Synthesis and characterisation of high-T_c metal hydride thin-films at megabar pressure

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Abstract

The discovery of the hydride superconductor H_3S in 2015 with a T_c record of 203 K at 155 GPa ignited the search for high-T_c superconductivity in compressed hydride compounds [1]. Since, several other hydride compounds have been synthesised such as LaH_{10} [2, 3], YH_6 [4, 5] and YH_9 [5], exhibiting superconductivity close to room temperature under megabar pressures. At present, hydride synthesis is typically carried out via *in-situ* laser heating of bulk precursors together with a hydrogen donor material at high-pressures inside a diamond anvil cell (DAC). One common challenge is the synthesis of single-phase hydrides, in-part due to partial or inhomogeneous hydrogenation during laser heating, yet it is important for careful interpretation of the intrinsic superconducting properties. Toward this objective, our group in Bristol has developed a novel approach to synthesise hydrides from an elemental thin film evaporated directly onto the diamond anvil, with ammonia borane (NH_3BH_3) as a hydrogen donor [6, 7]. Thin film deposition techniques are also used to fabricate robust electrodes, with low electrical resistance, capable of withstanding pressures of up to 250 GPa. This approach facilitates the formation of superhydrides by ensuring a high hydrogen to metal ratio during synthesis and permits accurate control over initial sample dimension and placement relative to the use of bulk precursors. Moreover, the thin films adhere very well to the culet surface, make excellent electrical contact to the underlying electrodes, and remove the requirement for the manipulation of very small (~ 10 μm) air sensitive bulk samples on the culet. Within our team, development of such techniques has greatly increased the success rate for hydride synthesis.

In this poster, we present a detailed overview of the methods used for the preparation of thin-film hydrides, including electrode preparation, film evaporation, and the laser-heating techniques. Experimental developments will be illustrated with examples such as the discovery of high-T_c superconductivity in the novel clathrate hydride La_4H_{23} [7], as well as our recent synthesis of the record superconductor LaH_{10}. We will present high-resolution structural and electrical characterisation of our high-T_c films and demonstrate that their properties are consistent with those reported in bulk samples. We believe thin-film hydride synthesis could pave the way for future detailed and controlled studies of promising ternary and quaternary hydrides.

References

[1] A. P. Drozdov, et al., Nature 525, 73 (2015).
[2] A. P. Drozdov, et al., Nature 569, 528 (2019).
[3] M. Somayazulu et al., Physical Review Letters 122, 027001 (2019).
[4] I. A. Troyan et al., Advanced Materials 33, 2006832 (2021).
[5] P. P. Kong et al., Nature Communications 12, 5075 (2021).
[6] J. Buhot et al., Physical Review B 102, 104508 (2020).
[7] S. Cross et al., Physical Review B 109, L020503 (2024).

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