Phase controlled synthesis and low temperature electronic transport properties of ultrathin, single crystal WC and W_2C nanoplates

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The transition metal carbide (TMC) family has historically been studied and applied for their high hardness, chemical stability, and electrocatalytic activity. Initially studied in bulk, non-layered morphologies, TMCs have received renewed interest with the development of novel top-down and bottom-up approaches to isolate layered TMCs (MXenes)[1] and ultrathin, non-layered TMCs (UThTMCs)[2], respectively. While the MXene family has an impressive range of applications,[3] electronic transport properties can be difficult to probe owing to small domain size. Measurements of the superconducting properties of bulk TMCs have historically fallen in wide ranges owing to poor crystallinity and multiple phases present in measurements.[4] Recently, UThTMCs were isolated as single crystal nanoplates with molybdenum carbide (Mo_2C) showing thickness,[2] phase, and pressure dependent superconducting features[5] with sharp superconducting transitions. Additionally, semimetallic single crystal tungsten carbide (WC) has been shown to exhibit anisotropic magnetoresistance.[6] However, no other UThTMC tungsten carbides have been reported, and their superconducting properties have not been studied in this ultrathin limit. Following recent works in bottom-up synthesis of UThTMCs[6,7], we synthesize single crystal nanoplates of WC ($P\bar{6}m2$) with copper/tungsten foil stacks and W_2C (Pbcn) from gallium/tungsten substrates using a liquid-metal-assisted chemical vapor deposition approach, and we probe their low temperature electronic transport properties.

Atomic force microscopy reveals that the thickness of these crystals is below 50 nm under specific reaction conditions. We find that modifications to the surface area of the gallium substrates lead to notable changes in the coverage, nucleation density, and lateral size of W_2C platelets. In both systems studied, we use Raman spectroscopy to study the formation of and interactions between the carbide phases and graphitic carbon. We then fabricate four-probe devices on WC and W_2C single crystals to measure low temperature electronic transport properties. We measure the resistivity with and without an out of plane magnetic field on WC and find that down to 10 mK, WC does not enter a superconducting state. In the W_2C system, we observe a superconducting transition with a T_c of 2.85K. We also probe the temperature dependence of critical fields both in and out-of-plane to assess the dimensionality of this superconducting state. From these data, we extract Ginzburg-Landau coherence lengths both in-plane and out-of-plane for W_2C. This work was supported by the Basic Office of Science of the Department of Energy under Award DE-SC0018025.

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