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INVESTIGATION OF SIS MULTILAYER FILMS AT HZB

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ABSTRACT **The systematic study of multilayer SIS films (Super-conductor-Insulator-Superconductor) is being conducted in Helmholtz-Zentrum Berlin. Such films theoretically should boost the performance of superconducting cavities, and reduce some problems related to bulk Nb such as magnetic flux trapping. Up to now such films have been presented in theory, but the RF performance of those structures have not been widely studied. In this contribution we present the results of the latest tests of AlN-NbN films, deposited on micrometres-thick Nb layers on copper. It has, also, been shown previously at HZB that such SIS films may show some unexpected behavior in surface resistance versus temperature parameter space. In this contribution we continue to investigate those effects with the variation of different parameters of films (such as insulator thickness) and production recipes.**

SIS SAMPLES

SIS layered samples from the current study have been coated by the University of Siegen [2] within the ARIES program [3]:

- The first SIS sample (**J-lab SIS**) measured at HZB, prior to ARIES, was prepared at Jefferson Lab using ***DC MS*** sputtering technology [1].
- The **first ARIES** sample was coated with the ***DC MS*** sputtering technology. For this sample prior to NbN-AlN coating the RF test of the base Nb layer was performed. The sample with 4 μm Nb layer on copper was transported to HZB from Siegen. Then the sample was tested with the QPR, and sent back to Siegen for the subsequent NbN-AlN coating. As a result the Nb layer was exposed to air between the coatings.
- The **second ARIES** and **third ARIES** samples were coated in one run with ***HiPIMS*** method [2].

	SIS films tested	Method	Structure	Base test?	Produced by
J-Lab SIS [1,2]	NbTiN – AlN – Nb(bulk)	DC MS	75nm – 15 nm – bulk Nb	Yes	J-lab 2018
ARIES 1st SIS	NbN – AlN – Nb(film)/Cu	DC MS	197nm – 35 nm – 3 μm Nb	Yes	Siegen 2020
ARIES 2nd SIS	NbN – AlN – Nb(film)/Cu	HiPIMS	180nm – 8 nm – 4 μm Nb	No	Siegen 2021
ARIES 3ed SIS	NbN – AlN – Nb(film)/Cu	HiPIMS	180nm – 24 nm – 4 μm Nb	No	Siegen 2021

*The measurement setup of the Quadrupole Resonator is comprehensively described in [4].

Layered ARIES sample structure: the SIS coating is based on electropolished Cu surface

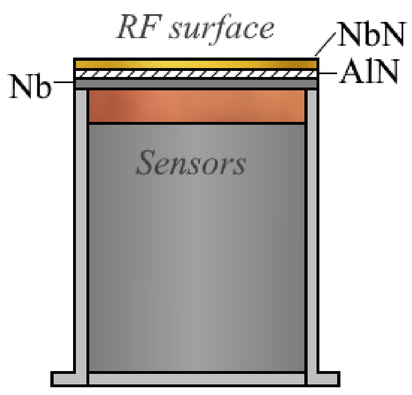
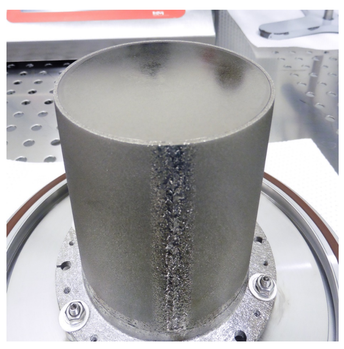
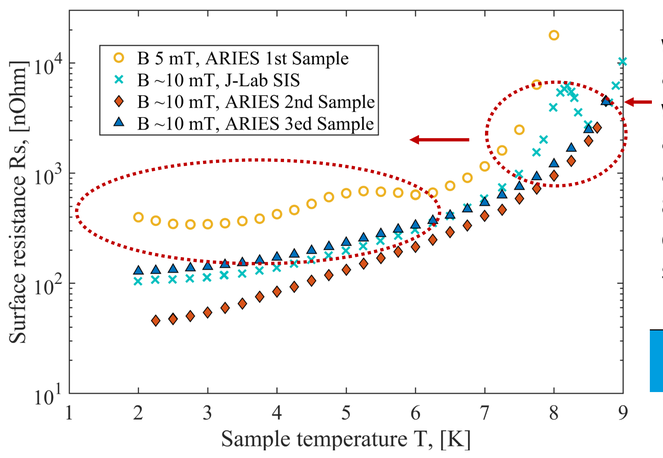


Photo of one of the ARIES samples, coated by the University of Siegen



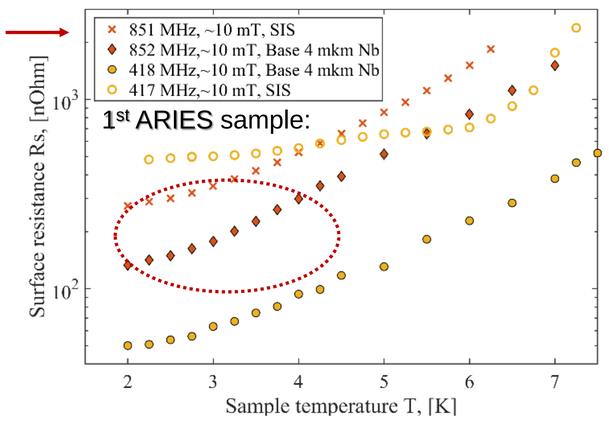
SURFACE RESISTANCE VERSUS TEMPERATURE



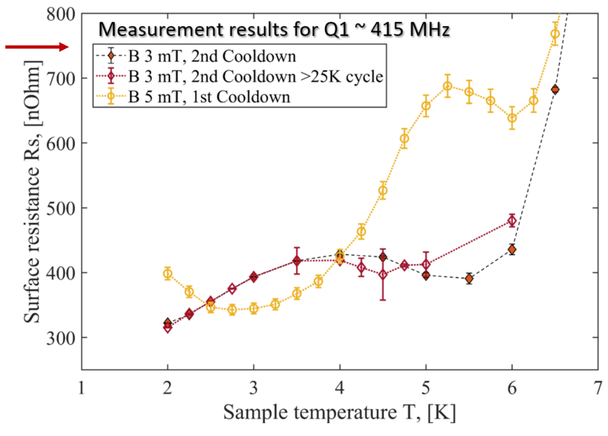
A non-monotonic temperature behavior that was first discovered in the early JLab sample is also seen in the **first ARIES** sample. This feature was very pronounced in the **JLab sample** at around 8 K and less pronounced and shifted to around 5 K in the **1st ARIES** sample. At around 850 MHz the surface resistance peak was not observed on the ARIES sample (contrary to JLab sample, where it shifted to lower temperatures).

Sample	Residual resistance at 416 MHz [nOhm]	Layers thickness [nm]
Bulk Nb	23	Bulk
ARIES 1st	>400	197/35/3000 Nb
ARIES 2nd	≈45	180/8/4000 Nb
ARIES 3ed	≈128	180/24/4000 Nb

Although the appearance of the peaks in the samples is still not entirely understood, it was suggested that their appearance is an indicator of the **extrinsic performance bias (i.e. poor film quality or trapped flux)**, rather than an intrinsic property of multilayer structures in general. Moreover the surface resistance of the **1st ARIES** sample was much higher than expected at low temperatures (the region where this peak appeared). From figure it can be seen that at **416 MHz the surface resistance before 4.5K is even higher than at 850 MHz**, and clearly deviates from a standard BCS behavior.



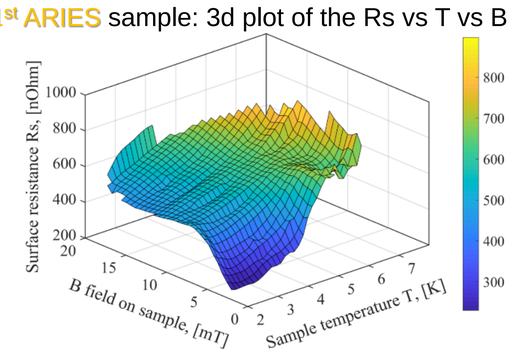
In order to investigate that extrinsic impact on the unusual behavior of the 1st ARIES sample it was thermally cycled. The yellow curve shows the surface resistance after the initial cooldown, the red curves show a subsequent measurement run after warm-up to the room temperature. The curves looked very different. In order to test if the change of the curve was caused by magnetic flux trapping, a short warmup of the full cavity above Tc was performed (>25 K thermocycle). The resulting curve was almost identical to previous up to temperatures of 3.5 K. Above 3.5 K the curves begin to differ. However, these changes are not strongly significant and only slightly beyond the statistical error bars (which are obtained from statistical averaging).

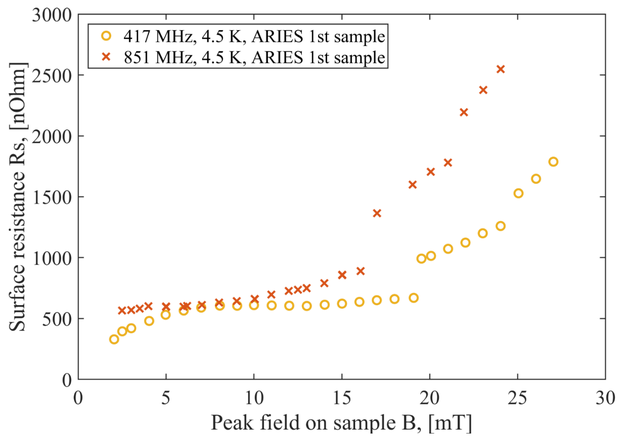


SURFACE RESISTANCE VERSUS FIELD

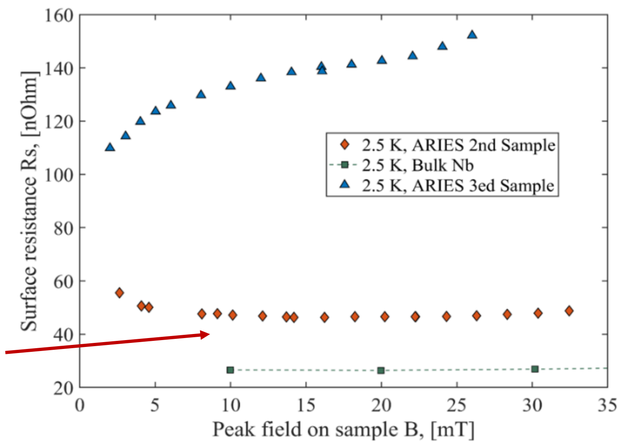
On the Surface resistance versus field parameter space **1st ARIES** sample also showed non-monotonic behaviour (although those features are not unexpected and can be explained by known effects such as "Q-switches").

1st ARIES sample: 3d plot of the Rs vs T vs B





The best result of the field dependant component of the Surface resistance was achieved by the **2nd ARIES** sample, which showed quite low "Q-slope" (apart from the lowest Residual resistance), equivalent to bulk Nb (see Figure 9). The only drawback of the film was that the maximum achieved magnetic field for NbN top layer **was about 30-35 mT**. For two frequencies: 415 and 850 MHz.



CONCLUSIONS

- Some of the SIS samples presented unusual (never observed) behavior on the surface resistance versus temperature parameter space. The nature of this feature is still not entirely understood, however, the result of this phase of the study suggests that its appearance is an indicator of the extrinsic performance bias (i.e. poor film quality), rather than an intrinsic property of multilayer structures in general.
- Another interesting result was obtained from the measurements of the samples with different insulator layer thickness. As a general trend, the surface resistance is better, the thinner the insulator layer is. The likely explanation for this behavior is that the dielectric losses in the insulator layer are proportional to the layer thickness. Also, measurements showed that HiPIMS coated samples generally exhibit a better (i.e. smaller) surface resistance.
- The latest satisfying result was achieved with one of the SIS samples, which exhibited a comparably low residual resistance (about 45 nOhm compared to 23 nOhm, measured for bulk Nb) and low "Q-slope" or field dependent increase of surface resistance, equivalent to bulk Nb. The only drawback of that film (and one of the feature of all other films) was that the maximum achieved field for NbN top layer was about 35 mT, which also needs to be studied and improved.

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