REASEARCH ON MICRO-SIZED ACOUSTIC BANDGAP (ABG) STRUCTURES

LABORATORY DIRECTED RESEARCH & DEVELOPMENT

Sandia National Laboratories

Roy Olsson (PI), Ihab El-Kady, Yasser Soliman, Drew Goettler, Mike Sinclair,
Willie Luk, Melanie Tuck, Rick McCormick and Jim Fleming

Goal:

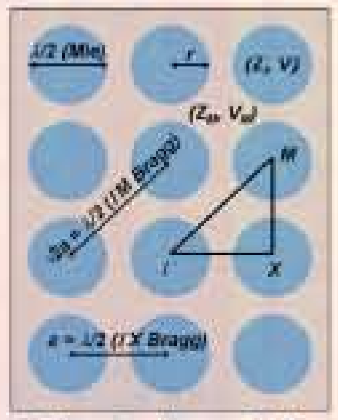
Realize the 1st BAW bandgap technology at frequencies commonly used in acoustic imaging and RF communications.

- Frequency from 1 MHz to 1 GHz
- Size (lattice constant) from 1 mm to 1 μm
- Hand assembled to batch fabricated
- Difficult experiment to rapid electrical characterization
- Low-loss ABG cavities, filters and waveguides

Approach:

- Develop a fundamental understanding of μABG physics
- Finite difference time domain and plane-wave expansion modeling
- Microfabrication for rapid construction and scaling to technologically interesting frequencies
- Integrated piezoelectric couplers for acoustic crystal interrogation and characterization
- Elastic materials for low-loss devices (cavities, filters and waveguides)

Origins of Wide Acoustic Bandgaps



Schematic diagram of a 2D square lattice acoustic crystal.

- ***Overlap Bragg and Mie resonances***
- ***Maximize bandgap width and depth by maximizing acoustic impedance, Z, mismatch***

$$f(Bragg)_{\Gamma X} = \frac{V_{avg}}{2a} \qquad \Gamma^2 = \left(\frac{Z_i - Z_M}{Z_i + Z_M}\right)^2$$

$$f(Bragg)_{\Gamma M} = \frac{V_{avg}}{(2a)\sqrt{2}} \qquad Z = \rho V = \sqrt{E\rho}$$

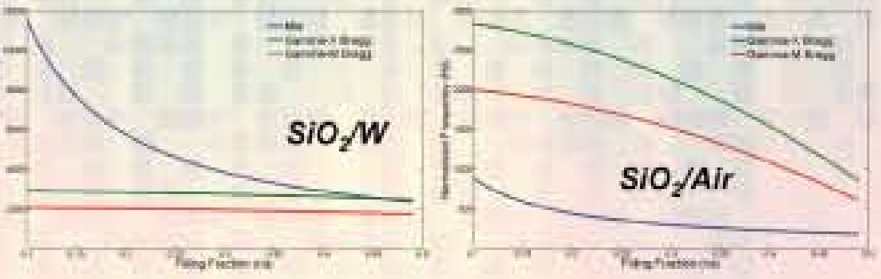
$$f(Mie) = \frac{V_i}{4r} \qquad V = \sqrt{\frac{E}{\rho}}$$

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

Approach

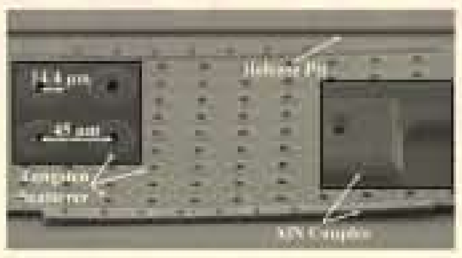
Impact of Material Properties

- Maximize mass density, ρ, mismatch but moderate acoustic velocity, V, mismatch to overlap Bragg and Mie resonances and improve manufacturability
- Greater flexibility than non-magnetic photonic crystals because velocity and impedance are independent variables
- W inclusions in a SiO_2 matrix provides highest Γ while maintaining moderate velocity mismatch and is CMOS compatible

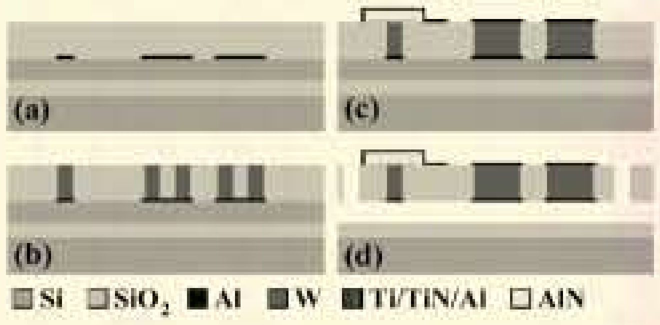


Plots of the Mie and Bragg resonant frequencies used to open an acoustic bandgap vs. the acoustic crystal filling fraction, r/a, for (Left) a SiO_2/W acoustic crystal with moderate velocity mismatch and (Right) a SiO_2/air acoustic crystal with high velocity mismatch.

Results-μABG Fabrication



- Deposit/pattern release layer, Al interconnect and SiO_2 matrix
- Form part (1.5-μm wide rings) of high-Z tungsten inclusions
- Complete W inclusions and form AlN couplers for electrical characterization
- Suspend ABG from the substrate by removing Si release layer in SF_6



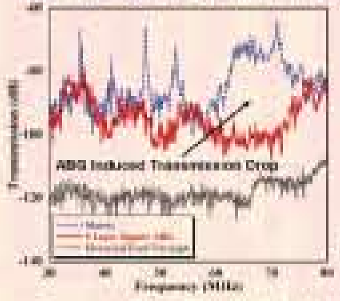
(Top) SEM image of a 67 MHz acoustic crystal

(Bottom) μABG fabrication — process flow

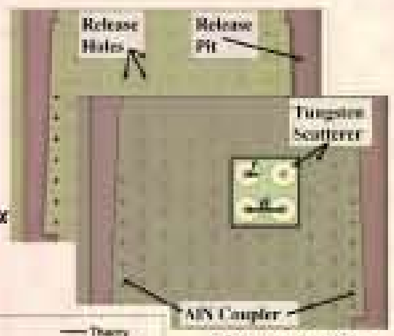
Results

μABG Characterization

- Measure μABG device and remove effects from the AlN couplers by normalizing to a blank matrix structure

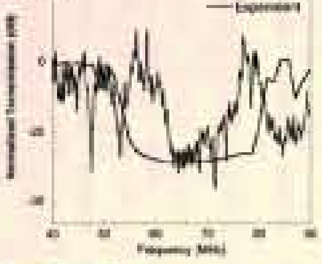


Transmission of the matrix, 9 layer square lattice ABG and on-wafer electrical feed-through showing an acoustic bandgap



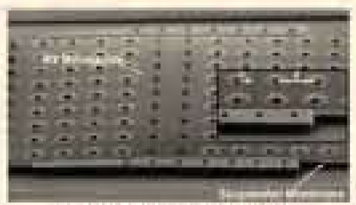
SiO_2 matrix

Square lattice ABG



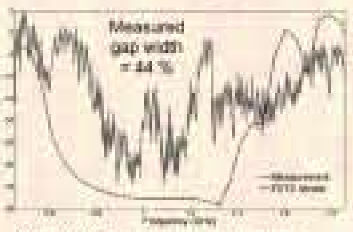
Normalized transmission from experiment and as predicted by FDTD modeling

μABG Waveguides and GHz Devices



MHz W2 ABG waveguide

Measured W2 ABG waveguide. Normalized transmission of 1 indicates low loss.



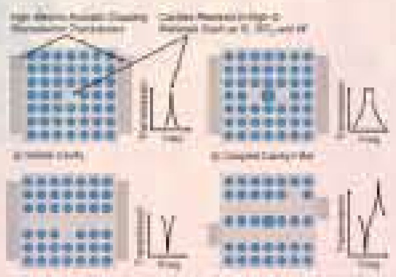
GHz ABG normalized transmission

GHz ABG with chirped coupler

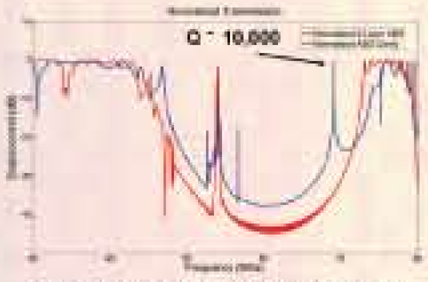
μABG Future Work, Devices, and Goals

- Record fQ product acoustic resonators with low insertion loss
- Novel ABG coupled filters and time delays
- Waveguiding for acoustic imaging and processing
- Thermal phonon control and manipulation

1 GHz ABG Cross Section



Examples of ABG cavities and filters



ABG line defect cavity with designed using FDTD modeling

Significance

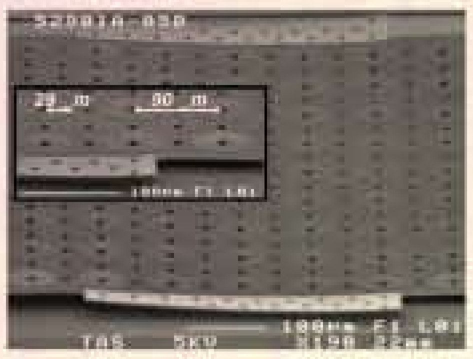
Project Metrics and Achievements

Significance-Devices

- 1st microfabricated BAW crystal at 67 MHz
- 1st μABG based devices (waveguides)
- 1st GHz solid-solid acoustic crystal

Publications and Presentations

- 2 journal articles published
- 1 invited review article on micro-acoustic crystal technology (in press)
- 4 high-impact conference presentations including 1 invited plenary lecture



33-MHz μABG

Significance

- Solid-solid ABG approach developed from underlying physics and to achieve low-loss ABG based devices
- Advanced FDTD and PWE modeling and computing facilities
- Advanced MESA design, fabrication and characterization facilities

Sandia is a multiprogram laboratory operated by Sandia Corporation,
a Lockheed Martin Company, for the United States Department
of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.
SAND 2008-3632J CreativeArts 98429.LW.8.08

National Nuclear Security Administration

Sandia National Laboratories