# Microwave Properties of Ferroelectric Thin-Film Varactors

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**Introduction:** Ferroelectric materials have unique electronic properties, which hold great promise for significant utility in applications of interest to the Navy. Recent advances in deposition techniques for thin ceramic films have opened the door to a wide variety of new possibilities for ferroelectric materials in frequency-agile electronic applications. Ferroelectrics is a class of materials that exhibits an electric-field dependent relative dielectric constant. When incorporated into electronics devices, this allows manipulation of the microwave properties of the material with a dc bias voltage. The most basic application for these materials is in the production of interdigitated capacitors used as varactors in high-frequency circuits. Ferroelectric thin films of $Sr_{0.5}Ba_{0.5}TiO_3$ deposited on MgO $LaAlO_3$ and $SrTiO_3$ substrates have been fabricated into interdigitated capacitors [1]. Microwave reflection measurements have been used to characterize these devices in the frequency range from 50 MHz to 20 GHz. These devices have tuning ranges and high-frequency losses that are comparable to semiconductor varactors.

**Fabrication and Characterization Procedures:** The ferroelectric thin films used in this study were deposited by pulsed-laser deposition. This technique deposits a thin film on a substrate, which is attached to a heated stage and positioned in proximity to a target of source material. The target is composed of a sintered pellet of $SrTiO_3$ and $BaTiO_3$ in the correct ratio to result in a deposited film of the desired stoichiometry. A pulsed eximer laser is used to ablate material from the target, and this material is deposited on the substrate at a rate of approximately 0.2 nm per laser pulse. Typically, films of about 0.5-µm total thickness are deposited.

These films are fabricated into interdigitated capacitors using standard photolithographic techniques. In order to keep high-frequency metal film losses to a minimum, a 1.5-µm silver film followed by a 0.06-µm gold film is employed for the capacitor metallization. The device processing uses metal liftoff patterning so as to minimally damage the thin ferroelectric layer. This process involves the initial deposition and patterning of photoresist, then the depositing of the metal film through windows in the resist. The metal film is removed from the undesired areas by dissolving the underlying photoresist and floating the unwanted overlying metal off the sample in these regions. The mask used to delineate the electrode pattern contains devices with a variety of dimensions suitable for microwave characterization. A typical device has two contact pads, each with dimensions of 200 x 100 µm. The active area of the device is contained between the contact pads and consists of six pairs of 80-µm-long, 10-µm-wide fingers separated by 5-µm-wide gaps.

Microwave characterization of these devices is accomplished by measuring the one-port scattering parameters. An HP 8510 vector network analyzer is used in conjunction with a Picoprobe probe station to measure the microwave reflection $S_{11}$ from the device. Data are collected at room temperature in the frequency range from 50 MHz to 20 GHz Dc bias is supplied to the capacitors by means of an external biasing circuit, which is connected to the probes through the internal bias tees of the network analyzer. Bias voltages are typically in the range of -40 to +40 volts, as determined by the limitations of the biasing circuitry. Figure 1 shows a typical device under test.

**Microwave Performance:** Figure 2 shows typical microwave reflection data plotted on a Smith chart, which shows the data normalized to the 50-ohm characteristic impedance of the circuit.

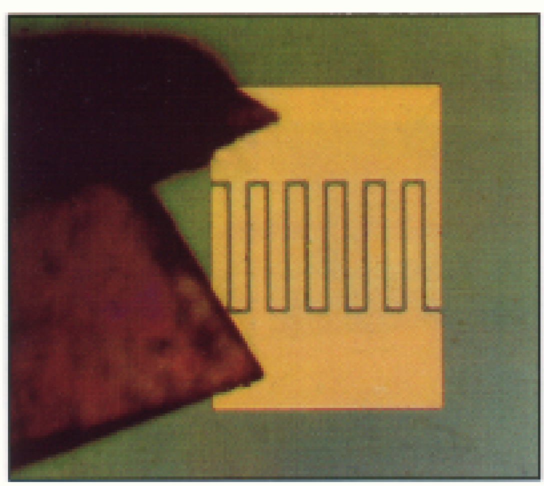
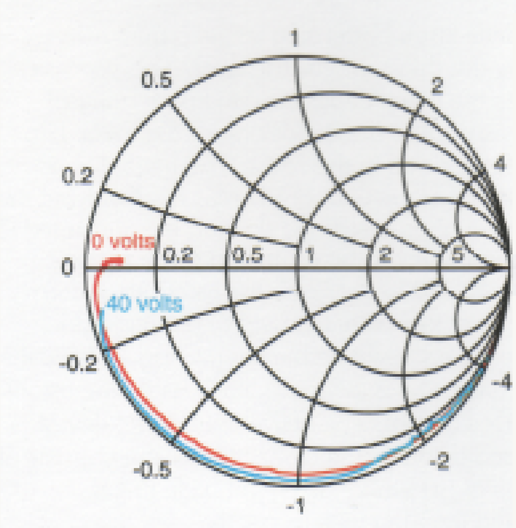


Fig. 1 — A 200 by 300 µm ferroelectric interdigitated capacitor under the microwave probe.




Fig, 2 — Polar plot of the microwave reflection data from 50 MHz to 20 GHz plotted on a Smith chart for dc biases of 0 volts and 40 volts.

The low-frequency data begin near the open circuit point, and continuously sweep around the unit circle toward the short circuit point as the frequency increases. At the high-frequency end, the data depart significantly from this simple capacitive behavior because of electrical size effects. This is a natural consequence of the high dielectric constant of this material, which reduces the radiation wavelength in the layer to such a degree that the device no longer appears as a lumped-element capacitor. Figure 3 shows the capacitance, device quality factor Q, and relative dielectric constant as a function of bias voltage for this device. The capacitance and Q are calculated by modeling the device as a simple circuit composed of an ideal

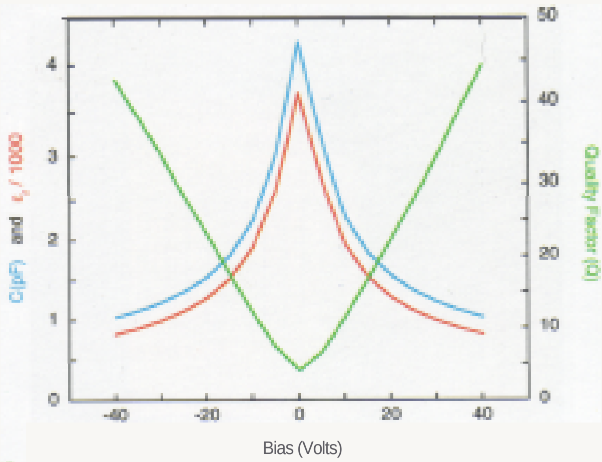



Fig. 3 — Plot of capacitance, relative dielectric constant (er) and device quality factor as a function of dc bias for the device of Fig. 2.

capacitor in parallel with a resistor. The dielectric constant is calculated using the model of Gevorgian [2]. These data demonstrate a capacitive tuning range of 4:1 at 10 GHz.

**Summary:** This research demonstrates the promising potential for advanced ferroelectric thin films as varactors in microwave applications. We expect improvements in film quality as the deposition technique is further refined. This should result in improved varactors with use in a wide variety of frequency-agile microwave circuits.

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**References**

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## Reconnaissance Sensor Development

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The Navy is developing improved capabilities for reconnaissance and intelligence gathering and dissemination. The primary Navy capability for manned reconnaissance and battle damage assessment has been film cameras in the Tactical Airborne Reconnaissance Pod System (TARPS) on F-14 aircraft. TARPS uses a short-range camera directed forward or downward in the front bay, a medium-range camera directed side oblique in the second bay, and a wide field-of-regard infrared scanner operated in a whisk broom fashion in the third bay. The film system is limited because of the time delays and chemical handling for wet film processing. Prototype and future reconnaissance cameras will record electronic images in spectral bands that allow day/night operation and that can be disseminated in a more real-time manner. To replace the existing TARPS film reconnaissance capability, the Navy is exploring TARPS CD (completely digital)