Piezoelectric Micromachined Ultrasonic Transducer Integrated With Field Effect Transistor for Acoustic Sensing

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***Summary*—In this work, a piezoelectric micromachined ultrasonic transducer (PMUT) is investigated for acoustic sensing applications that utilizes an integrated field effect transistor (FET) as the readout mechanism. The FET having a 6 µm gate length and aluminum nitride (AlN) as the gate dielectric is integrated at the center of the PMUT. The acoustic waves generated by the PMUT travel across the substrate thickness and get reflected back to the FET region where they are detected by modulating the current-voltage (I-V) characteristic of the FET due to the strained channel effect. The amount of reflection, therefore I-V modulation, is affected by the acoustic properties of the material underneath the substrate, hence providing the sensing scheme. Preliminary measurements indicate that the contrast in acoustic reflection from different materials can be detected.**

Keywords— acoustic sensing; FET; PMUT

I. Introduction

Recently, piezoelectric micromachined ultrasonic transducers (PMUT) have shown promising performance for time-of-flight measurements [1], fingerprint detection [2], and characterization of acoustic properties of material [3]. Conventionally, the readout scheme for PMUTs includes external circuits that are fabricated on a separate substrate [4] or in more compact solutions on the same substrate as the PMUTs but on its own designated area [5], therefore posing a limitation for further miniaturization of this platform. Additionally, many applications call for dense arrays of PMUTs for enhanced sensitivity [6] which makes the use of external electronics further complicated. Owing to the piezoelectric properties and CMOS compatibility of aluminum nitride (AlN), this work explores the application of AlN-based PMUTs having a field effect transistor (FET) integrated within, for acoustic sensing with the goal of reducing the need for external circuitry.

II. Methods/Results

Fig. 1 shows the conceptual device schematic. The PMUTs along with their integrated FETs are fabricated on an AlN on Si substrate. The FETs having a channel length of 6 µm perfectly fit within the PMUTs having a footprint of 279 x 279 µm. The

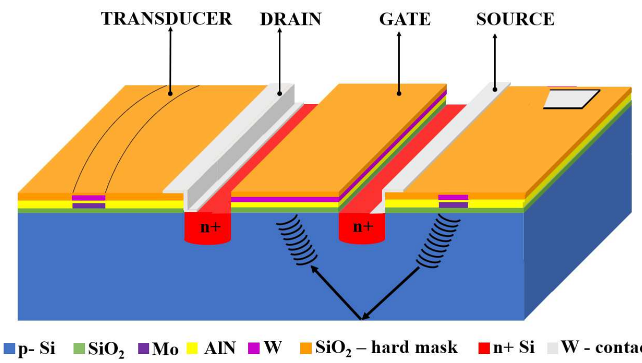

Figure 1: 3D schematics cross-section

operation principle involves the generation of GHz range acoustic waves via the PMUTs which travel across the thickness of the substrate, face a mismatch in acoustic properties at the bottom of the substrate, bounce back to the top of the substrate, and cause strain-induced channel modulation in FETs. This can be picked up from the deviation in the current-voltage (I-V) curves of the FET. An important parameter for the performance of the FET is the unity gain bandwidth (f_T), which is the frequency at which the input to output current gain becomes 0 dB [7]. To obtain the f_T, channel

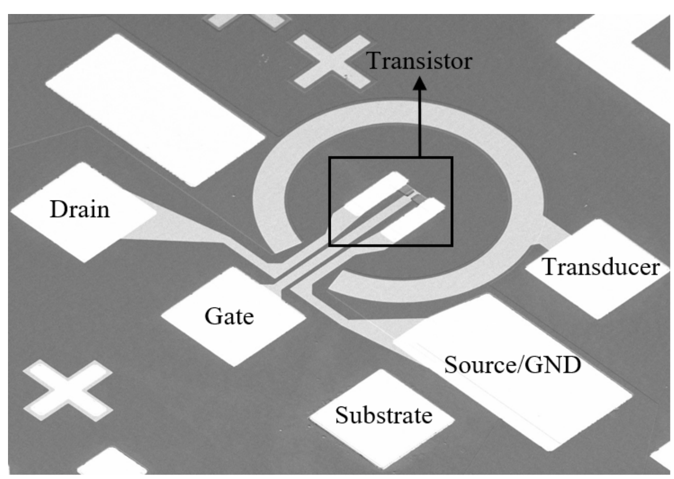

Figure 2: SEM of PMUT with integrated FET

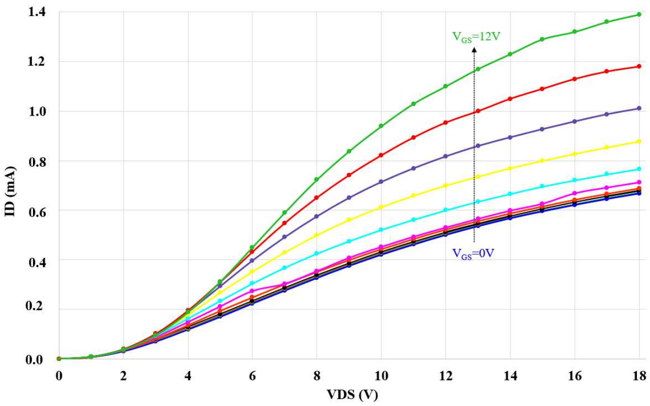

Figure 3: IV curves of piezoelectric FET located at the center of the PMUT

length (L), gate bias voltage (V_{GS}), electron mobility of silicon (μ) and threshold voltage (V_T) are needed as seen in (1) [8].

$$f_T = 0.24((\mu(V_{GS} - V_T))/L^2) \quad (1)$$

The f_T of the FET is 4.17 GHz which is above the chosen frequency for acoustic excitation for the device. The SEM of a fabricated device is shown in Fig. 2 and the measured I-V curve of the integrated FET is plotted in Fig. 3. In order to preliminarily evaluate the acoustic sensing capability of the presented device the substrate is mounted in two different configurations and the RF and DC responses are recorded as shown in Fig 4. These configurations are first, the substrate being mounted on an absorbent paste and second, the substrate being placed on spacers to form an airgap underneath the substrate. These configurations respectively yield low vs. high reflections at the bottom of the substrate. Fig. 5 shows the change in the roundtrip amplitude of the acoustic wave as a function of the drain-source bias for a fixed gate-source voltage (12V). The acoustic excitation is a 1.6 GHz signal at 16 dBm power while the roundtrip amplitude picked up from the drain is around -28 dBm; the high roundtrip loss is expected to be improved by carefully selecting the device stack for better acoustic transmission. From the preliminary results, it can be inferred that the higher the reflection at the bottom of the substrate, the more sensitive the roundtrip transmission change to the operating point of the transistor. As such, materials with different acoustic properties could be distinguished through the presented scheme.

III. Conclusions

PMUTs with integrated FET were designed, fabricated, and characterized for GHz range acoustic wave sensing. The active area of the device is only 279 x 279 µm and the acoustic signals transmitted by the PMUT can be recovered by the piezoelectric FETs after reflecting from the bottom of the substrate where the material/media under test lies. Future work includes optimization of the PMUT for focusing the reflections on the FET as well as tailoring the stack for higher acoustic transmission to improve performance.

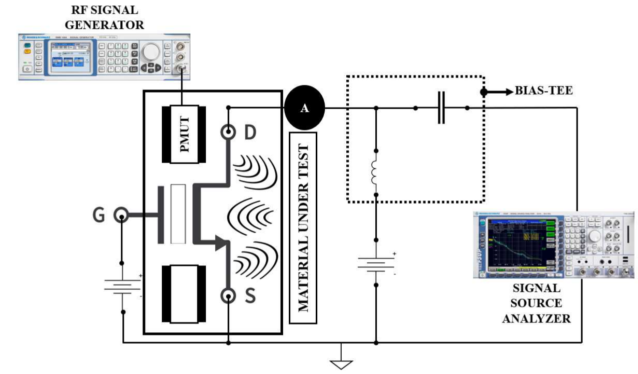

Figure 4: Block diagram of measurement setup

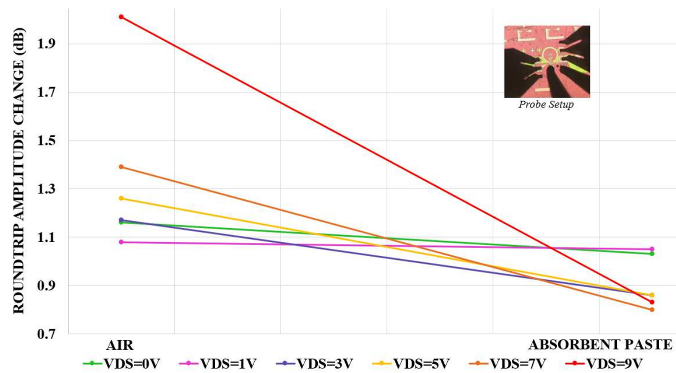

Figure 5: The change in round trip amplitude, picked up at the drain, for the 2 measurement configurations, highlighting the effect of FET operating point

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