Ferroelectric Thin Films for Reconfigurable RF Electronics in Next Generation Wireless Communications

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Abstract:

Ferroelectric materials exhibit field-dependent permittivity effects that are useful in making voltage-dependent capacitors (varactors) that can be applied to electronically tunable radio frequency (RF) circuits, tunable filter circuits, and other wireless communication devices. The purpose of these experiments was to maximize the tunability of ferroelectric thin-film capacitors by varying material process parameters. The materials used in these experiments were barium strontium titanate (BST) and barium titanate (BTO), which were deposited by pulsed laser deposition. The thin film deposition parameters under study were deposition and annealing temperature, oxygen partial pressure, laser energy, material thickness and material/deposition type. BST has shown lower current leakage allowing a higher applied electric field, while BTO has shown a greater degree of dielectric tunability. Efforts to minimize the leakage in BTO while maintaining its tunability included depositing a thin layer of BST on either side of a BTO deposition and depositing a thin amorphous "dead" layer of BTO at lower temperatures prior to a higher temperature deposition. Initial direct current (DC) testing yielded positive results with various deposition parameters, which were reproduced in the fabrication of capacitors with planar waveguide contacts for high frequency testing.

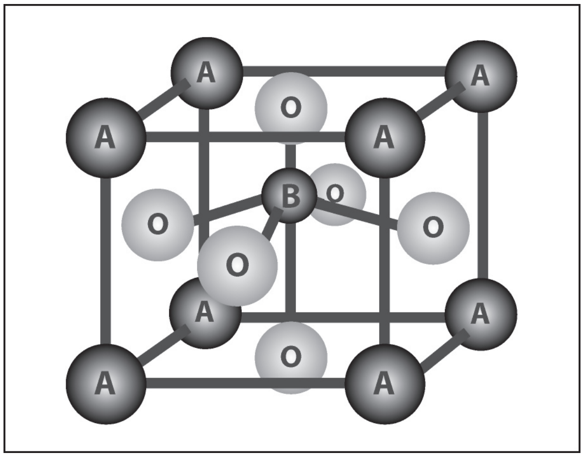

Figure 1: Generalized form of the perovskite structure.

Introduction:

Tunable capacitors (varactors) are desirable for use in frequency-agile microwave devices. Ferroelectric materials can be employed to create varactors, as the permittivity of such materials varies with an applied electric field. This phenomenon arises due to the perovskite crystalline structure these materials assume. In this arrangement, the material takes the generalized form of ABO_3 (Figure 1) where A and B represent varying metallic atoms, such as barium and titanium (BTO).

The purpose of these experiments was to study the influence of pulsed laser deposition conditions, annealing conditions, and material structures to create tunable capacitors with low current leakage and high tunability.

Experimental Procedure:

Our experiments focused on the study of the dielectric properties of barium strontium titanate (BST) and barium titanate (BTO) thin films deposited via pulsed laser deposition. The variables studied during these experiments included the oxygen partial pressure during deposition, the deposition and annealing temperatures, laser power, and the material type/configuration.

First, substrates of platinum/silicon dioxide/silicon were loaded onto a heater stage using silver paint and placed in a vacuum chamber. The target material to be deposited was placed opposite the substrate at a distance of seven centimeters. The chamber was then closed and pumped down to approximately 2×10^{-6} Torr. Once the chamber reached the target pressure, the substrate was heated to between 600°C and 700°C for a ten-minute thermal cleaning process. Oxygen was then introduced into the chamber at a

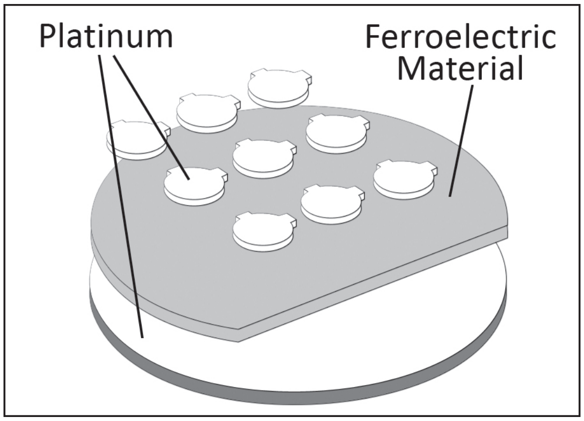

Figure 2: Completed array of simple capacitors after device fabrication.

predetermined pressure. Initial experiments were done using a pressure of 100 milliTorr (mTorr) and later experiments were performed at 200 mTorr. A pulsed KrF excimer laser (248 nm) struck the target material (either BTO or BST) which created an ionized plume of material that deposited onto the substrate. When the deposited film reached the desired thickness, it was annealed for 1h at the deposition temperature and an oxygen partial pressure of 100 Torr.

Capacitor structures, based on the thin films, were fabricated using the platinum (Pt) on the substrate as the bottom electrode, and using standard photolithography, metallization, and liftoff procedures to deposit top Pt electrodes. Through another photolithography step, a small strip of the sample was exposed and developed, and then placed in a 20:1 hydrofluoric acid solution to etch the exposed area down to the base Pt. This allowed access to the bottom contact in all parallel plate capacitor devices (Figure 2).

Once the sample was processed, it was electrically tested using a Keithley 4200 Semiconductor Characterization System to determine current-voltage and capacitance-voltage characteristics.

Results and Conclusions:

Experiments with BST yielded lower current leakage than BTO, allowing a higher applied electric field, while BTO showed a greater degree of dielectric tunability. Efforts to minimize the leakage in BTO while maintaining its tunability included depositing a thin layer of BST on either side of a BTO deposition, and depositing a thin amorphous layer of BTO at lower temperatures prior to a higher temperature deposition. These techniques drastically decreased the tunability of the material, but greatly decreased the current leakage. Thinner amorphous layers may provide a more desirable result with a more optimal tradeoff between leakage current and dielectric properties.

Higher temperature depositions increased the dielectric tunability of the deposited material but also increased the current leakage. Experiments combining higher temperature depositions with thinner low-temperature amorphous layers are underway. A partial oxygen pressure of 200 milliTorr significantly reduced the particulates that were prevalent at 100 milliTorr depositions. This decreased the deposition rate significantly, but resulted in a cleaner sample with fewer defects.

The best results obtained were from BTO deposited with a laser fluence of 250 milliJoules, an oxygen partial pressure of 200 mTorr, and a deposition and annealing temperature of 600°C. The greatest measured tunability range of the resulting devices, defined as the maximum permittivity divided by the minimum permittivity measured, was 7.4 (Figure 3) with a peak permittivity value of 1250 (Figure 4).

Future Work:

Devices will be tested at microwave frequencies to get an accurate representation of the material's response in communications devices. Planar waveguide devices have been fabricated using successful deposition parameters and are currently being tested. Results of those tests will dictate whether a variance in deposition parameters is necessary in future fabrication of microwave devices. Additionally, other materials such as lead zirconate titanate (PZT) will be tested, as will a rapid thermal annealing process.

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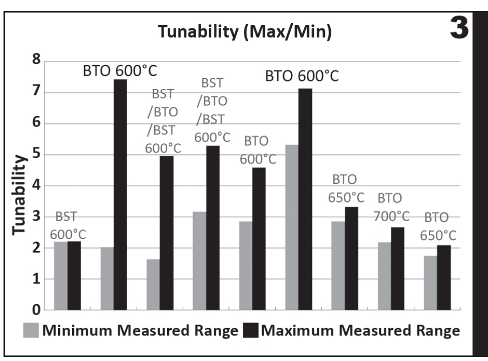

Figure 3: Tunability range of fabricated capacitors.

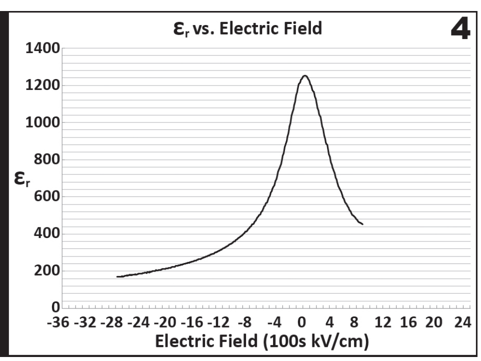

Figure 4: Relative permittivity versus electric field graph of best result.