Thermomechanical Nanomolding of Single Crystalline CoSn Nanowires

CNF Summer Student: Bruce Pan
Student Affiliation: College of Chemistry, University of California, Berkeley

Summer Program(s): 2026 Cornell NanoScale Facility Research Experience for Undergraduates (CNF REU) Program

Principal Investigator(s): Judy J. Cha, Cornell University

Mentor(s): Jack Coyle

Primary Source(s) of Research Funding: NSF SUPREME REU

Contact: judy.cha@cornell.edu, bdp@berkeley.edu, jdc384@cornell.edu

Summer Program Website(s): https://www.cnf.cornell.edu/education/reu

Research Group Website: cha.mse.cornell.edu

Primary CNF Tools Used: Nabity NPGS Nanometer Pattern Generator System; Carl Zeiss GeminiSEM 560 scanning electron microscope

Abstract:

Copper interconnect resistivity climbs as line dimensions shrink because electrons scatter at surfaces and grain boundaries. CoSn is a kagome metal that carries current more easily along the c direction than in the basal plane, which makes c direction CoSn nanowires worth evaluating as a replacement conductor. This project used thermomechanical nanomolding to press bulk CoSn into nanoporous anodic aluminum oxide and release wires in dilute hydrofluoric acid. Scanning transmission electron microscopy found many single crystal wires with [001] long axes, and energy dispersive X ray spectroscopy returned normalized fractions of 50.64 atomic percent cobalt and 49.36 atomic percent tin. Four terminal devices were built on single wires, but rectifying contacts prevented extraction of an intrinsic resistivity.

Summary of Research:

Cobalt atoms in CoSn sit on kagome nets stacked along the c axis, which produces flat bands near the Fermi level [4]. Single crystal measurements put the basal plane resistivity more than an order of magnitude above the c axis value [5], and films reach about 13 microohm centimeters along c [6]. Neither geometry shows how resistivity behaves once the conductor is confined to a nanoscale cross section [7]. The aim was to mold c direction single crystal nanowires and measure them individually.

Feedstock was pressed against a nanoporous anodic aluminum oxide template at 550 degrees Celsius and 250 megapascals for two hours, so metal fills the pores by pressure driven diffusion rather than melting [1,2,3]. The template was dissolved in 5 weight percent hydrofluoric acid and the wires sonicated and drop cast onto marked substrates. Of five molding runs, CS4 yielded nothing, which we attribute to insufficient effective pressure.

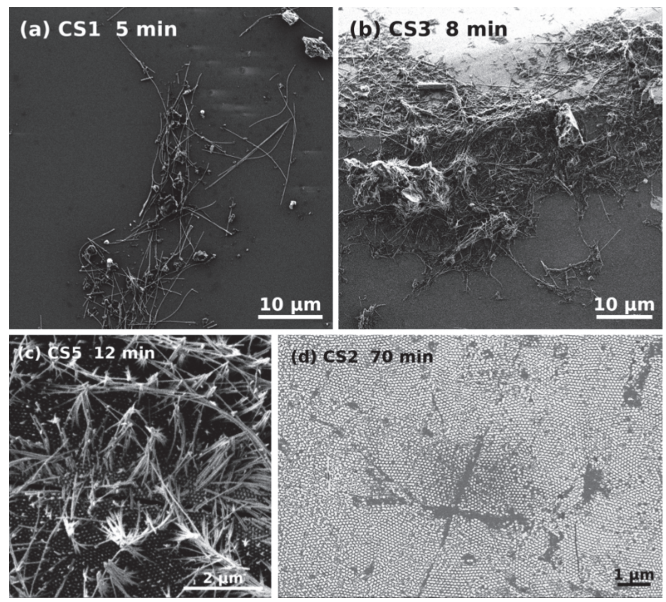

Figure 1: Released material after 5, 8, 12 and 70 minutes in 5 weight percent hydrofluoric acid. Twelve minutes gave the cleanest dense arrays in this sample set.

Release time controls how much product survives, and Figure 1 brackets it. Five minutes left sparse fragments in undissolved template. Eight minutes freed more material but left it matted in residue. Twelve minutes gave the cleanest dense arrays. Seventy minutes removed the wires and left only stubs. Filling fraction, delamination and handling also varied between runs, so this is a usable window rather than a universal optimum.

Scanning electron microscopy showed structures several micrometers long at the 40 nanometer nominal diameter set by the template. One frame gave an apparent width of 52.19 nanometers, which we did not treat as physical because aperture and stigmation were not optimized. Collaborator imaging at the Cornell Center for Materials Research resolved the lattice directly. Figure 2 shows wires along [120] and [110], both single crystalline with [001] long axes, so many wires grow with the fast axis

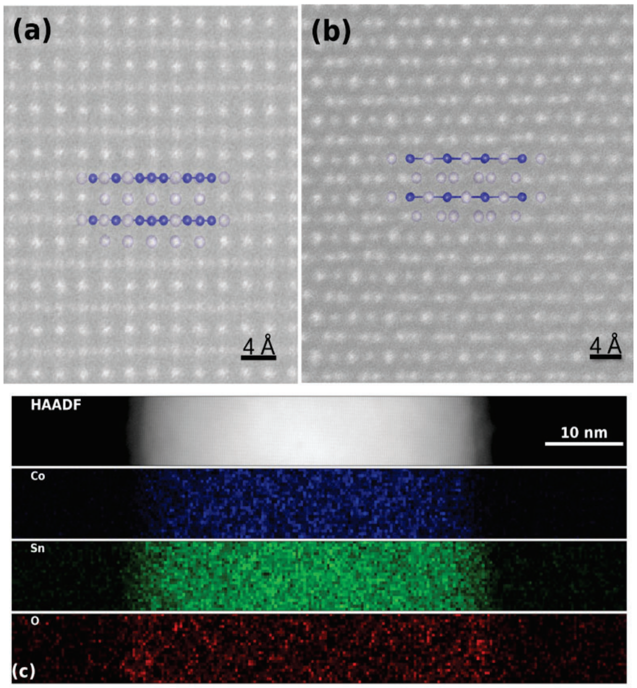

Figure 2: Atomic resolution high angle annular dark field imaging of single crystal CoSn nanowires along [120] in (a) and [110] in (b), both with [001] long axes, with elemental maps across a wire cross section in (c) showing cobalt and tin in the core and oxygen at the surface.

along the wire. Elemental maps confirm cobalt and tin throughout the core. Quantification normalized to those two elements gave 50.64 and 49.36 atomic percent, each with 3.17 percent reported error, consistent with 1:1 stoichiometry. Oxygen at the surface suggests a thin tin oxide shell of undetermined thickness.

Four electrodes were patterned across a single wire by electron beam lithography on the Nabity Nanometer Pattern Generator System at the Cornell NanoScale Facility, with contact metal deposited at the Cornell Center for Materials Research. Inner probe spacing was 2.49 micrometers. Figure 3 shows a completed device and the most common failure mode, where the wire dislodges during processing and the electrodes land on bare substrate. Yield was limited more by wire retention than by lithography.

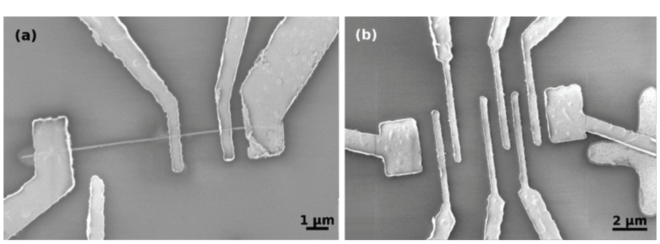

Figure 3: Four terminal device on a single CoSn nanowire in (a), and in (b) a set of electrodes left with no wire after the wire was dislodged during processing.

Electrical testing used a Keysight B1500A parameter analyzer. Two point sweeps between contact pairs are collected in Figure 4. Most pairs were close to linear over plus or minus 100 nanoamperes, which initially suggested usable contacts, but one pair rectified strongly and is plotted against the right hand axis. Alternating current measurement then identified one contact as Schottky and returned roughly 12 megohms of apparent four terminal impedance. Because drive frequency, amplitude and phase were not retained, that number cannot be assigned as a resistance. Other devices were also nonohmic, so no intrinsic resistivity or contact resistance was extracted.

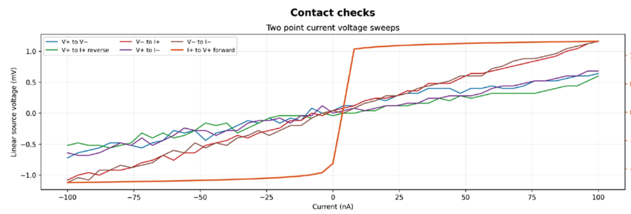

Figure 4: Two point current voltage sweeps between contact pairs. The rectifying pair uses the right hand axis. Alternating current measurement later identified one Schottky contact on this device.

Conclusions and Future Steps:

Nanomolding produced long CoSn nanowires, microscopy confirmed many single crystal wires with [001] long axes and the expected composition, and four terminal device fabrication was demonstrated. The contacts, not the supply of wires, stopped the transport measurement. Next steps are to treat the wire surface before metal deposition, improve wire adhesion during processing, check every contact pair for ohmic behavior before a four terminal sweep, and keep the full alternating current settings and raw data. Resistivity can then be measured across several diameters to test scaling directly.

References:

[1] Z. Liu et al., "Nanomolding of Crystalline Metals: The Smaller the Easier," Physical Review Letters 122, 036101 (2019).

[2] N. Liu et al., "General Nanomolding of Ordered Phases," Physical Review Letters 124, 036102 (2020).

[3] M. T. Kiani and J. J. Cha, "Nanomolding of Topological Nanowires," APL Materials 10, 080904 (2022).

[4] M. Kang et al., "Topological Flat Bands in Frustrated Kagome Lattice CoSn," Nature Communications 11, 4004 (2020).

[5] H. Huang et al., "Flat-Band-Induced Anomalous Anisotropic Charge Transport and Orbital Magnetism in Kagome Metal CoSn," Physical Review Letters 128, 096601 (2022).

[6] T. Nakatani et al., "Fabrication and Characterization of Single-Crystalline CoSn (10−10) Kagome Metal Thin Films for Interconnect Applications: Structure and Anisotropic Electrical Resistivity," Applied Physics Letters 127, 203302 (2025).

[7] M. T. Kiani and J. J. Cha, "Shrinking Interconnects beyond Copper," Science 390, 572 to 573 (2025).

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