Changing the Geometry of VO_2 and SmB_6 Crystals

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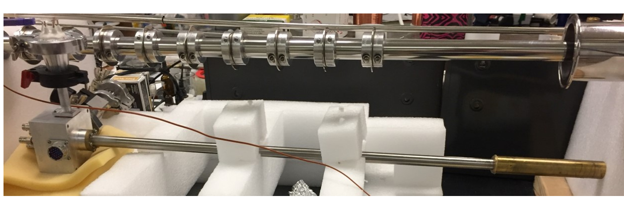
August 9, 2017

1 Background

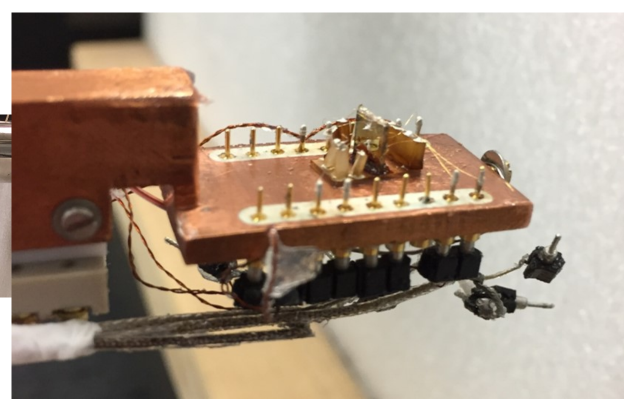
Certain properties of crystals depend on the crystal's geometry. By changing the geometry of the crystal, we can change these properties. This summer, I created a polishing tool to reduce the dimensions of VO_2 crystals and change the surface texture of SmB_6 crystals.

Vanadium dioxide (VO_2) is an interesting material and worthy of study. It has a metal-insulator transition (MIT) at around 68°C or 341K. Although other materials undergo this phase change, most do it at much lower temperatures. The transition in vanadium dioxide is not that far from room temperature. The electrical and optical properties of this transition are of much interest. The fast MIT could be used as a switch in electrical devices. In the metallic phase, it is not. Researchers propose using this property in smart windows to stop infrared radiation from entering a building once it is too warm. However, for most applications, researchers would like the MIT temperature to be at or slightly below room temperature. Researchers have successfully used doping and swift ion radiation to change the transition temperature [1]. Vanadium dioxide requires further study before its full potential can be used.

2 High Temperature Probe



(a) Probe



(b) Probe Head

Figure 1: The high-temperature probe and a close-up image of the head of the probe.

I helped Lu Chen, a graduate student in the lab, finish her high-temperature vanadium dioxide probe (Figure 1a). I assisted in preparing the sample and testing. The purpose of these tests was to measure the thermopower (or Seebeck coefficient) of a VO_2 sample. This sample was a vanadium dioxide thin film on a sapphire substrate (Figure 1b). It was placed upright on a sapphire chip and attached with epoxy. Two type E thermocouples were attached to the sapphire side of the sample, one at the top and one at the bottom. Four gold wires were attached with silver paste to the side of the sample, just barely touching the thin film. These were used to measure voltage. Four small heaters were attached to the top of the sample with gold wire connecting them. The entire arrangement was placed on the copper head of the probe and the wires were attached underneath. The entire head was covered with a brass cap and sealed with vacuum grease. The probe was then pumped down to vacuum. It was then ready for testing.

Once the probe was completed, it was time to run tests. We measured the thermopower and resistivity of the sample. To measure thermopower, we increased the overall temperature of the probe head. Once it had stabilized at a certain temperature, we turned on the little heaters on top of the sample. This created a temperature gradient across the sample. We recorded the thermocouple readings and voltage across the sample for that overall temperature, then turned off the heaters, increased the overall temperature and did it over again. The ratio of the temperature difference and the voltage difference gave the Seebeck coefficient. The van der Pauw method was used to measure resistivity. This method is used to measure the resistivity of thin, flat, hole-less, homogeneous samples. Four wires are hooked up to the very edge of the sample. The voltage and current are measured diagonally across the sample. From these measurements, resistivity is calculated. The thermopower and resistivity measurements both show the MIT (Figure 2). The probe can be used with new samples to find the transition temperature.

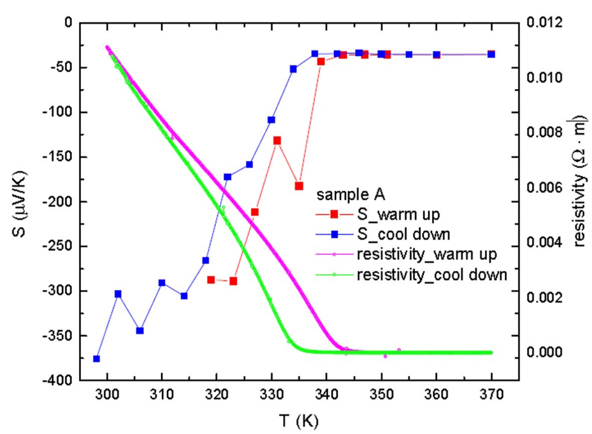
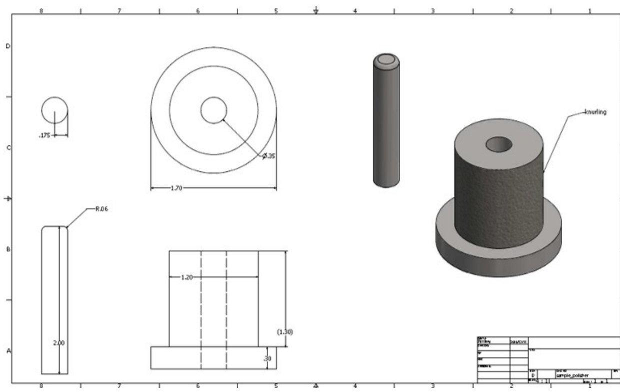


Figure 2: Resistivity and thermopower from the test of the high-temperature probe. Both show the MIT at around 70°C. The thermopower measurement suffers due to the high thermal noise of the system. Graph by Lu Chen

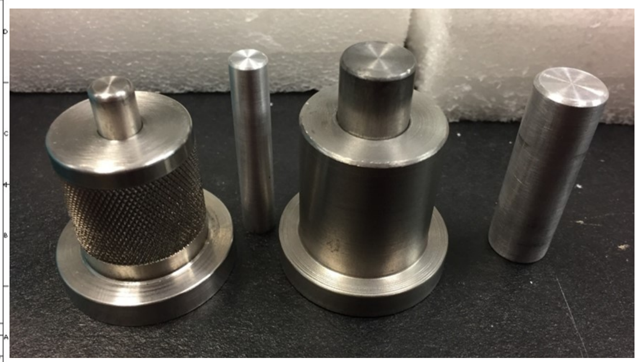
3 Sample Polisher

As mentioned above, the transition temperature of VO_2 can be changed with radiation. However, this only works for thin film samples. Bulk crystal samples are much easier to make and therefore cheaper. Therefore, I created a polishing tool to polish bulk crystal samples of VO_2 to a width of 100 microns.

After helping with the probe, I worked on creating a new sample polisher for crystal samples. The original design was done by Ziji Xiang (Figure 3a). The design consists of two parts, a post and a holder. Both are made of stainless steel. The sample is attached to the bottom of the post with SPI Supplies Crystalbond 509. The post is then placed in the holder and the entire thing is placed on 600 grit sandpaper. Once the sample is polished, the Crystalbond is dissolved with acetone and the sample falls off. Li Lab had a sample polisher based on this design at the beginning of the summer. This design underwent a few alterations. Firstly, a new sample polisher with a larger post (0.625 inches as opposed to 0.35 inches) was made, also out of stainless steel (Figure 3b). This was to accommodate the large VO_2 samples. Aluminum posts were also made for both polishers. Once the samples get very thin, the weight of the stainless steel can cause the sample to crack. The new polishing procedure dictates that once the sample gets thin, the researcher switches from the stainless steel post and 600 grit sandpaper to the aluminum post and 1500 grit sandpaper. Unfortunately, the larger samples of vanadium dioxide have not arrived at the time of writing, so this design and process remain untested.



(a) Polisher CAD drawing



(b) Two polishers with extra aluminum posts

Figure 3: The initial CAD drawing of the polisher and the final result. The polisher on the right is the newer design.

4 Samarium Hexaboride

Samarium hexaboride is a topological insulator. This means that although the bulk crystal is insulating, the very surface can conduct electricity under the right conditions. When members of Li Lab went to the National High Magnetic Field Laboratory, they looked for quantum oscillations in two samples of SmB_6. The surface of one of the samples was roughened using a sample polisher. The point of this was to see how the texture of the surface of the sample affected the measurement.

When looking for quantum oscillations, the researchers used the de Haas-van Alphen effect.

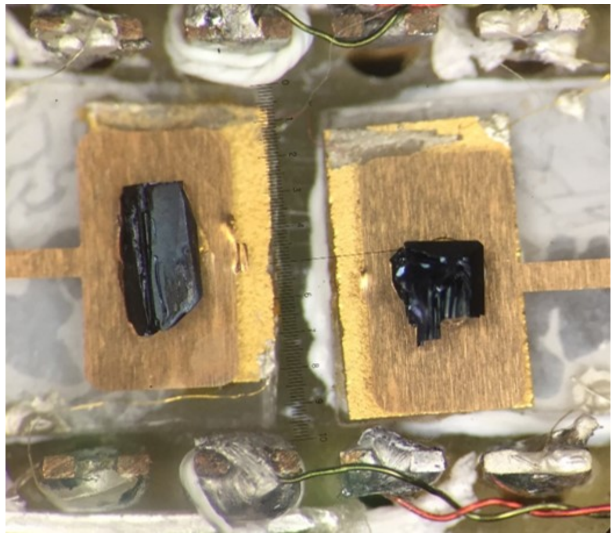


Figure 4: The set-up for the samarium hexaboride test. The left sample was roughened by the polishing process and is therefore duller.

This is a quantum mechanical effect observed at low temperatures and high magnetic field. If the field is increasing in intensity, the magnetic moment of a crystal sample oscillates[2]. This is due to the quantization of electron orbits.

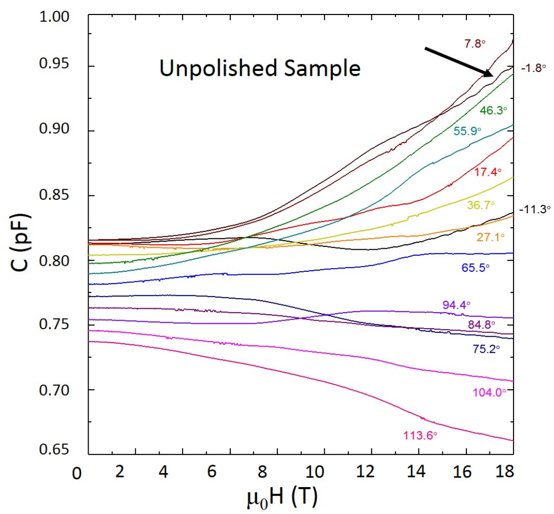
The experimental setup is as follows. The two samples were mounted on two small cantilevers (Figure 4). The cantilevers are placed in a low-temperature, high-field environment. The angle between the normal to the cantilever and the magnetic field is measured. Then, the magnetic field is increased. This causes a torque on the cantilever which will change its position relative to the substrate beneath it. This changing capacitance is recorded (Figure 5). The de Haas-van Alphen effect causes the magnetic moment of the samples to oscillate, which is observed as small bumps in the curve of the capacitance versus field. Although the data has not been analyzed yet, the -1.8°curve in the unpolished sample at high field strength seems to show quantum oscillations. The same text on the polished sample does not show these bumps. Further analysis is needed before drawing any meaningful conclusions from this data.

5 Conclusion

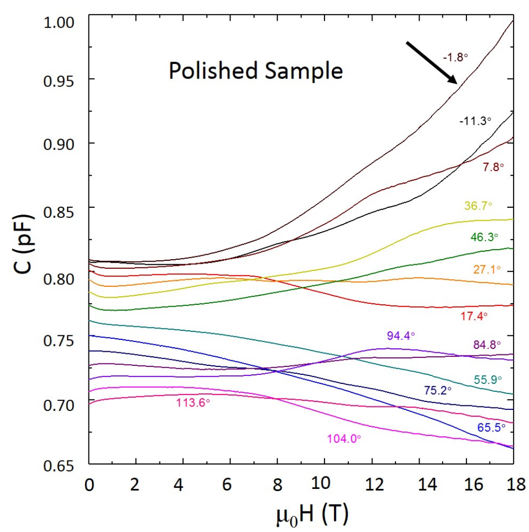
This summer, I worked on finishing and testing a probe to measure thermal and electrical properties of vanadium dioxide. I created a polishing device to reduce the dimensions of VO_2 bulk crystals. I worked on a test to see if changing the surface texture of a SmB_6 crystal changed its quantum properties.

Acknowledgements

I would like to thank the National Science Foundation for funding the REU program. I would like to thank my advisor Prof. Lu Li as well as Ziji Xiang, Lu Chen, and the other members of



(a) Unpolished Sample Data



(b) Polished Sample Data

Figure 5: The results from the test for quantum oscillations in polished and unpolished samarium hexaboride. Although further analysis is needed, the data from -1.8°(see arrows) shows some oscillation in the high field in the unpolished sample and not in the polished sample. Graphs by Ziji Xiang

Li Lab. This project could not have happened without their support. I would like to thank the University of Michigan, especially Myron Campbell, Jim Liu, and Angela Germaine for putting on this program. Jim Tice gave advice on how to machine the second sample polisher. Finally, I would like to thank my fellow REU students for making this an amazing summer.

References

[1] G. R. Khan, A. Kandasami, and B. A. Bhat, "Augmentation of thermoelectric performance of VO_2 thin films irradiated by 200 MeV Ag^{9+} -ions," *Radiat. Phys. Chem.*, **123**, 55-62 (2016).

[2] N.W. Ashcroft and N.D. Mermin, *Solid State Physics*, 264-271, Holt, Rinehart and Winston (1976).