Temperature Stable Silicon and Piezo-MEMS for Timing and Frequency Reference Applications

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Silicon MEMS resonators for timing and frequency reference applications have taken significant performance steps in recent years. Of fundamental importance is the temperature stability of Si versus quartz. We have developed passive compensation of Si based on modifying materials properties. In many-valley semiconductor like Si the electronic properties exhibit a coupling to the elastic constants that can be tailored by doping to yield temperature stable resonance modes in properly chosen resonator geometries. The temperature stability can be reached not only in the linear temperature coeffiecient of frequency but also in the second order resulting in Si MEMS resonators on par with quartz in temperature stability: we report frequency within ±15 ppm over -40 to +85 C range (Fig. 1.)

As Si is not intrinsically piezoelectric like quartz, the driving force for oscillation has to generated either electrostatically, thermally, or by an integrated piezoelectric thin film transducer. We have developed a versatile AlN-on-CSOI piezoMEMS platform with various advantages and some trade-offs as compared to electrostatic MEMS. We report work in improving the electromechanical coupling coefficient K^2 of the resonators up to 0.3 % via using piezo-drive and discuss the other benefits and drawbacks of the approach. Other applications of the piezo-MEMS platform, including the possiblities opened up by introducing ScAlN with much stronger piezoelectric effect than that of AlN in strength are discussed.

As an application demonstration, we report an agressively miniaturised integrated generic timing system performing real time clock and on-demand programmable frequency synthesizer developed in the Go4Time project. This system utilises piezo-actuated AlN-on-CSOI MEMS platform to co-integrate a 440 kHz tuning fork resonator for the RTC function with an 26 MHz bulk wave resonator for the frequency reference, metal-based wafer level sealing, and Cu through-Si vias. The oscillator IC is matched in size to the MEMS die.

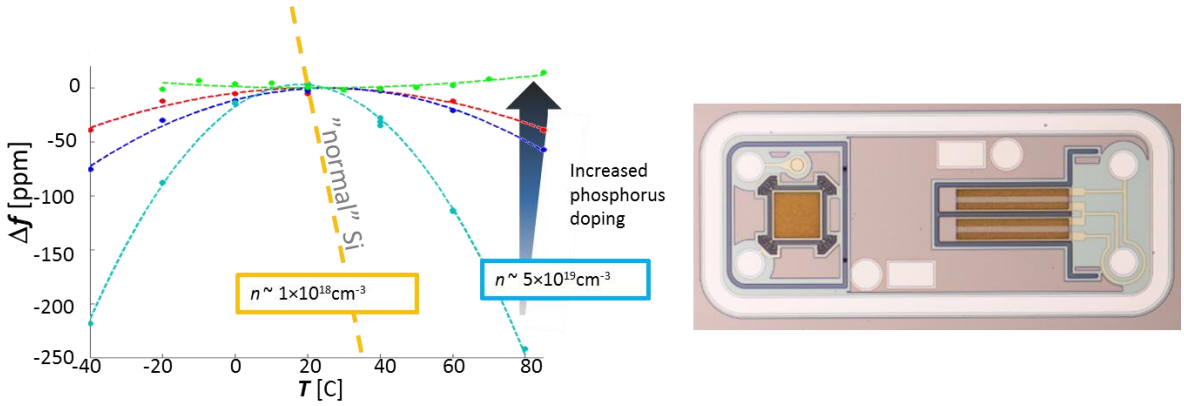

Figure 1 : Frequency vs. Temperature curves for resonators having different levels of compensation doping (left). Photograph of the Go4Time dual-resonator chip with a 26 MHz square resonator and 440 kHz tuning fork, both piezo-driven (right).