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Tunable dielectric RF and microwave integrated circuits

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Goals

- Deposition of tunable dielectric materials on substrates suitable for microwave circuit integration (i.e. alumina, copper).
- Improvement of the temperature stability of the dielectric response in the tunable dielectrics.
- Exploration of tunable dielectric materials as an alternative for SNL phase shifter applications.
- Development of a suitable microwave integrated circuit technology utilizing this technology.
- Demonstration of tunable capacitors and key microwave circuits.

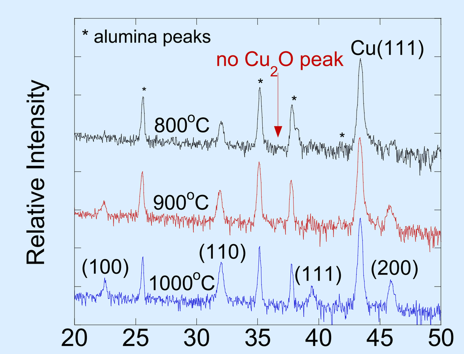
Motivation and background

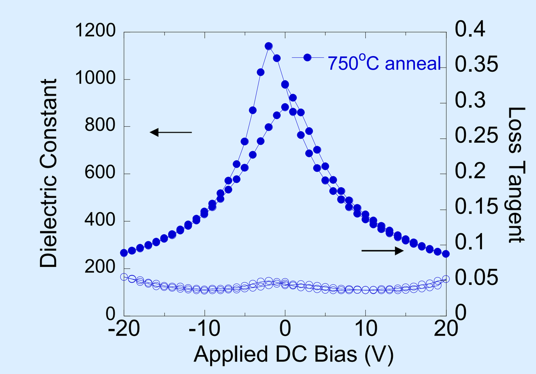
Modern RF and microwave subsystems require a variety of tunable, switchable, and reconfigurable circuits and components. These devices must have high-Q, fast tuning speed, small footprint, and wide tuning range.

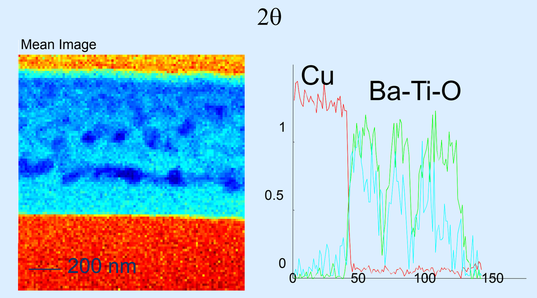
A variety of technologies have been applied to meet these types of needs, with specific drawback and benefits to each approach. Solid-state devices such as PIN diodes and FET switch banks are established, reliable, fast, and inexpensive, but generally have high losses and introduce substantial non-linearity for high-power signals. RF MEMS have very high linearity, very low-loss (and high-Q), but are immature, have unproven reliability, and have slow switching speeds.

Tunable dielectric materials, such as $(Ba,Sr)TiO_3$, (BST) offer low-cost synthesis and deposition on a variety of substrates, very high capacitance density, and voltage tuning. The purpose of this project is to explore the potential for tunable dielectric films for RF and microwave tunable circuits. Developing tunable dielectric enabled circuits allows the project team to understand the issues associated with RF design of these types of circuits, materials synthesis on a variety of substrates, processing of these materials for circuits, and test procedures for evaluating the technology.

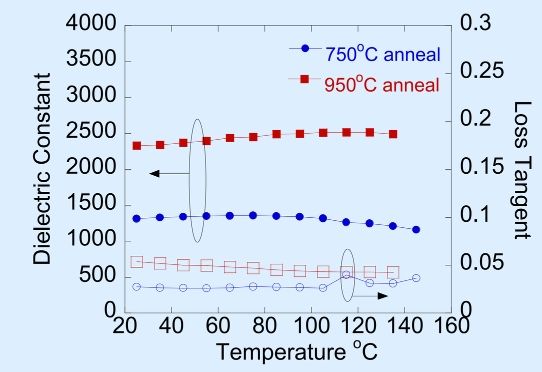
$(Ba,Sr)TiO_3$ films were integrated on copper electrodes to develop high Q metal devices







Special processing was used to avoid copper oxidation, but keep BST as an oxide.



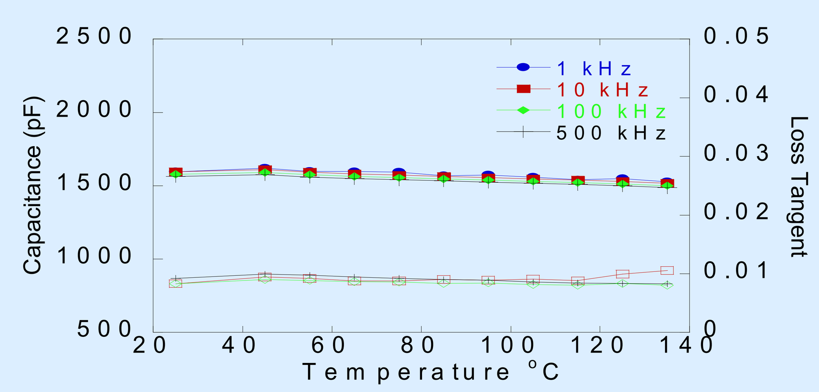
$BaTiO_3$, 0.8μm film 25°C, 0.05V_{AC} 100 kHz

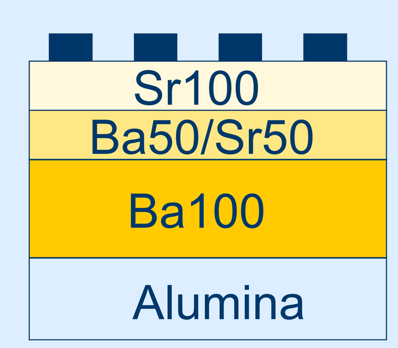
XRD and TEM results show no Cu_2O formation.

Films withstand bias voltages of >25V/μm

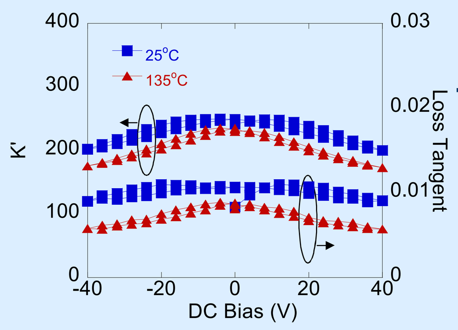
Composition and processing of $(Ba,Sr)TiO_3$ were tailored for a temperature stable response

Temperature coefficient of capacitance ~ 150ppm/°C





Device with interdigital capacitors (IDC) or in-plane electrodes



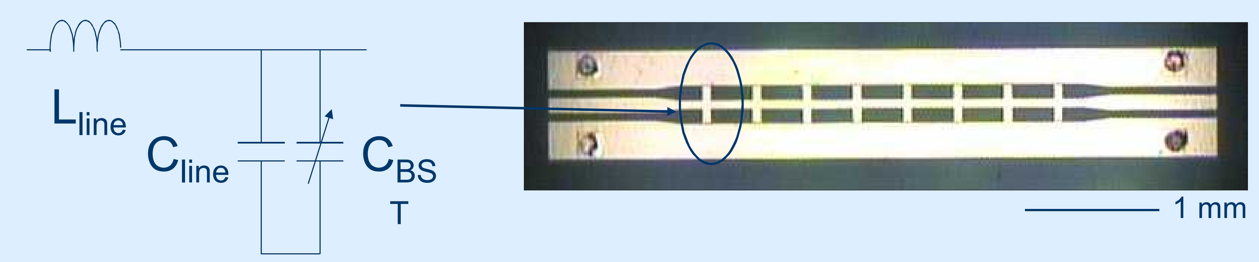
Tuning (±40V), 500kHz, 0.1V_{AC}, 0.8μm at 25°C 17%, at 135°C 24%

Tuning % is also temperature stable

Combining the best grading scheme with best annealing conditions to improve temperature stability without sacrificing Q or capacitance tuning.

Distributed transmission line phase shifter was fabricated

Load transmission line with capacitance to slow velocity

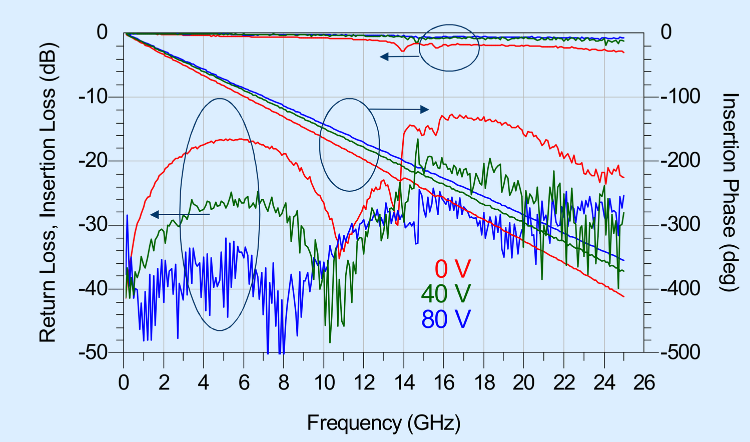


$$\upsilon_p = 1/\sqrt{LC}$$

Designed to vary 40-60Ω → $$Z_p = \sqrt{LC}$$

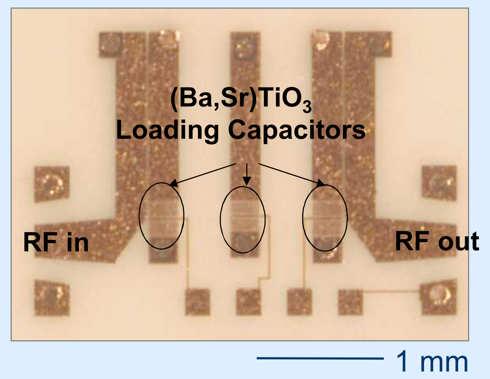
Analog tuning achieved:

33° at 16.7 GHz with <1.8 dB loss: 2.8 ps/dB FOM;

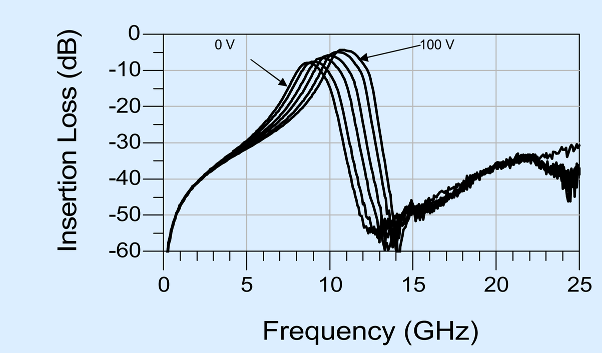


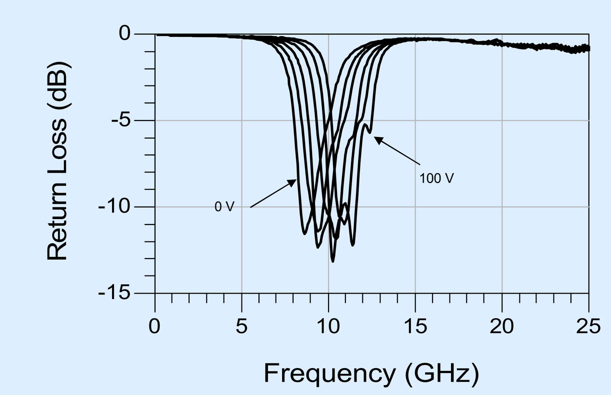
Lower loss with capacitance loading means possibility of doubling phase shift with doubling of capacitance loading with redesign.

Tunable combline filter was also fabricated



Measured response: 22% tuning with a 100V Bias, 4-8dB insertion loss 1.7 +/- 0.1 GHz bandwidth





Use loading capacitors to tune edge-coupled resonators and change resonance frequency

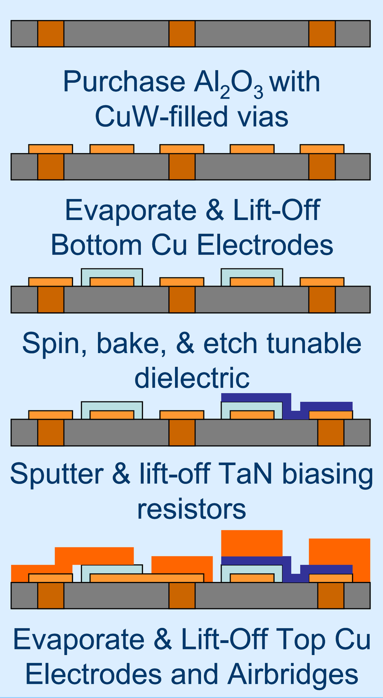
Adv: compact, allow for large tuning ranges

Dis: Sensitive to loss and mismatch in loading capacitors

The use of alumina substrates with copper vias for backend connections reduced line inductance and improved filter response.

Fabrication

Alumina with CuW-filled via holes is fabricated by an outside vendor from a design file provided by the Sandia designer.[1] Bottom electrodes are deposited and patterned by evaporation and lift-off to cap the via holes and define the lower electrodes for the parallel-plate capacitors and the bottom trace for any crossovers. The tunable dielectric film is deposited by chemical solution deposition and annealed in a controlled atmosphere tube furnace.[2-3] The dielectric is then patterned using photolithography and etched in an buffered HF solution to define the capacitor areas and make contact to the lower electrode plates. A resistive tantalum nitride (TaN) film is deposited and patterned using sputtering and lift-off. This film has a sheet resistance of approximately 1-10 kohm/square and is used to route DC biasing signals to the circuits while minimally impacting the RF performance of the circuits. A deep UV photoresist is used to define the airbridge gap prior to evaporation and lift-off of 2 μm of copper as the upper electrode.



1. Microsubstrates Corporation, 2400 South Roosvelt St., Tempe, AZ, 85282
2. J. Sigman, P.G. Clem, J.J. Richardson, J.T. Dawley, C.D. Nordquist, "Effect of Microstructure on the Dielectric Properties of Compositionally Graded (Ba,Sr)TiO3 Films," J. Appl. Phys., accepted.
3. J. Sigman, P.G. Clem, C.D. Nordquist, "Compositional Grading Effects on Permittivity Temperature Stability in (Ba,Sr)TiO3 Films," Appl. Phys. Lett.. 89, 132909 (2006).

Conclusions

- Demonstration of tunable dielectrics on copper substrates for better integration.
- Demonstration of processing control to tailor the properties of BST for specific applications.
- Easier and lower cost process than RF MEMS or similar devices.

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