Nanomolding of Topological Materials for Interconnects

CNF Summer Student: Richard A. Remias
Student Affiliation: Physics, University of Rhode Island

Summer Program(s): 2024 Cornell NanoScale Science & Technology Facility Research Experiences for Undergraduates (CNF REU) Program
Principal Investigator(s): Judy Cha, Materials Science and Engineering, Cornell University
Mentor(s): Quynh Sam, Khoan Duong; Materials Science and Engineering, Cornell University
Primary Source(s) of Research Funding: National Science Foundation under Grant No. NNCI-2025233
Contact: riskoalbi@live.com, jc476@cornell.edu, qps2@cornell.edu, nd399@cornell.edu
Summer Program Website: https://cnf.cornell.edu/education/reu/2024
Primary CNF Tools Used: Oxford FlexAl ALD, Zeiss Supra SEM, Bruker EDX, Veeco Icon AFM, Woollam RC2 Ellipsometer

Abstract:

The increasing resistivity of copper (Cu) interconnects with decreasing dimensions poses many challenges for the continued downscaling of integrated circuits and computer chips. At the nanoscale, electron scattering at grain boundaries and surfaces of the interconnects causes an increase in resistivity leading to higher energy consumption and signal delay in computer chips. Conversely, topological materials may show decreasing resistivity with decreasing size at nanoscale dimensions due to their topologically protected band structures that are predicted to suppress electron scattering. Thus, transport studies of topological materials at the nanoscale are critical to find alternative metals to Cu interconnects. Nevertheless, current nanowire synthesis methods such as molecular beam epitaxy (MBE) and chemical vapor transport (CVT) struggle to create uniformly sized nanowires. We use nanomolding to fabricate nanowires of topological materials, where a bulk material is pressed into a porous anodic aluminum oxide (AAO) mold to create high aspect ratio nanowires. To promote more facile nanomolding and to prevent oxidation of the molded nanowires, we coat the AAO mold pore walls with a thin film of aluminum nitride (AlN) and tantalum nitride (TaN). The CNF's Oxford FlexAl atomic layer deposition (ALD) tool is used to deposit precise and uniform films due to its self-limiting reactions. Through energy dispersive X-ray spectroscopy (EDX), we determine the infiltration depth of AlN in our pores. Additionally, InBi is a topological material which may exhibit interesting quantum properties at few-layer thicknesses. We use nanomolding to compress InBi into thin flakes by encapsulating the InBi with hexagonal boron nitride (hBN). The CNF's AFM Veeco Icon tool is used to determine the resulting thickness of the InBi flake.

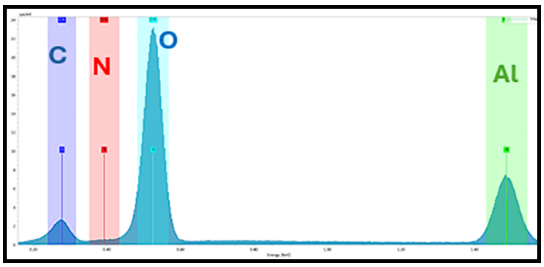

Figure 1: Cross-sectional EDX Spectrum of AAO Channels Post AlN ALD.

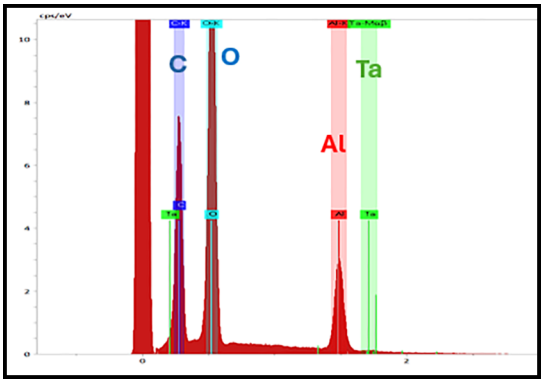

Figure 2: Cross-sectional EDX Spectrum of AAO Channels Post TaN ALD.

Summary of Research:

ALD was first used to deposit 20 nm of AlN onto the AAO mold which had a pore diameter of 120 nm. This deposition was done at 400°C for 334 cycles at 0.6Å/cycle, using trimethylaluminum (TMA) and H_2/N_2 plasma as precursors. These precursors were pulsed for 0.02 seconds and 5 seconds, respectively. To estimate deposition thickness, a blank silicon substrate was placed next to the mold in the ALD chamber and ellipsometry was used to determine the thickness of AlN deposited

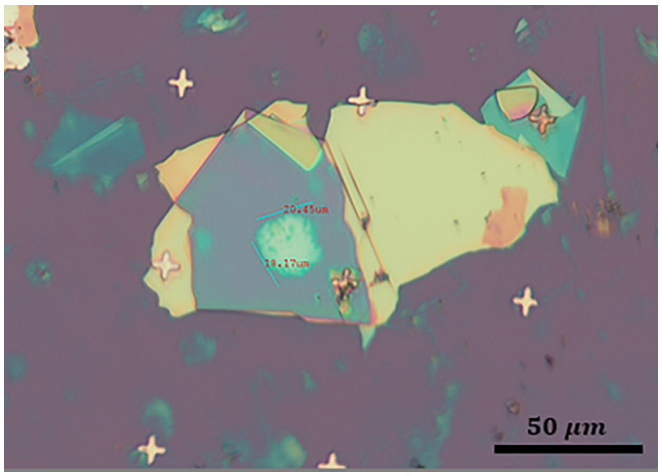

Figure 3: Optical Microscope Image of Compressed InBi Stack.

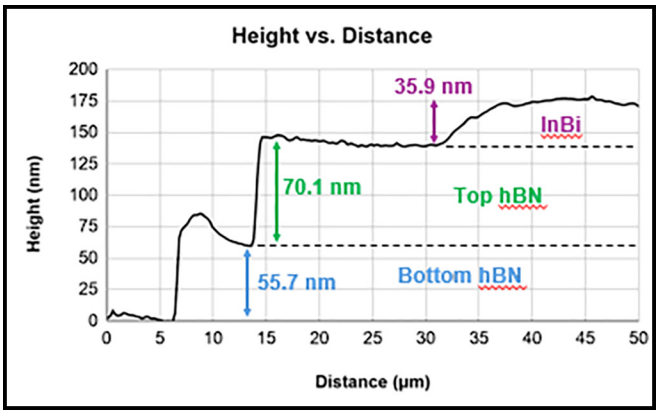

Figure 4: AFM Line Profile Graph of Compressed InBi Stack.

onto the substrate. The resulting thickness was estimated to be about 18.02 ± 0.027 nm. A scanning electron microscope (SEM) was then used to take a cross-sectional image of the AAO mold which was combined with EDX to map the elements deposited within the mold channel walls. However, due to low film thickness and low atomic weight of nitrogen, the infiltration depth of AlN in our pores was inconclusive as no nitrogen was detected on the pore walls (Figure 1).

Next, we used ALD to deposit 10 nm of TaN onto a mold of identical pore diameter. This deposition was done at 250°C for 250 cycles at 0.4 Å/cycle, using tris(diethylamido)(tert-butylimido)tantalum(V), or TBTDET, and ammonia (NH3) as precursors. The pulse time for these precursors was 6 seconds and 15 seconds, respectively. The same method was used to estimate the deposited film thickness, which was determined to be 6.87 ± 0.081 nm. SEM was used to take a cross-sectional image and EDX was used for element mapping. Unfortunately, no tantalum was detected in the pores so the infiltration depth of TaN is inconclusive (Figure 2). Through improvements in ALD parameters, we may be able to determine infiltration depth using EDX.

Additionally, we used nanomolding to press InBi into thin flakes. This was done by placing an hBN flake both on top of and underneath the InBi piece to create an hBN-InBi-hBN stack. The stack was made using tape exfoliation and the desired flakes of uniform thickness were found under a microscope and transferred using a glass slide with an epoxy drop. We used a hot press to compress the InBi stack at 80°C for 15 minutes. The resulting stack is shown in Figure 3.

To determine the final thickness, we used atomic force microscopy to create a line profile over the stack. We measured the thickness of InBi to be 35.9 nm (Figure 4). Different nanomolding parameters were also used on different stacks, such as pressing for 30 minutes at 100°C, however, no flakes were pressed to be thinner than 35.9 nm.

Conclusions and Future Steps:

EDX results after deposition of AlN and TaN show that a more sensitive elemental mapping method may be needed for accurate determination of infiltration depth into AAO channel pores. A method such as X-ray photoelectron spectroscopy may be more sensitive to thinner films as well as lighter elements. Also, increasing precursor pulse time in ALD processes may allow more time for gases to travel into high aspect ratio features, increasing infiltration depth. Increasing gas flow rates may also prove useful as it will increase delivery of gases deeper into the pores.

Results also show that nanomolding can be used to create sub 40 nm thin InBi flakes. Future work would include removing the top hBN flake and testing the resistance of the InBi flake.

Acknowledgements:

This work was made possible by the Cornell NanoScale Facility and funded by the National Science Foundation via grant no. NNCI-2025233. Special thanks to Judy Cha, Quynh Sam, Khoan Duong, Sihun Lee, and Melanie-Claire Mallison for their great help and guidance.

References:

[1] Chen, L., Wu, A.X., Tulu, N., et al. Exceptional electronic transport and quantum oscillations in thin bismuth crystals grown inside van der Waals materials. Nat. Mater. 23, 741-746 (2024). https://doi.org/10.1038/s41563-024-01894-0.

[2] Kiani, M. T., Sam, Q. P., Jin, G., Pamuk, B., Han, H. J., Hart, J. L., Stauff, J., and Cha, J. J. (2023). Nanomolding of metastable Mo4P3. Matter, 6(6), 1894-1902. https://doi.org/10.1016/j.matt.2023.03.023.