation, the capacitance of these tunable layers to individual tunable capacitors, as well as in circuits such as tunable filters will be discussed. Emphasis will be placed on the importance of electrodes in determining total device loss at high frequency, and solutions developed for integration of BST with thick electrodes to make very small parallel plate capacitors for high frequency use. Successful combinations of these processes have allowed production of devices with dielectric Q factors, the inverse of tan d, as high as 25000 (tan d <0.004) or measured by LP models and as high as 100 at 10 GHz (tan d =0.01). Overall device Q factors were over 50 at 30 MHz, comparable to or better than many conventional microstrip filter technology for similar large capacitance values. Low (<1%) dispersion of dielectric constant with frequency was seen up to 10 GHz. Tumble low pass and bandpass filters based on these varactors were also designed and fabricated. Tunabilities of 50% and 10% were inserted into a 10 MHz and 2.7 GHz cavity to determine the material performance in a real environment. The results demonstrated that the tunable filters exhibited lower loss tunable values and can be attributed to the proximity in temperature of the ferroelastic transition.

SESSION H2: BST FILMS AND APPLICATIONS
Chair: David S. Ginley and Robert A. York
Tuesday Afternoon, April 2, 2002
Salon 3/4 (Marriott)

1:30 PM - H2.1
INVESTIGATIONS ON SOL-GEL DERIVED TRANSITION METAL DOPED BST THIN FILMS FOR PHASE SHIFTER APPLICATIONS: R.S. Kizayi, J.M. Jain, S. Miranda, D. R. Matos, M. Ladizinski, Department of Physics, University of Puerto Rico, San Juan, PR, R.R.
Romino-Czyk, F.W. Van Keuls, and F.A. Miranda, National Aeronautics and Space Administration, Glenn Research Center, Cleveland, OH.

Highly (100) oriented manganese (Mn) doped Ba$_{0.5}$Sr$_{0.5}$TiO$_3$ (BST) thin films were prepared on (100) LaAlO$_3$ substrates by chemical solution deposition technique. The degree of texturing and quality of the in-plane epitaxy, characterized by X-ray pole figure analysis and RBS channeling measurements, were found to be improved with Mn doping of up to 3 at%. The broad nature of the dielectric maximum and its shift towards the higher temperature in thin films is compared to the bulk counterpart due to the finer grain size and for unrelaxed strain of the annealed films. The dielectric constant and loss tangent (measured at 1 MHz) was fitted to the phenomenological expressions based on Debye’s theory that enable us to calculate the order parameter ($a$) of the anharmonic interaction of the B-site cations and correlate it with the dielectric figure of merit (K factor, defined by the ratio of tunability and dielectric loss tangent).

The Mn addition remicrowave loss component is low for the undoped BST film, whereas with the increase in Mn content it dominates the capacitive loss component. We have fabricated eight element coated microwave phase shifter and characterized them in terms of their degree of phase shift and insertion loss characteristics measured at 14.5 GHz. The phase shift increases from 210$^\circ$ to 337$^\circ$ with 0.3 at% Mn doping. However, the insertion loss also increases (5.4 to 9.9 dB) with the increase in dopant concentration so that the effective attenuation (defined as phase shift/insertion loss) does not improve significantly and remains in the range of 33.4-44.8 dB. The observed dielectric characteristics are correlated with the epitaxial quality and surface morphology of the Mn doped BST thin films. These and other transistions metal doped dielectric data of textured BST thin films will be presented.

2:00 PM - H2.2
NOVEL TUNABLE THIN FILM FOR HIGH QUALITY TUNABLE MICROWAVE DEVICES: G. Li, R. Fu, S. He, J. Sun, X. Zhang and L. Sengupta, Paraske, Columbia, MD.
A new process has been developed in Paraske Microwave Inc. to formulate stable tunable thin film material. Varactors, with a co-planar diode grid electrode (CDE) structure, were fabricated using the new material. Varactor Q as high as 100 at 10GHz was characterized at tunability of 40% at 100V. The lifetime test showed that this material is very stable under continuous 100 Vdc bias both at the room temperature and at 70°C environment. Thus, this novel tunable thin film material opens new avenue to develop high quality tunable microwave devices. A tunable IF filter has also been built using this novel material.

2:30 PM - H2.3
A NEW FERROELECTRIC VARACTOR FROM WATER BASED INORGANIC PRECURSORS: T. Kirk Dougherty, John Drab, Mike Brand, Kathy Kehle, Raytheon, El Segundo, CA.

Solution deposition processes for the production of multi-element metal oxide thin films continue with great interest and varied success. Solution deposition via either solgel or MOD (Metal Organic Decomposition) methods are of interest due to the ability to produce a wide variety of compositions at low capital investment cost. This paper will review the materials and process challenges and related issues to production of consistent high quality metal oxide films via the MOD process. The solid solution Ba$_x$Sr$_{1-x}$TiO$_3$ will be used as an example. Several new water stable and water soluble ceramic precursors used to make the thin films are described. These new ceramic precursor materials offer a more environmentally friendly process and more importantly MAD improved thin films as compared to the prior art. Details of the MOD to electronic varactor processes made from the new water based precursors are shown. Devices made from the new thin film materials including a high power, high Q varactor will be described. The new varactor is built from a design approximately 50% to 15% by reducing film thickness from 600 nm to 15 nm. This reduction comes at the same expense in reduced total tunability. In addition, the application of varactors on a design.
specific to the application as a high power RF modulator and offers a tuning capacitance range of over 5 to 1 using less than a 20 volt controlled voltage. The tuning response is a result of the parallel-plate effects of this device in a high power RF circuit will be shown. The device offers a low cost and smaller replacement to semiconductor based varactor diodes.

2:45 P.M. H2.4

MICROSTRUCTURAL AND ELECTRICAL CHARACTERIZATION OF BARIUM STRONTIUM TITANATE-BASED SOLID SOLUTION THIN FILMS DEPOSITED ON CERAMIC SUBSTRATES BY PULSED LASER DEPOSITION.

Corey G. Fountoulakis, Daniel M. Potereka, and Steven C. Tidrow, Weapons Materials Research Directorate, Army Research Laboratory, Aberdeen Proving Ground, MD; Sensors and Electronics Directorate, Army Research Laboratory, Adelphi, MD.

This film, from novel Baite substituted barium strontium titanate (BSTO) deposited, has been deposited using the pulsed laser deposition (PLD) technique. The measured electrical properties of these thin films will be compared with the electrical properties of the bulk materials. The dielectric constant of the BSTO ferroelectrics can be changed by applying an electric field. Variable dielectric constant results in a change in phase velocity in the device allowing it to be tuned in real time for a particular application. The microstructure of the film influences the electronic properties which in turn influence the performance of the film. Baite substituted BSTO thin films were synthesized at ambient temperature and 30 mTorr partial pressure, at 500 mJ laser energy and 10 pulses per second on LaAlO3 (100) substrates, previously coated with La2SrCuO4 conductive buffer layer, using the pulsed laser deposition technique. The characteristics of the mass-annealed thin films studied using x-ray diffraction, SEM, Rutherford backscattering, and capacitance measurements will be discussed in detail.

3:30 P.M. H2.5

OFF AXIS GROWTH OF STRONTIUM TITANATE FILMS WITH HIGH DIELECTRIC TUNING AND LOW LOSS.

Charles T. Rogers, Shengwei Kung, Department of Physics, University of Colorado at Boulder, Boulder, CO.

The development of low-loss ferroelectric materials is useful for applications such as tunable band-pass filters, voltage tunable filters, phase shifters, and frequency agile antenna at RF and microwave frequencies. Strontium titanate (STO) is a well characterized material. We have studied nonlinear dielectric properties of thin film strontium titanate grown on neodymium gallate (NGO) and lanthanum aluminate (LAGO) substrates using off axis pulsed laser deposition.

Laser ablation of a STO target is used to direct the material onto the substrate at 830°C under 600 mTorr of oxygen background. We measured the film dielectric constant and loss tangent in the 1 to 1 MHz frequency range from room temperature down to 4K. We also obtained a figure of merit from the relative variation of the dielectric constant caused by the loss tangent in the presence of a DC electric field up to 4KV/mm. The resulting films have significant variations in dielectric properties with the position of the substrates with respect to the axis of the plume during the growth. STO films on LAGO substrates show low loss and high electric coupling, whereas bulk STO in regions near the center and the edges of the plume. On the other hand, STO on NGO shows this effect only on the films grown far from the plume axis. Careful mapping of the plume cross-section allowed us to improve the quality and reproducibility of the dielectric films, yielding dielectric constant, loss tangent, and figure of merit at 35K and 1MHz close to bulk values. The effect of the film thickness on the dielectric properties is in progress.

4:35 P.M. H2.6

MICROWAVE DIELECTRIC PROPERTIES OF (Ba, Sc)TiO3 THIN FILMS.


Epitaxial and polycrystalline Ba, Sc(TiO3) thin films have been deposited onto single crystal and polycrystalline substrates by pulsed laser deposition. The microwave dielectric properties have been measured using interdigitated and gap capacitors at room temperature and microwave frequencies (1-20 GHz) in a function of electric field (± 20 V/cm). Recent studies have also been used to characterize the microwave dielectric properties in the × 2 GHz. The room temperature dielectric constant, change in dielectric constant under a DC bias and the dielectric loss are strongly affected by film composition (ratio of Ba/Sc) and oxygen vacancies in the film. Oxygen vacancies can be used to alter the nucleation and growth of the film and minimize the strain. For all values of x, an oxygen depletion pressure can be found which results in the growth of a strain free, oxygen deficient film. Oxygen deficient films were grown using the composition that is paraelectric at room temperature, the minimum strain condition yields a maximum microwave figure of merit (K = dielectric Q × % tuning). For films that are ferroelectric at room temperature, the minimum strain condition corresponds to a minimum value in the microwave figure of merit. Films have been post-annealed in oxygen. The post-deposition anneal fills oxygen vacancies and causes the lattice parameter to decrease. Acceptors such as W and Mn have been used to reduce the free carrier concentration generated by the oxygen vacancies and further reduce the dielectric loss.

4:00 P.M. H2.7

THE IMPACT OF THERMAL STRAIN ON THE DIELECTRIC CONSTANT OF BARIUM STRONTIUM TITANATE THIN FILMS.


Barium strontium titanate (BST) thin films were deposited by sputtering on Pt/SiO2 structures using five different host substrates: mica, basalt, crown glass, strontium titanate, and YSZ. Strontium titanate films of the BST films deposited on Pt/SiO2 structures using five different host substrates: mica, basalt, crown glass, strontium titanate, and YSZ. The BST films have been annealed in order to reduce the dielectric loss.

PECVD was used to deposit 60 nm of SiO2 on all the samples simultaneously. The thin SiO2 layer provided each sample with a similar growth surface for the platinum electrode and subsequent oxide film. The BST film (100 nm) and platinum electrode (100 nm) were deposited concurrently and Φ15K to avoid variation between samples. A spin-on Zr layer (2.5 nm) was used as an adhesion layer for platinum and SiO2. All films have a weakly textured microstructure. Temperature dependent dielectric measurements from 100-540 K determined that the decreasing thermal expansion coefficient of the host substrate (i.e. larger tensile thermal strain) reduces the film dielectric permittivity in agreement with Shaw et al. [APhys. Lett. 75, 2129 (1999)]. The experimentally determined Curie-Weiss temperature (constant=7100) were used as 29K and Zr (0.01 K/T, 1K, 1.1 K, 1.3 K, 1.5 K, 0.5 K) 1.1 and 1.3 K for monoclinic oxide, strontium titanate, sodium, silicon, and zirconia glass respectively. The Curie-Weiss temperature decreases with increasing tensile thermal strain and the Curie-Weiss constant increases with tensile strain as predicted by Pertsev et al. [APhys. Lett. 85, 1608 (1999)].

SESSION H3: POSTER SESSION

Chair: Steven C. Tidrow
Tuesday, Evening, April 2, 2002
8:00 PM
Salon 1-7 (Merriot)

H3.1

CHARACTERISTICS ANALYSIS OF SAW FILTER USING AlxGa1-xN ONSiO2 THIN FILMS.

Sun-Ki Kim, Min-Jung Park, Chong-Woo Jung, Hyun-Chul Choi, Jung-Tae Lee, Yong-Hyun Lee, Kyungpook National University, School of Electronic & Electrical Engineering, KOREA.

Acoustic wave devices are necessary for contemporary mobile communication systems. AlxGa1-xN, and their alloys are important piezoelectric semiconductors which are suitable for SAW (Surface Acoustic Wave) applications as well as blue/green light emitters and high-power/high frequency transistors. SAW propagation of AlxGa1-xN and GaN are 5700 m/s and 4800 m/s respectively. Theoretical SAW velocity of AlxGa1-xN is expected to be from 4800 m/s to 5700 m/s varying with x=0.5 to x=1, which indicates that the frequency of the SAW can be controlled by simply changing Al mole fraction. AlxGa1-xN sample used in this work was epitaxially grown on sapphire by MOCVD. Al mole fraction of x=0.36 was measured by RDS. Characteristic parameters of the fabricated SAW filter were measured by HP 8715C network analyzer. SAW velocity of 5420 m/s and TCF (temperature coefficient of frequency) of 51.20 ppm/°C were measured, when k value was 0.078, and temperature was ranged between 30° and 60°, where k is wave number and h is thickness of GaN thin film. Electro-mechanical coupling coefficient was ranged from 1.26% to 2.29%. The fabricated SAW filter had good device performance with insertion loss of ≤33.83 dB and side lobe attenuation of 20 dB. SAW filter using AlxGa1-xN/GaN structure was, for the first time, fabricated and demonstrated a good device performance. This is very important in fact that the SAW velocity and the related operating frequency can be controlled by simply changing Al mole fraction. This work was supported by grant No. 2001-3-30290-006-2 from the Basic Research Program of the Korea Science & Engineering Foundation.

H3.2

MICROWAVE DIELECTRIC SPECTROSCOPY OF FERROELECTRIC THIN FILMS.

Beejin Kim, Minki Jeong, Sunggi Baik, Pohang University of Science and Technology, Dept of Materials Science and Engineering, Pohang, KOREA; Victor
Kuzmenko, Yuriy Poplawko, National Technical University of Ukraine, Dept of Microelectronics, Kiev, UKRAINE.

We devised a measurement method of microwave dielectric constants of dielectric thin films without applying electrodes. The method uses a rectangular waveguide in which the dielectric thin films prepared on a substrate are filled vertically at the center. The frequency dependence of S parameter measured by network analyzer enables us to calculate the dielectric constant and loss factor of the films at the microwave region through simulation. We prepared B_{2-x}Sr_xTiO_3 thin films on MgO (001) substrate by metalorganic chemical vapour deposition (MOCVD) and determined their dielectric constants and loss factors as a function of its composition (x) at ~10GHz using this method.

H3.3 SYNTHESIS OF NONSTRUCTURED MAGNETIC MIXED-OXIDE FERRITE POWDERS BY USING A NOVEL CHEMICAL METHOD. N.N. Ghosh, Birsa Institute of Technology and Science, Chemistry Group, Dhanbad, Rajeshwari, INDIA.

Research in the field of nonstructured ceramic powders have gained immense importance because of their potential application in many areas of technology. Technologically, fine-particle ferrites have been of interest due to their wide spectrum of applications as inductor cores in RF systems, circuits, permanent magnets, advanced memories, sintered electrodes, microwave devices, anti-detection (stealth) technology applications, catalysts etc. The surface properties and the microstructures of such powders, which control most of the parameters required for any particular application, often depend on the method of their preparation. In the conventional ceramic method for the preparation of ferrites long heating schedules and high temperatures, sinter the final product and result in the loss of the fine particle nature of the powders. This method is thus affected by a poor control over the particle size, morphology, magnetic properties, etc. In the present investigation, an attempt has been made to establish a new chemical route for synthesis of the nonstructured mixed oxide ferrite powders. By using this chemical method a variety of ferrite powders having spinel structure and doped with Co, Ni, Mn, Zn etc has been prepared. In this method nitrate salts of the different metals were used as starting materials. The aqueous solutions of the metal nitrates were mixed according to the molar ratio of the compositions. Then these mixtures were mixed with an aqueous solution of water soluble polymer. This mixture after drying yield a brown powders. These powders were then calcined at different temperatures ranging from 600°C to 900°C. Nanopowders were obtained from the thermal decomposition of the brown powders. The powders, prepared by calcinations at different temperatures, were characterized by using X-ray diffraction analysis, IR spectroscopy, TG/A, DTA, and TEM. It was observed that the average particle size of the powders are in nanometer scale with a narrow size distribution. The average particle size of the powders was increased with the increase of calcinations temperature. This chemical method has proved to provide a convenient process for the preparation of nonstructured ceramic powders at low temperatures and offers the potential of being a simple and cost-effective route.

H3.4 THE EFFECTS OF PLASMA INDUCED DAMAGE ON THE CHANNEL LAYERS OF ION IMPLANTED GaAs MESFETS DURING REACTIVE ION ETCHING (RIE) AND PLASMA ASHING PROCESSES. Heunkyun Ahn, Jaekyung Man, Heechun Kim, Electronics and Telecommunications Research Institute (ETRI), Advanced Micro-Electronics Research Laboratory, Taejon, KOREA.

The gate length of GaAs MESFETs is required to be shorter for their higher microwave frequency applications. The side-wall process using silicon nitride is one of the useful processes to fabricate short gate length GaAs MESFETs. The side-wall process consists of deposition and anisotropic etching of silicon nitride and delivers plasma induced damages at the sidewalls of the lower gates of the ion implanted GaAs MESFETs during reactive ion etching and plasma ashing processes. In this study, the effects of plasma induced damage on the channel layers of ion implanted GaAs MESFETs during reactive ion etching and plasma ashing processes have been investigated. The plasma induced damage was characterized by sheet resistance measurement, X-ray photoelectron spectroscopy (XPS), Auger electron spectroscopy (AES) of different etched surfaces compared with a chemically wet-etched reference surface. Also the effect of the plasma induced damage on the device performance was investigated. As a result, plasma ashing can deteriorate the plasma induced damage by RIE.

H3.5 RF SPUTTERED BZT THIN FILMS FOR VOLTAGE TUNABLE DIELECTRIC DEVICE APPLICATIONS. Young Pyo Hong, Seok Ha, Ha Yong Lee, Young Cheol Lee, and Kyung Hyun Ko, Department of Material Science and Engineering, Ajou University, Suwon, Korea.

The ferroelectric B_{2-x}Sc_xTiO_3 single crystal was prepared by pulsed laser deposition. Capacitive waveguide (CPW) type phase shifter controlled by external dc bias field were fabricated on B_{2-x}Sc_xTiO_3 films using a 400nm thick metal layer to reduce metal loss. Microwave properties of the CPW phase shifter were measured using a HP 8510C vector network analyzer from 0.045-20 GHz. The fabricated CPW type phase shifter at 4.4GHz exhibits a stable differential phase angle of 60° - 255° at 10 GHz with a dc bias field of less than 40 kV/cm between center and ground conductors. By controlling film growth condition, phase shifter exhibited a large differential phase shift and a low insertion loss at the same time. Furthermore, a stable differential phase angle (within 3.5°) was observed while changing the power of incident microwave from -10 to 430 dBm. These results demonstrate the possibility of ferroelectric tunable devices on a high power wireless telecommunications using the nonlinear response of ferroelectrics. In this presentation, detailed microwave properties of the ferroelectric CPW will be presented.

H3.6 MICROWAVE PHASE SHIFTERS USING FERROELECTRIC (Ba,Sr)TiO_3, B. B. Kim, Eun-Kyu Kim, Seung-Eun Moon, Su-Jae Lee, Kwang-Yong Kim, and Seok-Ki Han, Electronics and Telecommunications Research Institute, Taejon, KOREA.

The ferroelectric B_{2-x}Sc_xTiO_3 films were prepared on (001) MgO single crystal by pulsed laser deposition. Capacitive waveguide (CPW) type phase shifter controlled by external dc bias field were fabricated on B_{2-x}Sc_xTiO_3 films using a 2000nm thick metal layer to reduce metal loss. Microwave properties of the CPW phase shifter were measured using an HP 8510C vector network analyzer from 0.045-20 GHz. The fabricated CPW type phase shifter at 4.4GHz exhibits a stable differential phase angle of 60° - 255° at 10 GHz with a dc bias field of less than 40 kV/cm between center and ground conductors. By controlling film growth condition, phase shifter exhibited a large differential phase shift and a low insertion loss at the same time. Furthermore, a stable differential phase angle (within 3.5°) was observed while changing the power of incident microwave from -10 to 430 dBm. These results demonstrate the possibility of ferroelectric tunable devices on a high power wireless telecommunications using the nonlinear response of ferroelectrics. In this presentation, detailed microwave properties of the ferroelectric CPW will be presented.

H3.7 STUDIES OF THIN FILM FERROELECTRICS WITH CHARGE-COMPENSATED SUBSTITUTIONS IN BST. Daniel Potrepka, Steven Tidrow, Arthur Stack, Kevin Kirchner, Bernard Red, SEDD, U.S. Army Research Lab, Adelphi, MD. Daniel Bulik, Seton Hall Univ, South Orange, NJ, James Horowitz, Naval Research Lab, Washington, DC

Thin films were prepared from bulk targets by PLD techniques. The targets were composed of B_{2-x}Sr_xTiO_3 with charge-compensated substitutions for x=0.5. Results of the dielectric characterization measurements will be presented and compared to the results of similar measurements in bulk materials with the same composition.

H3.8 MICROFABRICATION OF PLASMA INDUCED DAMAGE ON THE CHANNEL LAYERS OF ION IMPLANTED GaAs MESFETS DURING REACTIVE ION ETCHING (RIE) AND PLASMA ASHING PROCESSES. Heunkyun Ahn, Jaekyung Man, Heechun Kim, Electronics and Telecommunications Research Institute (ETRI), Advanced Micro-Electronics Research Laboratory, Taejon, KOREA.
To study the effect of the orientation of ferroelectric Ba$_{1-x}$Sr$_x$TiO$_3$ (BST) films on the microwave dielectric properties, the surface orientations of the ferroelectric BST films were engineered by controlling the growth condition of pulsed laser deposition with MgO single crystals with different surface normal directions, such as (100) and (110). Structural properties and surface morphologies of BST films were investigated using a 4-circle X-ray diffractometer and a scanning electron microscope, respectively. The microwave properties of orientation engineered BST films were investigated using coplanar waveguide transmission lines which were fabricated on BST films using a thick metal layer by photolithography and etching process. Phase shifters fabricated on (110) BST/MgO exhibited larger differential phase shift and figure of merit at 10 GHz than those fabricated on (100) BST/MgO. ($\Delta \phi \approx 48^\circ$ and $63^\circ$ for phase shifters on (100) and (110) BST/MgO, respectively.) In this paper, details of physical and electrical properties along the crystallographic orientation of BST films will be discussed.

H3.10
MICROWAVE MEASUREMENTS OF DIELECTRIC CONSTANT AND LOSS TANGENT OF TUNABLE MICROWAVE MATERIALS AS FUNCTIONS OF TEMPERATURE AND FREQUENCY USING AN OPEN CONFOLCAL RESONATOR

The dielectric constant and loss tangent of several tunable microwave materials have been measured and are reported for the temperature range of 4-300 K and frequency range about 10 GHz. The apparatus used for making the measurements is an open confocal resonator that uses well-established Gaussian beam theory and can be used to make measurements in the 10 to 100 GHz range. In order to evaluate microwave materials to meet military specifications, the resonator has been placed in an environmental chamber to cycle the sample temperature from -50 to 100°C. In the present configuration, the resonator is capable of providing measurements on dielectric constants ranging from about 1 to 1000 and loss tangents ranging from about 0.1 down to as low as $1 \times 10^{-8}$. In addition to providing dielectric constants and loss tangents of both tunable and non-tunable microwave materials, some of the particular of the resonator theory and resonator configuration are presented.

H3.11
SUB 0.1 $\mu$m ASYMMETRIC GAMMA-GATE PHEMT PROCESS USING ELECTRON BEAM LITHOGRAPHY

We studied the fabrication of GaAs-based pseudomorphic high electron mobility transistors (PHEMT's) for the purpose of millimeter-wave applications. To fabricate the high performance GaAs-based PHEMT's, we performed the simulation to analyze the designed epitaxial structures. Each unit processes, such as 0.1 $\mu$m Gamma-gate lithography, silicon nitride passivation and airbridge process were developed to achieve high performance device characteristics. The fabricated PHEMT's were measured at 70 $\mu$m unit gate width of 2 $\mu$m fingers, and showed a good pinch-off property ($V_P = -1.75$ V) and a drain-source saturation current density (Ids) of 3.73 $\text{mA/mm}$. Maximum extrinsic transconductance (gm) was 252.4 $\text{mS/mm}$ at Vgs = -0.3 V, Vds = 1.5 V, and Ids = 0.1 Ids. The RF measurements were performed in the frequency range of 1.0 - 50 GHz. For this measurement, the drain and gate voltage was 1.5 V and -0.3 V, respectively. At 50 GHz, 9.2 dB of maximum stable gain (MSG) and 4.2 dB of 50% gain were obtained, respectively. A current gain cut-off frequency (fT) of 10.64 GHz and a maximum frequency of oscillation (fmax) of 180 GHz were achieved from the fabricated PHEMT at 0.1 $\mu$m gate length.

H3.12
ELECTRICALLY TUNABLE MICROWAVE PHASE SHIFTER WITH AIR-DIELECTRIC SANDWICH STRUCTURE
Maki Jeong, Beumsoo Kim, Sungwook Ha, University of Science and Technology, Dept. of Materials Science and Engineering, Pohang, KOREA, Victor Kuzmenko, Yuriy Poplavsko, Dept. of Microelectronics, Kiev, UKRAINE.

We propose an air-dielectric sandwich structure as a new concept of tunable phase shifter. The structure consists of very thin air layer and relatively thick dielectric material inside a waveguide. Electrically tunable phase angles are added to the dielectric core to control the thickness of air gap. Variation in the thickness ratio between air gap and dielectric plate leads to the change in the effective dielectric constant of the structure. For instance, if we use BaTiO$_3$ (+e37) as the dielectric, the variation in the thickness of air gap by only several tens of micrometers significantly changes the effective dielectric constant, which induces phase shift for the microwave transmitting through the air-dielectric sandwich. The major advantage of the proposed phase shifter is that low dielectric loss could be realized by precise control of dielectric materials. The reverse tuning could be determined by the selection of the electromechanical actuator.

H3.13
DEPOSITION OF POLYCRYSTALLINE ZnO FILMS BY TWO-STEP METHOD AND CHARACTERIZATION OF THERMAL ANNEALING EFFECTS

With the rapid progress of communication technology, there has been an increasing interest in developing thin filmbulk acoustics filters, including surface acoustic wave (SAW) filters and film bulk acoustic resonators (FBARs). These devices require the thin film to have c-axis oriented growth nature, excellent crystallinity, and high electrical resistivity. Poly crystalline ZnO has been considered as one promising materials for such device applications. The sputtering has widely been used to obtain the c-axis oriented ZnO film. Various methods, such as doping with impurities (Li, Cu, etc.) and addition of oxygen during deposition, have been used to increase the resistivity. However, it has not been shown with these methods that both the c-axis growth nature and the resistivity of ZnO can be enhanced together. Furthermore, the sputtered ZnO film may include considerable grain boundaries, as a result it can degrade its crystalline property. In this paper we propose a novel deposition method enabling to achieve a high-quality ZnO film and present experimental results regarding to the thermal annealing effects. ZnO films were deposited on ZnO/SiO$_2$/Si substrate by RF magnetron sputtering. The method that we propose consists of a 1 st -step deposition at 100 W without adding oxygen and the 2 nd -step deposition at 100 W (or higher) with adding the oxygen ($O_2/Ar+O_2=10-50\%$). Texture coefficient (TC) for the (100)-peak size of deposited ZnO films were evaluated from the XRD patterns. The L-V characteristics was measured to estimate the film resistivity. Raman spectra were monitored in all experiments to identify the wurzite phase of the ZnO lattice. By using the two-step method, a strongly c-axis oriented (TC $>100\%$) and highly resistive ($>10^9 \text{Tcm}$) ZnO film could be successfully deposited. It was also observed that the crystalline size of deposited film was noticeably increased after thermal annealing.

H3.14
ON THE GHZ FREQUENCY RESPONSE IN NANOCRYSTALLINE Fe3N ULTRA-SOFT/SOFT MAGNETIC FILMS
N.G. Chechel'm, C.B. Gross, A.R. Cherem, D.O. Boehm, and L. Nollett Materials Science Centre, University of Groningen, Groningen, THE NETHERLANDS.

Nano crystalline Fe$_3$N films have been proved to have excellent ultrasonic magnetic properties with a high magnetic susceptibility in the frequency region above 1 GHz. The influence of the grain size, D, on the dc-magnetism has been analyzed in Hoffmann papers [1] and ref therein. The high-frequency magnetic susceptibility was measured at 20 K in the frequency range of 0.1 - 1 GHz. The resonance field (Hz) was measured from the resonance frequency (fR) of the initial permeability and the resonance (fg) frequency of the initial permittivity. The high-frequency resonance (Hf) is the magnetic field at which the magnetic susceptibility is a maximum. The magnetic anisotropy (A) is determined from the magnetic field at which the magnetic susceptibility (Ms) is a maximum. The magnetic anisotropy (A) is determined from the magnetic field at which the magnetic susceptibility (Ms) is a maximum.

SESSION H4: BST FILM CHARACTERIZATION
Chair: Chonglin Chen
Wednesday Morning, April 3, 2002
Salaon 3/4 (Marriott)

8:00 AM PH4.1
A STATISTICAL ANALYSIS OF LA SER EXHIBITED BST/STO/IO FILMS FOR MICROWAVE APPLICATIONS
The NASA Glenn Research Center is constructing a 5100 element scanning phased array antenna using Ba$_2$Sr$_{1-x}$TiO$_3$ doped device, which is used to produce phase shifts in a 3D insertion loss and at least 350 degrees phase shift with 3 percent bandwidth. It is well known that there is a direct relationship between dielectric tuning and loss due to the Kramers-Kronig relationship and this material and strain, affected by the substrate, does not play an important role. Ba$_2$Sr$_{1-x}$TiO$_3$ films, nominally 400 nm thick, are deposited on 50 0.25 mm thick, 5 cm diameter LaAlO$_3$ wafers. Although previous results suggested that Mn-doped films on MgO were inferior in a phase shift per unit length, this research shows that for this application phase shift per unit length was more important. The composition was selected as a compromise between tuning and loss in the microwave domain (e.g. crystalline BSTO thins due to the substrate). Microstructure and dielectric properties of the thin-film BST. Y.G. Wang, M.E. Reeves, F.S. Rachford, Applied Physics Letters, 1990, p.2965 (1990). Y.G. Wang, M.E. Reeves, W.J. Kim, J.S. Horwitz, and F.J. Rachford, Applied Physics Letters, 1990, p.3072 (1990).

9:30 AM H4.5 LATTICE DYNAMICS AND PHASE TRANSITIONS IN Ba$_2$Sr$_{1-x}$TiO$_3$ FILMS STUDIED BY Raman SPECTROSCOPY
D.A. Tanne, A. Sokolinska, A.M. Clark, and X.X. Xi, Pennsylvania State University, Dept. of Physics, University Park, PA.

Barium strontium titanate thin films grown by pulsed laser deposition on SrTiO$_3$ and LaAlO$_3$ substrates with SrRuO$_3$ buffer layers were studied by Raman spectroscopy in the temperature range from 5 to 300 K. The soft phonon modes were observed in Raman spectra of Ba$_2$Sr$_{1-x}$TiO$_3$ films with $x \leq 0.1$ at the temperature dependence of the soft phonon frequencies and the splitting of the triply-degenerate soft mode into two components of A and E symmetries indicate the ferroelectric phase transition. In the films with higher Ba content the E soft mode is overdamped over a broad range of temperatures. The overdamping region becomes narrower with increasing Ba concentration. For Ba$_2$Sr$_{1-x}$TiO$_3$ films with $x \leq 0.1$ the E soft mode is not observed in the whole range of temperatures. This is because the A soft mode frequency increases with Ba content. The temperature dependence of the soft mode frequency in the ferroelectric phase shows that the spontaneous polarization has discontinuity at the Curie point for films with Ba content $x \geq 0.1$, while for lower Ba content the frequency tends to zero. This indicates that the phase transition is of the first order for the films with $x \geq 0.1$, while for smaller Ba concentrations it changes into the second order. The relative Raman intensity of the A soft mode and hard phonon modes decreases gradually over a broad range of temperatures. This indicates a thermally broadened ferroelectric phase transition in the thin films. Raman spectroscopy results are correlated to the temperature dependence of dielectric constant. The reduction in films grown over SrTiO$_3$ but not on SrRuO$_3$ layer indicates the influence of strain in the temperature of the ferroelectric phase transition. The differences in strain state in films grown on these two layers of substrates are explained by different structure of underlying SrO layers.

SESSION H5: BST BULK MATERIALS AND APPLICATIONS
Chair: Amir S. Bihain
Wednesday Morning, April 3, 2012 Salon 3/4 (Abstracts)

10:15 AM H5.1 RANDOM FIELD DESCRIPTION OF INDUCED RELAXOR BEHAVIOR IN DOPED BST
Frank Crowne, Steven Titow, Daniel Potrepka, and Arthur Tuchier, Army Research Laboratory, Adelphi, MD.

The dc and microwave responses of the barium-strontium titanate (BST) family of ferroelectrics doped with various ion impurity species are analyzed using the random-field technique and the mean-field (Landau-Devonshire) theory of ferroelectricity, along with a self-consistent computation of the dielectric constant in the host material in the presence of the impurity fields. The fields in the material are assumed to arise from associations between positive and negative ions (charge compensation) that lead to dipole formation. The dc conductivity is calculated using a random placement of positive and negative ions generates a Holtzmark distribution of electric field, with infinite second moment and hence extremely large fluctuations in field strength. The association into dipoles leads to much lower fluctuations in field and a distribution with finite second moment, which makes a self-consistent dielectric constant meaningless. The theory contains the value of the self-consistent dipole moment as a fitting parameter. Reasons why this quantity can differ from a naive value of the ion.

This presentation will discuss the development of a novel, low-cost, phased-array antenna, being funded by the U.S. Defense Advanced Research Projects Agency (DARPA). The phased-array antenna scans its beam by electronic means without moving mechanical structures. This capability can benefit many defense and commercial applications, however, traditional phased-array antennas are expensive. The new antenna concept uses bulk voltage-tunable dielectrics (VTDs) to provide the phase shifts needed to scan the beam. VTDs currently used are compositions of Barium Strontium Titanate and low-loss ceramic dielectrics. The dilation of the BST with a lower dielectric constant material aids in impedance matching of the VTD to a microwave feed and to air. Test results demonstrating electronic beam scanning of prototype antennas will be presented. VTDs for this application can be conveniently characterized by their dielectric constants and figures of merit (FOM), i.e., the loss sustained by a wave passing through the material to achieve 360 degrees of phase shift. At 10 GHz a representative VTD material has a dielectric constant of 100 and a FOM of about 2 dB/360 degree phase shift. Loss increases with frequency for these materials. At 55 GHz current materials exhibit a dielectric constant of approximately 80, one of the best FOM of about 5 dB/360 degree phase shift. More information about the VTDs will also be presented.

11:15 AM H5.3 AN S-BAND REFLECTIVE PHASE SHIFTER - A DESIGN EXAMPLE USING FERROELECTRICS. Dongsoo Kim, J.S. Kenney, Georgia Institute of Technology, Athens, GA; David Kesling, David Stollberg, MicroConix Technologies, Inc., Athens, GA.

One of the challenges faced in using ferroelectrics in high frequency devices is how to effectively use the material in a circuit design. A compact reflective phase shifter on a substrate coated with ferroelectric barium strontium titanate (BST) thin-films has been built which shows the promise of using BST thin films in the design of tunable microwave devices. The phase shifter, fabricated as one monolithic assembly, consists of a 34B coupler, monolayer inductors, and tunable interdigital capacitors. A continuously variable phase shift range of more than 120° was obtained at a center frequency of 2.0 GHz, and better than 90° over a 500 MHz bandwidth. The insertion loss minimally was 1.8 dB at 1.85 GHz, and less than 2.0 dB over the 500 MHz bandwidth. The return loss was better than 15 dB for the 90° phase shift range over the 500 MHz bandwidth. Along with presenting the measured data, design data will be shown that will establish the critical ranges that must be achieved for the materials electrical properties in order to take the device from the bench-top into the marketplace. The loss of the BST phase shifter presented in this work is one of the lowest currently available RF front-end components, such as bandpass filters and RF switches. This holds promise for the practical realization of smart antenna systems in cellular handsets and wireless LAN cards. This work was supported in part by U.S. Air Force SBIR contract number F30601-95-C-1590.

11:30 AM H5.4 TUNING OF A DIELECTRIC RESONATOR USING FERROELECTRIC THICK FILM. Peter Kr. Petrov, Kumaniniothanan Sarma, and Neil McAlister, Physical Electronics and Materials Centre, EEE, South Bank University, London, UNITED KINGDOM.

An electrical tunable resonator comprising a cavity within which is mounted a dielectric resonator (DR) and ferroelectric thick film grown on a metal substrate is proposed. On applying a dc bias, the relative permittivity of the ferroelectric thick film decreases and hence affects the dielectric resonator electric field and changes the resonance frequency. The coupling between the DR and BSTO film is balanced so as to be strong enough to provide tuning and yet not so strong as to reduce the Q-factor of the device below practical values. The thick Ba,Sr,Zr,TiO subструкций used in this study were prepared by ceramic processing. The Ba/Sr ratio varied from 50/50 to 75/25. Discussed in this paper is the dependence of the BSTO films quality and permittivity of the doped dielectric thick film on the tuning range and Q-factor reducing. We examined dielectric resonators made in our laboratory (TiO, Al2O3 and Ca,Ti,Nd,Al,O with permittivity of 100, 10 and 47 respectively). The preliminary results showed a resonant frequency shifting by 2 MHz while the Q factor was above 10,000 GHz.

11:45 AM H5.5 THE DEPENDENCE OF DIELECTRIC PROPERTIES ON COMPOSITION VARIATION IN Ba0.85Sr0.15yTiO3-yO2.0. Daniel Potapkin, Steven Tidrow, Arthur Tushar, Kevin Kercher, Matthew Egan, Krishna Deb, Bernard Rod, Frank Crowe, U.S. Army Research Lab, Adelphi, MD.

Ba0.85Sr0.15yTiO3-yO2.0 has been shown to have properties which are promising for tunable applications requiring low dielectric constant [1]. Ba0.85Sr0.15yTiO3-yO2.0 with y < 0.5 has been synthesized in bulk and characterized using x-ray diffraction, EDAX, and Roman Spectroscopy. The dependence of the dielectric properties on concentration, y, of Y and Ta will be presented along with implications for improved performance in device applications. [1] D.M. Potapkin et al., Mat. Res. Soc. Symp. Proc. 60/2 D13.1 (2001).

SESSION H6: NEW MATERIALS AND APPLICATIONS
Chair: James S. Horwitz and Mark E. Reeves Wednesday Afternoon, April 3, 2002
Salon 3/F (Marriott)

1:30 PM H6.1 FIELD TUNABLE DIELECTRICS FOR MICROWAVE ELECTRONICS. Amar Bhalla, Materials Research Laboratory, MRL, Pennsylvania State University, University Park, PA.

This paper overviews the scope of designing, developing and exploiting the dielectric materials with field controllable properties that are utilized in frequency agile components for a wide range of applications in the various desired temperature zones. Several interesting material systems with low dielectric loss, high tunability and wide temperature range applications have been identified in the polycrystalline single crystal, composite, and film form. Results on the dielectric and tunability characteristics of [Ba,Sr]TiO3, [Pb,Sr]TiO3 in the pure compound and in the composites of these materials with MgO, MgTiO3, Al2O3 etc. will be discussed.

2:00 PM H6.2 DIELECTRIC AND ROOM TEMPERATURE TUNABLE PROPERTIES OF MAGNESIUM DOPED BCTZ THIN FILMS ON PLATINUM/MAGNESIUM OXIDE SUBSTRATES. T.S. Kokkar, W.C. Yi, Microelectronics Research Laboratories, University of Colorado, Colorado Springs, CO; Elliott Philofsey and Lee Kammerdiner, Applied Ceramics Research, Colorado Springs, CO.

Ba0.96Ca0.04Ti0.94Zr0.06O3 (BCTZ) has been proposed as a promising material for high dielectric constant device applications since it has a bulk dielectric constant up to 30,000 at room temperature. In this paper we are reporting the results of magnesium [Mg] doped BCTZ film on magnesium oxide (MgO) substrate with platinum[Pt] as the bottom electrode. Mg doped BCTZ films were fabricated by spin on wet atomic decomposition (MOD) method. The films were annealed in the temperature range of 608-900°C in flowing oxygen environment. The structures of the films were determined by x-ray diffraction. The capacitance vs voltage characteristics of the BCTZ films showed very good tunability (greater than 60%) at room temperature.

2:15 PM H6.3 Abstract Withdrawn.

2:30 PM H6.4 EVIDENCE FOR ANTIFERROELECTRIC BEHAVIOR IN KNO3/KTaO3 SUPERLATTICES. David Norton, J. Sigman, Univ. of Florida, Dept. of Physics and Engineering, Gainesville, FL; Hans Christen, Penn Fleming, Lynn Bosmer, Oak Ridge National Laboratory, Oak Ridge, TN; Mark Reeves, George Washington Univ, Washington, DC.

In recent years, the atomic layer-by-layer growth of K(Nb,Ta)O3 thin films and superlattice structures have been investigated. Specifically, the properties of KNO3 / KTaO3 superlattices grown by pulsed laser deposition on KTaO3 (001) have been studied. We have recently investigated the dielectric properties of 1 unit cell x 1 unit cell KTaO3/KNO3 superlattices. An anomalous dielectric tunability is observed in the superlattice structures, with capacitance increasing with applied dc bias for temperatures just below those corresponding to a structural transition. This behavior is not observed in alloy films of comparable thickness, and is consistent with the nonlinear response expected for either paraelectric or ferroelectric material. However, an increase in dielectric constant with applied field is consistent with antiferroelectric behavior. The antiferroelectric ordering appears to be induced by the artificial B-site modulation imposed by the superlattice along the growth direction.
2:45 P.M. H8.5
THE FERROELECTRIC SLAB: A GEOMETRY FOR MICROWAVE COMPONENTS THAT INCORPORATE FERROELECTRIC MATERIALS
Frank Crowe, Steven Tidrow, Army Research Laboratory, Adelphi, MD.

A slab geometry is proposed for incorporating the properties of ferroelectric materials into microwave components such as delay lines, patch antennas, and filters. Using a standard dielectric slab geometry, the ferroelectric is inserted between two cladding layers and a microstrip electrode is placed on top of it. The wave eigenmodes of this structure distribute the propagating microwave fields between the ferroelectric and the cladding, so that the effective dielectric constant is a weighted average of the dielectric constants of the two materials. The mode spectrum of the structure is discussed, along with issues of impedance matching and power coupling. It is shown that the geometry drastically reduces dissipation due to dielectric losses in the ferroelectric. In an ideal case, this also curvatures the electric field, the dielectric constant of the ferroelectric layer can be varied with it and with the propagation properties of the structure. For the specific application of delay lines based on BST, it is shown that this approach is superior to making a uniform composite material by diluting the ferroelectric with a low-dielectric filler such as MgO.

3:30 P.M. H8.6
GROWTH AND CHARACTERIZATION OF HEXAFERRITE-BSTO COMPOSITE THIN FILMS. R. Hajird, J. Sanders, H. Sarkesh, Dept. of Physics, Univ. of South Florida, Tampa, FL; J. N. Dreyfus, Solid State Div., Oak Ridge National Laboratory, Oak Ridge, TN.

There is a vital need for tailored materials exhibiting tunable electromagnetic response in the RF and microwave frequency range. This may be best achieved in ferroelectric-ferrite composites where the combined dielectric and magnetic properties play a role in determining the overall response. We have synthesized a series of such composite thin films by magnetron sputtering in order to study the magnetic and high frequency characteristics. Barium-strontium-titanate (BSTO) and barium-iron oxide (hexagonal ferrite) class of materials were our choice for the ferroelectric and ferrite components of the composites. Films of varying ratios of those two materials were grown and structurally analyzed. In addition, ion implantation facility at ORNL was used to implant Cobalt dopants to possibly explore changes in magnetic anisotropy due to altered microstructure of the films. The X-ray diffraction scans of the composites show a clear distinction between the phases of the two materials, which indicates that there is no degradation of the different components. Barit ferrite grains of size ~0.5 μm are visible on the SEM images. Magnetic measurements done using a Physical Property Measurement System (PPMS) reveal a very interesting trend in the hysteresis loops. While the pure hexaferrite films show a well-defined M-H loop, the composite films show a distinct double-transition in the M-H loops. These results will be discussed in the context of the microstructure and surface modification of the thin films. The frequency-dependent impedance of the films up to 1 GHz will also be presented.

3:45 P.M. H8.7

Yttrium iron garnet (YIG) films have been deposited onto single crystal gadolinium gallium garnet (GGG) substrates by the technique of pulsed laser deposition. The investigation focuses on the influence of the laser repetition rate on the properties of the films. For a given set of experimental parameters, the oxygen background pressure and the substrate temperature were optimized to achieve the smallest linewidth of the ferromagnetic resonance (FMR). The repetition rate was then varied from 10 to 50 Hz. There is a clear transition from films with low saturation magnetization \( M_s \approx 300 \text{ G} \), high coercive fields \( H_C \approx 30 \text{ Oe} \), and broad FMR lines \( \Delta H \approx 100 \text{ Oe} \) to films with \( M_s \approx 1400 \text{ G} \), \( H_C < 10 \text{ Oe} \), and \( \Delta H < 10 \text{ Oe} \). This transition occurs when the laser repetition rate is changed from 20 to 30 Hz. Films deposited at 10 and 20 Hz possess a large number of holes. No significant differences could be detected in all of the investigated properties: crystalline structure, composition, and surface roughness do not depend on the repetition rate. The results are discussed in terms of the different timescale of the laser pulses and the resulting different energies transferred from the ablated species to the film per unit time.

4:00 P.M. H8.8
RAPID PROTOTYPING OF FERROELECTRIC COMPOSITES. Jennifer Synowczyzny, Samuel Hirsch, and Bonnie Gersten, Weapons and Materials Research Directorate, Army Research Laboratory, Aberdeen Proving Grounds, MD.

The objective of this paper was to develop a method to allow RF designers the flexibility to create high precision complex three-dimensional components from high-dielectric constant, low-loss BaSrTiO_3 / MgO ferroelectric composites. This was accomplished through a combination of lost wax rapid prototyping and ceramic gilded casting. This new method also allows material scientists to create new materials based on composite structures where the connectivity between the phases in the composite can be directly controlled on a submillimeter scale. In the lost wax lost wax method, the inverse of the structure was deposited from a low melting point thermoset using a high precision Sanders Rapid Toolmaker. The inverse served as a mold into which a stable ceramic slurry (viscosity between 200-300cps) was cast. The slurry contained between 50-80 wt% of the ceramic powders (BaSrTiO_3, MgO), a 12-20 wt% solution of monomers and crosslinkers, and a free radical initiator. The ceramic powders were immobilized in place by thermally activating a polymerization reaction at 50°C. The wax mold was then removed by drying the green body in a high humidity oven at 120°C. The green body contained between 5-15 wt% binder depending on the solids loading. It was then thermally treated at elevated temperatures between 1350-1450°C to remove any residual organics and fully densify the part. SEM investigations of the unfired part determined that if the atmosphere is not controlled during the reaction, the binder distribution on the surface of the part is different from the bulk. SEM analysis was also used to characterize the microstructure and precision of the sintered part. The low frequency dielectric properties (permittivity, loss tangent, tunability) of the composites were reported. This study addressed the effect of casting process, binder removal, and shrinkage during sintering on the final material. It also discusses methods to stabilize the ceramic suspension, monitor the reaction, and the correlation between the solids loading and the green and sintered densities.