

Resistivity Scaling in PdGa Nanowires

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Primary CNF Tools Used: Zeiss Supra SEM, Nabity NPGS Nanometer Pattern Generator System, Oxford 81 RIE, SC4500 Even and Odd-Hour Evaporator, Westbond 7400A Ultrasonic Wire Bonder, Veeco Icon AFM

Abstract:

Topological semimetals possess topologically protected surface states that suppress carrier backscattering, and in contrast to traditional metals, are predicted to possess enhanced conductivity at reduced dimensions. PdGa is predicted to host topologically protected Fermi arcs, and its relatively low bulk resistivity ($23 \mu\Omega\cdot\text{cm}$) motivates its study as a potential post-copper interconnect material. In this work, we synthesize PdGa nanowires with diameters between 20 and 150 nm using thermomechanical nanomolding (TMNM). High angle annular dark field scanning transmission electron microscopy (HAADF-STEM) confirms single-crystal $P2_13$ structure in the nanowire core, while electron energy loss spectroscopy (EELS) reveals a Ga-deficient shell attributed to wet etch damage during device processing. We observe the resistivity of the molded nanowires to be higher than bulk, but also that the resistivity decreases with decreasing wire diameter within batch. We attribute the elevated resistivity to the Ga vacancies induced during wet etching. However, because resistivity decreases on a per-batch basis, we hypothesize that surface states are still partially intact.

Summary of Research:

To fabricate PdGa nanowires, we use thermomechanical nanomolding, in which bulk PdGa is extruded through a nanoporous anodic aluminum oxide (AAO) mold under heat and pressure. Following KOH etching of the mold, nanowires are detached via sonication and dropcast onto substrates, yielding wires with diameters spanning 20–150 nm. Atomic-resolution HAADF-STEM imaging of freestanding nanowires confirms a single-crystal $P2_13$ structure in the wire core. STEM-EELS elemental mapping, however, reveals

a core-shell structure: the core is stoichiometric PdGa, while the shell is deficient in gallium, which we attribute to damage introduced during the wet etch step.

Four-point probe devices are fabricated on individual nanowires via e-beam lithography using equipment at the CNF. Low-temperature transport measurements indicate metallic behavior with a residual resistance ratio (RRR) of ~ 1.2 , indicating that resistance is dominated by surface scattering rather than phonon scattering. Across five fabrication batches, measured resistivity is higher than bulk ($23 \mu\Omega\cdot\text{cm}$) but decreases with decreasing wire diameter within each batch. This suggests that surface-state conduction pathways remain intact despite the shell of Ga vacancies. Notably, absolute resistivity varies appreciably from batch to batch, which we interpret as reflecting differences in etch damage. Line resistance is presently well above that of copper across the measured size range (roughly an order of magnitude higher at 20 nm).

Conclusions and Future Steps:

Our results show that PdGa nanowires exhibit elevated resistivity relative to bulk, which we attribute primarily to gallium vacancies introduced by etch damage during device fabrication. The decreasing resistivity with decreasing diameter on a per-batch basis suggests that the underlying surface-state transport channel remains intact despite this damage. Next steps focus on quantifying etch-induced damage directly on bulk PdGa crystal. In parallel, theoretical calculations modeling the effect of Ga vacancies on transport are underway.

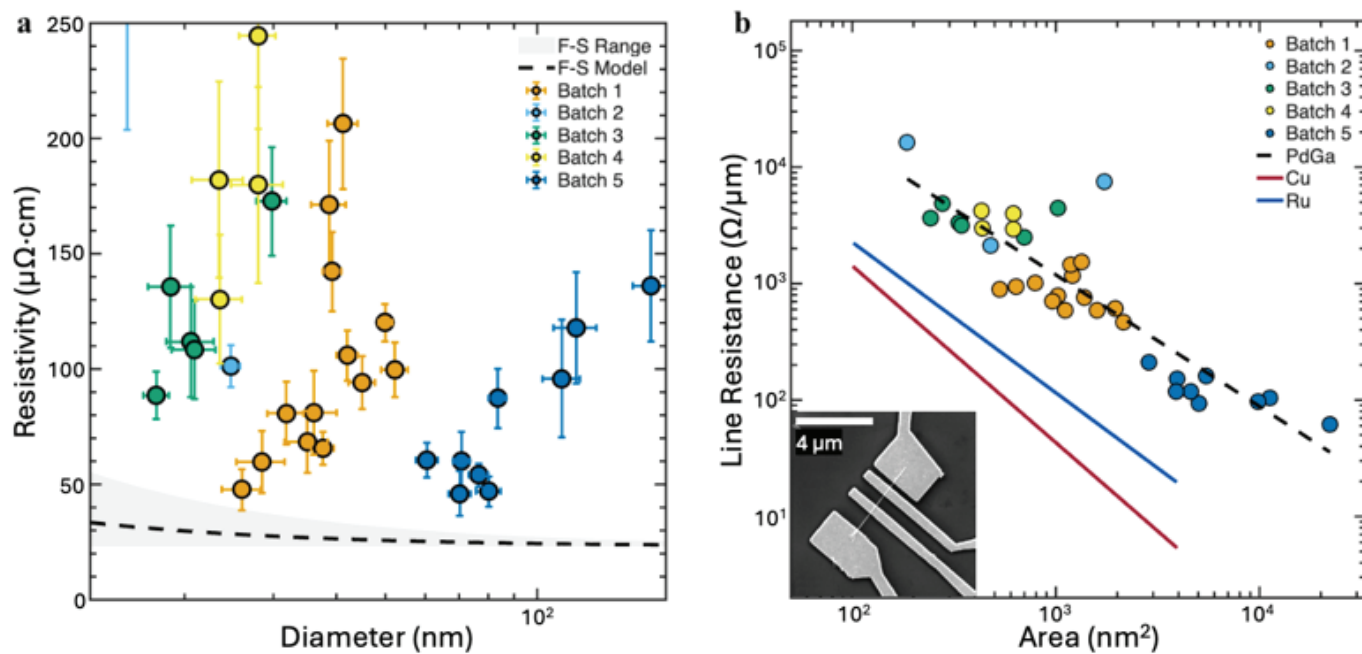


Figure 1: (a) diameter-dependent resistivity of five different batches of PdGa nanowires. (b) Cross-sectional area-dependent line resistance scaling of nanowires. Inset: a representative four-point probe device.