Modeling MEMS Resonators for High-Temperature Applications

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ABSTRACT

Micro-electromechanical systems (MEMS) resonators are used in a variety of devices to act as frequency references, and, in some applications, frequency stability is required for temperatures well above 300°C. The material properties of silicon carbide (SiC) imply that SiC resonators could perform better at high temperatures than the current polysilicon resonators. In this project, SiC and polySi MEMS resonators are designed and modeled to predict their frequency stability over temperature. The predictions are compared to determine the possible advantages of SiC in high-temperature resonator applications.

MOTIVATION

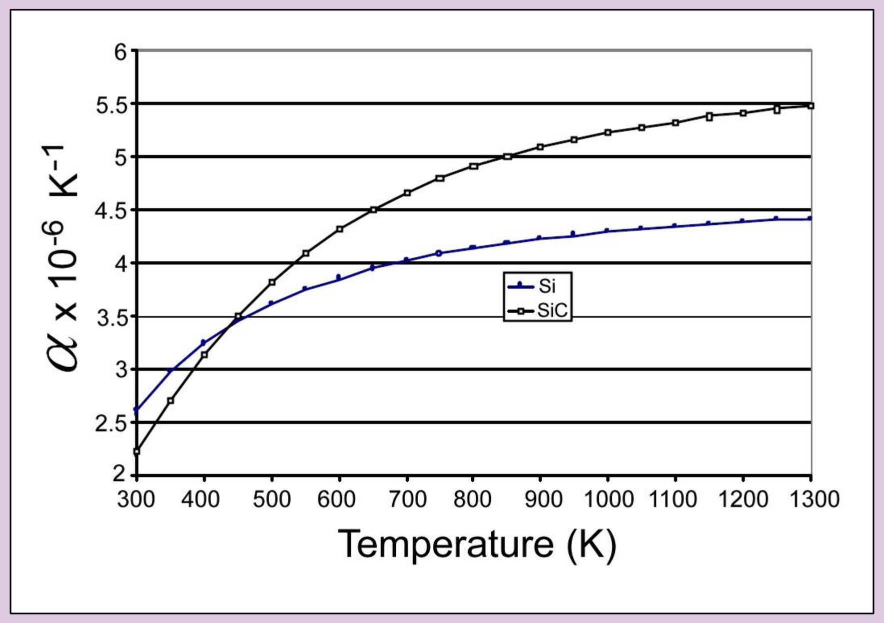
- Sensors need frequency references to convert analog signal to digital
- Current frequency references
  - Quartz Crystals: most common, but unusable above approx. 140°C
  - Polycrystalline Si MEMS: used for *high-temperature* applications, looking for improvement of temperature stability
- Possible High Temperature Improvement: use silicon carbide (SiC) as MEMS resonator material

MATERIAL PROPERTIES

Parameters that affect MEMS resonator frequency (f_o)

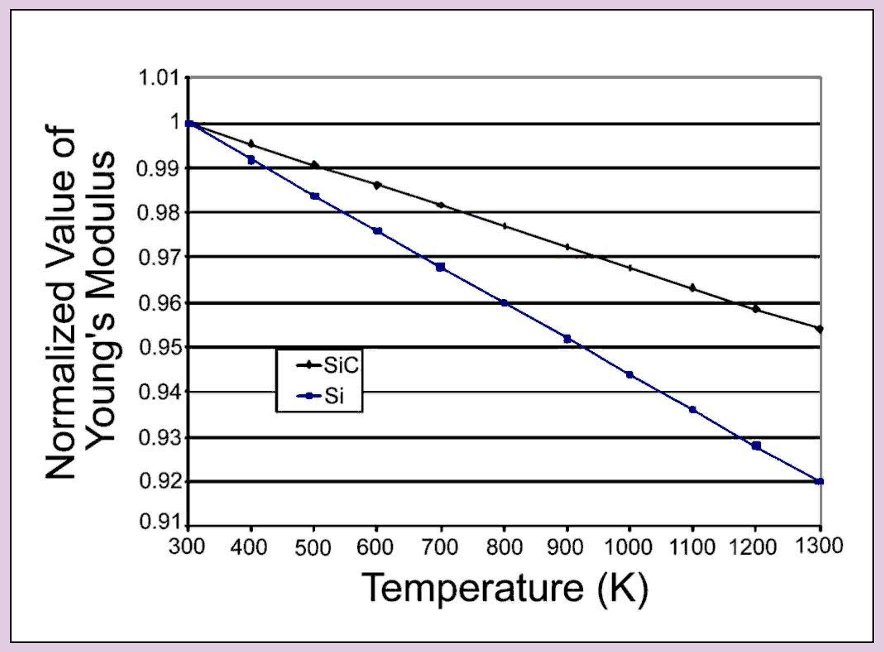
- Geometric dimensions
- Effective spring constant of structure

Temperature-dependent material properties determine these parameters:



Coefficient of Thermal Expansion (α):

- Causes changes in **geometric dimensions** over temperature
- α of SiC varies more over temperature than α of polySi



Young's Modulus (E):

- Key parameter in **effective spring constant** of structure
- E of SiC changes less over temperature than E of polySi

Graphs from R.G. DeAnna, S. Roy, C.A. Zorman, and M. Mehregany, *Proceedings of the International Conference on Modeling and Simulation of Microsystems*, San Juan, Puerto Rico, 1999, p. 644

GOALS

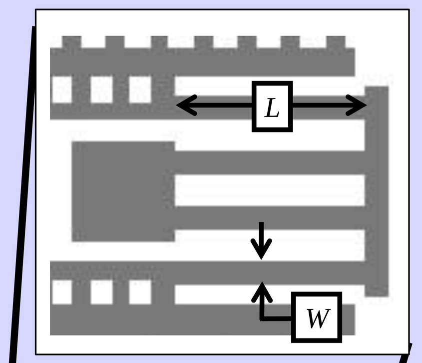
- Design two single-mask MEMS resonator geometries
  - Resonant frequency appropriate for sensors: 1-10 MHz
  - Each geometry designed for both polySi and SiC
- Confirm design calculations using finite-element-modeling
- Predict frequency stability over temperature
- Compare predictions to determine superior device material

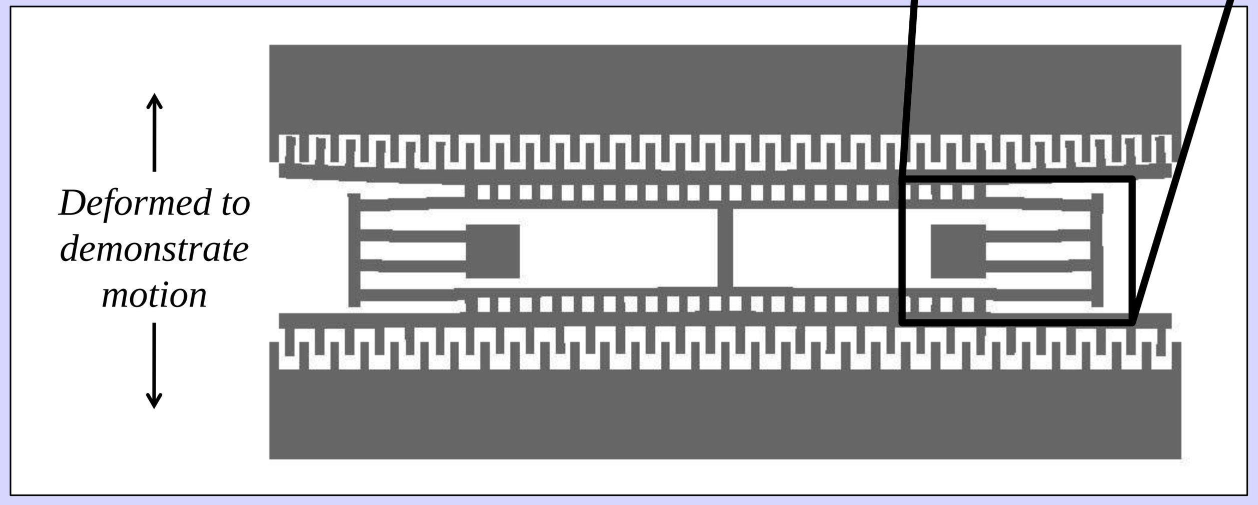
DESIGN: FOLDED-BEAM RESONATOR

- Resonant Frequency Expression:

$$f_0 = \frac{1}{2\pi}\left(\frac{2Eh(W/L)^3}{M_{eff}}\right)^{1/2}$$

- Advantage
  - Comb fingers produce large signal
- Disadvantage
  - Difficult to design for higher frequencies
- Designed Resonant Frequencies
  - 1.1 MHz (SiC)
  - 0.9 MHz (polySi)



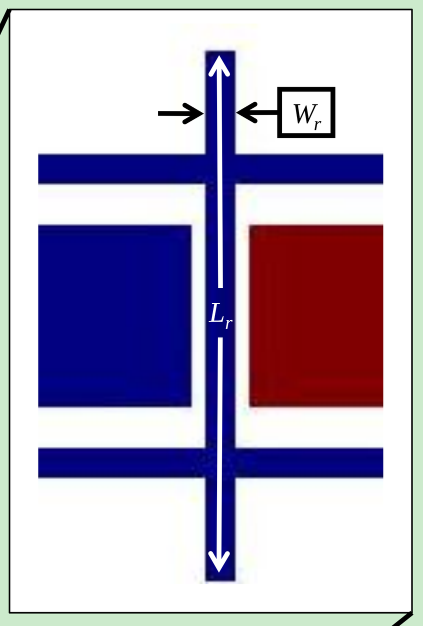


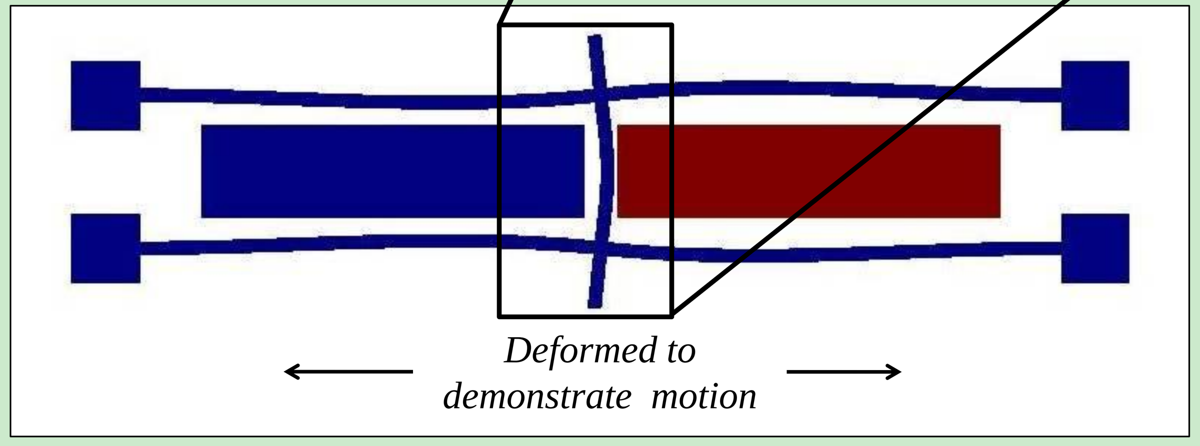
DESIGN: FREE-FREE BEAM RESONATOR

- Resonant Frequency Expression:

$$f_0 = 1.03\sqrt{\frac{E}{\rho}}\frac{W_r}{(L_r)^2}$$

- Advantages
  - Easy to design for high frequencies
  - High Q-factor
- Disadvantage
  - No comb fingers → weak signal
- Designed Resonant Frequencies
  - 9.0 MHz (SiC)
  - 7.4 MHz (polySi)





FINITE ELEMENT MODELING

- Folded Beam Resonant Frequency
  - SiC: 1.08 MHz modeled (1.1 MHz calculated)
  - PolySi : 0.88 MHz modeled (0.9 MHz calculated)
- Free-Free Beam Resonant Frequency
  - SiC: 2.5 MHz modeled (9.0 MHz calculated)
  - PolySi : 2.0 MHz modeled (7.4 MHz calculated)
  - Unlike analytical expression, finite-element modeling takes tether mass into account, causing disagreement

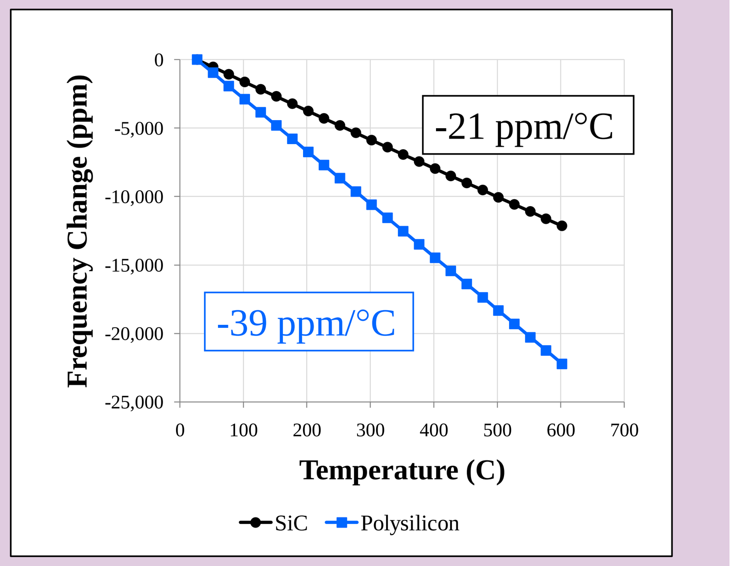
RESULTS: TEMPERATURE STABILITY

Calculated f_0 vs. T

- For both SiC and polySi versions of each geometry
- Taking into account changes in E and α

Folded Beam

- SiC: -21 ppm/ °C
- PolySi: -39 ppm/ °C
- f_0 of SiC varies less over temperature than f_0 of polySi for this geometry



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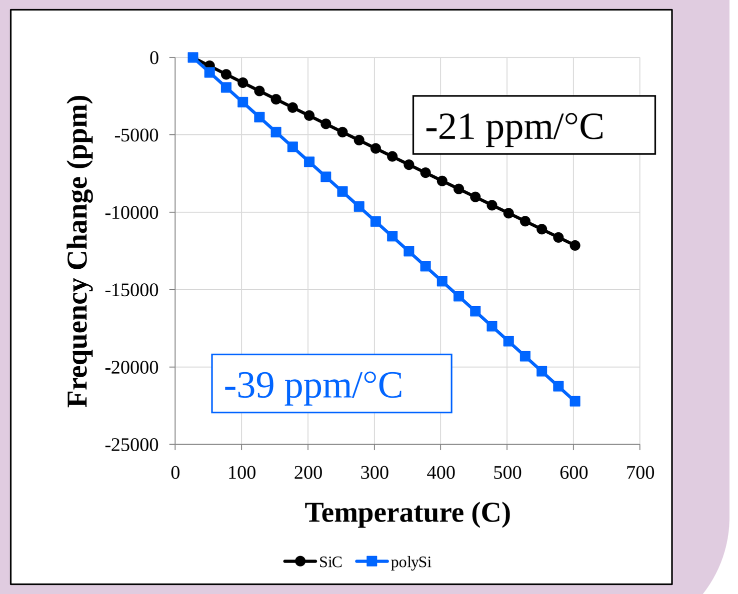

CONCLUSIONS AND FUTURE WORK

Advantage of SiC

- Because of the nature of resonators, thermal expansion cancels in resonant frequency expression
- Superior performance of E over temperature for SiC results in more stable SiC MEMS resonators

Future Work

- Fabricate resonators in both SiC and polySi
- Test resonators, determine accuracy of model, and compare device materials' performance

ACKNOWLEDGEMENTS

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