2D lattice with defects at the corresponding frequency. Indeed, for the first case the appearance of the second-order mode is practically twice the fundamental frequency (34GHz) since the 2D lattice appears extremely opaque up to 65GHz. In contrast for the second case the second mode occurs at 19.3GHz, lower than the expected frequency for a width of 13.64mm. This is a consequence of a deeper penetration of the EM wave within the walls. High contrasts between the on- and off-states can be achieved using this technique based on photonic bandgap engineering. Fig. 3 shows a difference of ~35dB between the on- and off-states at 15GHz, with a quasi-full transmission (–0.002dB) for the on-state.

Conclusion: The operation of an active waveguide patterned in a mixed 2D-3D photonic crystal has been simulated. Switching was obtained between the on- (–0.002dB) and off-states (–35dB) assuming full capacitance modulation using integrated varactor diodes which induced control of the waveguide wall reflectivity. We are currently investigating the use of the tuning concept proposed here to stub-like devices [7] and branch line couplers.

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Single-crystal ferroelectric microwave capacitor fabricated by separation by hydrogen implantation

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Microwave ferroelectric capacitors have been fabricated using separation by hydrogen ion implantation and transfer of a 500nm thick single-crystal $SrTiO_3$ layer to an insulating glass substrate. The capacitor films are of high quality with a measured quality factor of nearly 100 at 10GHz.

Introduction: Ferroelectric materials such as $SrTiO_3$ are attractive for tunable microwave capacitors [1 – 5]. These capacitors are typically fabricated using thin-film grown material. In this Letter, we describe the first use of separation by hydrogen ion implantation (also known as Smart-Cut [6]) and wafer bonding to transfer a 500nm thick single-crystal $SrTiO_3$ layer to an insulating glass substrate at temperatures less than 300°C and the subsequent fabrication of microwave capacitors. The flexibility of this approach promises electronic and physical properties that are more compatible with present microwave technologies than bulk ferroelectric materials [7], and lower microwave losses than approaches that utilise the growth of thin-film $SrTiO_3$ materials [1 – 5].

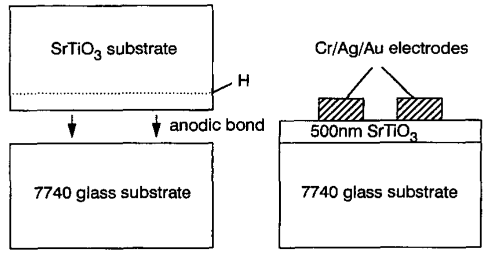

Fig. 1 *Interdigitated finger capacitor fabrication approach using separation by hydrogen ion implantation*

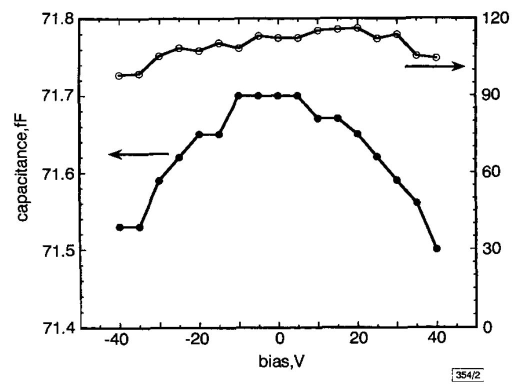

Fig. 2 *Capacitance and quality factor against frequency for 0, 20, and 40V bias*

Fabrication: The fabrication approach for transferring single-crystal $SrTiO_3$ material to an insulating glass substrate using hydrogen ion implant layer splitting and wafer bonding to make planar microwave ferroelectric capacitor is shown in Fig. 1. A 500μm thick single crystal (100) orientation $SrTiO_3$ with a surface roughness less than 5nm RMS was first implanted with $4.5 \times 10^{16} cm^{-2}$ H_2^+ at 130keV. The $SrTiO_3$ and glass surfaces were cleaned using a CO_2 jet and UV ozone process prior to bonding. The implanted $SrTiO_3$ substrate was then anodically bonded to a 1mm thick Corning 7740 Pyrex substrate at 200°C using a 1000V bias. The 500nm thick film was observed to split from the $SrTiO_3$ substrate at 250°C. The RMS surface roughness after splitting, as measured by a surface profilometer, was 2nm. Complete splitting was achieved over the entire $5 \times 5 mm^2$ $SrTiO_3$ substrate.

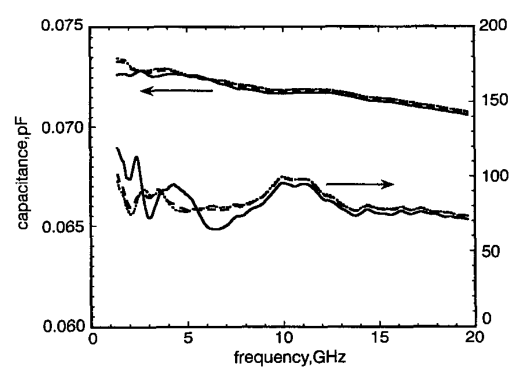

Fig. 3 *Capacitance and quality factor against bias voltage*

——— 40V
– – – – 20V
- - - - - 0V

A planar interdigitated finger capacitor were fabricated on the as-hydrogen-split surface with no further cleaning or processing steps. The metal electrodes for the interdigitated finger capacitors consist of a 20nm thick chromium adhesion layer, 1.5μm thick silver layer, and a 50nm gold cap layer to ensure a good probe contact and to prevent tarnishing. A typical capacitor contains six finger pairs with 10μm finger width, 6μm finger gaps, and 80μm overlap length.

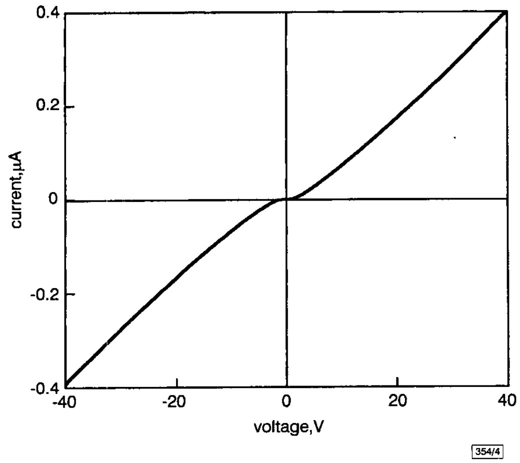

Fig. 4 *Interdigitated capacitor DC leakage current against bias voltage*

Six finger pairs with 10μm finger width, 6μm finger gaps, and 80μm overlap length

Results: Microwave reflection measurements using Cascade ground-signal-ground probes were employed to characterise the capacitor ferroelectric film properties in the frequency range 50MHz to 20GHz and under DC bias from –40 to 40V (Fig. 2). Measured capacitance values of 71fF (Fig. 2) yielded values for the dielectric constant of the hydrogen layer split film that are consistent with the known room temperature dielectric constant of bulk $SrTiO_3$. As shown in Fig. 3, the capacitor quality factor is nearly 100 at 10GHz. The measured DC resistance was greater 50Ω a 40V bias (Fig. 4).

Conclusions: Planar microwave single-crystal ferroelectric capacitors have been fabricated for the first time using separation by hydrogen ion implantation and transfer of a 500nm thick single-crystal $SrTiO_3$ layer to an insulating glass substrate. The capacitor quality factor is nearly 100 at 10GHz and the DC resistance was greater than 50Ω 40V bias. The hydrogen implant layer splitting technique in combination with wafer bonding will lend itself well to the fabrication of vertical electrode capacitors.

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Transmission resonances in ultra-wideband composite metallic photonic crystals

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Two-dimensional metallic photonic crystals with different lattice period and/or filling factor are combined to provide an ultrawide photonic bandgap starting from zero frequency. It is shown that either sharp resonances or relatively broad transmission windows with high transmission level can be created in this gap by inserting a small number of point defects in the crystals. Results from experiments carried out between 27 and 50GHz are presented.

Two (and three)-dimensional photonic crystals consisting of a periodic ensemble of metallic rods or wires are simple structures potentially applicable to low-cost filters, reflectors and substrate antennas in the microwave domain [1, 2]. In addition to their simplicity, the interest in metallic structures compared to dielectric structures is due to the existence of a wide photonic gap starting from zero frequency [1, 3]. In this Letter, we show that ultrawide gaps can be obtained by combining metallic photonic crystals with different lattice period and/or filling factor, i.e. by using composite photonic crystals. The idea of combining photonic crystals with overlapping stop-bands was first proposed by Agi *et al.* in dielectric materials [4], but the present extension to a two-dimensional lattice of metallic rods is new. Moreover, we show that sharp resonances can be obtained in the ultrawide gap by inserting a small number of point defects in the crystals. The approach is different from that used in the early studies of wire grating interferometers [5], where the microwave or optical beam incident angle has a strong influence on the Fabry-Perot type resonance frequencies. Because of the near-cylindrical (spherical) symmetry of 2D (3D) point defect modes, the use of photonic crystals consisting of multilayer stacks with point defects could lead to microwave filters with a larger angular tolerance.

The 2D photonic crystals were constructed with 5cm long copper rods arranged in a square lattice structure. The rod diameter was $d = 2$mm. Two lattice periods were used, one of 6mm (~8.7% filling factor) and the other of 5mm (~12.6% filling factor). These two crystals will be referred to as L1 and L2, respectively. Point defects were created by locally removing rods. The transmission spectra were measured from 27 to 50GHz with a collimated microwave beam of relatively small width (~3cm at 50GHz). Only TM field polarisation (electric field parallel to the rods) was considered since metallic rods are almost transparent for TE polarisation. The microwave setup was the same as reported in [6] and consisted of a vectorial network analyser HP 8510C connected to two identical horns. Absorbing foam was used to eliminate off-axis parasitic waves diffracted by the crystal. The noise floor was measured to be –45dB. The field propagation in finite crystals with their surroundings was simulated with a proprietary finite difference time domain (FDTD) software where the metallic rods were taken as lossless conductors. A pulsed plane-wave excitation was assumed and the transmission spectra were calculated after applying a fast Fourier transformation.