Surface Acoustic Waves on Lithium Niobate for Van der Waals Metamaterials

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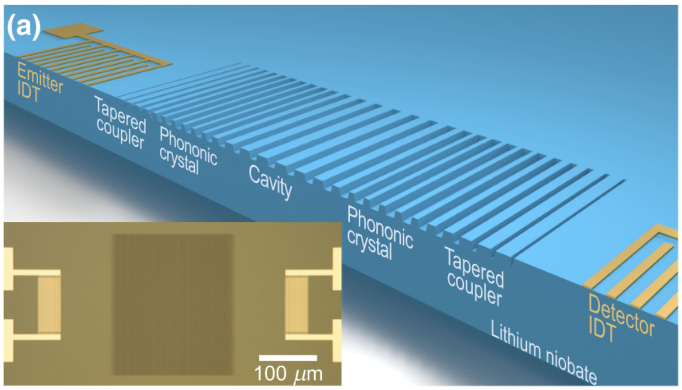
Objective

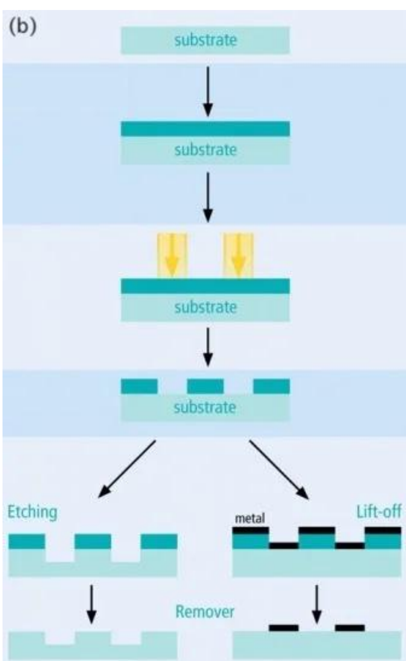
Van der Waals (VdW) heterostructures, stacks of single atomic layer "two-dimensional" materials, have been the subject of recent excitement for their diverse, tunable, and exotic properties, such as superconductivity. However, current fabrication methods are time-intensive and expensive, which limits exploration of these materials. To save time and money, we can prototype these quantum materials using simpler classical metamaterials that mimic properties of interest. Recently in the Hoffman group, we have made metamaterials with air cavities and channels that mimic the tight-binding electron models of twisted bilayer graphene (Dorrell et al., 2020 and Gardezi et al., 2021) and kagome. While good first steps, these metamaterials are millimeter-scale and cannot, given space constraints, replicate the wide range of VdW materials with larger Moiré patterns, such as that of twisted bilayer graphene.

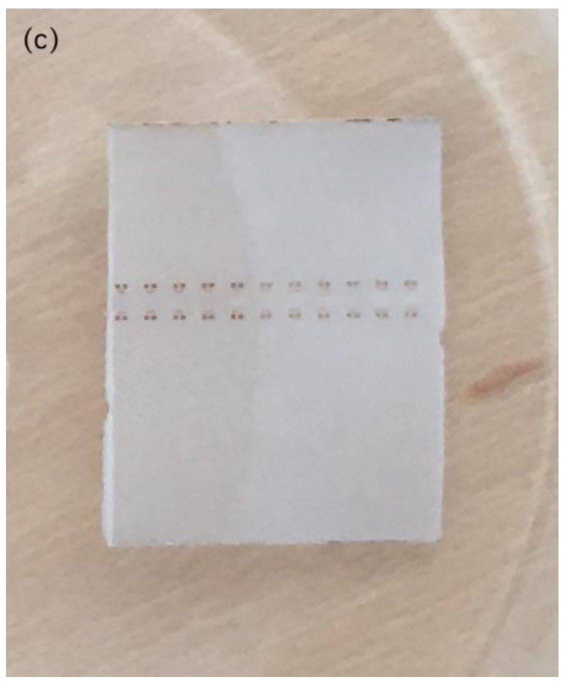
In this project, I harness micron-scale surface acoustic waves (SAW) in lithium niobate (LiNbO3) to replicate these larger Moiré patterns. To achieve this, I first develop the relevant fabrication techniques by replicating a simpler 1D phononic crystal (PnC) and then a monolayer graphene metamaterial. For the former, I began with a PnC device with a band gap on the order of 10 MHz (Shao et al., 2019). This past summer, I learned methods for etching LiNbO3 and depositing the metal contacts (interdigital transducers, or IDT's) that electrically drive SAW propagation. My fall objective has been to finish fabricating the PnC, then build a transmission measurement setup and test the PnC to determine whether it exhibits the desired band gap.

Accomplishments

This fall, I successfully finished fabricating the PnC device and confirmed that it exhibits the desired band gap. The PnC device consisted of a series of etched grooves between two IDT's (Figure (a)). It was fabricated in two stages: the grooves were etched following the left process in Figure (b), and the IDT's were deposited following the right process. The final chip (Figure (c)) contains an array of many copies of this PnC device; the gold IDT's are visible in the array.

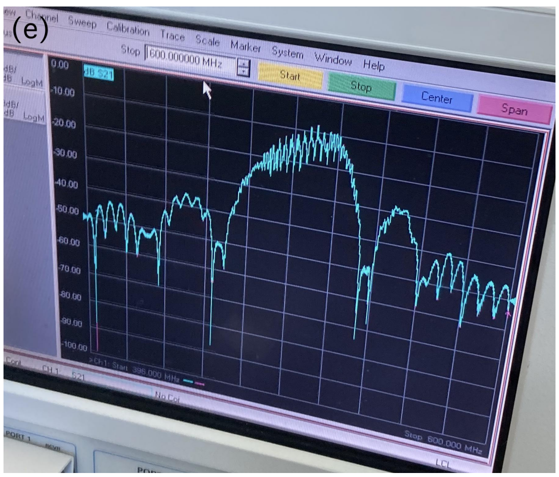






Next, I conducted a transmission study by exciting SAW of varying frequencies through the PnC and analyzing the transmission coefficient for each frequency. The setup is shown in Figure (d). According to Shao et al. (2019), a band gap of around 25 MHz at above 500 MHz

was expected, half the size reported in Shao et al. (2019) due to doubling of the feature sizes. Indeed, there was a drastic decrease in transmission around the 490-525 MHz range in Figure (f) (entire range 440-600 MHz) compared to the baseline in Figure (e) (entire range 400-600 MHz).



The next step of this project will be to design, simulate, fabricate, and then test and image a LiNbO3 graphene metamaterial. With my new research partner Federico Maccagno (Harvard College '25), we have started simulating the graphene metamaterial and planning for imaging.

Reflection

I am very grateful to have conducted my research in-person this fall. Though I spent less time with my undergraduate labmates in the office as we did during the summer, I met many other people who helped me in my project, including Federico. I also spent much more time on my project this semester than on my different project in freshman spring, yet I was still able to balance it with my classes and other extracurriculars. I appreciated my mentors' flexibility in supporting me when I put in less hours during busy weeks and vice versa, regularly meeting with me to check in. This gives me confidence that I could complete my full project working term-time for the next three semesters of college.

Faculty Interaction

Ben is a grad student in my group (the Hoffman lab) and my primary mentor with whom I meet for general guidance. David is a postdoc in the Lončar group who serves as my primary fab mentor; I meet with him weekly to ask specific questions. Sophie is a grad student in the Lončar group and co-author on Shao et al. (2019) who helped me design the electrical readout setup for PnC testing. Gage Hills is a SEAS Assistant Professor of Electrical Engineering and also helped with the PnC testing. Jenny Hoffman is my professor and has supported my project funding and checked in with me on a weekly basis.

References

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