Tunable Interdigital Capacitors and Phase Shift Unit Cell Fabricated on $Ba_{0.29}Sr_{0.71}TiO_3$ Grown by Hybrid MBE

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Two-port, tunable interdigital capacitors (IDC) were fabricated on electric-field tunable $Ba_xSr_{(1-x)}TiO_3$ (BST) thin films. The high-quality films were grown by hybrid molecular beam epitaxy (MBE) on $LaAlO_3$ (LAO) substrates, previously described elsewhere, which allowed for a broad temperature growth window and self-regulating stoichiometry. For this work, 450 nm of 29% Ba composition BST was grown to ensure a sufficiently large tuning range while allowing for a high quality factor. X-ray diffraction (XRD) scans show that the film is fully relaxed but epitaxial. A high-quality electrode interface was achieved by *in-situ* annealing in oxygen at 825˚C followed immediately by sputtering epitaxial platinum electrodes at 825˚C. The devices were passivated with ZrO_2 deposited by atomic layer deposition (ALD) and metallized with 1 µm of gold to reduce the series resistance. Plated gold airbridges allowed for the fabrication of a lumped-element, all-pass phase shifting unit cell which utilized two tunable IDCs and two spiral inductors.

Measurements were made on the IDCs and phase shifter unit cell from 100 MHz to 40 GHz then de-embedded and fitted to a frequency-dependent RLC equivalent circuit model. The electric-field-dependent series capacitance was fitted to closed-form equations derived from first principles and demonstrated an exceptionally close fit when an extra non-tunable fringing capacitance term was included in the equation. The IDCs demonstrate an exceptionally high zero-bias quality factor (600) at 1 GHz combined with 2.1:1 tunability at 700 KV/cm and a self-resonant frequency above 30 GHz. Under bias, an as-yet unknown frequency-dependent loss arose which lowered the Q-factor at 1 GHz to 40. The quality factor was further suppressed at frequencies above 5 GHz by the finite self-resonant frequency of the devices and the resultant roll-off in quality factor as the IDC's parasitic inductance begins to dominate the reactance of the device. The IDCs were also evaluated using a commutation quality factor described by I. Vendik which captures the IDC tunability as well as the loss at zero and maximum bias points. The devices yielded a commutation quality factor exceeding 15,000 at 1 GHz which exceeds any results at this frequency for BST interdigital capacitors.

The phase shifter unit cell was measured to 80 V which resulted in a phase shift of 100 degrees with low loss, giving a figure-of-merit of 76.68 degrees/dB at 9.1 GHz which is competitive with existing technologies. This good performance is despite the circuit operating well above the optimum performance frequency band of the IDCs and biased to a lower voltage. Future work in the coming months will expand the technology to RF parallel plate capacitors (PPC). Compared to IDCs, PPCs offer improved high frequency performance into the millimeter waves with increased tunability, reduced parasitics, and lower tuning voltages.