The Development of HiPIMS Multilayer SIS Film Coatings on Copper for SRF Applications

SRF 2021

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Introduction

In recent years, alternatives to bulk Nb, including novel materials and fabrication techniques, have been extensively explored by the SRF community. One of these new methodologies is the use of a superconductor-insulator-superconductor (SIS) structure. Typically, these have been envisaged for use with bulk Nb cavities. However, it is also conceivable to apply SIS film coatings to Cu cavities, which have the advantage of being able to operate at 4.2 K. This can potentially delay the onset of the Q-slope observed with coated Cu cavities.

In light of this, two series of multilayer SIS film coatings, with a Nb-AlN-NbN structure (fig. 1 (a)), were deposited onto electropolished OFHC Cu samples, with the use of HiPIMS, in order to determine the efficacy of this approach. The critical difference between the two series was the NbN coating pumping speed, with the lower pumping speed used in series 1 resulting in pressure fluctuations during the coating. The thicknesses of both the AlN and NbN layers were varied, indicated in fig. 1 (b) and (c).

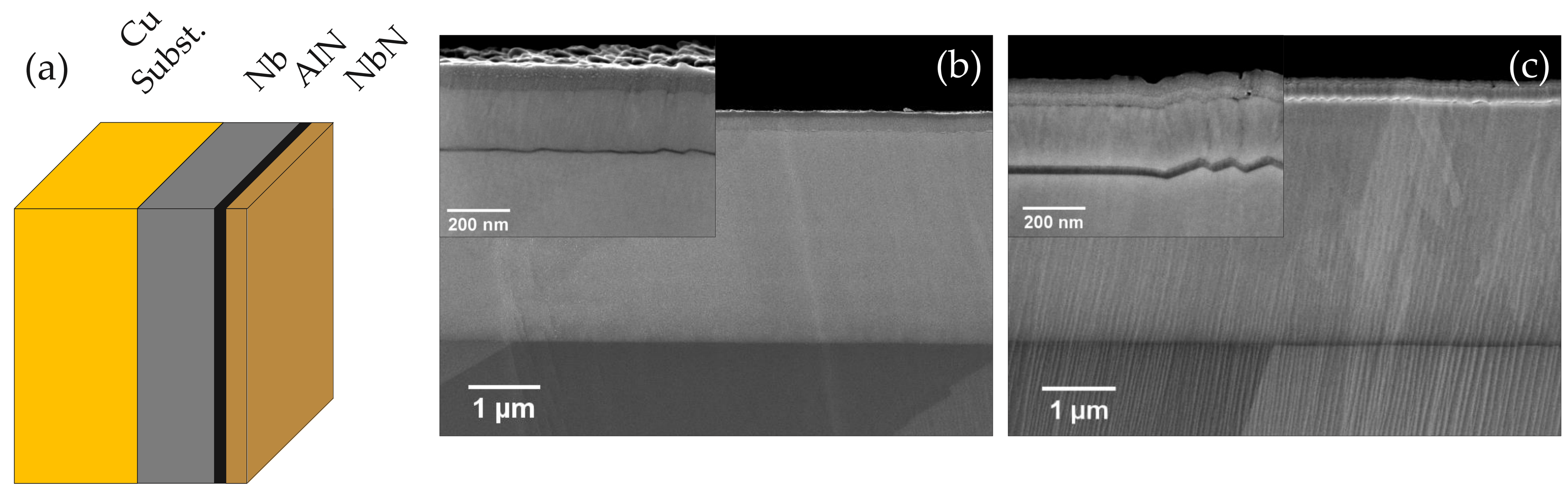

Figure 1: (a) Illustration of the SIS films deposited in this study. SEM images of the cross-sections of SIS films deposited with (b) 9 nm AlN and 173 nm NbN layers and (c) 29 nm AlN and 179 nm NbN layers.

Morphological and Topographical Results

- The resultant surface grain morphology is dominated by the underlying Nb base layer. The NbN is essentially "superimposed" on top of the Nb grains. A multitude of different grain structures are observed, detailed in fig. 2.
- HiPIMS deposition lead to significant improvements to the base Nb layer and a rounding of the NbN film surface, both of which resulted in a subsequent lower surface roughness compared to previous DC MS results.
- TEM investigations (fig. 3) revealed no interfacial voids between the Nb base layer and the Cu substrate or between the subsequent Nb/AlN and AlN/NbN layers.
- The layers display coherent, epitaxial growth on top of one another.

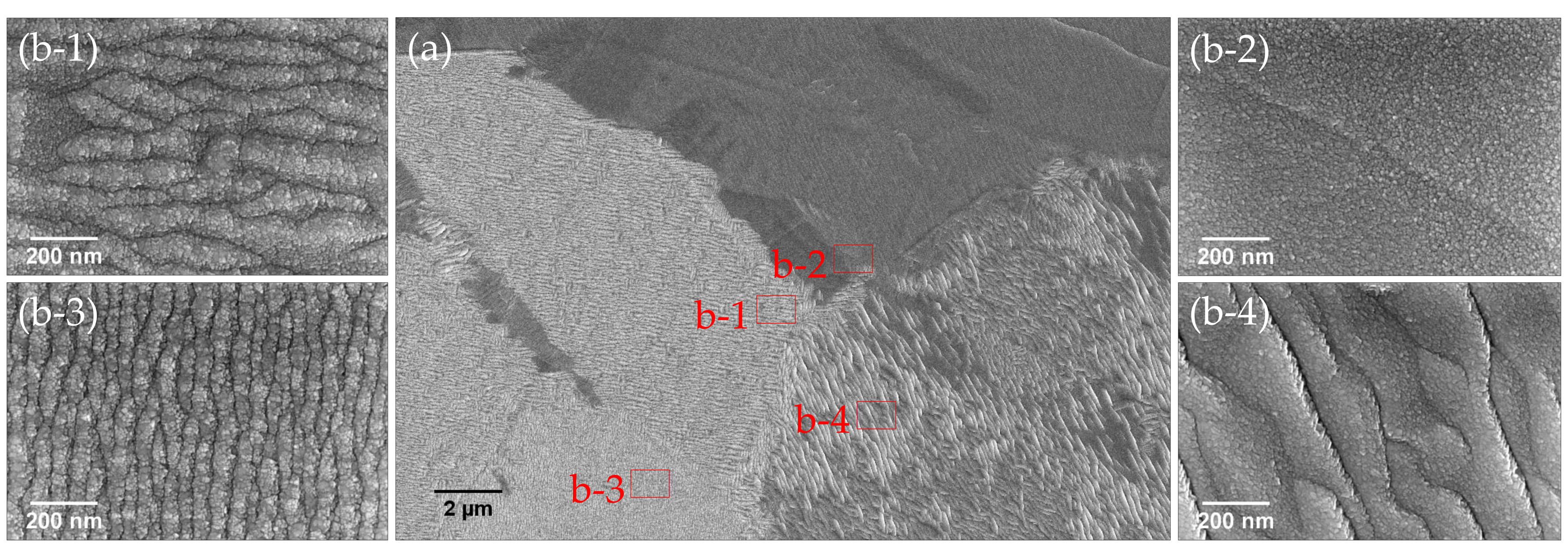

Figure 2: SEM images of the typical surface microstructure of HiPIMS based SIS films. (a) Overview image showing multiple grain structures. (b) Magnified images showing NbN microstructure grown on different Nb grain structures.

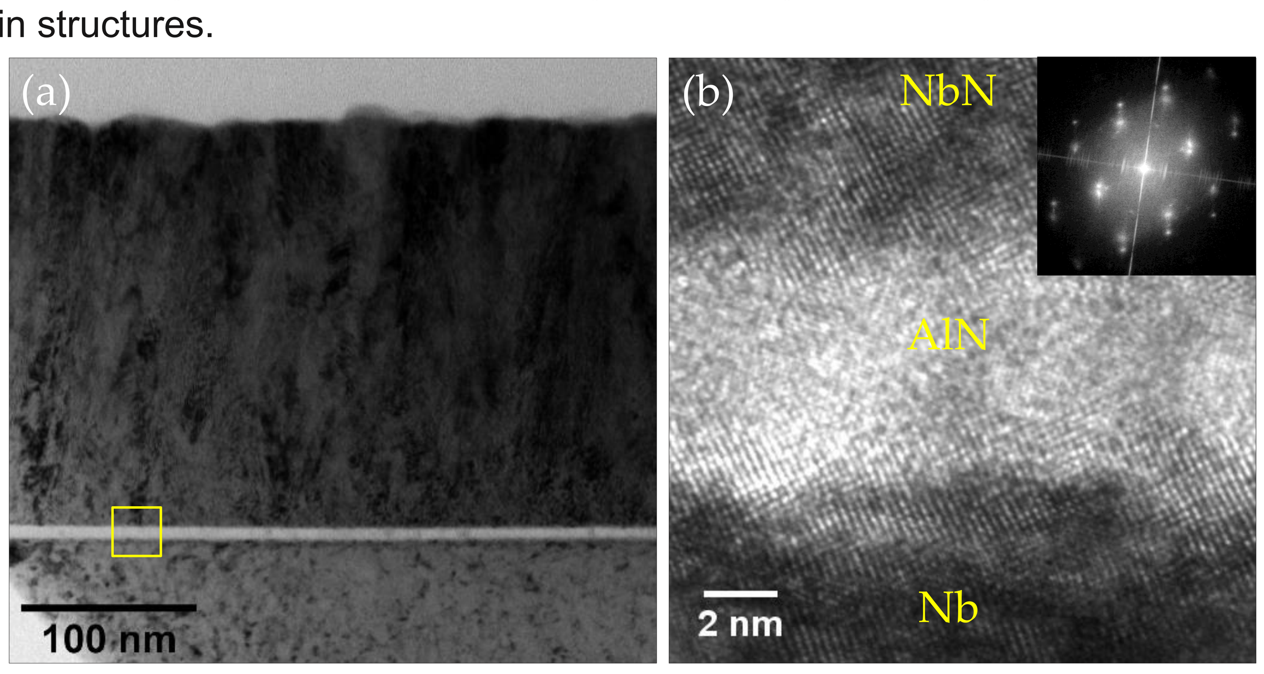

Figure 3: (a) TEM BF image of the SIS film coating. (b) HRTEM image of the interface between the three SIS film layers with corresponding FFT image inset. Imaged position in (b) indicated in (a)

- STEM EDX (fig. 4) revealed no presence of oxygen within the NbN layer for HiPIMS-deposited SIS films. This is a significant improvement over previous DC MS results which showed penetration of oxygen between the NbN grains. Oxygen signal present due to glue used in TEM sample preparation
- The lack of oxygen was further observed with SIMS investigations, not shown here.

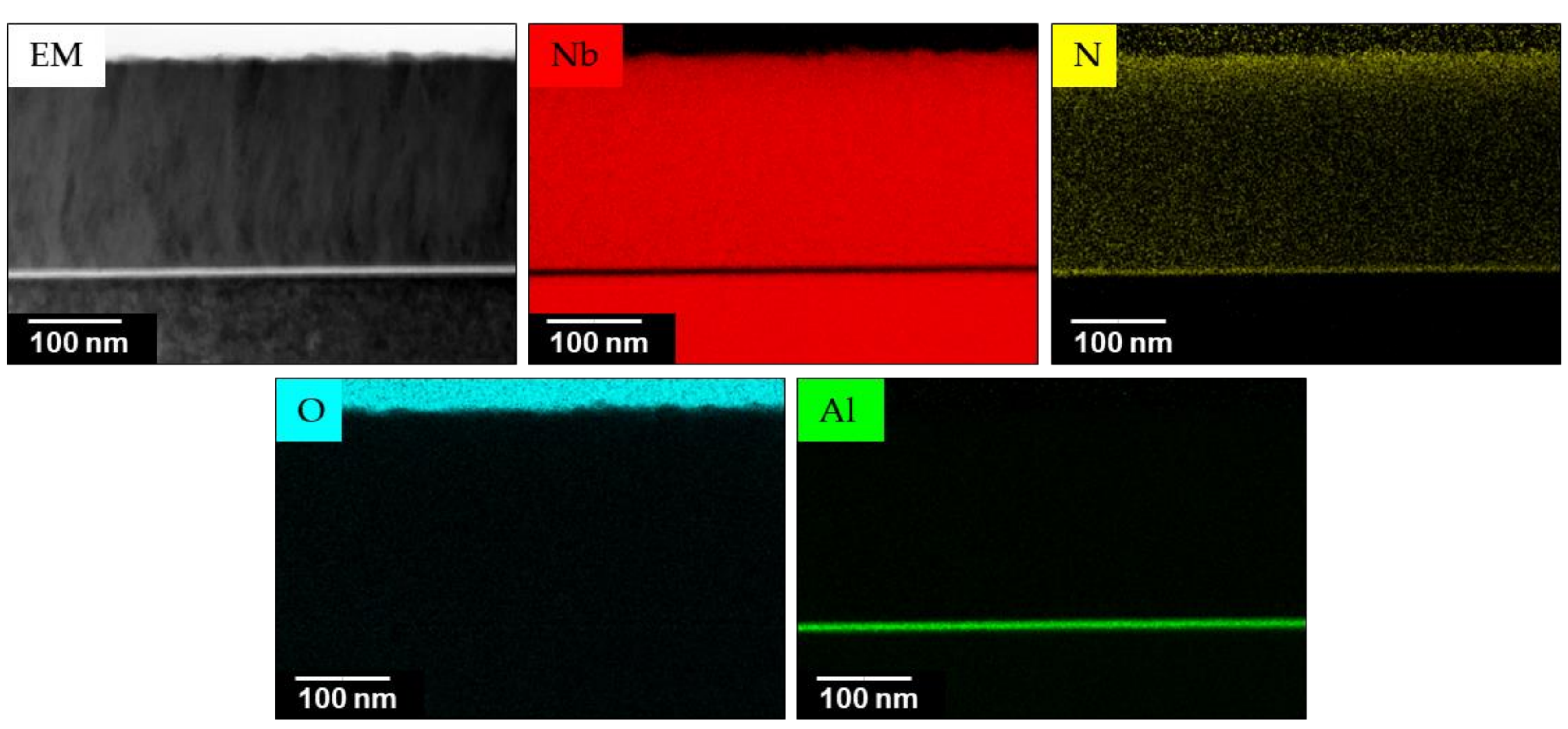

Figure 4: STEM EDX mapping results from a representative HiPIMS SIS film sample, displayed in atom percent.

Superconducting Results

- Nb T_c = 9.3 K, consistent with individual layers. Decreased NbN T_c in first series compared to individual layers.
- Increasing NbN T_c with increasing AlN and NbN thickness. NbN layer thickness of 180 – 200 nm provides optimal shielding performance based on H_{en}.
- Highest SIS film H_{en} = 88.0 mT achieved with HiPIMS deposition (compared to 64.5 mT achieved with DC MS).
- Significantly improved magnetisation loops showing good reversibility and low amounts of trapped flux. Lower AlN thickness (10 nm here) leads to lower trapped flux.

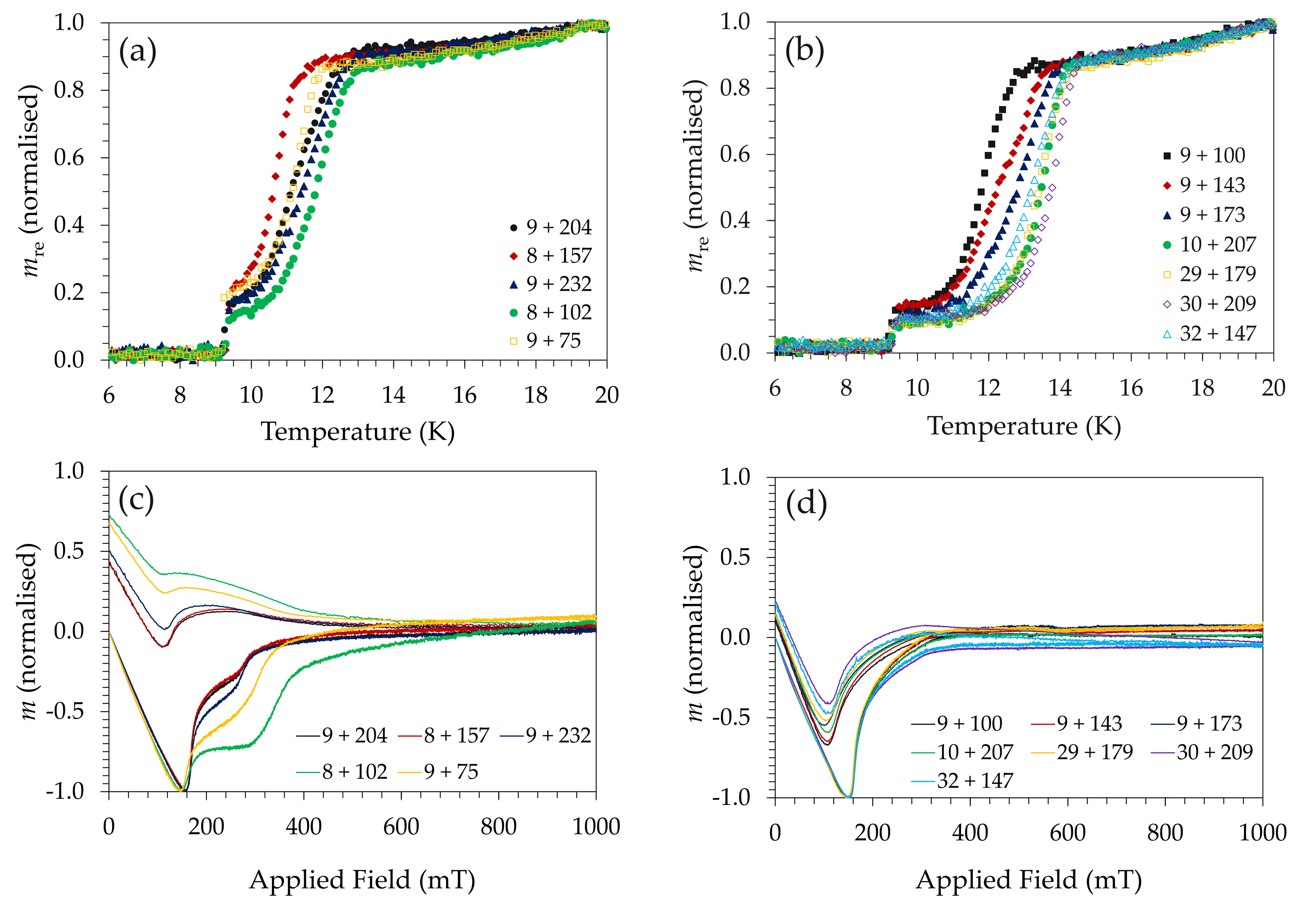

Figure 5: Superconducting results for the two sets of HiPIMS SIS films. (a) and (b) display the normalised real component of the AC susceptometry measurements, detailing the transition temperatures of both the Nb and NbN layers in the two series of HiPIMS SIS films. (c) and (d) display sections of the normalised magnetisation loops of the first and second series of samples respectively. **The thicknesses of the AlN and NbN layers, in nm, are detailed in the legend.**

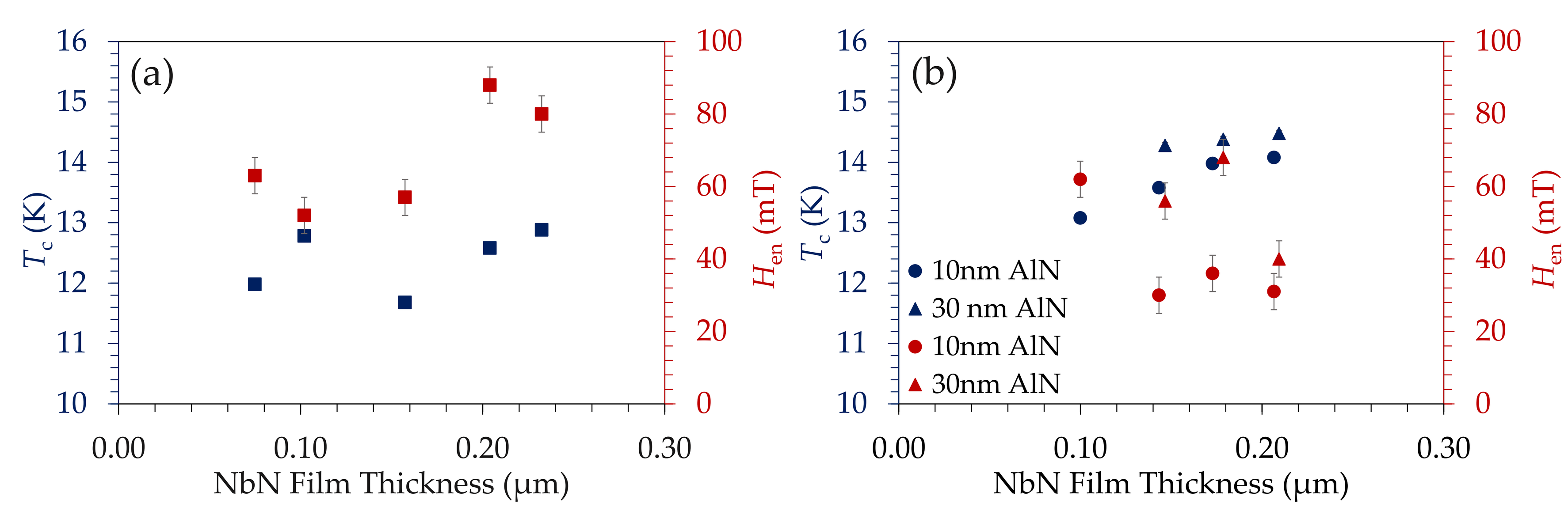

Figure 6: Superconducting transition temperature and entry field values as a function of NbN film thickness for the two series of HiPIMS SIS films. (a) Pertains to series 1, deposited with a fixed 10 nm AlN layer thickness and (b) pertains to series 2, with the different AlN layer thicknesses indicated.

Conclusions

- HiPIMS deposition significantly improves the density of the deposited SIS films, leading to decreased oxygen content in the NbN layer and improved surface roughness.
- Coherent, epitaxial layers successfully grown via HiPIMS.
- Increased AlN layer thickness leads to increased NbN T_c and improved H_{en}. Thinner AlN layer results in smaller magnetisation loop and lower levels of trapped flux.
- Two QPR samples were coated with HiPIMS SIS films with different AlN layer thickness. Detailed investigation presented in **SUPFDV006**

Acknowledgements

Authors acknowledge the EASITrain program, which has received funding from the European Union's H2020 Framework Programme under Grant Agreement no. 764879. Authors further recognize the ARIES collaboration H2020 Research and Innovation Programme under Grant Agreement no. 730871.
Part of this work was completed at MNaF, Universität Siegen.

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