HIGH PURITY FERROELECTRIC MATERIALS BY SOL-GEL PROCESS FOR MICROWAVE APPLICATIONS

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ABSTRACT

Ferroelectric materials (FEM) have a dielectric constant which can be modulated at high frequencies (up to the optical range), under the effect of an electric field bias. The bias is perpendicular to the direction of propagation of the signal. This property is very attractive and can be used to develop a new family of devices operating in the microwave and millimeter range. Among these devices, tunable delay phase shifters for electronically scanned arrays, tunable filters, variable power dividers, are the most promising. The reason FEM materials haven't been used at high frequencies is due to the large bias voltage required to change their dielectric constant, and due to the high losses of the materials. In this paper a new chemical process for the synthesis of high quality low loss thin film and thin ceramics of $BaTiO_3$(BTO), $Ba_xSr_{1-x}TiO_3$ (BST) and $PbTiO_3$ (PTO) is presented. The high quality of these materials and the use of strontium as a dopant for BTO, or calcium for the PTO helps to reduce the losses. Also use of the Sol-Gel process for deposition of thin film of FEM having thickness below 0.1mm, reduces the required bias voltage below 10V, making these devices fully compatible with analog circuits. Thin film and thin ceramic devices operating up to 3 GHz are presented and characterized as examples.

1. INTRODUCTION

The possibility of having a material where the electric properties (ε or μ) can be changed under the effect of a controllable parameter (as voltage or current) and their modeling at microwave frequencies has been the subject of extensive research in the recent past [1], [2]. Ferrites have been successfully employed because at their property of the magnetic permeability being controllable under the effect of an external magnetic field [3]. Ferroelectric materials are in many ways dual to ferromagnetic materials, but they have a number of advantages over magnetically controlled ferrites, due to the nature of the operating principle. In ferroelectric materials less power is required to control the property of the material. FEM also allow faster phase shifting compared to ferromagnetic materials, they have smaller and lighter structure, and allow high power capability.

2. FERROELECTRIC SYNTHESIS AND CHARACTERIZATION

A method well suited for the preparation of thin film and high purity thin ceramics is the Sol-Gel process [4], [5]. We have developed a new method of synthesizing Sol-Gel precursor for making barium titanate (BTO), strontium-modified barium titanate (BST), lead titanate (PTO) powers and thin films. For the BTO the precursor is prepared with barium hydroxide octahydrate, $Ba(OH)_2$-$8H_2O$, which is dissolved in methanol at a concentration of 0.1 M titanium isopropoxide, $Ti(C_3H_7O_4)$, is then added to the solution to yield a 1:1 molar ratio of barium-titanium complex alkoxide solution. This precursor is produced at room temperature and in dry nitrogen atmosphere. BTO powder can be obtained by calcimining the precursor to 550°C. BTO thin films can be fabricated by first spin-coating the

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precursor onto a substrate and subsequently heating the substrate at 750°C. A similar procedure is used for the production of BST and PTO. This new approach of producing ferroelectric material presents several advantages, such as high purity and the absence of the undesirable barium carbonate (which is non ferroelctric). Resonant cavity measurements [6] were performed to evaluate the electrical property of our ceramic with commercial products. The measurement employs an iris coupled reaction type cavity, constructed from standard rectangular wave guide operating in the TE_{101} mode. The reflection coefficients with different sample of BTO and BST are shown in Fig.1.

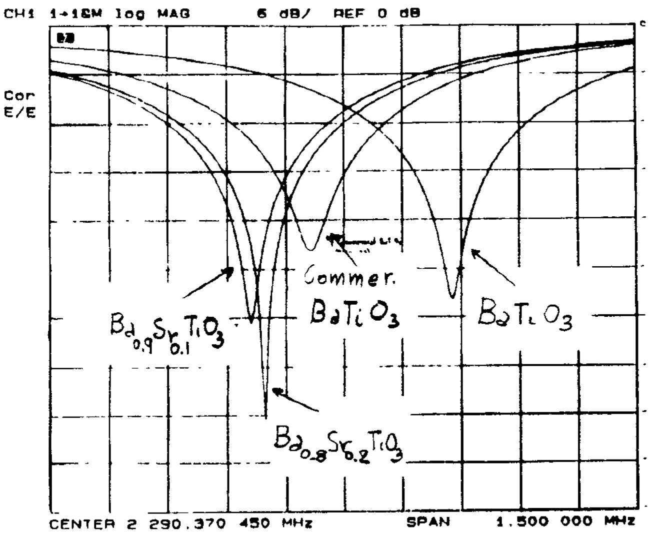
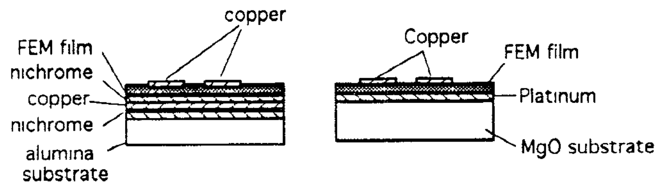


Fig.1 S_{11} measurement obtained for the cavity with different samples.

Since the Q of the cavity is directly related to the losses of the sample (assuming all the samples are placed in the same position and all have the same volume and shape as in our case) and the frequency deviation from the empty cavity resonance is related to the dielectric constant, it is clear since our ceramic sample has lower dielectric constant, lower losses of ceramic are obtained using commercial powder. Also the doping of strontium (10% and 20% respectively) increases the dielectric constant, and helps to reduce losses.

3. ELECTRICAL MEASUREMENT

A first set of low frequency measurement on thin film and thin ceramic is performed to investigate the dielectric tunability of thin film PTO and thin ceramic BTO. Capacitance measurement versus bias voltage for different frequencies (for the two thin films PTO based devices shown in Fig.2) is reported in Fig.3 and Fig.4.



a) b)

Fig.2 Schematic layout of the two types of FEM thin film based capacitors.

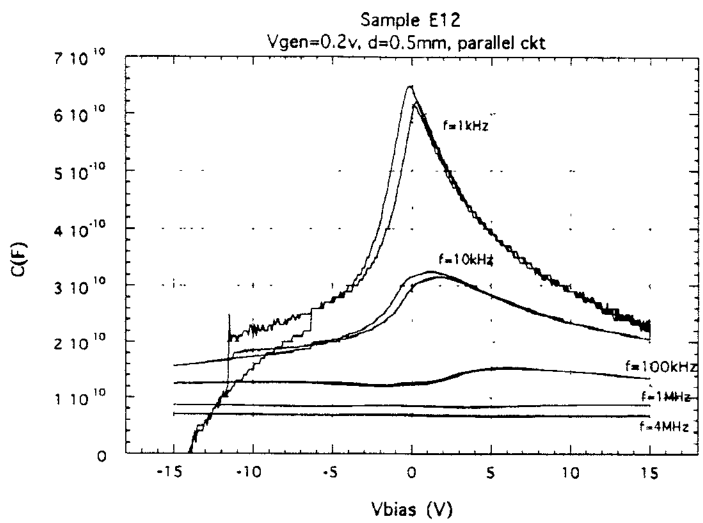


Fig.3 Electrical measurement of thin film capacitor having Nicrome-60-copper as ground contacts.

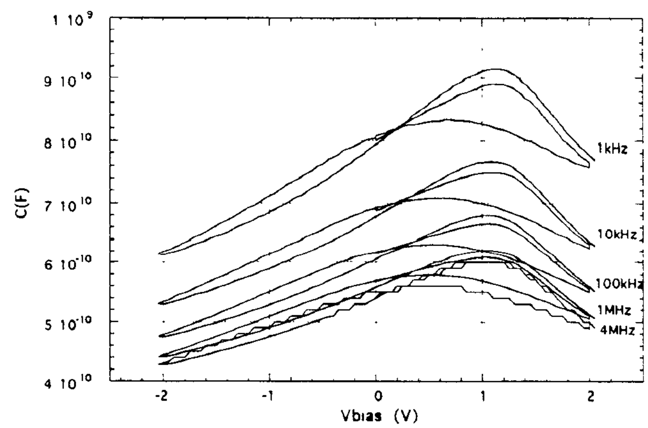
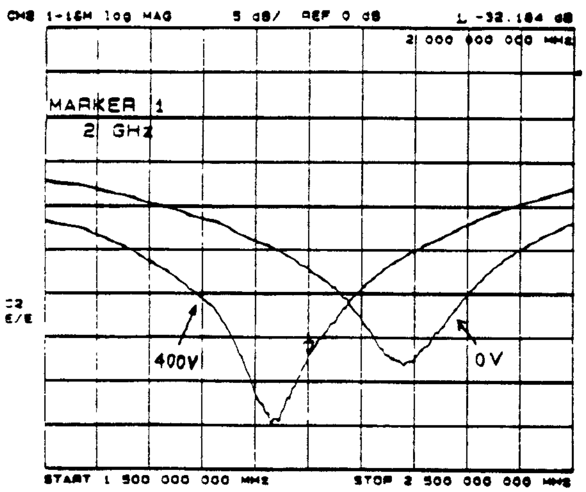
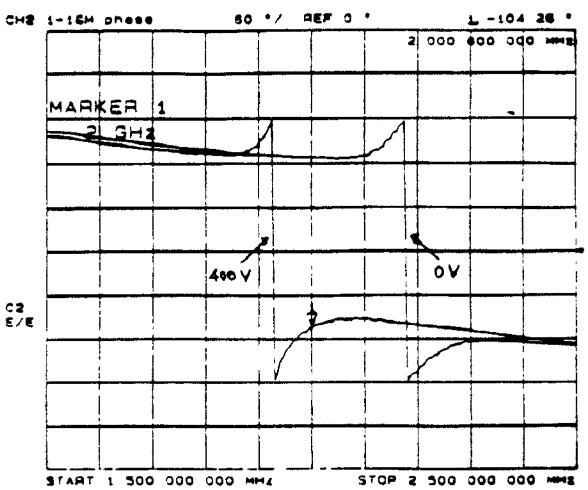
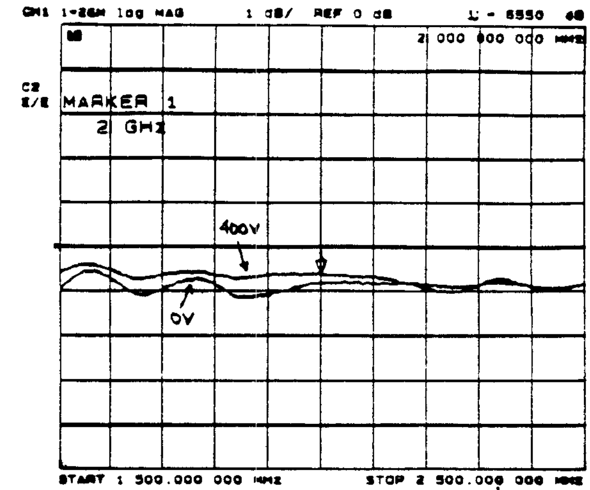


Fig.4 Electrical measurement of thin film capacitor having platinum as ground contacts.

The behavior is in perfect agreement with theory, and the strong frequency dependence of capacitance for the first sample cad rashly be modeled by a Debye relaxation due the interface layer between the film and the metal contact. The interface problem is eliminated by using platinum as ground contact for the film (Fig.2b). This prevents diffusion of the metal into the film thus giving less sensitive frequency dependence as shown in Fig.4. After this preliminary test at low frequency, a lumped capacitor imbedded in a microstrip set-up operating at 2 GHz was realized and tested. The calibration was done at the connector section, so the losses due to the connector and the microstrip are not taken into account. The result for the S parameters in the frequency range between 1.5 GHz and 2.5 GHz for the two cases of unbiased (Vb=0V) and biased capacitors (Vb=400V) are reported in Fig.5.







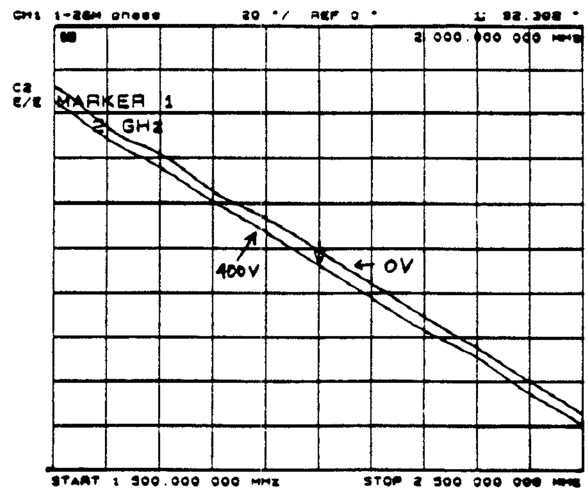


Fig.5 S parameter measurement for BTO based tunable capacitor.

Almost 10 degrees phase shift is obtained at 2.0 GHz, with a change in the magnitude of the S_{21} below 0.3 dB, and keeping the S_{11} below -20dB for both cases. Also from Fig.4 we see as under the effect of the bias voltage the quality factor of the circuit increase, as prove of reduction of losses. Using a simple model on MDS (Microwave Design Simulator from Hewlett Packard), to model the connectors, the transmission line and wire bonds, a change of 35% of the dielectric constant in the lumped capacitor is estimated. This phenomenon is clear from Fig.4 where no change in the difference of phase of S_{21} is observed in the overall bandwidth. This unique property enables the use of this material for extremely wide band devices. Additional applications will be presented for tunable phase shifter design for the frequency range between 3GHz and 5 GHz.

4. CONCLUSIONS

A new technique to produce high purity thin ceramic has been presented. The performance superiority compared to commercial products has also been shown. Use of high purity thin ceramic as substrate for tunable capacitors operating with driven power below 2mW as been demonstrated. Further reduction of losses can be achieved by doping the ceramic with strontium. When low bias voltage is required, use of thin film of the same material is possible.

5. ACKNOWLEDGMENTS

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