SAW Devices with Piezoresistive Graphene Pickup

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ELECTRONICS

Abstract:

Surface acoustic wave (SAW) devices are used as filters in communication systems, and are also being investigated to realize Coriolis force based gyroscopes. This study presents the fabrication and measurements of SAW devices using an added graphene electrode for SAW measurement using the piezoresistive and direct electrical induction. This pickup was added to the SAW delay line interdigital transducer (IDT) structure in order to enhance the sensitivity of wave amplitude measurement. These devices were fabricated on a piezoelectric crystal substrate (lithium niobate, $LiNbO_3$). The devices in this study were designed for a 200 MHz center frequency, and Y-cut 128° $LiNbO_3$ crystals were used as the piezoelectric substrate with a ~ 20 µm wavelength.

Background:

Hosseinzadegan, et al. (engineers of the SonicMEMS Lab at Cornell University), have previously reported a high gauge factor of a piezoresistive graphene sensor for the first time [1]. The gauge factor (GF) is a measure of the piezoresistivity of a material. Based on the published work [1], the GF of graphene that was placed on top of electrodes was measured to be around 18,000, which is two orders of magnitude larger than any commercialized materials (single crystal silicon has the highest commercial GF at about 200).

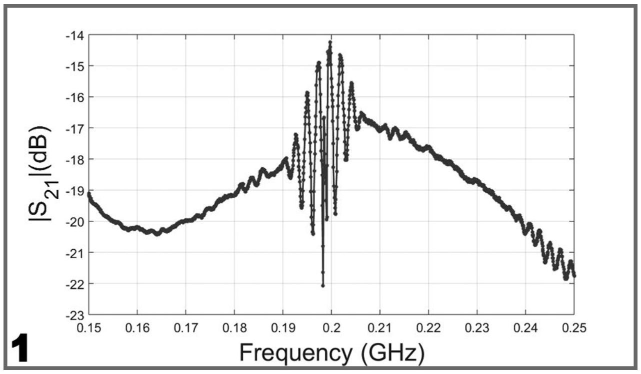
Another study by Roshchupkin, et al. [2], showed that when a constant voltage is applied to electrodes with graphene over them, at some point when a SAW propagated through the graphene, the current measured zero. The SAW applies stress in the form of tension and compression to two electrodes, each of which generates a charge that is equal and opposite to the other. This difference in charges is what would allow the net current to reach zero. A change in charge carrier concentration also means there is a change in resistance that relates back to the phenomenon of the high gauge factor that was seen. Our study aims to conduct a similar experiment that will allow us to study this effect, in hopes of acquiring initial measurements of piezoresistivity using a piezoresistive graphene electrode pickup.

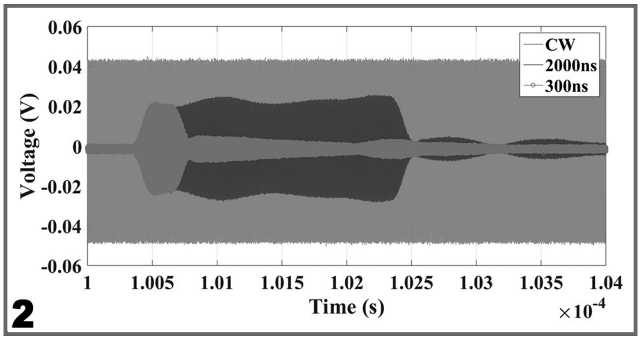
Summary of Research:

Both metal etching and lift-off photolithography processes were used to pattern metal electrodes on the substrates. Due to the piezoelectric and pyroelectric properties of the $LiNbO_3$ crystals, complications occurred during the photolithography process that caused defects in the devices. Hence, the metal etching process showed better yield. In addition, for metal etching, both wet and plasma etching techniques were used for etching the metal (Al/Ti) thin films. For our measurements, we used devices that were wet etched because that is when the best uniformity across the wafer occurred for the given feature sizes and crystal properties.

Two different types of devices were tested for this study. One was a SAW gyro-drive delay line, and the second device was one with a piezo-resistive graphene pick-up. Two types of measurements were conducted. Frequency domain measurements were performed on the gyro devices and the resulting data is plotted in Figure 1. This plot represents the ratio of power transfer for the device from the input to output over a range of frequencies. There is a peak at ~ 197.5 MHz, which is close to the designed value of 200 MHz.

Time domain measurements were performed for both the gyro device and the graphene device. Figure 2 is the resulting plot for the gyro, and we can see a clear





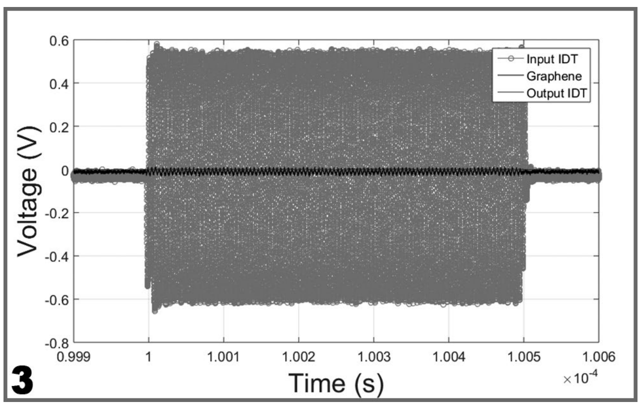


Figure 1, top: *Plot of frequency domain measurements for gyro device.* ***Figure 2, middle:*** *Plot of pulsed wave input time domain measurements for gyro device.* ***Figure 3, bottom:*** *Plot of pulsed wave input time domain measurements for graphene device.*

difference in voltage amplitude from the continuous wave response to the pulsed wave response, regardless of pulse width. The distorted pulsed wave output signals can be accounted for by standing waves formed by reflections of the SAW wave from the edges of the device. Figure 3 is the resulting plot for the graphene device. This plot shows the input IDT voltage, the output IDT voltage, and the graphene active probe voltage over time. It is evident from this plot that the graphene pickup shows an increased output voltage as compared to the output IDT.

Conclusions and Future Work:

The graphene probe detected a higher output voltage as compared to the output IDT, which suggests that the graphene pickup has an increased sensitivity in measuring SAW amplitudes. Further tests must be completed to confirm this and determine the mechanism of action. However, if this is confirmed, it may be possible to exploit the high gauge factor that was previously seen for further voltage amplification.

Impedance matching using the graphene pickups will significantly improve the device performance and should be considered as one of the next steps in this research. Furthermore, replacing the metal IDT electrodes with graphene electrodes could increase the SAW wave generation efficiency. These electrodes can be created using photolithography and oxygen plasma etching.

CNF Tools Used:

SUSS MicroTech MA/BA 6 contact aligner, SC4500 odd-hour evaporator, Oxford PlasmaLab 80+ RIE system, PT720-740 etcher, DISCO dicing saw, Westbond 7400A ultrasonic wire bonder.

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References:

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