Etching of Topological Metals for Interconnect

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Primary CNF Tools Used: Scanning electron microscope (SEM), Nabity Nanometer Pattern Generator System, Reactive Ion Etcher PT720, Atomic Force Microscope (AFM), RC2 ellipsometer

Abstract:

On-chip interconnects are electrical wiring systems that connects transistors and other components in an integrated circuit. Copper (Cu) has been our main interconnect for over two decades. Over the years, the dimensions of Cu interconnects have decreased for better computing performance, and finally Cu has reached its limitations where under 15 nm of the interconnect width, signal delays and larger energy consumptions are significant due to the high resistivity of Cu interconnects stemming from surface and grain boundary scattering of electrons.

In contrast, topological metals, especially molybdenum phosphide (MoP), have shown promise as our next interconnect metals owing to their topological surface states that are resistant to scattering. We convert molybdenum sulfide (MoS_2) flakes to MoP by chemical vapor deposition and use electron beam and etching to create narrow nanoribbons. Four-point probe measurements show the resistivity to be 13 microohm-cm, demonstrating the viability of MoP as future interconnects.

Summary of Research:

Within the first two weeks of the program, we had several conferences, an in-person safety training course, a general online chemical safety training and lastly a cleanroom safety training while simultaneously reading relevant publications.

First, we got trained in the atomic force microscope (AFM). Then we got trained on the scanning electron microscope (SEM) with Nabity alongside. Later we were trained on how to use the RC2 ellipsometer. Then we were trained in the reactive ion etcher (RIE), specifically the PT720 Model. And lastly, we were trained on the electron beam evaporator that uses a method of deposition to deposit various metals on wafers.

To start, our group already had silicon (Si) wafers coated with silicon dioxide (SiO_2) which only required us to clean the wafer to use. After cleaning the wafer using acetone and N-Methylpyrrolidone (NMP) for three minutes each, we exfoliated $MoSi_2$ on the SiO_2/Si wafer by pressing $MoSi_2$ crystals on the coated wafer using a double-sided tape.

We would then put our substrate under an optical microscope (OM) to see if any flake can potentially be used for the project. The flake would then be transferred to another wafer using either wet or dry transfer. This process was done by my mentors (Gangtae and Han) because it involved hydrofluoric acid (HF).

Later, using phosphine gas (Ph_3) in a tube furnace for one and a half hours, we were able to convert $MoSi_2$ to MoP. Shortly, after determining the thickness of our MoP flake under the AFM and optical microscope, we can now use a computer aided design (CAD) to cut out our desired width which was < 300 nm. Then protect our sample with 495 PMMA A4 resist by spin coating the wafer and baking it for two minutes at 2000 revolutions per minute (rpm) twice.

Then using the electron-beam and reactive ion etcher (RIE) etcher, we exposed and etched the target areas on the flake to get our desired width. We looked under both the AFM and the OM to see if both of those processes were successful. If we were successful, we then developed our samples in acetone for five to six hours to remove any residual resist. We then had to re-coat our sample with PMMA to prepare for the next e-beam exposure. This consisted of patterning 4-probe electrodes using CAD. Then go through the e-beam process to allow us to deposit chromium (Cr) and gold (Au) using the e-beam evaporator to facilitate contact when measuring the nanowire's resistivity. If the second e-beam process was successful, we would then develop the sample with isopropyl alcohol (IPA) for about two minutes or less to see if the exposure was successful so we can do deposition then measure the resistivity of the nanowire.

Conclusions and Future Steps:

We successfully fabricated our narrow MoP nanoribbons to determine the resistivity of MoP under 20 nm. The resistivity of the etched nanoribbon was high, possibly due to damage during the fabrication process.

Potential improvements to this process include exploring other etching processes and limiting ambient exposure during the whole fabrication process. Also use X-ray diffraction (XRD) throughout the fabrication process to determine whether our sample changed states or if it remains MoP throughout the fabrication process.

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References:

[1] Gall, D., Cha, J.J., Chen, Z. et al. Materials for interconnects. MRS Bulletin 46, 959-966 (202jj1). https://doi.org/10.1557/s43577-021-00192-3.

[2] Han, H. J., Kumar, S., Jin, G., Ji, X., Hart, J. L., Hynek, D. J., Sam, Q. P., Hasse, V., Felser, C., Cahill, D. G., Sundararaman, R., Cha, J. J., Topological Metal MoP Nanowire for Interconnect. Adv. Mater. 2023, 35, 2208965. https://doi.org/10.1002/adma.202208965.

[3] Wang, W., Qi, J., Zhai, L., Ma, C., Ke, C., Zhai, W., Wu, Z., Bao, K., Yao, Y., Li, S., Chen, B., Repaka, D. V. M., Zhang, X., Ye, R., Lai, Z., Luo, G., Chen, Y., He, Q., Preparation of 2D Molybdenum Phosphide via Surface-Confined Atomic Substitution. Adv. Mater. 2022, 34, 2203220. https://doi.org/10.1002/adma.202203220.

[4] Wang, W., Qi, J., Zhai, L., Ma, C., Ke, C., Zhai, W., Wu, Z., Bao, K., Yao, Y., Li, S., Chen, B., Repaka, D. V. M., Zhang, X., Ye, R., Lai, Z., Luo, G., Chen, Y., He, Q., Preparation of 2D Molybdenum Phosphide via Surface-Confined Atomic Su.

[5] Wang, J., Wu, Z., Mao, C. et al. Effect of Electrical Contact Resistance on Measurement of Thermal Conductivity and Wiedemann-Franz Law for Individual Metallic Nanowires. Sci Rep 8, 4862 (2018). https://doi.org/10.1038/s41598-018-23291-9.

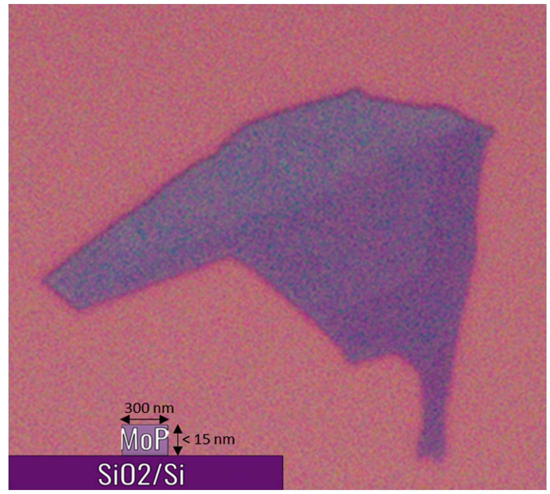

Figure 1: MoP flake.

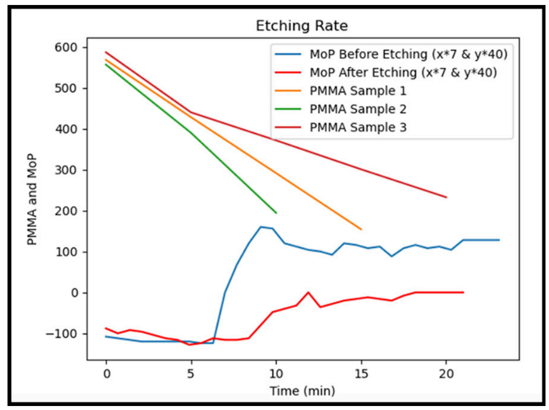

Figure 2: PMMA and MoP etching.

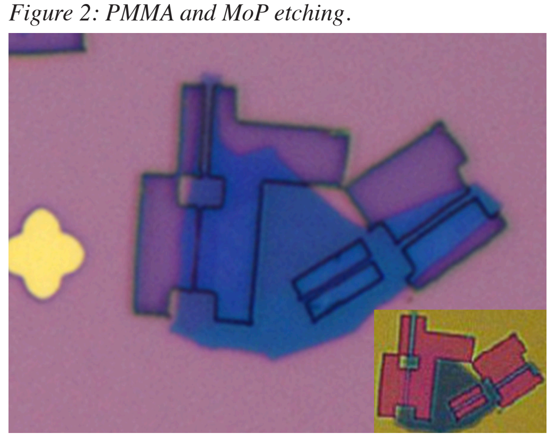

Figure 3: MoP before and after etching.

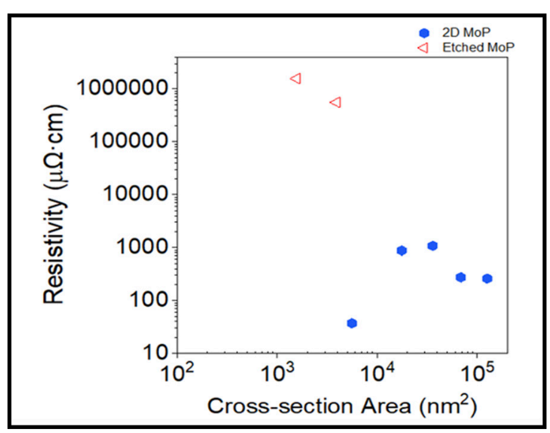

Figure 4: Resistivity measurement.