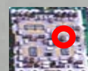
Electro-Mechanical Analysis of AlN Micro-Mechanical Beam Resonators

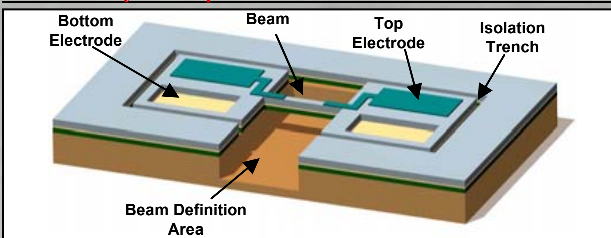
C. Lombardo, A. Wickenden, L. Currano, J. Grim, S. Hullavarad, R.D. Vispute

Enabling Solider Performance



The Army Research Laboratory, in conjunction with the University of Maryland is working to investigate the loss mechanisms present in AlN MEMS resonators. Loss mechanisms were identified using an electro-mechanical model which was analyzed using *Advanced Design System 2003C* by Agilent Technologies. The identification and mitigation loss mechanisms present within these resonators will improve their performance and allow them to be utilized in RF applications such as filtering thus miniaturizing the military radios of tomorrow.

Device Theory and Implementation



Si <100> – Substrate. Selected due to wide use in industry and ease of VLSI integration.

SiO_2 – Structural layer, deposited to a thickness of 5000 Å at 250° C via PECVD or thermal oxidation of the Si wafer.

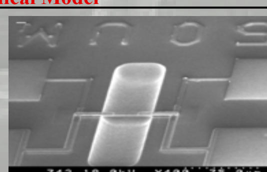
Pt – Conducting medium for top and bottom electrodes. Top: 1600 Å, RF sputtered at 25° C. Bottom: 1600 Å, RF sputtered at 300° C including a 200 Å Ti adhesion layer is sputtered below Pt layer.

AlN – Piezoelectric material that translates electrical signals into mechanical actuation in the clamped-clamped beam, producing movement at its resonant frequency. Sputter deposited at 500° C or PLD deposited at 1050 ° C.

Challenges and Accomplishments

Challenge 1: Develop Electro-Mechanical Model

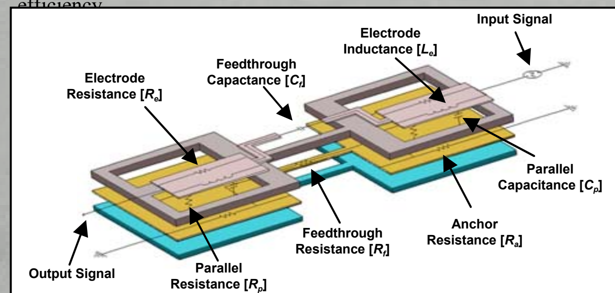
To analyze various beam geometries and materials, a computer model was needed so that fabrication of each new beam revision would not be required. A computer model saves both financial resources and man hours by only fabricating the designs that show promise.



SEM Image of 50 µm Beam Resonator

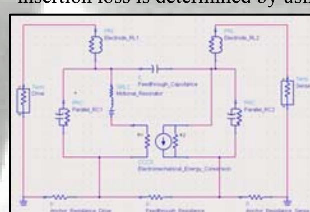
Accomplishment 1: Modified and Updated Existing Model

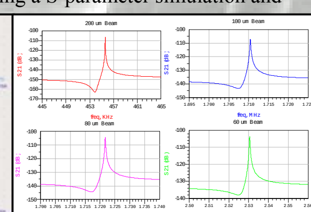
A PZT resonator model and conceptualizations of the beam and parasitic losses developed at UMD [1], were modified and updated so that it would conform to our AlN resonator design. The electro-mechanical model analyzes all of the motional and parasitic elements using lumped electrical components. The motion of the beam is modeled using a RLC resonator with a current controlled current source (CCCS) to model the electro-mechanical energy conversion efficiency.



Parasitic losses are present in the electrodes, anchors, and beam area. The electrodes exhibit a self-inductance and a resistance due to the non-zero resistivity of Pt. There is capacitive and resistive leakage through the piezoelectric material because of the voltage between the upper and lower electrodes, and AlN is not an ideal dielectric. Along the beam area there is a capacitance between the top electrodes due the voltage between them. On the bottom of the beam as well as in the anchor area there is a resistance due to the non-zero resistivity of Pt.

AlN beam resonators with lengths of 200 µm, 100 µm, 80 µm, and 60 µm are modeled using ADS 2003C by Agilent Technologies. The insertion loss is determined by using a S-parameter simulation and





Circuit Diagram of Electro-Mechanical Model Frequency Response of Modeled Resonators

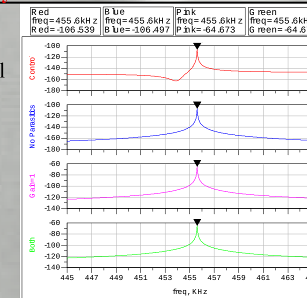
Challenge 2: Determine Loss Mechanisms in AlN Resonators

A computer model allows users to easily change design parameters without the need to fabricate devices to determine sources of insertion loss. The loss mechanisms can be modeled and analyzed to determine how to remove insertion loss from the resonant structure.

[1] B.A. Lynch, *Electromechanical Modeling of Piezoelectric Microresonators*, Masters Thesis, University of Maryland, 2002.

Accomplishment 2.1: Loss Analysis of AlN Resonators

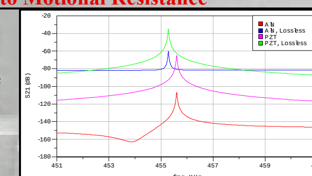
AlN resonators were modeled without the presence of parasitic losses and the electro-mechanical energy conversion losses (CCCS gain=1). The parasitic losses account for < 0.1 dB of insertion loss. By eliminating the electro-mechanical conversion loss, the insertion loss is decreased by 40 dB, but 64 dB of insertion loss still remains. This shows that there are other mechanisms contributing to insertion loss.

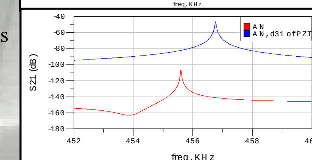


Loss Analysis of AlN Resonators

Accomplishment 2.2: Loss due to Motional Resistance

Losses due to the motional resistance, which are dependent on the Young's Modulus and the piezoelectric coefficient (d_{31}), dominate the insertion loss present within the resonator. In this design PZT has a motional resistance of 5 kΩ where AlN has a resistance of 171 kΩ. This difference shows a improvement of 45 dB in insertion loss. By artificially replacing AlN's d_{31} with PZT's d_{31}, we can see that the low d_{31} is degrading the performance of resonators.

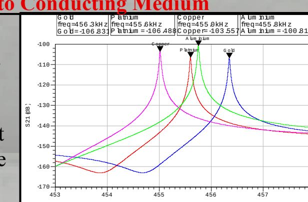




AlN and PZT Comparison

Accomplishment 2.3: Loss due to Conducting Medium

Losses due to the conducting medium are modeled for Pt, Au, Cu, and Al. The insertion loss is related to the density of the conductor with Al being the least dense and lossy and Au being the most dense and lossy.



Loss Comparison of Various Conductors

Conclusion

Due to its large Young's Modulus, AlN provides a high theoretical maximum frequency which is believed necessary for RF applications. Our analysis shows that the elimination of parasitic and conductor losses will not achieve the desired resonator performance. The only way to greatly decrease the insertion loss is to find a way to enhance AlN's d_{31} or to change resonator designs. AlN FBAR's have exhibited acceptable insertion losses, so AlN still shows promise as an active material in other types of RF resonators.