Surface Acoustic Waves in Magnetic Materials

CNF Project Number: 598-96
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Primary CNF Tools Used: JEOL 6300, SC4500 evaporator, Zeiss Supra SEM, AJA sputter, 5X stepper

Abstract:

We have developed both photolithography and e-beam lithography recipes for interdigital transducers (IDTs) based on multiferroic $BiFeO_3$ (BFO) thin films. Using ultra-high-frequency lock-in (UHFLI) measurements, we successfully demonstrated the generation of surface acoustic waves (SAWs) in BFO epitaxial films. Pulse echo measurements and vector network analyzer are deployed to further characterize the properties of the SAWs.

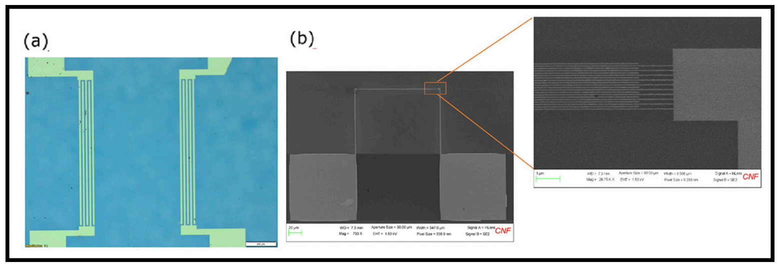

Figure 1: (a) Optical image of IDTs patterned by photolithography and (b) SEM image of IDTs patterned by e-beam lithography.

Summary of Research:

SAWs have been extensively used in electronic components which include delay lines, filters, transformers, etc., devices that are based on transduction from electric energy to mechanical energy in piezoelectric materials. Because SAWs can be easily generated and launched into elastic materials, they become a powerful tool for fundamental research in condensed matter physics, widely used to characterize, manipulate, and detect electrical and magnetic properties. For instance, mismatch of sound velocities in SAW substrate and fluidic medium is exploited to drive fluid actions such as pumping, mixing and jetting. Intrinsic parameters of a material can be obtained by measuring the speed and attenuation of SAWs. The combination of SAWs with magnetism gives rise to novel phenomena such as acoustically driven spin pumping, SAW-induced ferromagnetic resonance, magnetic domain motion as well as nonreciprocal SAW propagation, via magnon-phonon coupling. Dynamic strain field induced by SAWs allows manipulation of photoluminescence in low-dimensional materials.

BFO is a room temperature multiferroic where ferroelectricity, antiferromagnetism, and a weak spin-canted magnetization coexist. It would be interesting to investigate the coupling between these order parameters. Since all ferroelectric materials are intrinsically piezoelectric, SAWs are also expected to be generated in BFO. Via piezoelectric effect, an IDT converts electrical energy into mechanical energy that propagates at the surface in the form of surface acoustic waves. In this project, we aim to fabricate input and output IDTs to verify the generation of SAWs in BFO-based devices, which would open new possibilities to control, manipulate and detect the change in these order parameters.

The fabrication was done on a 100 nm thick BFO sample. 15 pairs of IDTs are patterned in a 10 mm by 10 mm square using 5X stepper. An IDT consists of two interlocking comb-shaped arrays of metal electrodes. The geometry of these electrodes determines the wavelength of the SAW. For the IDT shown in Figure 1(a), it has five fingers that span a distance range of 101.25 μm, which means the width of each finger is 11.25 μm, and the wavelength is four times that, 45 μm. As shown in Figure 1(b), we have also developed method for patterning IDTs using e-beam lithography. These IDTs can have extremely small wavelength (down to 20 nm) and hence gigahertzworking frequency range.

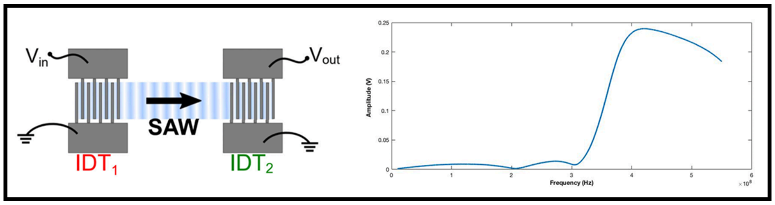

Figure 2: UHFLI measurement.

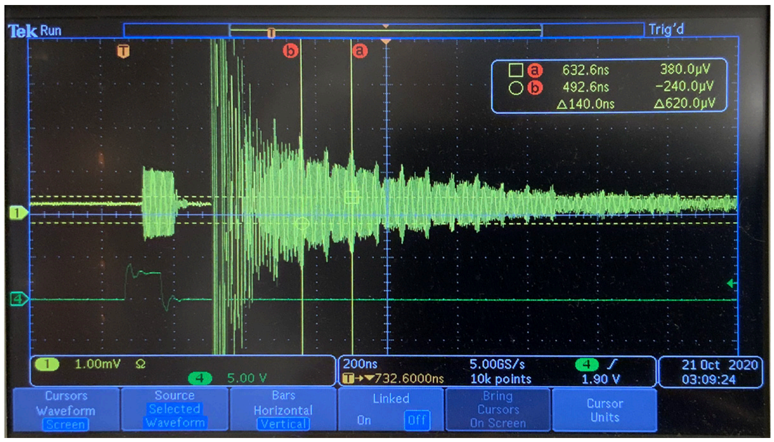

Figure 3: Pulse echo measurement.

UHFLI measurement was performed on the photolithographically defined IDTs (Figure 2). The amplitude of the voltage at output IDT is measured at different frequency with a fixed input voltage of 1 V. We observe a sharp increase of amplitude after 300 MHz and amplitude peaks at around 410 MHz. This indicates that in this range of frequency, SAWs are generated with highest efficiency. More SAWs are generated at these frequencies, and they propagate to the output IDT and are converted back into electric signal.

We also performed a pulse echo measurement on the same sample. For this measurement, we excited SAW at 410 MHz to generate as many SAWs as possible. The SAWs are bouncing back and forth between the IDTs and thus we observed echoes with an oscilloscope. Considering that the transmission at the IDTs, the echo signal will decay eventually. Ideally, we would like to see separated packs of signal with decreasing amplitude, but our echoes are overlapping making them hard to be distinguished. This can be solved by increasing the spatial separation between IDTs and shorted the pulse width. Still, we observe evenly spaced spiles, which also indicate the generation of SAWs. From the spacing between the echoes, we can calculate quantities such as SAW velocity, attenuation, etc.