Supporting Information

A Chemical Solution Approach for Superconducting and Hard Epitaxial NbC Film

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S1. Experimental Details

Nb precursor solution: The precursor used for the growth of NbC films was prepared by an aqueous solution of Nb ion bound to polymer. High purity (>99%) $NbCl_5$, NH_4OH, and 20% HF were dissolved in water where the water was purified using a Milli-Q water treatment system. Ultrafiltration was carried out under 60 psi nitrogen pressure using Amicon stirred cells which have a 3000 molecular weight cut-off. In details, 2 g of $NbCl_5$ were converted to $Nb(OH)_5$ by addition of ammonium hydroxide into the solution according to literature procedures.[21] The $Nb(OH)_5$ was then dissolved in 30 mL of deionized water and 7.5 mL of 20% HF. Polyethyleneimine (PEI) was then added in 31 g aliquots (total 3.0g) and mixed after each addition. After stirring, the solution was placed in an Amicon filtration unit containing a filter designed to pass materials with molecular weight < 30,000 g/mol. The solution was diluted 3 times to 200 mL and then concentrated to 35 mL in volume. Inductively

coupled plasma-atomic emission spectroscopy showed that the final solution was 400 mM Nb.

The film preparation: The prepared Nb precursor solution was spin-coated on *c*-plane sapphire substrates at 3000 rpm for 20 s. The film was heated to 650 ^{o}C at a rate of 10 ^{o}C/min under the mixture gases of ethylene (10 sccm) and forming gas (10 sccm), and then annealed at 650 ^{o}C for 2 h. The mixture gas was switched off and the argon gas (10 sccm) was turned on. Following that, the temperature was ramped from 650 ^{o}C to 1000 ^{o}C in one hour, and the film was annealed at 1000 ^{o}C for 3 h. Finally, the temperature was decreased to room temperature naturally. The thickness of the obtained film is about 30 nm for one spin-coat. Thicker film could be deposited by increasing the concentration of Nb and multiple spin-coats.

Characterization: Nb concentration in precursor solution was conducted by a Horiba Jobin Yvon Ultima II inductively coupled plasma-atomic emission spectrometer (ICP-AES). X-ray diffraction (XRD) was used to characterize the crystallographic orientation of the films. The surface morphology and element analyses of the films were analyzed by scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDAX), respectively. The microstructure of the films was analyzed by transmission electron microscopy (TEM). The resistivity and magnetization (as s function of temperature) were measured using a standard four-probe technique by a Physical Properties Measurement System (PPMS) and Superconducting Quantum Interference Device (SQUID), respectively. The hardness of the films was tested using a Nano-Mechanical Test Instrument. The hardness tests were performed by

making 49 nanoindents under a depth-control cycle. The hardness was then plotted with depth, and the indentation depth–hardness plot was examined carefully for avoiding surface and substrate effects. The hardness values considered were all within the flat part of the indentation depth–hardness curve. Additionally, the standard deviations of hardness and modulus are 0.2 GPa and 4.92 GPa, respectively.

S2. Surface morphologies of the epitaxial NbC film on a sapphire substrate.