Stiffness Trimming of High Q MEMS Clocks and Oscillators

A high resolution method to trim the resonance frequency of high-Q single-crystal silicon MEMS resonators coated with a thin-film germanium layer

Georgia Tech inventors have developed a new method to optically trim the resonance frequency of a low-loss micromechanical silicon resonator coated with a thin-film germanium (Ge) layer. A focused UV laser beam locally heats Ge to high temperatures, enabling selective micro-crystallization of SiGe. The stiffness of the optically crystallized SiGe regions decreases with increasing concentration of Ge. These stiffness variations lead to an overall downward shift of the resonance frequency. Large trimming range is demonstrated for low-frequency out-of plane resonant modes. In addition, fine frequency trimming of in-plane Lame mode resonators is achieved without introducing any damping throughout the trimming process, enabling fine frequency control of high-Q micro-resonators. The resonance frequency of a trimmed germanium-coated silicon resonator remains stable after being heated to 450°C for 30 minutes in a Rapid Thermal Annealing (RTA) chamber. Deposition of Ge on Si and growth of SiGe crystals has not introduced any significant damping in low-loss bulk-mode resonators.

Summary Bullets

- High resolution stiffness trimming of high-Q Lame mode silicon resonators
- Stable frequency characteristics of Ge-coated Si resonators at high processing temperatures
- Achieves trimming without introducing any damping throughout process

Solution Advantages

- High resolution stiffness trimming of high-Q Lame mode silicon resonators
- Stable frequency characteristics of Ge-coated Si resonators at high processing temperatures
- Achieves trimming without introducing any damping throughout process
- Material and set-up are foundry-friendly and can be scaled up

Potential Commercial Applications

- Control the resonance frequency of resonators used in high-accuracy time keeping
- High-accuracy mass balance applications
- Post-packaging trimming to compensate frequency variations

Background and More Information

From burning candles that tracked time in pre-historic times to Quartz clocks that synchronize electrical signals in everyday circuits, timekeeping is at the heart of much of civilization’s progress. To date, Internet of Things (IoT), Vehicles, Wearables and many other sectors crave for clocks that are tiny, precise and low-power (i.e. longer lifetime). Ensuring that the frequency of the clock stays within its targeted range uses a lot of power and shortens the lifetime of the clock. There is a need for a robust design, low-power actuation, and permanent frequency control that will drive the clock.

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IP Status

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Publications

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Figures

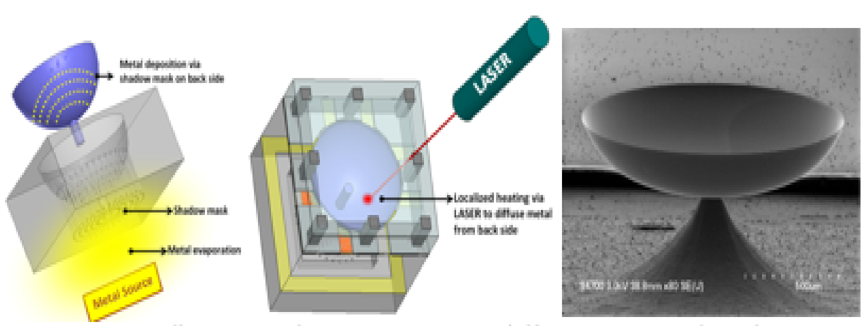

Figure 1: Pulsed laser stiffness trimming of packaged MEMS resonators (left) Backside deposition of a thin-film layer on the MEMS resonator prior packaging (center) Post-packaging frequency trimming via exposure of the thin-film layer to a focused laser beam (right) Scanning electron microscope image of a 3D MEMS resonator that can be trimmed with this technology.

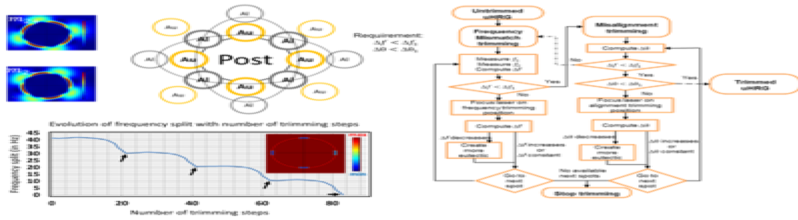

Figure 2: Numerical simulations of automatic frequency trimming. (top left) Strain energy density distribution dictates the relative locations of the thin-film dots depending on the Young's modulus of the binary compound they form with Silicon. (right) Algorithm to shift the frequencies while mode matching Coriolis-coupled modes in a MEMS gyroscope. (bottom left) Screen shot of a video where trimming is done automatically in a numerical simulation where the strain energy density was initially unknown.

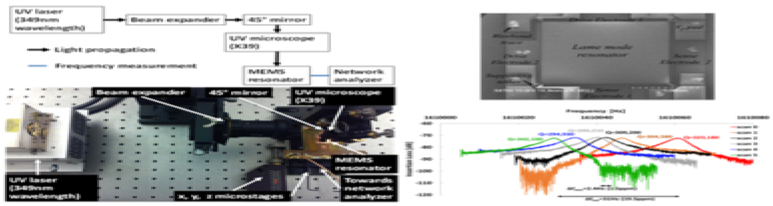

Figure 3: Experimental validation of pulsed laser stiffness trimming (left) Schematic and picture of a laser set-up suited for frequency control of MEMS resonators. (top right) Image of a square-shaped low dissipation Lame mode resonator with integrated capacitive gaps. (bottom right) Frequency shifting of high Q (~300,000) modes over 30ppm with a 2-4ppm step size.

Table 1: List of elements that form a binary eutectic with silicon

Material	CMOS/ AL-Ge compatible	Eutectic Temperature (C)	Melting point (C)	Young's modulus GPa
Silicon	Yes	NA	1414	169
Germanium	Yes	938	938	102
Aluminum	Yes	580	660	70
Silver	No	835	961	83
Beryllium	Yes	1085	1287	287
Zinc	No	419	419	108
Cadmium	No	321	321	50
Antimony	No	630	321	55
Gold	No	363	1064	78

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