Strain for Sliding Charge Density Wave in Quasi-Two Dimensional Materials

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Abstract

A charge density wave (CDW) transition occurs when the crystalline lattice shifts in its structure and periodicity at a certain temperature. When this change occurs, the band dispersion of the crystal also changes and there arises a gap in the bands and a new wavelike distribution of charges across the lattice (hence a charge density wave)[1]. With specific crystals under the correct threshold electric field, this wavelike distribution can be pushed or slid down the lattice. This is called a sliding CDW and has been primarily seen in quasi-one dimensional materials, up until a few years ago when it was seen, via x-ray diffraction, in various quasi-two dimensional rare-earth tritellurides[2]. There have also been papers published that discuss the effects of strain on quasi-two dimensional materials and how strain can isolate a unidirectional CDW[3]. I am interested in testing, via electrical transport, how strain may affect sliding behavior in quasi-two dimensional materials, specifically niobium diselenide($NbSe_2$). Here I demonstrate the methods and procedures I will use to to perform this testing.

Background

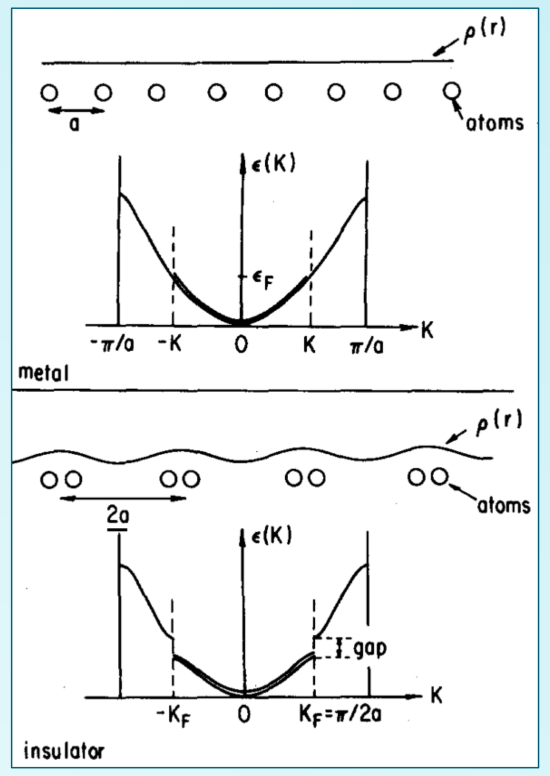


Figure 1- Schematic of CDW formation[1]: Figure explains how CDW affects the crystalline lattice, causing insulating behavior in a metallic crystal.

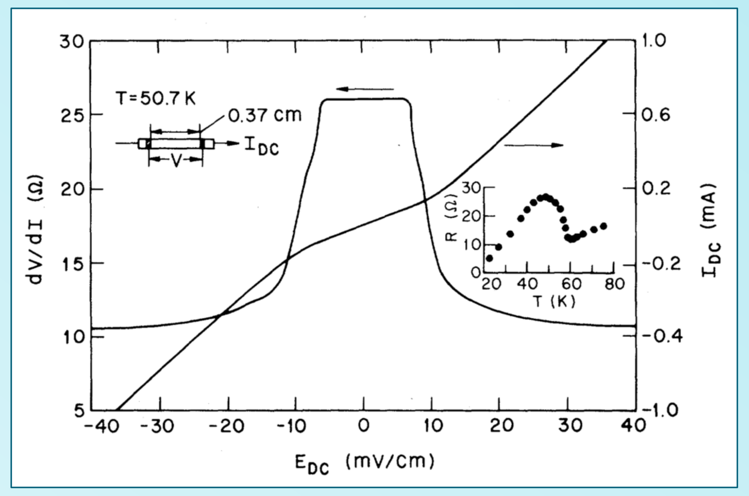


Figure 2- Sliding CDW Behavoir[4]: Figure shows change in differential resistance (left axis) and current (right axis) beyond the threshold field from sliding CDW in $NbSe_3$.

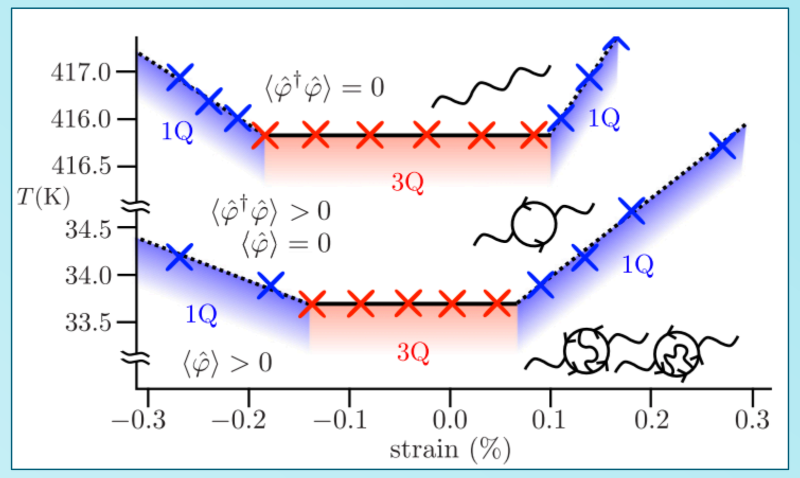


Figure 4- Strain vs Temperature $NbSe_2$[3]: Here we see the effect of strain on the lattice with CDW ordering, changing from 3Q to 1Q at an anisotropy in phonon energy of ~ 0.1% strain.

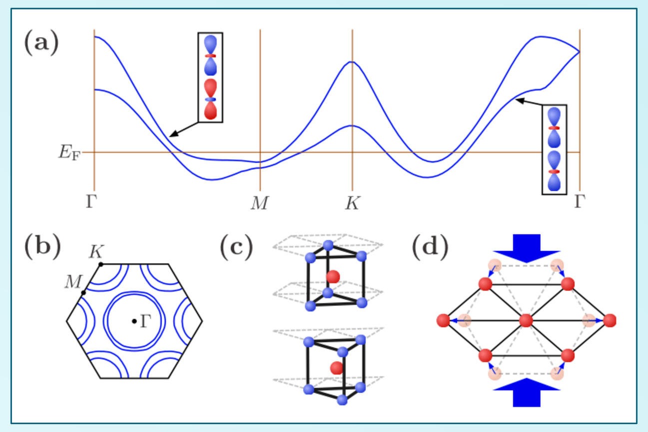


Figure 5- $NbSe_2$ Band Structure[3]: (a) The band structure of NbSe2 modeled by the tight-binding. Only the bands crossing E_F are shown. Only the lower band is involved in the CDW formation. (b) The Fermi surface consists of concentric barrel-shaped pockets around the Γ and K points (c) The layered structure of $NbSe_2$, with Nb red and S blue. (d) The atomic displacements.

Methods

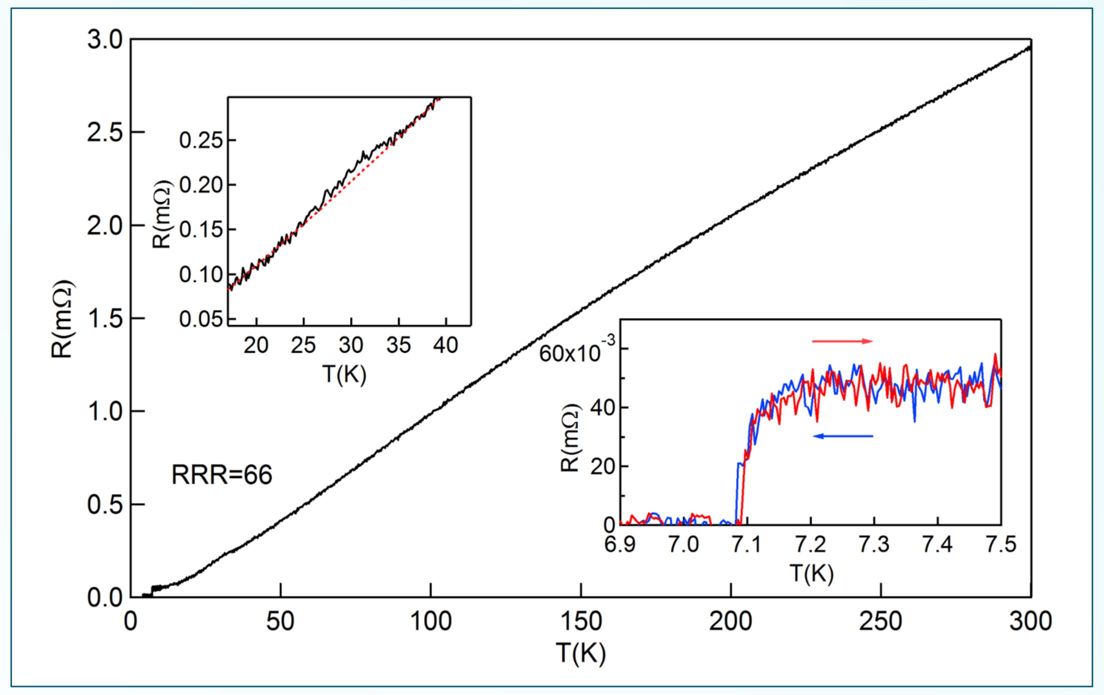


Figure 6- R vs T of $NbSe_2$: Resistance of $NbSe_2$ from 300K to 4.2K. Left inset: anomaly from a CDW transition at 33.5K. Right inset: superconducting transition at 7.2K.

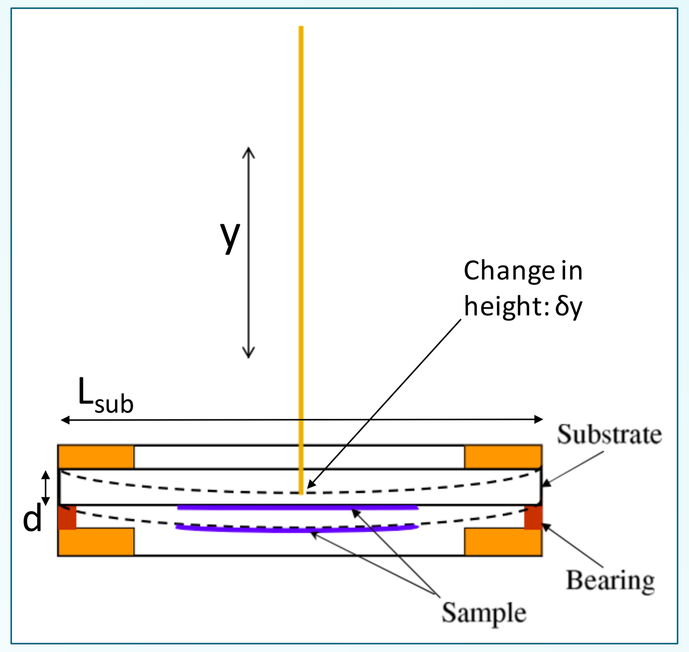


Figure 8- Sketch of Strain Device[5]: This device strains the sample by a screw (long yellow piece) which drives into the substrate that the sample is fixed to. When turned, the screw strains the sample.

$$\varepsilon = 4\delta y d / L_{\text{sub}}^2$$

Equation 1- Strain Equation[5]: This gives the percent of strain due to changing parameters.

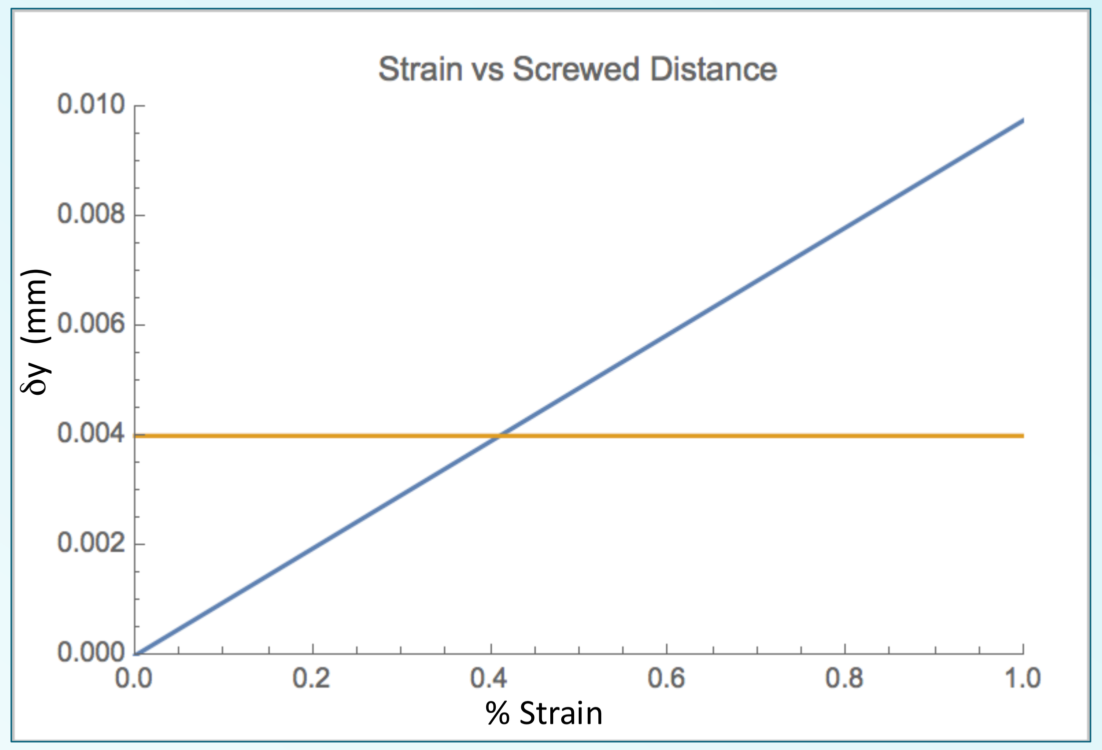


Figure 9- Strain vs Screwed Distance: With device measurements of substrate length 18mm, thickness .79mm (1/32 inch) and using a 0-80 screw (80 threads per inch), we will be able to precisely tune our sample to .4 percent strain by displacing the screw .4 mm, turning ~1.25 times.

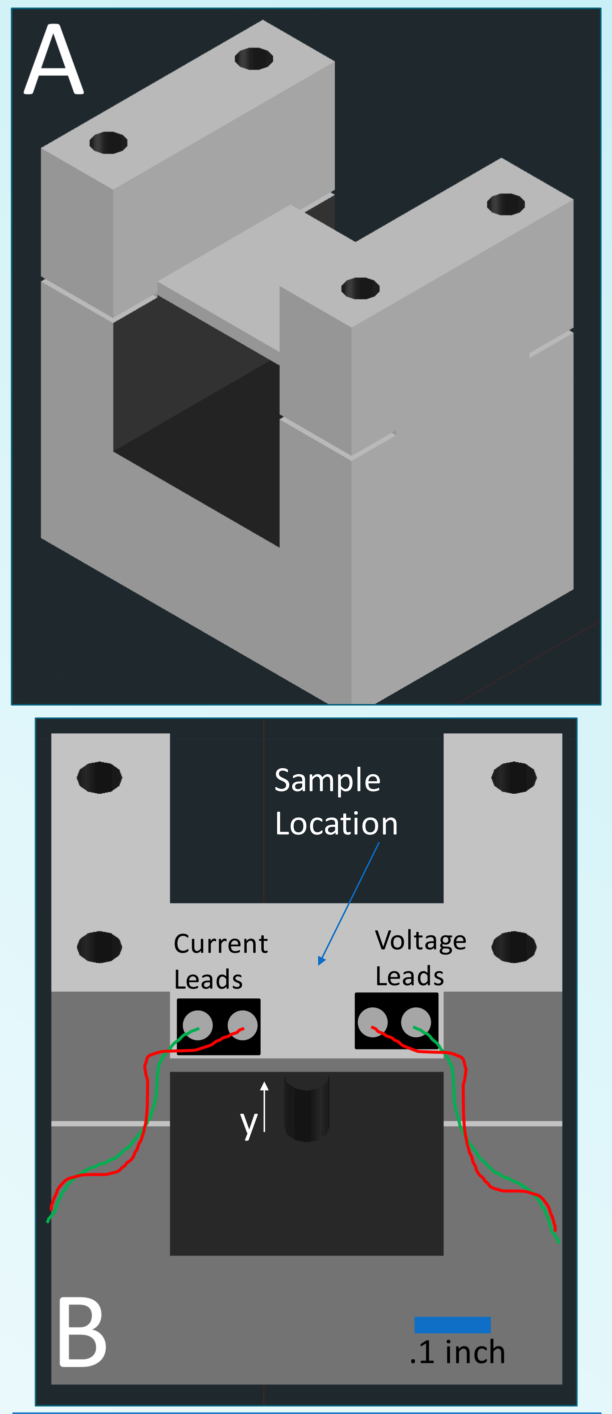


Figure 9- Strainer for PPMS*: Designs of the proposed strain device to be used in a PPMS cryostat. This follows the same designs as proposed in figure 6. Will be made from Copper. A: top corner view. B: side view. *Physical Property Measurement System

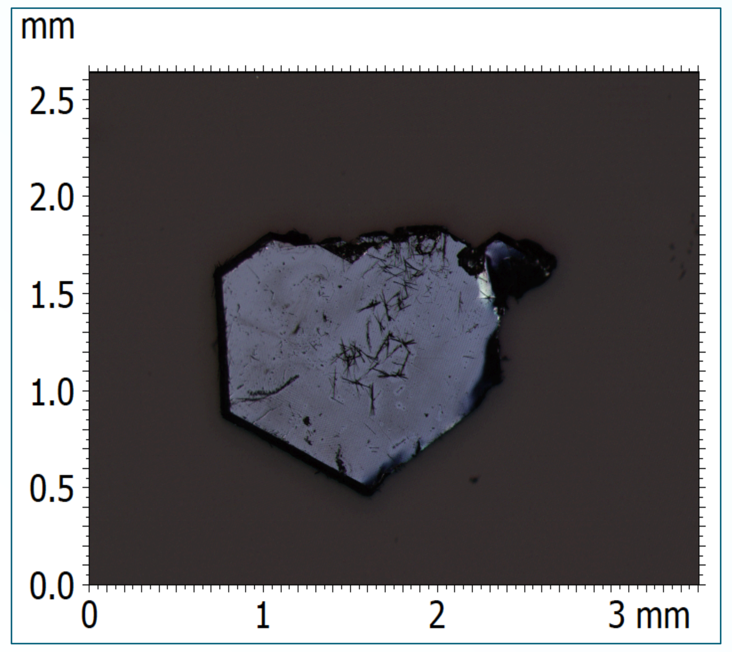
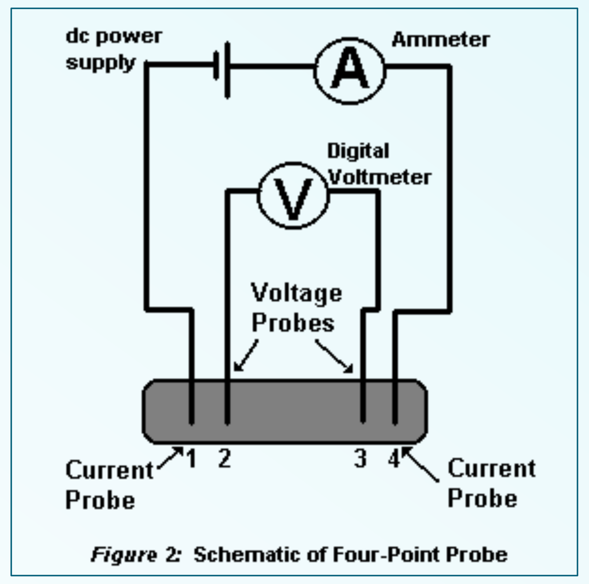


Figure 7- Synthesized $NbSe_2$ Crystal: $NbSe_2$ crystal synthesized through chemical vapor transport.



"THE FOUR POINT ELECTRICAL PROBE." Images. Scientific Instruments, n.d. Web. 4 Apr. 2017.

Figure 10- Schematic of Four Point Probe Measurement[6]: Figure diagrams how 4 point probe measurement works to test for resistance. This is a very effective measurement process and is utilized in my designs in Figure 9.

Conclusion

Going forward with this project, I plan to test these methods and begin making the strainer I designed. Upon completion of this I will begin testing $NbSe_2$ under various strain percentages and analyze how strain affects the CDW and if it is possible to force sliding behavior in the crystal

References

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