Temperature Compensated AlN based SAW Simulation using COMSOL

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Surface Acoustic Wave (SAW) Devices

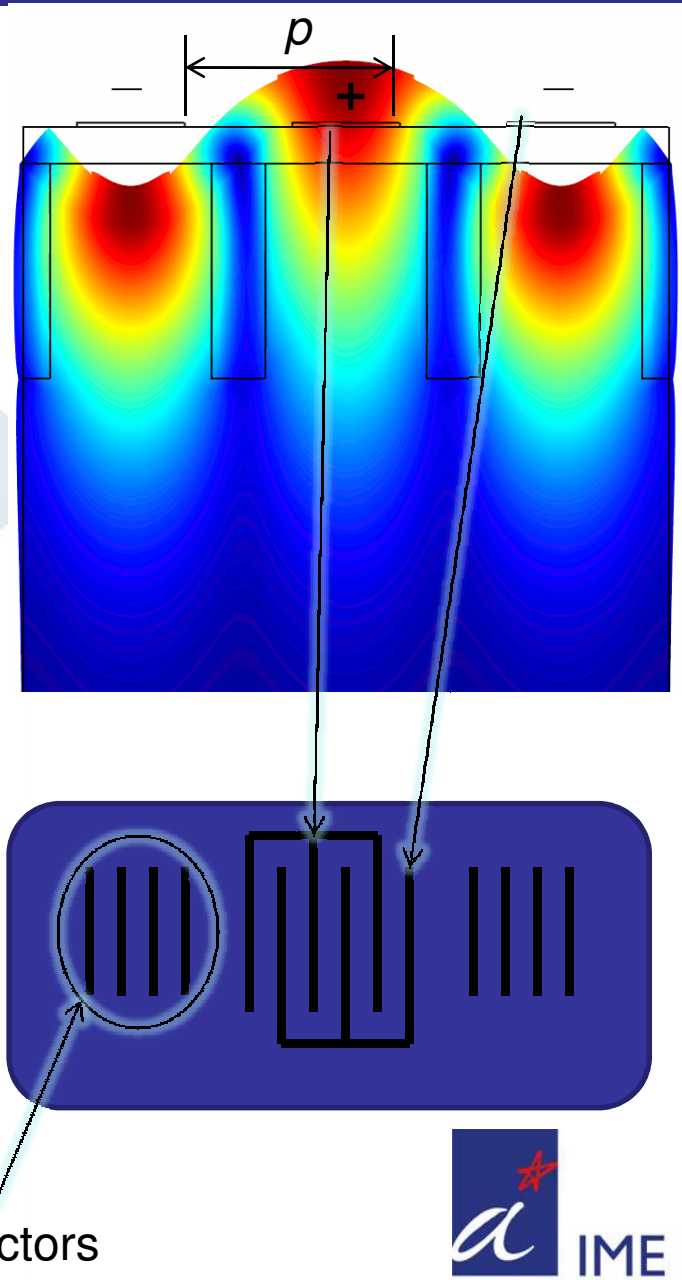
- Piezoelectric Material
  - Aluminum Nitride (AlN)
  - Lithium Niobate ($LiNbO_3$)
  - Quartz
- Resonant Frequency

$$f = \frac{v}{2p}$$

v ← Speed of sound (material dependent)

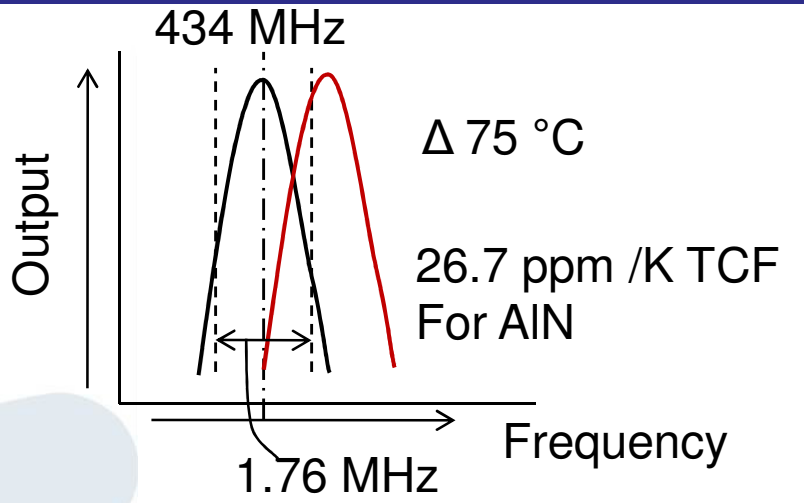
p ← Electrode Pitch (Fabrication)

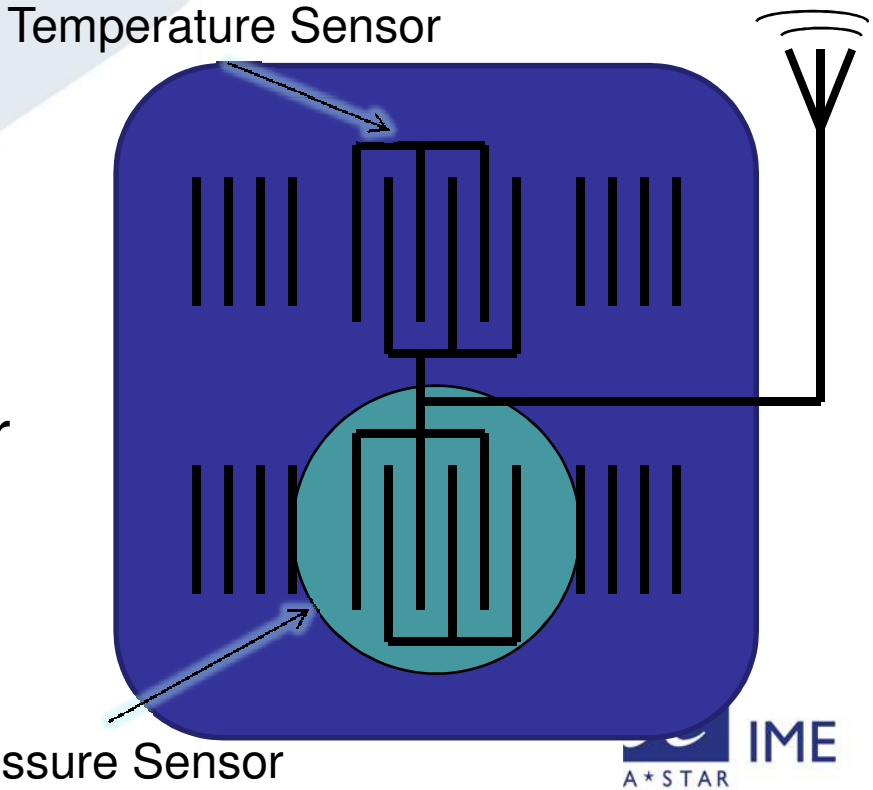
- Uses:
  - RF filters
  - Wireless sensors



Why Do We Need Temperature Compensation?

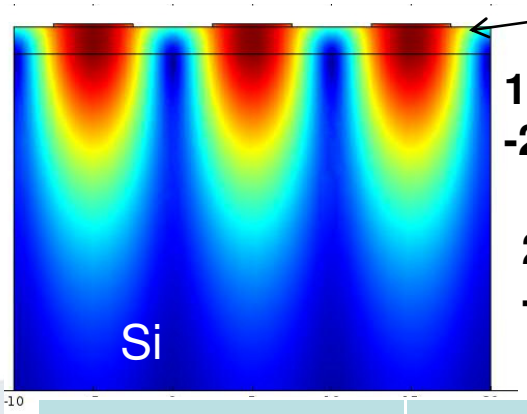
- **Hand Phone RF filters**
  - Stringent requirements for frequency stability
    - IEEE Std 802.16-2004 ± 10 ppm
- **Sensor networks**
  - ISM band limited to 1.76 MHz bandwidth
  - Limited number of sensors
  - Need temperature reference which further limits the number of sensors





Proposal and Method

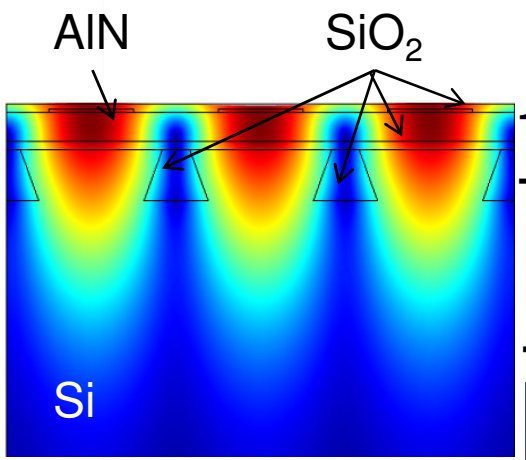
- Place SiO_2 at the vibration nodes
- Use developed Si DRIE to form precise trenches
- COMSOL Simulations
  - Use published values of thermal expansion and TCE for the different materials to simulate TCF of the structure
  - Run multiple simulations to find Zero TCF line for different frequencies
  - Investigate SiO_2 trench shape affect on 1st and 2nd order TCF



1st order
-26.7 ppm/K

2nd order
-24.7 ppb/K²

Material	Effect on TCF
AlN	↓
Si	↓
SiO_2	↑



1st order
+0.8 ppm/K

2nd order
-1.8 ppb/K²

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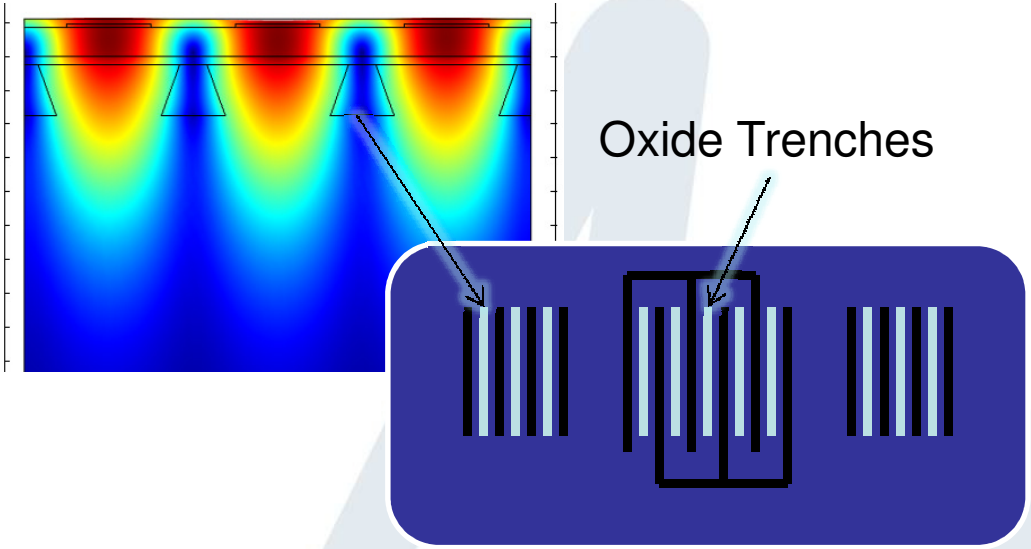
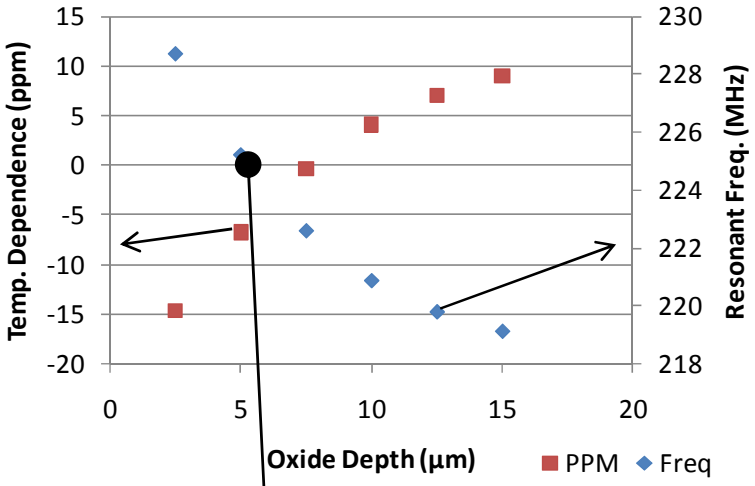
Simulation Method

- Basic Structure
- Boundary Conditions
- Integration of Temperature Dependent Coefficients
- Thermal Expansion
- Parametric Investigation

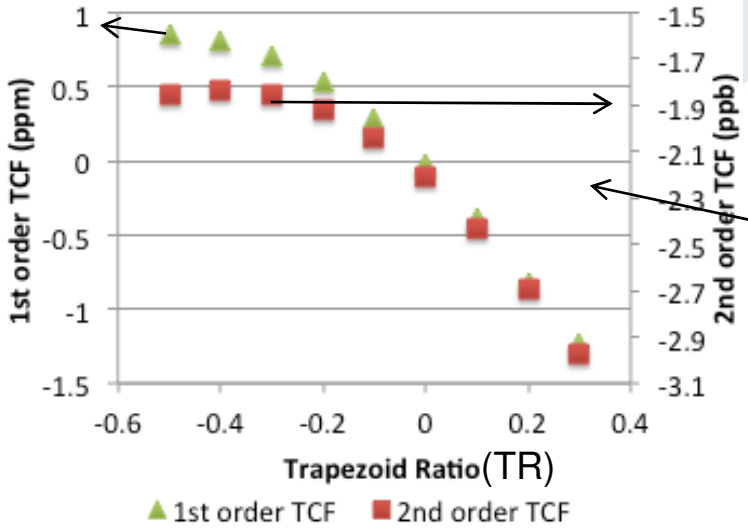
Simulation Results

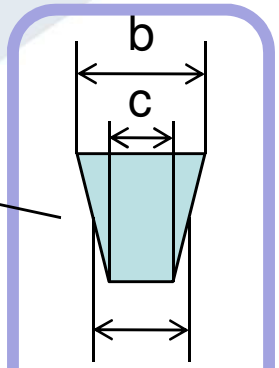


1st order TCF for different oxide depths for oxide width of 3 µm



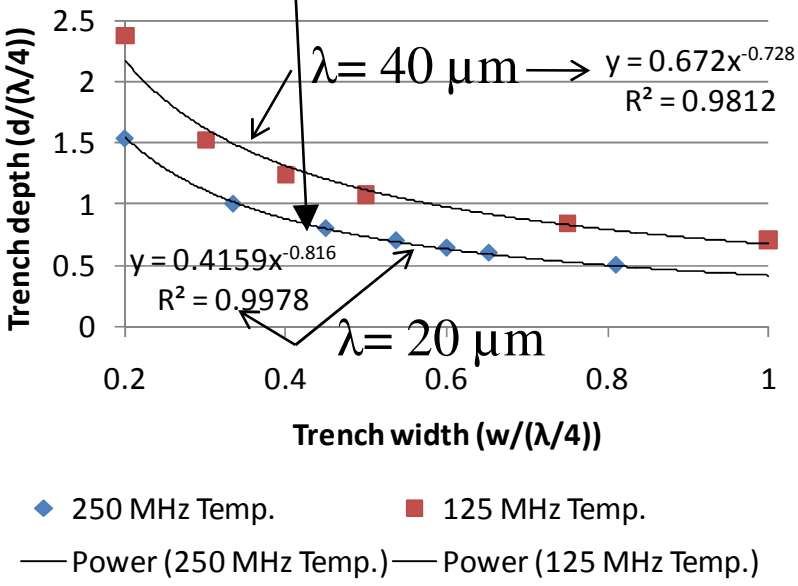
Trapezoid ratio 1st and 2nd order TCF





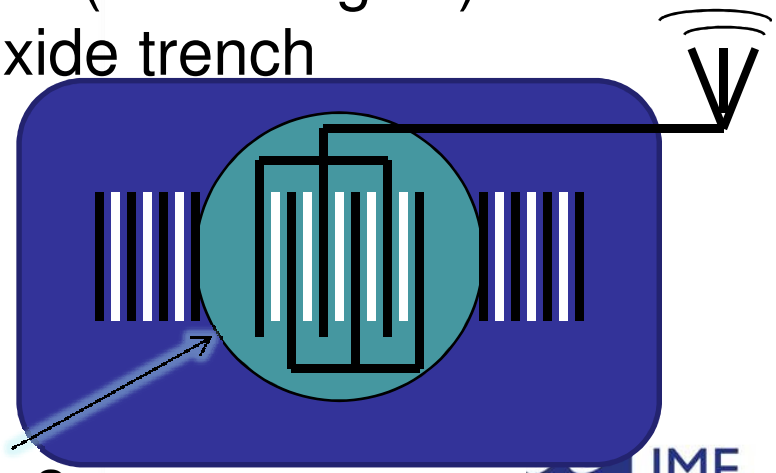
b=a(1+TR)
c=a(1-TR)

1st order 0 TCF Line



Conclusion

- Applications to RF filters, for extended temperature operation, beyond 100 ℃ (where 2nd order TCF also needs compensation)
- Passive wireless systems where there is a small bandwidth
- Improved readout accuracy for wired systems, no need for temperature sensor
- 1st order TCF can be customized
- On the same die multiple frequencies (wavelengths) can be compensated by changing the oxide trench dimensions



Pressure Sensor

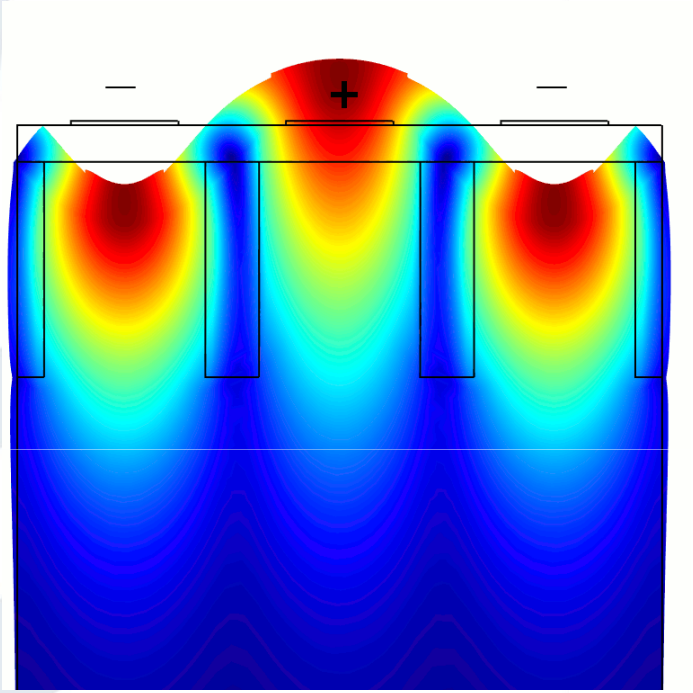
Parametric Investigation

- Add Some Plots

Things To Do COMSOL

- Full 3D simulation of a pressure sensor and SAW wave
- Map a stress distribution from 3D simulation onto a 2 simulation to study the result.

Questions?



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The Current State of the Art

- **Quartz**
  - Higher insertion loss
  - 2nd order TCF coefficient (30-40 ppb/K²)
- **SiO_2 on the surface**
  - For SAW devices, only achieves optimum TC for a certain frequency
  - No investigation of second order effects
- **Active TC using integrated heater**
  - Power needed to run heater
  - Broader temperature ranges require higher power