Probing Two-Dimensional Van der Waal Heterostructure and Height Characterization

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Primary CNF Tools Used: Heidelberg Mask Writer - DWL2000, AFM Veeco Icon, DWL2000, Angstrom Evaporator, Odd and Even Hour Evaporator

Abstract:

This study describes a method for creating metal probes on Si/SiO_2 substrates. These probes are important for making measurements on superconducting 2D flakes in order to understand the transport properties of our superconductor and determine the critical current specific to our material. The fabrication process involves depositing metal layers precisely using techniques such as photolithography and electron beam evaporation. We optimized key parameters including substrate preparation, metal deposition rates, and patterning resolution to produce high-quality metal probes with excellent electrical and mechanical properties. The resulting metal probes show superior conductivity, durability, and adhesion to the Si/SiO_2 substrates. This work shows that the proposed fabrication method is feasible and scalable, offering potential for developing high-performance devices in microelectronics and nanotechnology.

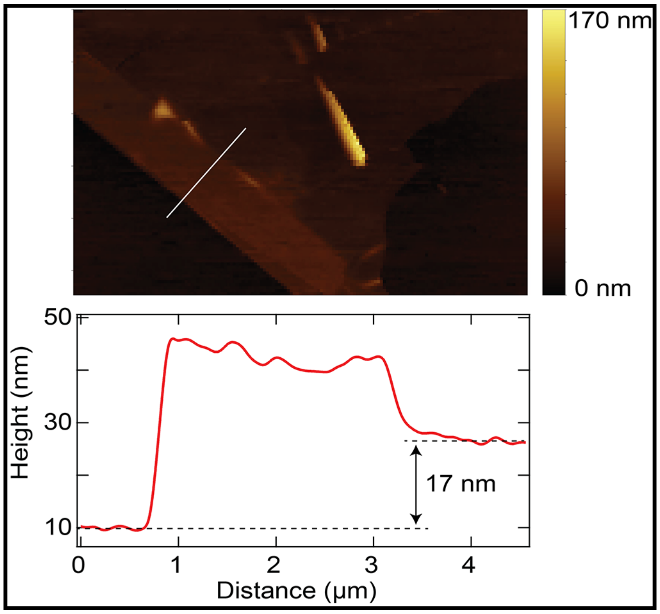

Figure 1: AFM study gives a thickness of 17.0 nm which corresponds to .28 layers [4].

Summary of Research:

Atomic Force Microscopy (AFM) is a widely used technique for measuring the thickness of two-dimensional (2D) materials down to a monolayer. Materials like graphene, molybdenum disulfide (MoS_2), and hexagonal boron nitride (hBN) have unique electronic, optical, and mechanical properties that depend largely on their thickness. Accurate determination of material thickness is essential for understanding and utilizing these properties in various applications, including electronics, photonics, and sensing. In AFM, a sharp tip attached to a cantilever scan over the sample surface. As the tip interacts with the sample, forces between the tip and the sample cause the cantilever to deflect. These deflections are measured by a laser beam reflected off the cantilever onto a photodetector. By maintaining a constant force (contact mode) or distance (tapping mode) between the tip and the sample, AFM can generate high-resolution topographic images of the sample surface.

The sample needs to be meticulously prepared in order to measure the thickness of 2D material flakes using AFM. This process usually entails separating the 2D material from a larger crystal onto a substrate, commonly silicon with a silicon dioxide (Si/SiO_2) layer. The flatness and cleanliness of the substrate are crucial for precise measurements.

After preparing the sample, we use AFM to scan the surface and generate a topographic image. We can then

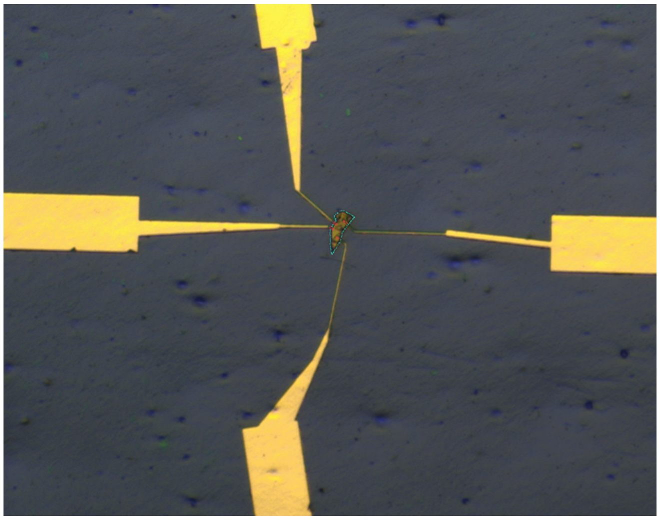

Figure 2: Ti/ Au contacts fabricated to probe superconducting flake Fe(Te,Se).

analyze the height profile of the image to determine the thickness of the 2D material flakes. The thickness is measured by comparing the height difference between the flake and the surrounding substrate. To ensure accurate measurements, it's important to select an area of the substrate adjacent to the flake as a reference point.

The critical current defines the operational limits of superconducting devices [4]. For applications in quantum computing and nanoelectronics, it is crucial to know the maximum current that the superconductor can handle without becoming resistive. Higher critical currents enable the development of more powerful and efficient superconducting circuits and devices.

Superconductors with higher transition temperatures can operate at more practical and potentially higher temperatures. This reduces the need for expensive cooling systems, which is especially important for developing superconducting electronics that can function at or near room temperature. This greatly enhances their practicality and cost-effectiveness.

By probing the critical current, researchers can identify the factors that limit superconducting performance. This knowledge can be used to engineer materials with higher critical currents through strain engineering, doping, or creating heterostructures [3]. We used DWL66FS to write directly on Si/SiO$_2$ substrates, followed by metal deposition in the Angstrom evaporator. Ti/Au – 5/95 nm was deposited on the developed substrates exposed in DWL2000. Different feature sizes were experimented with while doing the direct writing, and a dose test was performed to optimize the energy required in the exposure. The bilayer photoresist spin coating option was preferred for the direct writing to minimize the undercut for the metal lift-off with acetone. Optimizing Ic can lead to the development of superior superconducting materials with tailored properties for specific applications [1,2].

Understanding the factors that influence the critical temperature (T$_c$) in 2D superconductors is important, as this understanding can help in the synthesis of new materials with higher transition temperatures. This may involve exploring new material systems, such as transition metal dichalcogenides (TMDs) or other layered compounds and manipulating their structure at the atomic level to enhance their superconducting properties [4].

We will work on etching our material to create nanostrips and study its electrical and optical properties.

References:

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[3] Lee J, Lee W, Kim GY, Choi YB, Park J, Jang S, Gu G, Choi SY, Cho GY, Lee GH, Lee HJ. Twisted van der Waals Josephson Junction Based on a High-Tc Superconductor. Nano Lett. 2021 Dec 22;21(24):10469-10477.

[4] A. K. Pattanayak, et al. Temperature-Dependent Optical Constants of Nanometer-thin Flakes of Fe(Te,Se) Superconductor in the Visible and Near-Infrared Regime (Manuscript under communication).