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SILICON CARBIDE PHONONIC CRYSTAL CAVITY FOR MICROMECHANICAL RESONATORS

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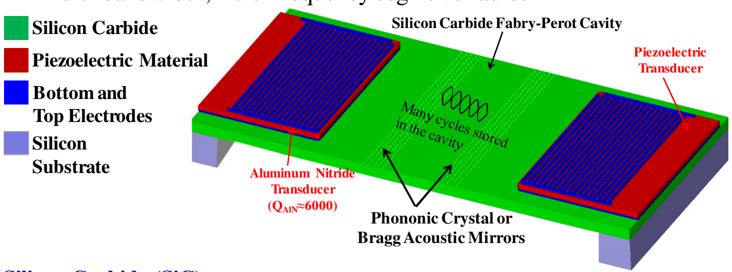
PHONONIC CRYSTAL CAVITY RESONATOR

- Phononic crystal acoustic mirrors decouples the Fabry-Perot cavity from the piezoelectric transducers resulting in high $f.Q$ and $k_t^2.Q$ at microwave and mm-wave frequencies.
- Lithographically defined frequencies and bandwidths → multi-bandwidth, multi-frequency cognitive radios



Silicon Carbide (SiC) :
Low Loss Material → High *Q*

SiC has the lowest phonon-phonon damping
SiC has high acoustic speed, high mechanical and chemical strength

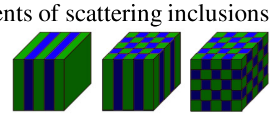
Aluminum Nitride (AlN) :
High Transduction Efficiency → High k_t^2

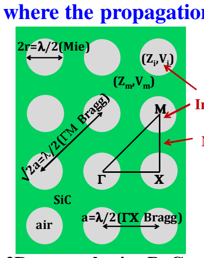
AlN is a piezoelectric material that efficiently couples the acoustic and electrical domains resulting in low motional impedance

PHONONIC CRYSTAL MODELING

Phononic Crystals (PnC) are periodic arrangements of scattering inclusions in a homogenous host material (matrix)

Acoustic bandgap is the range of frequencies where the propagation of phonons is prohibited





2D square lattice PnC

Overlapping Bragg resonances in Solid/Air Phononic Crystals opens a bandgap

$$f(Bragg)_{\Gamma X} = \frac{V_{avg}}{2a} \qquad f(Bragg)_{\Gamma M} = \frac{V_{avg}}{(2a)\sqrt{2}}$$

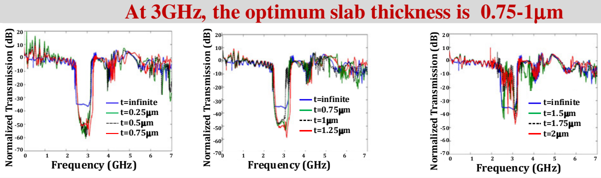
$$V_{avg} = \pi\left(\frac{r}{a}\right)^2 V_i + \left(1 - \pi\left(\frac{r}{a}\right)^2\right) V_M$$

Acoustic impedance and velocity $Z = \rho V = \sqrt{E\rho} \qquad V = \sqrt{\frac{E}{\rho}}$

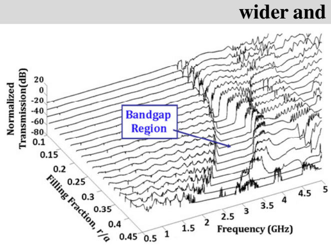
$$\Gamma^2 = \left(\frac{Z_i - Z_m}{Z_i + Z_m}\right)^2$$

→ Maximize band-gap width and depth by maximizing the acoustic impedance, Z, mismatch

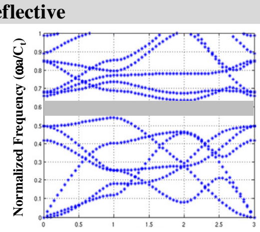
Slab thickness increases → Bandgap becomes narrower and less reflective
At 3GHz, the optimum slab thickness is 0.75-1µm



Filling Fraction (r/a) increases → Bandgap moves to lower frequencies, becomes wider and more reflective



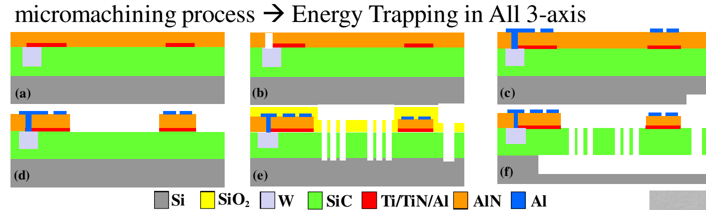
Finite-Difference-Time-Domain (FDTD) simulation of a 2D simple cubic SiC/Air Phononic Crystals with 7 layers, a=1.83µm, and r/a=0.35 µm



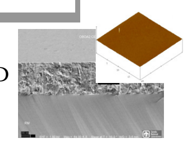
Plane Wave Expansion (PWE) simulation of a 2D simple cubic SiC/Air Phononic Crystal showing a full acoustic bandgap around 2.7 GHz. r/a=0.45, t/a=0.5

FABRICATION PROCESS

The Silicon Carbide cavities were fabricated in a CMOS-compatible surface micromachining process → Energy Trapping in All 3-axis



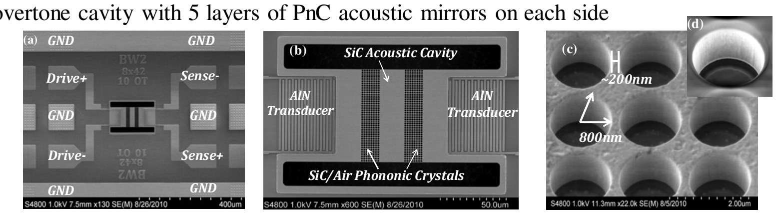
- Highly textured Cubic 3C-SiC (111) film was deposited using LPCVD
- SiC film has as-deposited tensile stress of <150MPa
- SiC film was polished to a surface roughness of <1nm, which is critical for high Q resonators



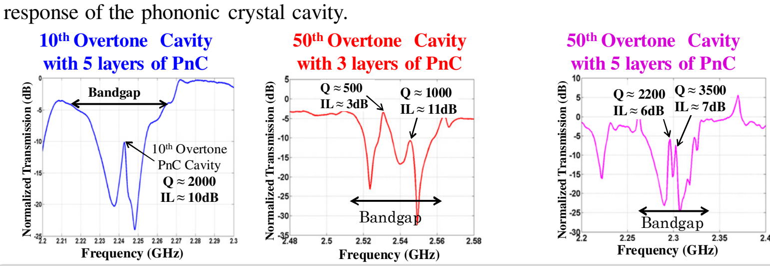
SEM and AFM of SiC polished using Tungsten CMP: rms < 1nm

RESULTS

Scanning Electron Microscope (SEM) images of a silicon carbide lateral 10th overtone cavity with 5 layers of PnC acoustic mirrors on each side



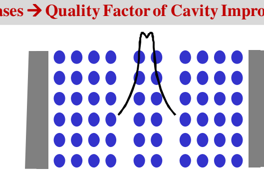
The normalized four port transmission response is calculated by subtracting the matrix transmission response, where no phononic crystal is present, from the transmission response of the phononic crystal cavity.



As the number of overtones and number of phononic crystal layers increases → Quality Factor of Cavity Improves

Future Applications:

Phononic Bandgap Circuits
Low loss acoustic filters, waveguides, mixers, modulators
Miniature "Slow Sound" delay lines
Phononic Bandgap Thermoelectric Energy Conversion
Acoustic Sensing: Chemical/Biological/Inertial Sensors
Acoustic Focusing for Ultrasound and Imaging applications



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