Piezoelectric RF SAW-Based Energy Detectors

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Abstract:

Extremely low-power electronic devices promise improvements in remote and distributed sensor networks, among other applications. Thus, we have designed and studied mechanisms based on piezoelectric surface acoustic wave (SAW) and graphene properties that detect and manipulate high frequency (200 MHz) electronic signals characteristic of radio frequency (RF) communications intercepted by such a device in hopes of using these signals as a power source. We demonstrate conversion of RF signals to SAWs on a lithium niobate (LN) substrate with standard interdigitated transducers. Electrodes of monolayer graphene placed on top of the substrate intercept the SAWs and convert them back to electric current via the acoustoelectric effect.

Summary of Research:

Our ultimate goal is to create devices that can trigger a nanoelectromechanical (NEMS) switch using a nanowatt radio frequency (RF) signal. To this purpose, here we build mechanisms that have the potential to rectify or otherwise modify such an alternating current (AC) RF signal at the Cornell NanoScale Science and Technology Facility (CNF).

A surface acoustic wave (SAW), a Rayleigh wave, can be excited on a piezoelectric substrate by means of an interdigitated transducer (IDT) — an array of electrodes with alternating electrical bias. Because the substrate is piezoelectric, such a wave carries with it an alternating electric field. Next, monolayer graphene placed on top of the substrate allows electron mobility. Electrons are pushed by the field caused by the SAW, namely, the acoustoelectric effect. This electron current can be captured by electrodes placed across the path of the SAW. The current across these electrodes is proportional to the SAW power density and cross-sectional area of the conductor [1]. We also note a related physical effect: the resistivity of graphene increases whenever the material undergoes strain [2], as when stretched by a passing SAW.

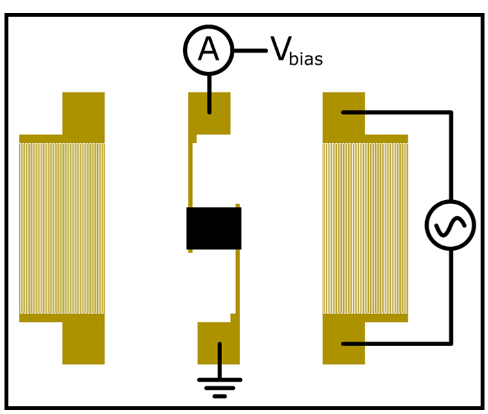

Figure 1: Schematic of tested device. Length of IDT fingers is approximately 1 mm. A rectangle of graphene (black, center) is placed on two electrodes and in between two IDTs.

We use 4-inch 128°Y-cut black lithium niobate (LN) wafers as device substrates. SAWs will propagate in the X direction. First, gold electrodes are patterned using a liftoff process — 75 nm of gold are evaporated with a 10 nm Ti adhesion layer on top of a 2.5 µm negative photoresist mask of nLOF 2020. The nLOF is dissolved in 1165 to isolate the electrodes. Gold IDTs use 5 µm electrodes at a 10 µm pitch for a 20 µm wavelength. We designed for 200 MHz signals.

Inspired by Trung, et al. [3], we attempted to use a liftoff process to pattern graphene on top of the gold. An alternative method was to pattern gold with an oxygen plasma RIE etch with a photoresist mask, but the CNF does not allow gold to be used in most RIE tools. We found that graphene transferred via (CITE) on top of our LN wafer with a 2 µm nLOF 2020 mask, baked overnight at 130°C, then placed in 1165 for half an hour and 30s in the ultrasonicator produces graphene features reliably. However, graphene resistors with thicknesses less than 100 µm cannot be manufactured reliably. Finally, the chips were diced with the Disco saw and wirebonded to printed circuit boards (PCBs) that connected to external instrumentation.

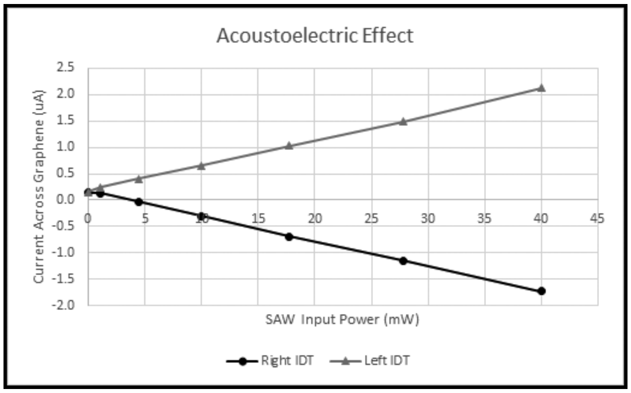

Figure 2: Power input to IDT to create SAW vs. current output from graphene for each IDT.

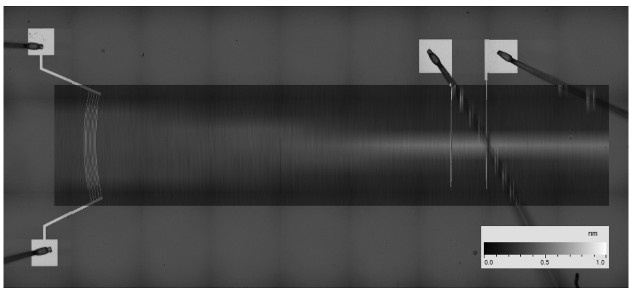

Figure 3: Another device. A curved IDT, left, creates a SAW that propagates right to an invisible piece of graphene placed across two electrodes. The SAW is concentrated at the graphene location.

Among other tests, we placed two IDTs opposing each other with a graphene electrode in the center, as shown in Figure 1. An alternating current fit into either IDT should induce an acoustoelectric current in the graphene, confirming the process's functionality. In Figure 2, we plot the current measured across the graphene with a Keithley 2400 when the instrument is set to source zero voltage bias. A 192.733 MHz wave, its frequency having been chosen as a resonance peak via an earlier frequency sweep on the device, was fed into the left, then right IDT at various powers through a 50 Ω waveform generator. We observed that current was affected linearly with IDT intensity as predicted by Bandhu, et al. [1], and the SAWs sent in opposite directions produced opposite changes, as expected.

We also measured the location intensity of a SAW generated from a curved IDT with a Polytec UHF scanning doppler vibrometer. Focusing the SAW had two benefits: first, it was easier to capture the entirety of the SAW energy with a graphene electrode, and second, the greater strain from the SAW amplitude should increase the graphene resistance, thus increasing the voltage induced across the graphene. The measurement is shown in Figure 3.

Results and Conclusions:

We have successfully replicated the acoustoelectric effect using a lithium niobate process in the CNF cleanroom, as well as a focused SAW. We conclude these processes may work for our purposes, namely, triggering a NEMS switch from an extremely low power RF signal.

Future Work:

Now that we can build this system in the CNF, we need to scale it to work with much less power. Once complete, this system can be combined with RF generating sensors and a NEMS switch.

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References:

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