Electromechanical Modeling of a new class of contour-mode AlN MEMS RF resonators

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What is a RF MEM resonator?

- Radio Frequency Micro-electro Mechanical resonator.
- Device that functions at a certain frequency, based on the geometry of the device.
- Used for filtering and frequency setting in wireless communications.
Contour-mode configuration of the resonator

- Contour-mode allows batch fabrication of arrays of piezoelectric resonators with different frequencies on a single chip.
- A contour-mode resonators fundamental frequency is defined by in-plane dimensions.
- One-port configuration has one input.
- Two-port configuration has one input and one output.
Project Goal Overview

- Fully understand the electrical response of the device:
  - To improve resonator layout
  - To create model libraries
- These devices, developed in the shape of disks, plates or rings, have the unique features, provide a wide range of frequencies and the ability to interface directly with 50 Ω systems.
Analogy between mechanical and electrical domain

piezoelectric crystal  \rightarrow  spring-mass mechanical system  \rightarrow  electrical equivalent (BVD model)  \rightarrow  characteristic sharp resonance

\begin{align*}
Q &= \frac{f_0}{BW_{10\%}} \\
\omega_0 &= \frac{1}{2m} \sqrt{\frac{K}{M}}
\end{align*}
Advantages of resonator configurations

- **One-port:**
  - Avoids unwanted modes
  - Minimizes motional resistance
  - Maximum energy is coupled

- **Two-port:**
  -Eliminates all kinds of feedthrough
  -Maintains high electromechanical coupling
Disadvantages of resonator configurations

- **One-port:**
  - Suffers parasitic feedthrough at high frequency

- **Two-port:**
  - Spurious modes are encountered
  - Fabrication process is more complicated
Parameter Analysis

Effect of parallel capacitance on resonator response curve.

\[ f_a = \frac{1}{2\pi} \sqrt{\frac{1}{LC} + \frac{1}{LC_o}} \]
Effect of the capacitance and inductor on the resonator response curve.
Parameter Analysis

Resistance effect on the curve of the resonator response curve.
Preparation of the samples

- Devices analyzed were previously manufactured, just needed to be cleaned and released.
- Cleaning: Plasma etching with $O_2$ to remove the photo resist layer.
- Releasing: Plasma etching with $SF_6$ to release vibrating element from substrate.
Measurement procedure

\[ Y = \frac{1 - S_{11}}{50 \cdot (1 + S_{11})} \]

\[ Z_R = R \]
\[ Z_A = \frac{1}{w_A^2 \cdot C_0^2 \cdot R} \]
\[ w_A^2 - w_R^2 = \frac{1}{L \cdot C_0} \]
\[ w_R = \frac{1}{\sqrt{L \cdot C}} \]
Admittance measured from Network Analyzer and admittance obtained from electrical parameters extrapolated.
Electrical parameters of 2-port device

Extrapolated parameters obtained from 2-port device compared to NA measured admittance.

- R = 2186 Ω
- C0 = 1.9229 \times 10^{-13} F
- L = 11.678 \times 10^{-4} H
- C = 3.47 \times 10^{-13} F
Conclusion and Future plans

- The extrapolation technique is a good first approximation for the admittance curve; improvement could be achieved by using more critical points and adding elements to the model.

- Bad measurements due to:
  - Contact issues (probes)
  - Probably oxidized devices (not manufactured recently)

- Use of features available at the probe station
  - Vacuum pump (down to 5 mTorr)
  - Reduction of temperature (300 K – 4.5 K)
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Questions?