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MICROMACHINED ACOUSTIC CRYSTALS

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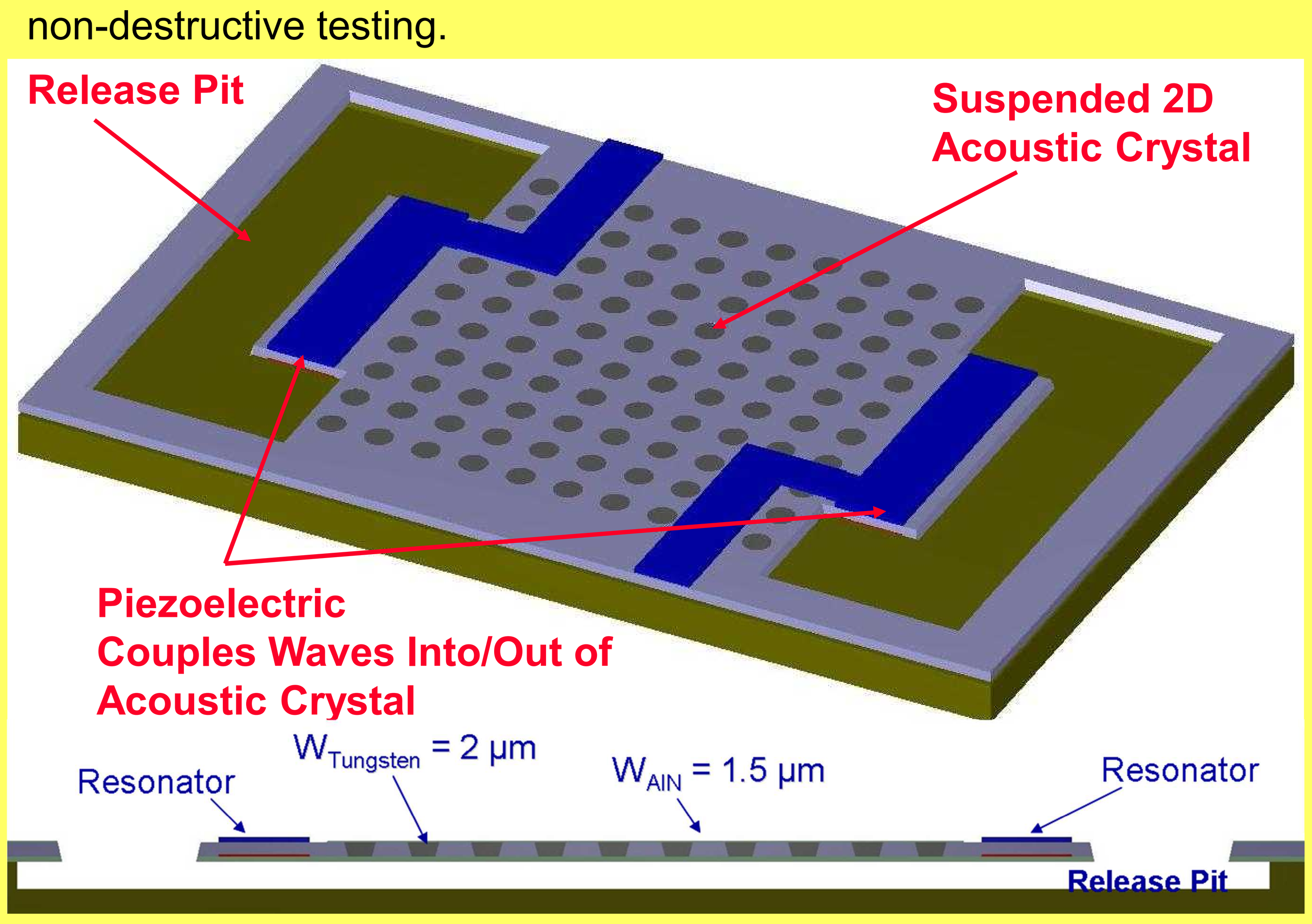
Introduction

Acoustic bandgap (ABG) [also referred to as acoustic crystal, phononic crystal, and phononic bandgap] is the acoustic wave equivalent of photonic bandgap (PBG), where a range of acoustic frequencies are forbidden to exist in a structured material. ABGs are realized by including periodic scatterers in a matrix that propagates an acoustic wave. Most of the prior ABG work has been done at low frequencies by hand assembling beads in epoxy or water. Mircofabrication allows the frequency of acoustic crystals to be scaled into the high MHz and low GHz and eliminates assembly. These µABGs are useful for acoustic isolation of devices such as RF resonators and gyroscopes. Furthermore, by strategically locating defects in the ABG through removal or distortion of the scatterers, micro-acoustic waveguides, filters, delay lines, power combiners/dividers, focusing, and high-Q cavities can be realized. These devices have applications in communications, ultrasound, and non-destructive testing.



Model of a W/AlN Acoustic Crystal with Integrated Electro-Acoustic Couplers. The cermet topology is used where isolated high-density, high impedance inclusions are placed in a low-density, low-impedance matrix.

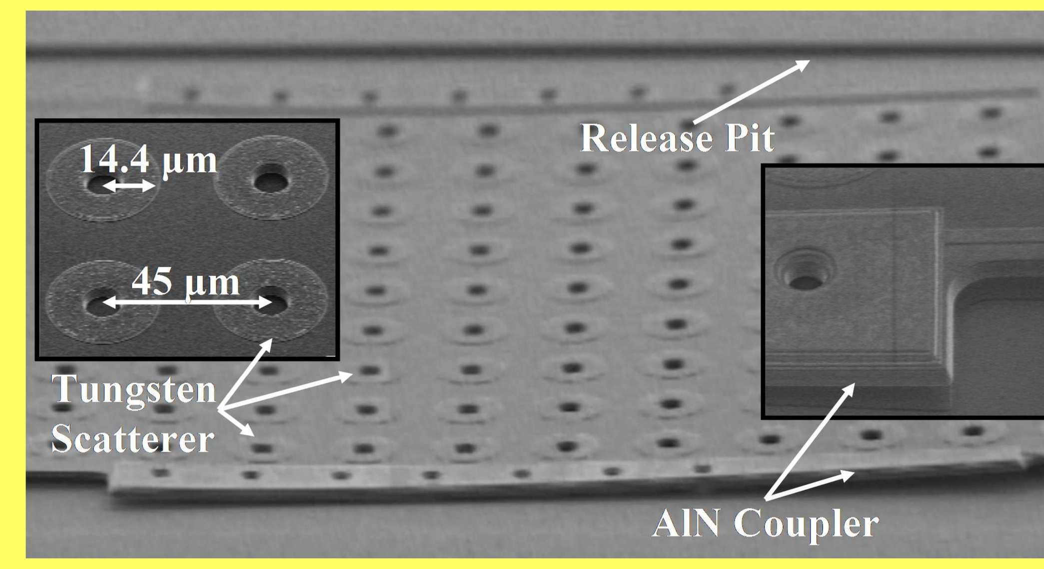
Materials

Material	Density (kg/m3)	Velocity (km/s)	Z (MΩ)	Q
Polymers	1190	1.84	2.2	≈ 10^2
AlN	3230	9.77	31.5	< 10^4
Si	2330	8.52	19.8	> 10^5
SiO_2	2200	5.84	12.8	< 10^4
W	19,300	4.6	89	> 10^5

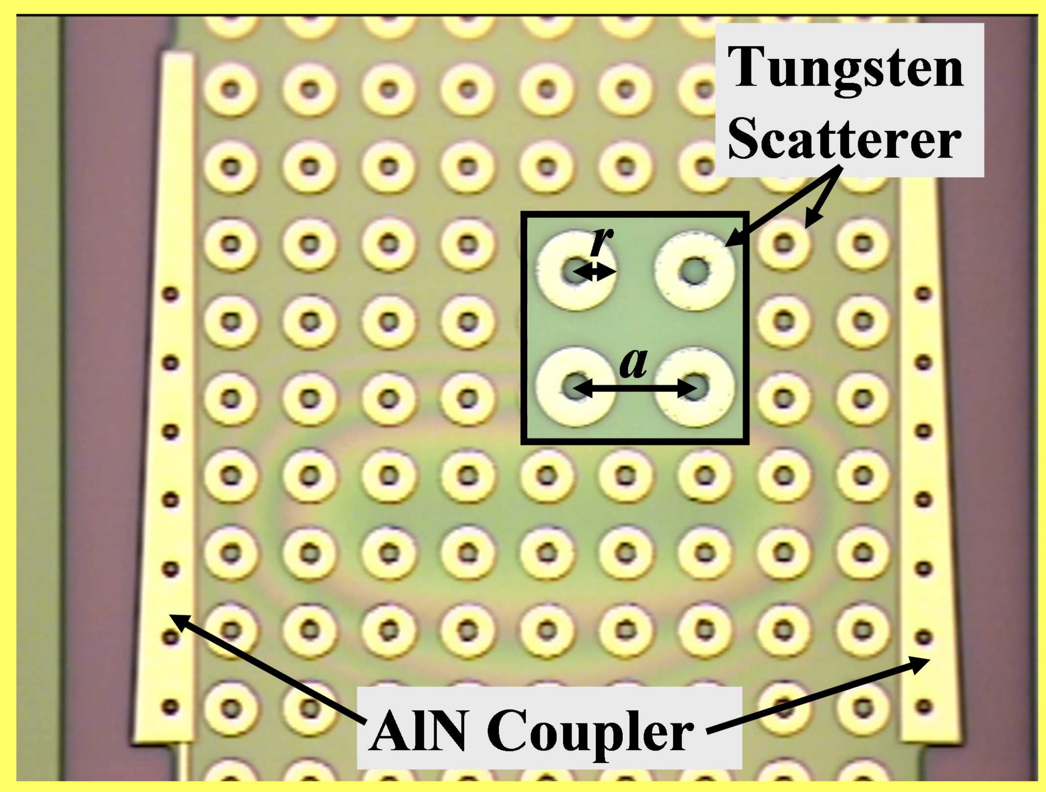
Table of potential ABG material properties. Desired characteristics to form a wide ABG with high isolation are high density and impedance contrast. Other desirable properties are high Q and high velocity.

Device Structure and Operation

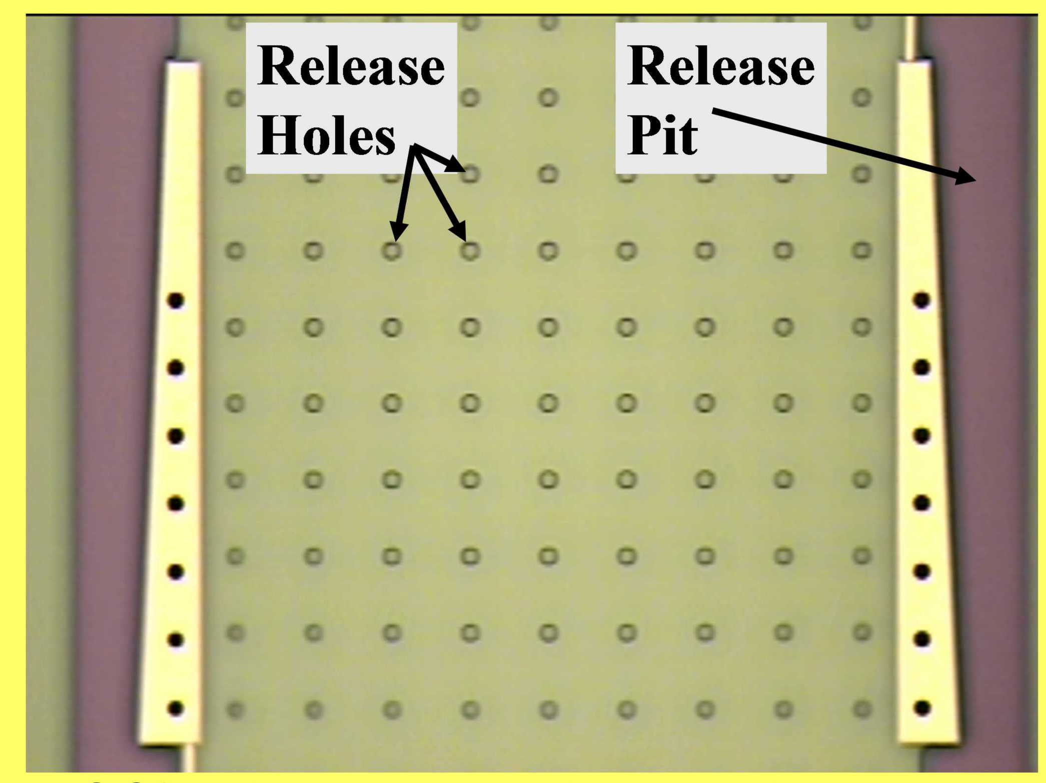
A 67 MHz microfabricated bulk acoustic wave (BAW) square lattice ABG is pictured below. Acoustic energy is coupled into and out of the device in the form of longitudinal acoustic waves using aluminum nitride (AlN) piezoelectric couplers. The couplers are tapered on the end to provide wide drive and sense bandwidths. Acoustic frequencies inside the gap cannot propagate between the two AlN couplers which is measured as a drop in transmission (S21) when compared to the matrix device (bottom right) which has no gap. An SEM image of the 67 MHz BAW ABG is shown in the upper right.



SEM Image of a 67 MHz Acoustic Crystal.



67 MHz µABG device with integrated AlN electro-acoustic couplers. The ABG is realized by including W scatterers in an oxide matrix. Acoustic frequencies within the gap can not pass between the AlN couplers.

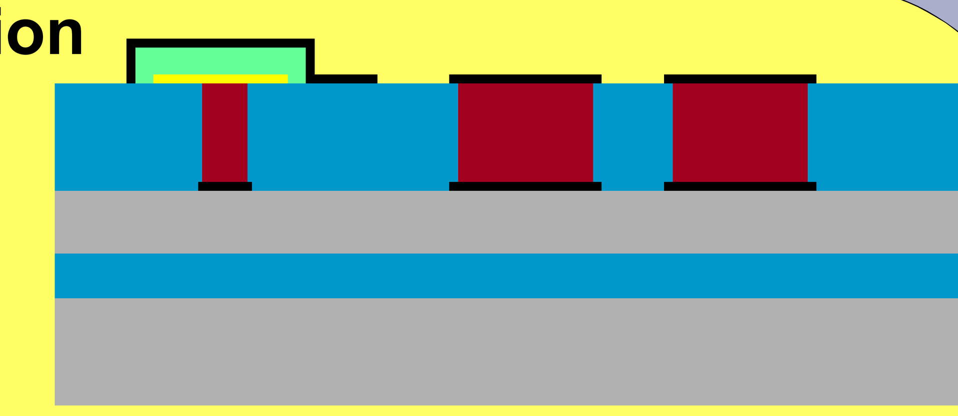


SiO2 matrix membrane with AlN electro-acoustic couplers. This structure contains no ABG and is used as a comparison to characterize µABGs.

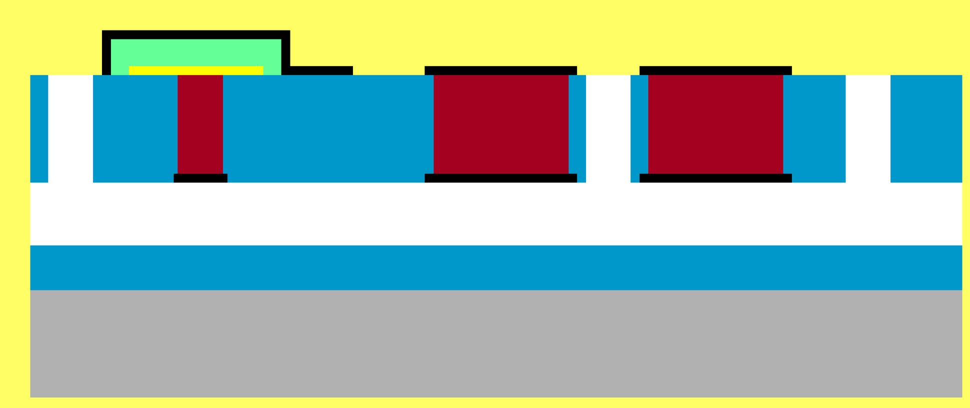
Fabrication

1) Process begins with the deposition of an oxide stop and PolySi release layer. Next Al interconnects are sputtered and patterned and a 4 µm oxide matrix layer is deposited and polished.

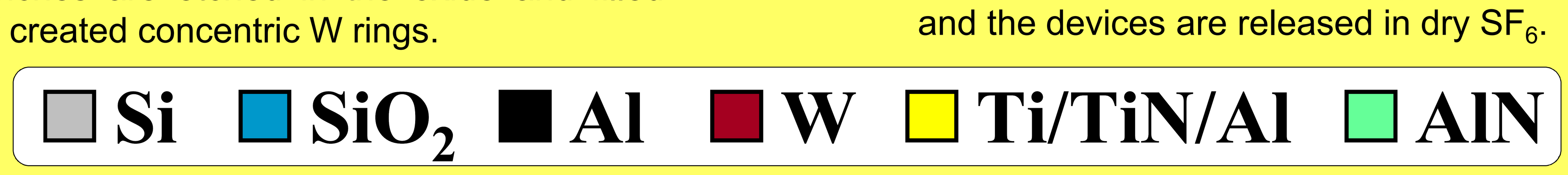
2) Trenches are etched in the oxide and filled with W created concentric W rings.



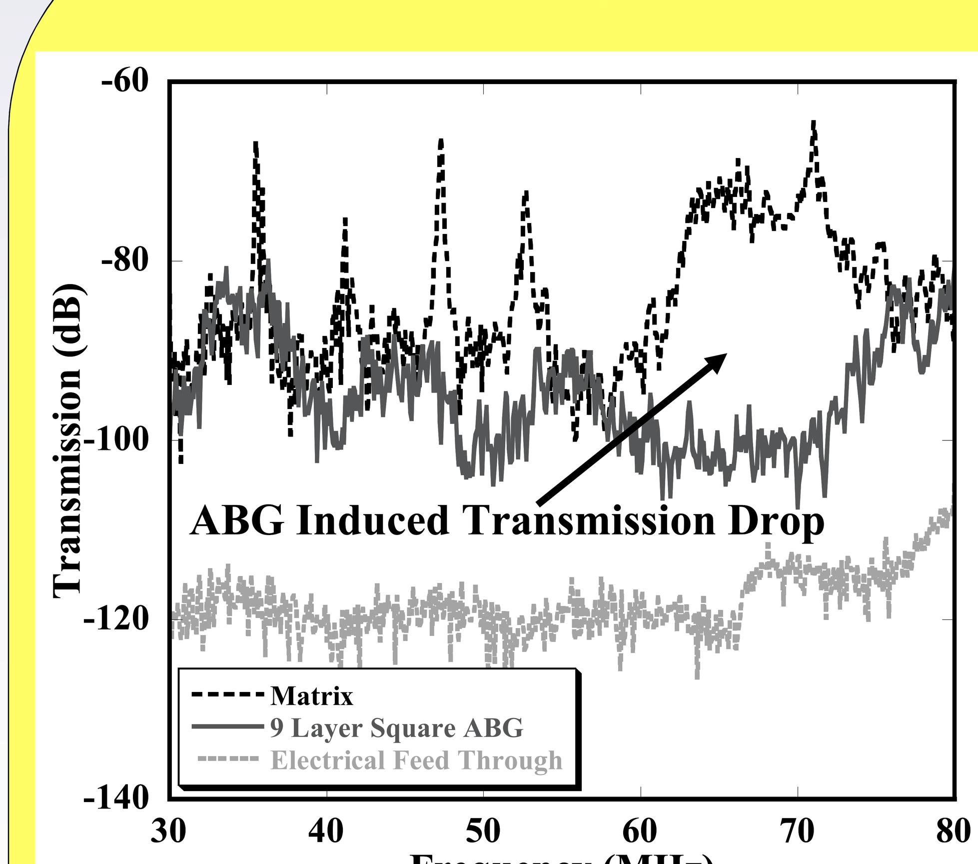
3) The rings formed in 2 are filled in by an additional oxide etch and W deposition. Next the piezoelectric couplers are formed by sputtering and then patterning Ti/TiN/Al, AlN and Al.



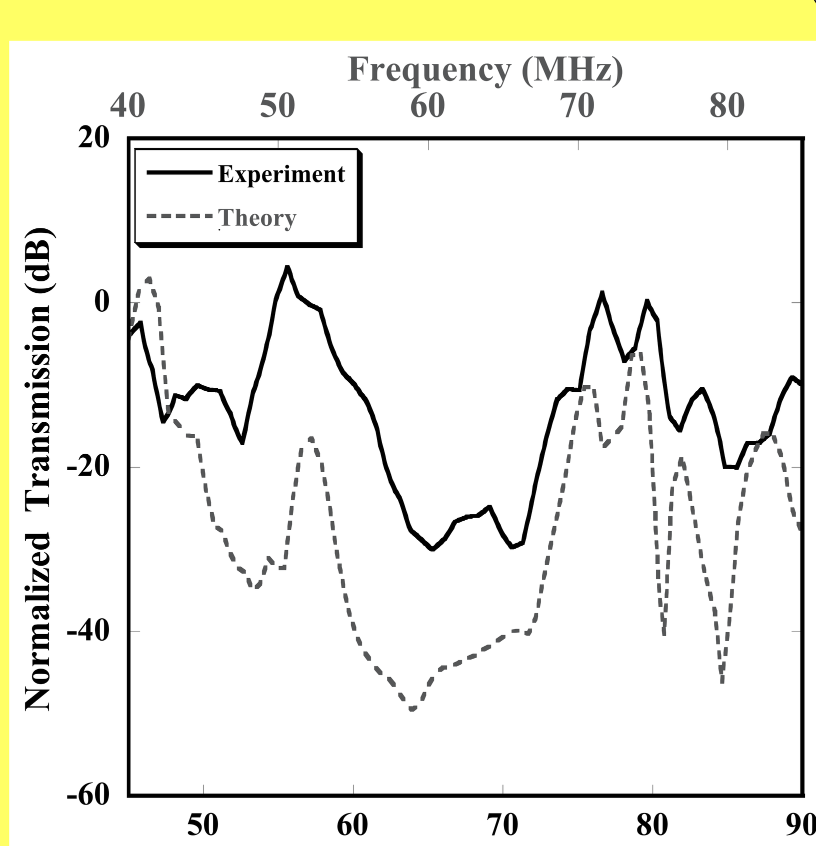
4) Holes are etched to the PolySi sacrificial layer and the devices are released in dry SF_6.



Experimental Measurements

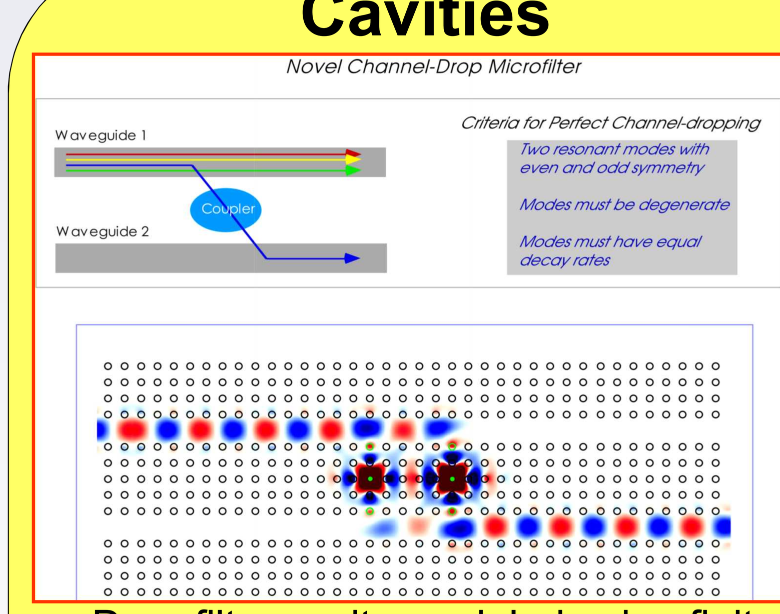


Measured transmission for the 9 layer square lattice ABG (above), the SiO2 matrix (above), and the on wafer electrical feed through of the test set up. A wide (17 MHz) region of acoustic attenuation > 25 dB is observed between 59 and 76 MHz.

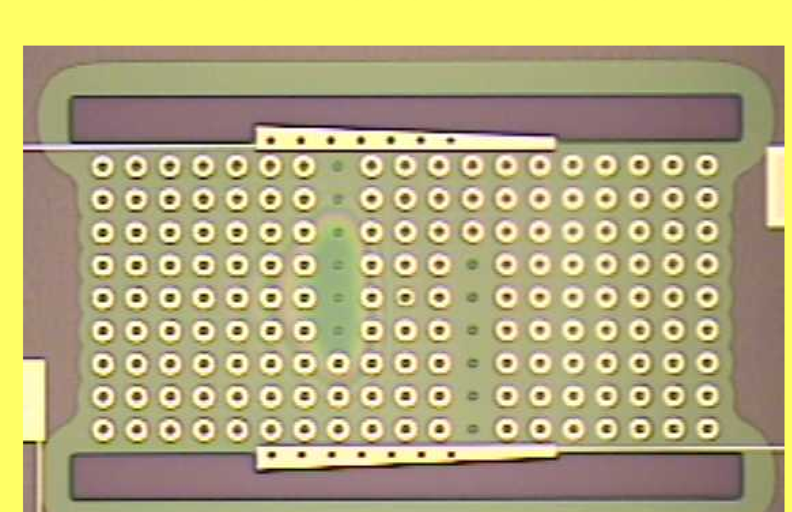


Normalized transmission of the ABG device derived by dividing the transmission of the square lattice ABG by the transmission of the matrix device. The measured bandgap appears between 59 and 76 MHz, 5 MHz higher than is predicted by FDTD simulations.

Cavities

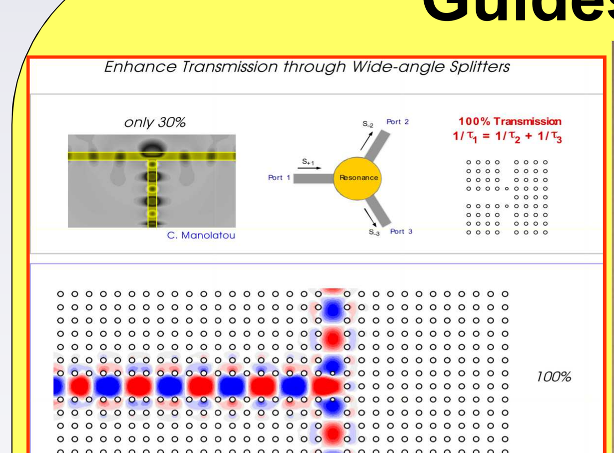


Drop filter cavity modeled using finite difference time domain simulations.

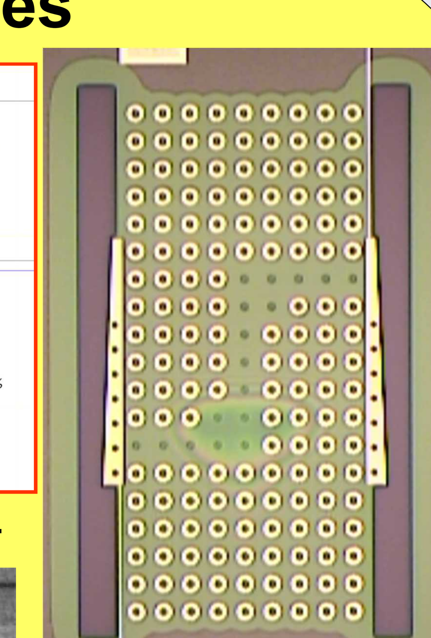


µABG cavity implementation.

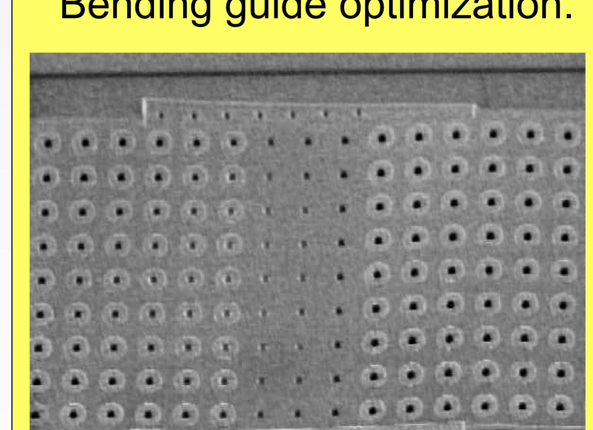
Guides



Bending guide optimization.



µABG waveguide bend.



SEM image of a W3 guide where 3 rows of W rods are removed.

Measured response of the W3 ABG waveguide.