Experimental demonstration of Surface Acoustic Wave propagation on α-GeO$_2$ for wireless, passive sensor design

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***Abstract*—On the path towards developing passive transducers for wireless sensing in high temperature (>560°C) environments, we experimentally demonstrate the design, manufacturing and interrogation of resonators patterned on GeO$_2$ substrates.**

***Index Terms*—GeO$_2$, surface acoustic wave, resonator, passive wireless sensor**

I. INTRODUCTION

Passive sensors using the linearity of piezoelectric effects for far-field wireless cooperative target short range RADAR measurement have been investigated for probing quantities in environments incompatible with a wired connection, whether moving targets or harsh environmental conditions. High temperature monitoring matches the latter context, with most investigations focusing on langasite family materials concluding to the long-term instability of this subtrate when exposed to high temperature. In this investigation, a material of the same crystal class (point group 32) as α-quartz and without phase transition up to its melting temperature (1116°C) – α-GeO$_2$ – is considered as the substrate for designing and realizing a passive transducer compatible with short range RADAR interrogation.

II. SURFACE ACOUSTIC WAVE PROPAGATION: SIMULATION

The propagation of Surface Acoustic Waves has been investigated numerically previously [1]. In this work, the mechanical and electrical constants extracted from [2] are used to define the mixed matrix acoustic wave propagation and reflection parameters [3]. Based on this analysis, and considering aluminum electrodes selected for their adequation to cleanroom manufacturing technologies for repeating multiple prototyping steps on a given substrate, the electromechanical coupling coefficient map, acoustic velocity map, and beam steering map are computed.

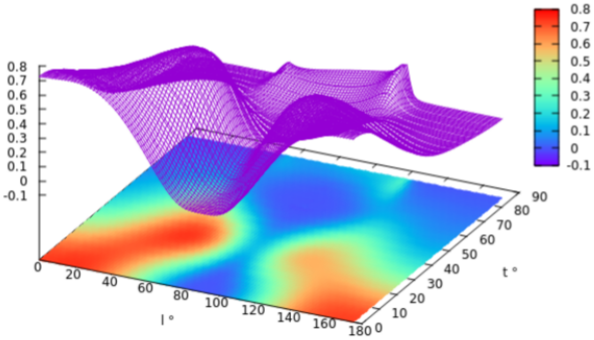

Fig. 1. Electromechanical coupling coefficient (%) of Rayleigh waves for α-GeO$_2$ $(YXlt)/l/t$ as a function of cut angle l and propagation angle t.

The electromechanical coupling coefficient K^2 is observed (Fig. 1) to remain below the 1% range, with a maximum at $l = t = 0$ in the IEEE Stds 176-1949 orientation standards. For this propagation direction, the velocity is slowest around 2100 m/s (Fig. 2), leading to lithography resolution challenges when designing Ultra-High Frequency (UHF) range transducers, e.g. meeting the radiofrequency emission regulations in the narrowband European Industrial, Scientific and Medical (ISM) band centered on 434 MHz.

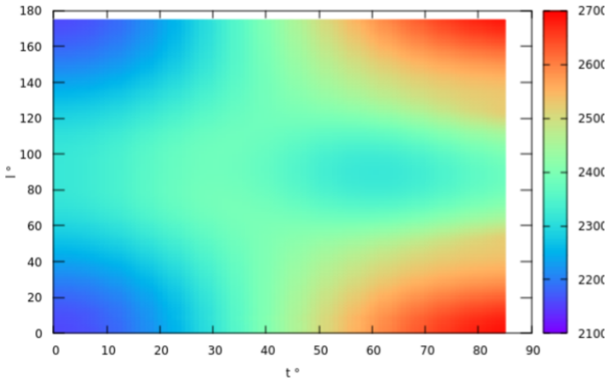

Fig. 2. Velocity map (m/s) of Rayleigh waves for α-GeO$_2$ $(YXlt)/l/t$ as a function of cut angle l and propagation angle t.

The beamsteering is negligible in this propagation direction (Fig 3), easing the design of a resonator, the only geometry compatible with delaying the transducer response beyond clutter for a wireless interrogation using a short range RADAR system.

From this acoustic propagation modelling, the (YX) cut of α-GeO$_2$ is selected for manufacturing tranducers.

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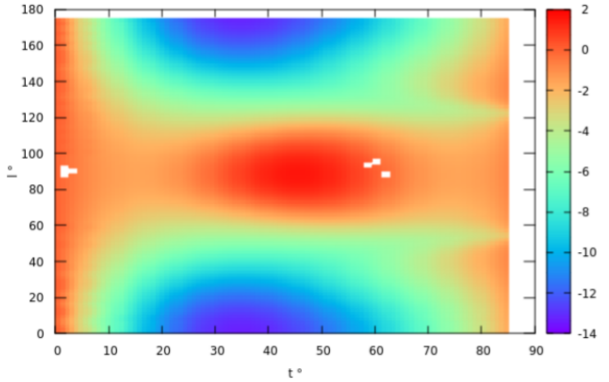

Fig. 3. Beam steering map (°) of Rayleigh waves for α-GeO$_2$ $(YXlt)/l/t$ as a function of cut angle l and propagation angle t.

III. TRANSDUCER DESIGN AND MANUFACTURING

From the previous analysis, the low electromechanical coupling coefficient prevents the design of a reflective delay line, and a resonator has been designed with 78 interdigitated electrode pairs in the transducer and 80 electrodes in the Bragg mirrors on each side, in either synchronous and asynchronous designs aimed at maximizing the quality factor Q at resonance frequency f. Indeed the objective of separating the sensor response decaying as $Q/(\pi f)$ from clutter is to reach a Q-factor high enough for clutter to have faded out, with an objective in the $Q \simeq 5000$ optimum between sensor identification and measurement speed to reach $\tau \geq 3.5$ μs assuming a short range RADAR distance detection limit of 150 m.

Due to the minute dimensions of the available substrates and the challenges of patterning 1.15 μm-wide electrodes separated by 1.15 μm, electron-beam (e-beam) lithography is employed to pattern interdigitated transducers with 180 μm acoustic aperture, mirrors and contact pads. A total of 11 resonators are patterned on the 6×10 mm^2 samples to assess the validity of the material constants used in the simulation. Etching the aluminum electrodes leads to increasing surface roughness and only a few patterning and etching steps aimed at scaling the electrodes to reach the 434-MHz ISM band can be performed before the sample needs to be polished again.

IV. WIRELESS MEASUREMENT

Multiple resonators with quality factors in the 2000-3000 range were manufactured and probed under a probe-station. The microwave probes were fitted with an helical monopole antenna and wireless interrogation in a sub-meter range was achieved using a dedicated short range RADAR system based on a frequency swept pulsed measurement for scanning the returned power as a function of frequency. The interrogation range is at the moment limited by the quality factor of the resonator due to excessive degradation of the surface roughness after multiple processing steps (Fig. 4).

Nevertheless, multiple temperature sweeps were performed in the ambiant to 200°C temperature range, allowing for a first estimate of the first and second order Coefficient of Temperature with Frequency CTF (Fig. 5).

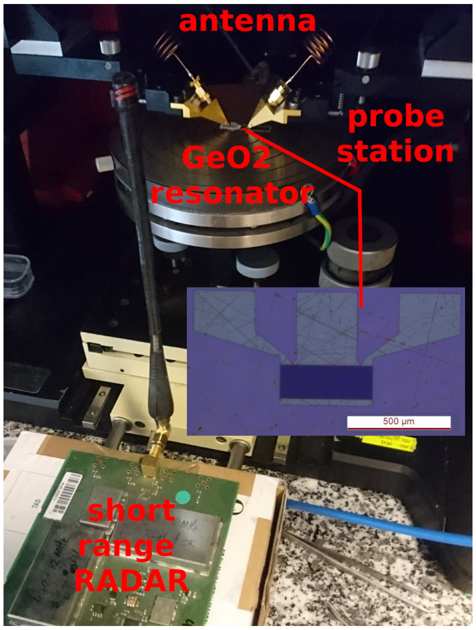

Fig. 4. Wireless sensing of the GeO$_2$ resonator shown in inset.

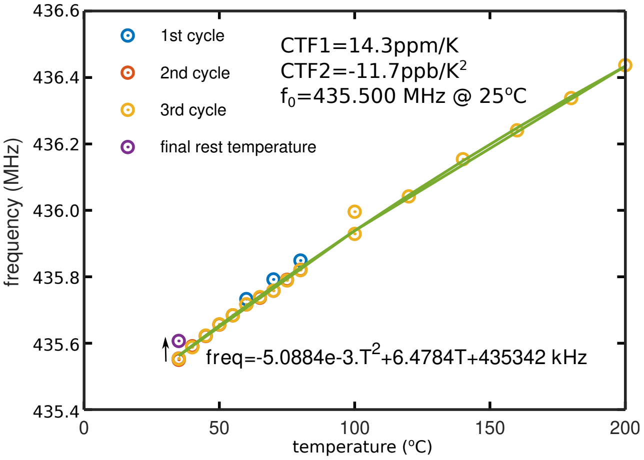

Fig. 5. Temperature dependence of the resonance frequency probed wirelessly by varying the substrate temperature through the heated chuck, and second order polynomial fit for extracting the first and second order coefficient of temperature with frequency.

V. CONCLUSION

An experimental demonstration of surface acoustic wave propagation on α-GeO$_2$ was achieved, allowing for wireless measurement of the passive transducer resonance frequency as a function of temperature at sub-meter range.

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