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Investigation of HiPIMS-Coated S(I)S Structures for SRF Cavities

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Abstract

The sustainable next generation particle accelerators require innovative solutions to overcome the current technological challenges set by existing bulk niobium superconducting radio-frequency (SRF) cavities. Thin film-based multilayer structures in the form of superconductor-insulator-superconductor (SIS) may be the long-sought-after breakthrough for higher performance SRF cavities by enhancing both accelerating gradients and quality factors. In order to understand better the underlying mechanisms of SIS structures to be coated onto (S)RF cavities, we study various material properties with the resultant superconducting properties of high-power impulse magnetron sputtering (HiPIMS)-coated S(I)S structures of Nb-(AlN)-NbN with different thicknesses which are designed to be coated mainly on OFHC copper (Cu) samples for more efficient SRF cavities. This contribution presents materials properties of the aforementioned HiPIMS-coated S(I)S structures as well as the superconducting and RF behaviours of these multilayers which are assessed comparatively via DC and AC magnetization techniques.

Introduction

The existing bulk niobium (Nb) superconducting radio-frequency (SRF) cavity technology, which has been the leading accelerator technology so far, is close to its theoretical field limit. Besides, field-dependent performance degradation along with local breakdown phenomena restrict not only achievable accelerating gradients, but also quality factors of bulk niobium SRF cavities [1]. Accordingly, innovative solutions need to be introduced to realize ever increasing high performances with reduced infrastructural and operational costs so as to build the next generation compact particle accelerators which would outperform the state-of-art particle accelerators based on bulk Nb, and surpass the expected accelerating gradients of 50 MV/m together with reduced RF losses.

In order to achieve these breakthroughs, one of the promising solutions is coating inner surface of (S)RF cavities with alternating thin film-based multilayers of superconductor-insulator-superconductor (SIS) structure given the fact that magnetic field penetration is a surface phenomenon (i.e., RF field penetration depth for bulk Nb is only about 40 nm.).

Experimental Methods

The multilayer SS and SIS structures in the form of Nb / NbN and Nb / AlN / NbN were coated mainly onto silicon as witness samples as well as onto the OFHC Cu substrates (QPR) by (reactive)-HiPIMS technique via a fully automated coating machine (CC800) of CemeCon AG GmbH at University of Siegen (USI) as shown in Fig. 1.

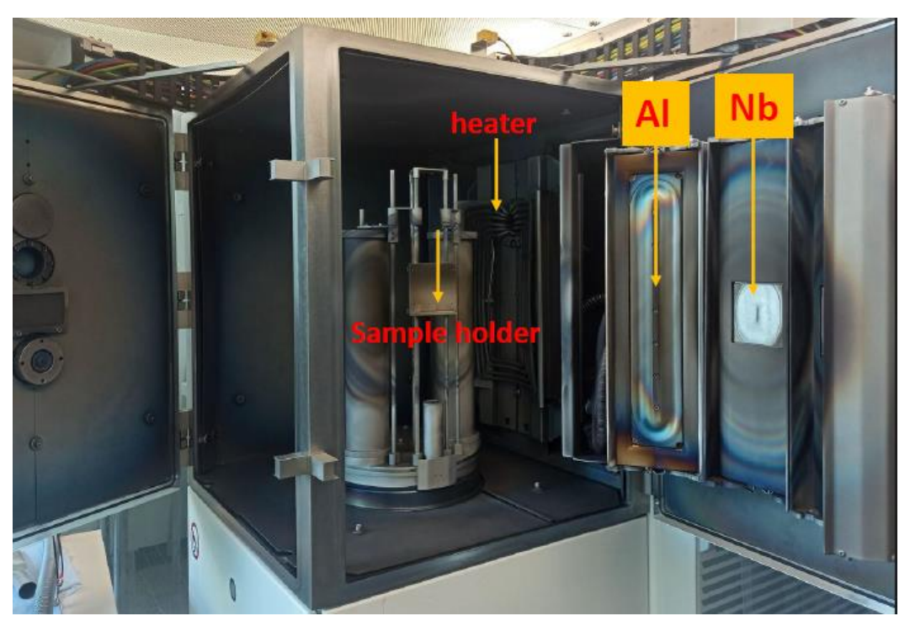

Figure 1: The overview of the sputtering machine (CC800) capable of DCMS and HiPIMS at USI.

The detailed description of the deposition processes as well as the details of the machine (CC800) components at USI were reported previously [2]. The materials characterizations of all deposited films were done at USI as well.

The superconducting properties of the deposited SS (Nb / NbN) and SIS (Nb / AlN / NbN) samples with thicknesses of (2.5 µm / 1µm) and (3 µm / 40 nm / 200 nm), respectively, whose deposition parameters are detailed in Table 1, were characterized at IEE SAS via vibrating sample magnetometer (VSM) technique as shown in Fig. 2 as well as HiPIMS-coated SIS and SS structures with thicknesses of (3 µm / 180 nm) and (3 µm / 35 nm / 180nm nm), respectively, analysed with Cu-QPR sample tests at HZB as shown in Fig. 3, whose deposition parameters are detailed in Table 1 again.

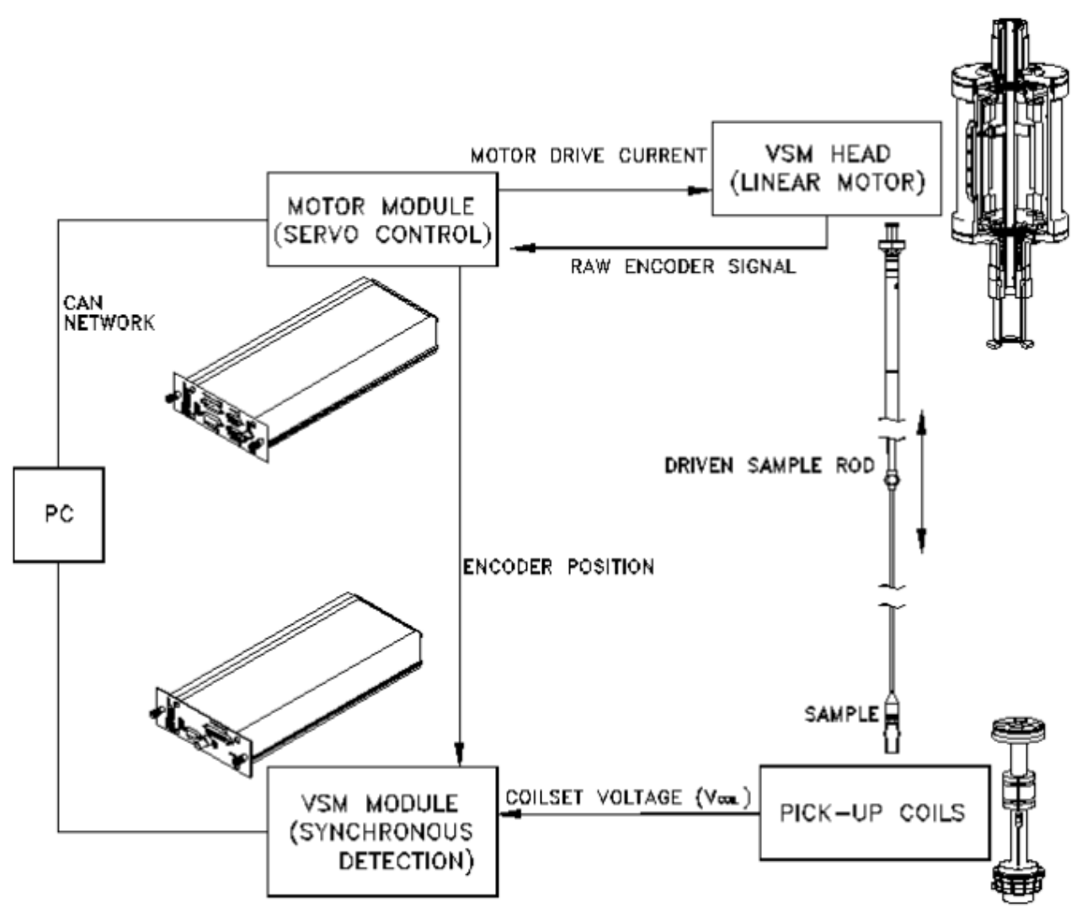

Figure 2: The operating principle of Quantum Design Inc., model 6000 with the VSM option at IEE SAS - adapted from [3].

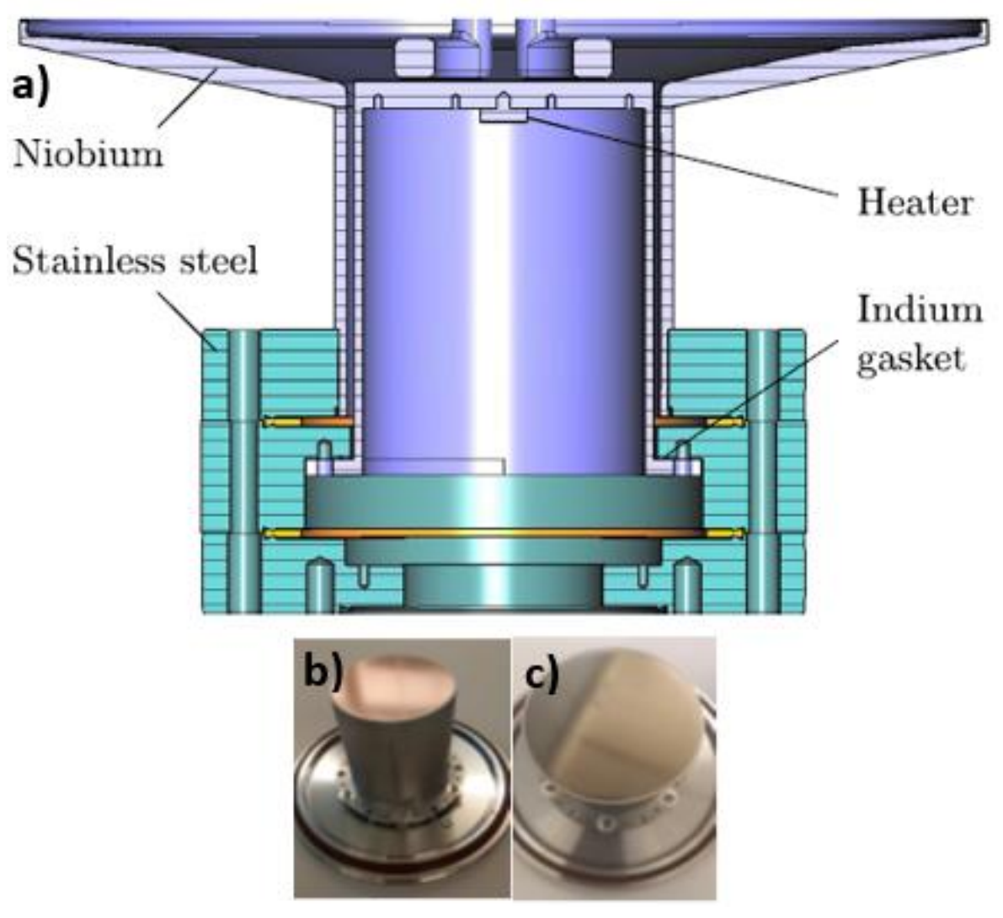

Figure 3: a) The schematic overview of the QPR system at HZB - adapted from [4], b) The uncoated Cu-QPR sample, c) The HiPIMS-S(I)S (Nb/(AlN)/NbN)-coated Cu-QPR sample.

Table 1: The deposition parameter window of HiPIMS-coated S(I)S structures for VSM* and QPR** tests

Material	Cathode Power Density [W/cm^2]	Substrate Bias [V]	Deposition Pressure [mbar]	N_2 Content [Vol%]
Nb	6.82*, 4.55**	50*, 50**	2.0 x 10^{-2}*, 8.0 x 10^{-3}**	0* & **
(AlN)	7.14* & **	0* & **	6.0 x 10^{-3}* & **	100* & **
NbN	6.82*, 4.55**	50*, 50**	2.0 x 10^{-2}*, 2.5 x 10^{-2}**	8*, 10**

Acknowlegments

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Materials, Superconducting, and RF Characterization Results

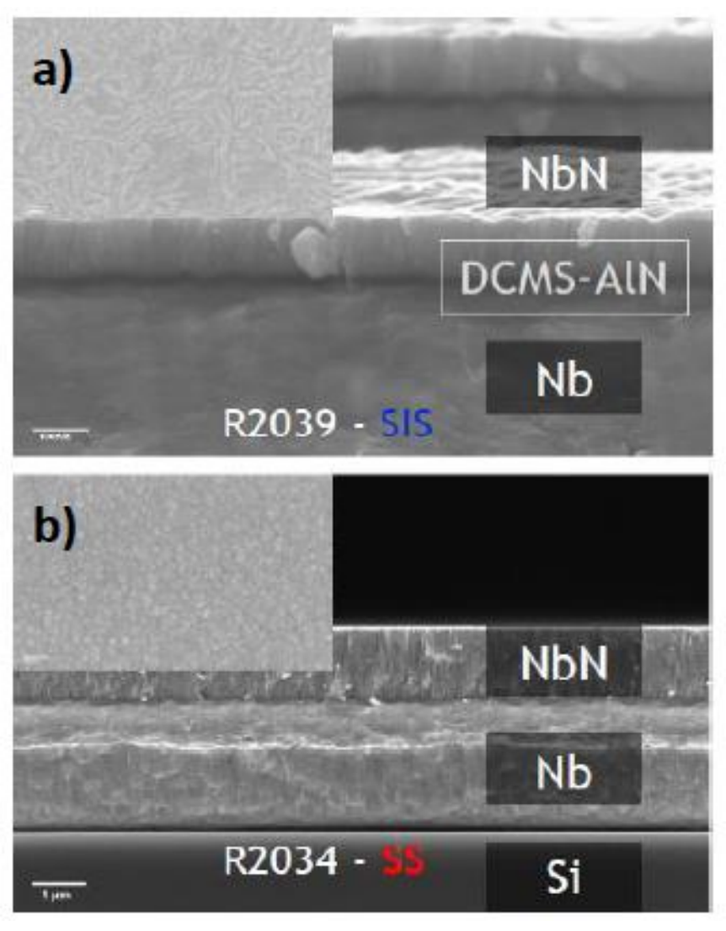

Figure 4: The SEM images of surface and cross-section of a) SIS, and b) SS structures deposited for VSM measurements – adapted from [2].

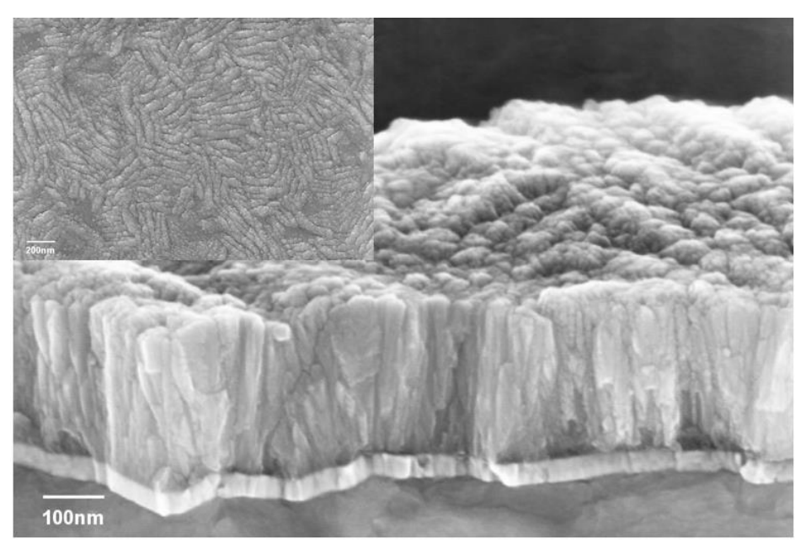

Figure 5: The SEM images of surface and cross-section of SIS structure deposited for QPR test.

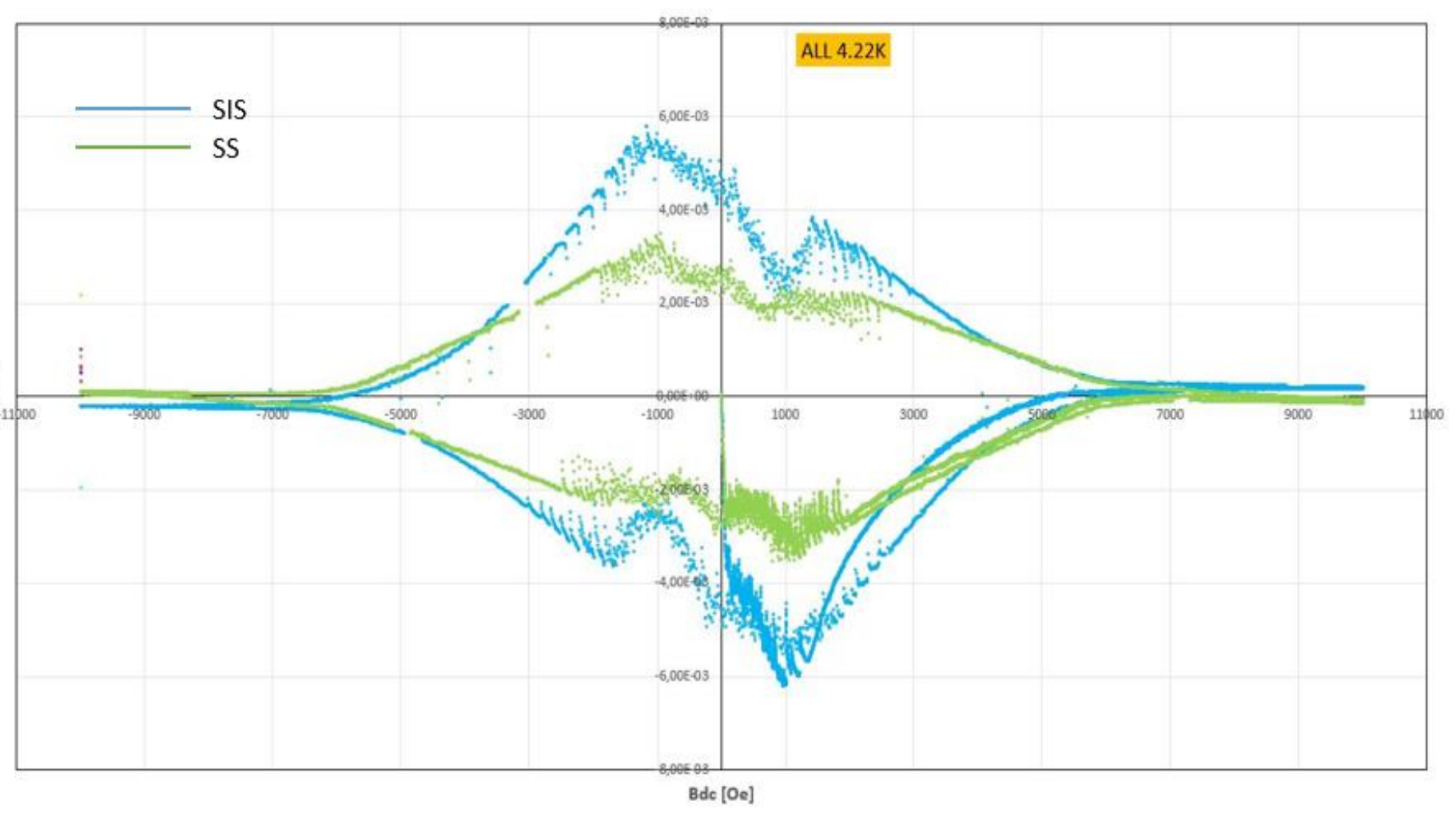

Figure 6: The dc magnetization curves of SIS and SS structures measured via VSM technique.

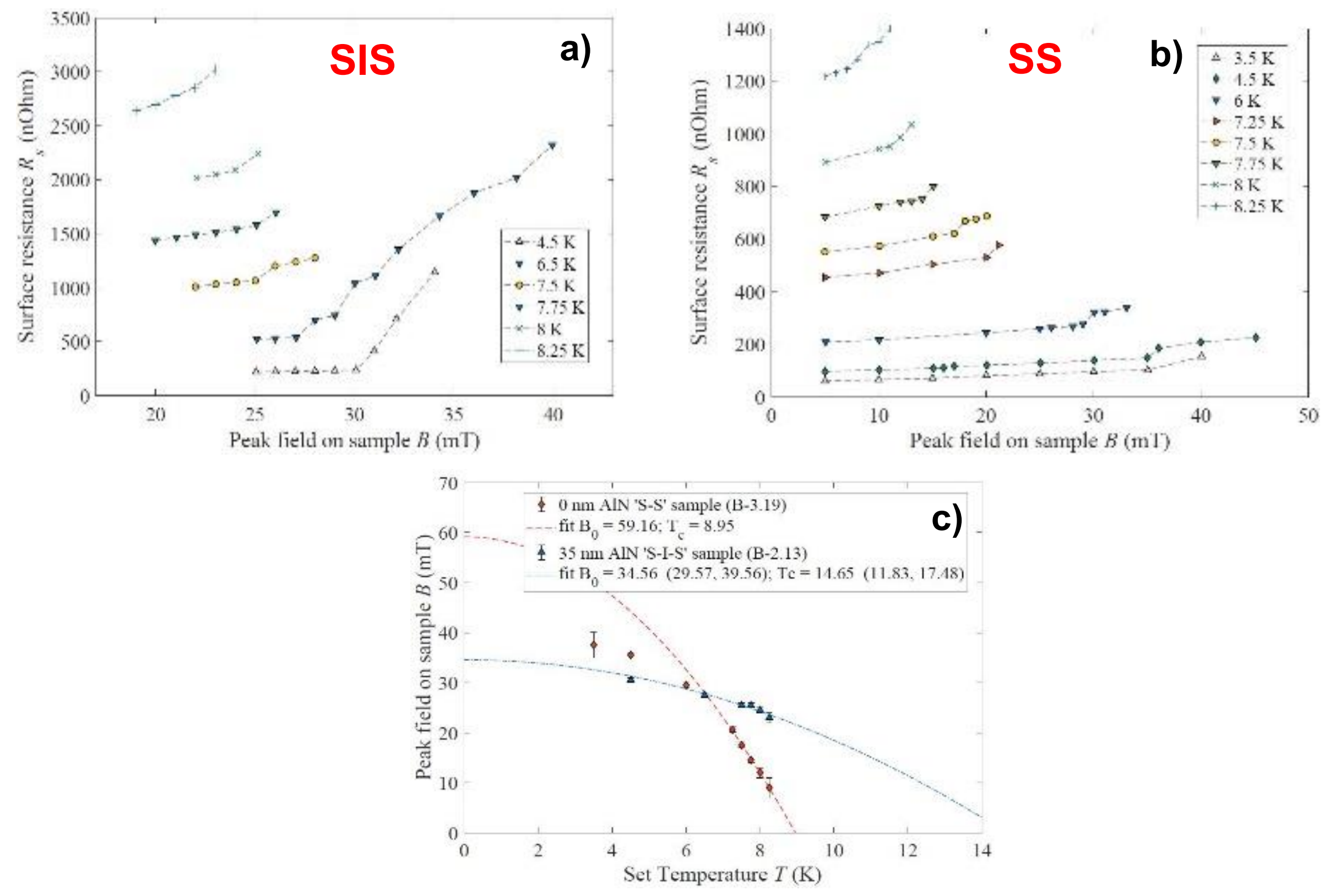

Figure 7: : Surface resistance as a function of peak field on sample for, a) HiPIMS-coated SIS, b) HiPIMS-coated SS structures at different temperatures. c) The combined peak field on sample versus set temperature curves of both HiPIMS-coated SS and SIS structures.

Conclusion

The recent RF characterization results suggest that SS structure is worth studying in depth along with SIS structures for a more comprehensive understanding of the fundamental mechanisms responsible for potentially higher SRF performance of the multilayer structures for the next generation compact particle accelerators.

References

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