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# Single-Channel Time Reversal Focusing of Ultra-High Frequency Acoustic Waves in MEMS Devices<sup>1</sup>

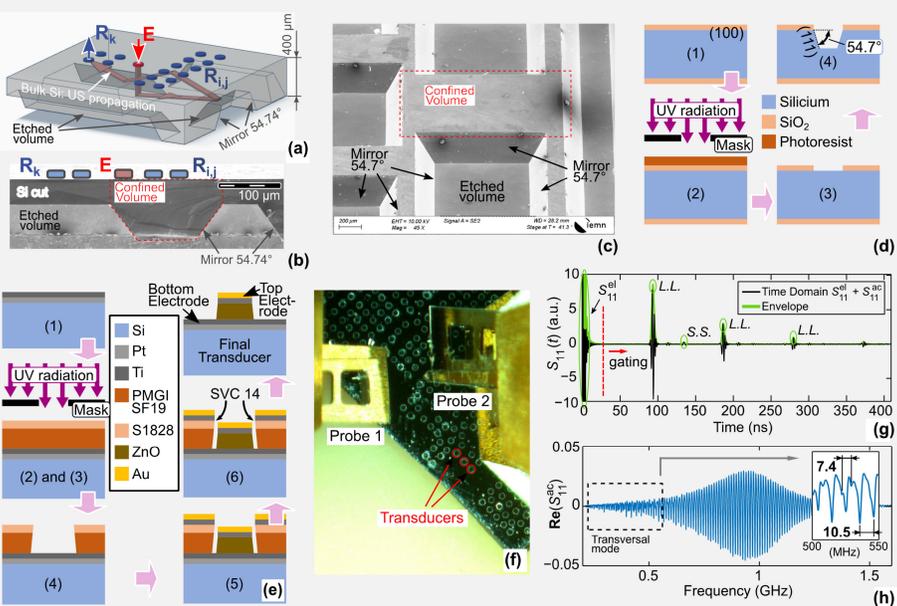
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## Abstract

In this study, we have designed, fabricated, and thoroughly characterized a silicon micro-machined cavity tailored for achieving micro-resolution Ultra-High Frequency (UHF) imaging in the fields of microfluidics and microbiology, employing single-channel time reversal techniques. Our approach involves the integration of ZnO transducer arrays with a 400  $\mu\text{m}$  thick silicon wafer that incorporates precisely engineered microstructures for the confinement of acoustic fields. The transducers exhibit wideband capabilities spanning the 0.2–2 GHz frequency range, with a central frequency peak at 0.9 GHz. This research encompasses a comprehensive examination of the diffused acoustic field and the application of time reversal (TR) retro-focusing. Our findings and insights from this characterization are presented in detail below.

## Overall schematics of the MEMS for TR imaging & Main fabrication steps



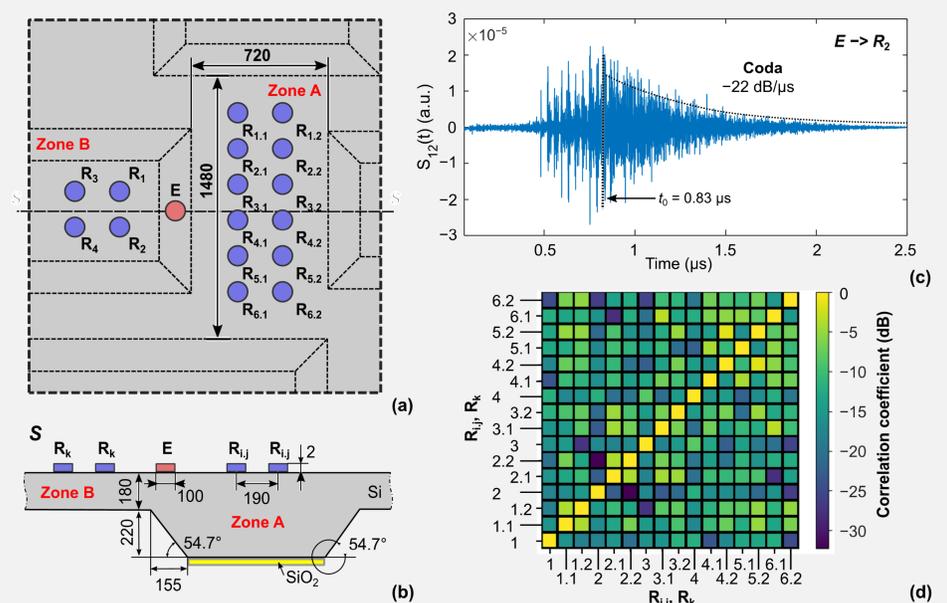
(a) Schematic representation of UHF ultrasound TRF on a MEMS ( $E$  is a piezoelectric emitter, and  $R_{x,y}$  are receivers). (b) SEM side-view of the etched silicon wafer. (c) SEM bottom-view of etched (110) Si wafer showing the zone of partial acoustic field confinement. (d) Technological steps for leaky cavity fabrication. (e) Technological steps for ZnO transducer fabrication. (f) Transducers' characterization using manual RF probes station and VNA. (g) Time domain signal of the full transducer reflection coefficient  $S_{11}$ . (h) Real part of  $S_{11}(ac)$  in the frequency domain.

- Two receiving transducer arrays referred to as  $R_{ij}$  and  $R_k$  were placed on the opposite side of the wafer, in the regions inside and outside the confined zone, respectively.
- Low intrinsic acoustical attenuation of silicon and high reflectivity of etched walls contribute to establishing long propagation paths and multiple reflections of acoustic waves.
- ZnO transducer's response shows that the latter can produce both longitudinal and shear waves in the 2 GHz range with a central frequency of 0.9 GHz for longitudinal waves.

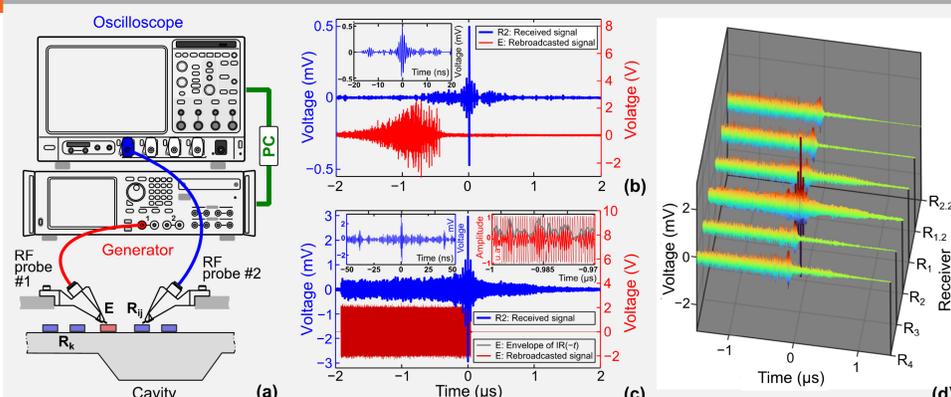
## Characterization of ergodic properties of the leaky cavity

(a) Scheme of a field confinement region and disposition of the ZnO transducers. (b) Side view  $S$  of the upper figure. (c) Impulse response  $S_{12}(t)$  between  $E$  and  $R_2$ . (d) The cross-correlation coefficients for the total of considered receivers.

- Features of  $S_{12}(f)$  reveal the presence of diffused field: several ballistic arrivals at the beginning of the signal, increasing wave mixture, and exponentially decaying coda "tail" starting at  $t_0 = 0.83 \mu\text{s}$ . The estimated decaying rate linked with the attenuation in bulk Si is of 22 dB/ $\mu\text{s}$ . Thus, the coda signal is observable during  $\sim 1 \mu\text{s}$ , which contains about 900 periods at the central transducer frequency of 0.9 GHz.
- Ergodic properties of the media were verified using cross correlation analysis. The correlation between coda signals in zones "A" and "B" is rather low (from -30 to -20 dB). On the contrary, several elevated values of the coefficient (from -10 to -5 dB) could be observed for adjacent receivers in zone "A."
- Using zone "B" external to the leaky cavity could be preferable due to better ergodicity.



## One-channel TR focusing of UHF ultrasonic waves



(a) Experimental setup for one-channel spatiotemporal focusing with TR. (b) Time-compressed signal (blue) on  $R_2$  using deconvolution and the rebroadcasted time inverted impulse response (red); the central peak is zoomed on the inset. (c) The same time-compressed signal (blue) using deconvolution and envelope normalization of impulse response (red); the inset in the top-left zooms in on the central peak; the inset in the top-right illustrates the normalization procedure. (d) Simultaneous signal reception by an array of transducers while focusing on  $R_2$  using impulse response normalization.

- In conclusion, we have shown the feasibility of focusing UHF (0.2 – 2 GHz) ultrasounds in the MEMS context with a single ZnO micro-transducer coupled to a silicon wafer and using the deconvolution TR process.