SUPERCONDUCTING THIN FILM RF MEASUREMENTS

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Abstract

A radiofrequency (RF) cavity and cryostat dedicated to the measurement of superconducting coatings at GHz frequencies was designed to evaluate surface resistive losses on a flat sample. The resonator has now been used for measurements on Thin Film samples. Results from a test on a sample previously tested at Cornell University are presented. In order to simplify the measurements and achieve a faster turnaround, the experiment will be moved to a cryocooler. This will limit the measurements to low power only, but will allow a much faster sorting of samples to identify those that would benefit from further investigation. A description of the system and initial results will be presented.

INTRODUCTION

The ASTeC Thin Film SRF program consists of the following parts:

- Surface preparation and deposition of the samples using PVD and CVD methods [1, 2].
- Characterisation of the samples using various surface analysis techniques including SEM, XPS, XRD, EDX, etc. [1-4]
- Measuring superconducting properties in DC and AC conditions: RRR, magnetisation (SQUID), magnetic field penetration, etc. [1, 4-6].
- Testing of the various samples at RF frequencies using a dedicated cavity design [7, 8].

A test cavity that uses RF chokes, rather than a physical seal, to contain the field is a promising method of SRF sample testing. This is especially in thin films research where the rate of sample production far outstrips that of full SRF characterisation. Choked test cavities operating at 7.8 GHz with three RF chokes have been designed and tested at Daresbury Laboratory.

The cavity was initially measured at room temperature as reported in [8], then at cryogenic temperature with a copper sample plate in order to ensure that no radiation could be produced. The first full cryogenic test of the thin film test cavity, carried out with a bulk niobium sample plate, was reported in [9].

CAVITY DESIGN

A radiofrequency (RF) cavity and cryostat dedicated to the measurement of superconducting coatings at GHz frequencies was designed to evaluate surface resistive losses on a flat sample. The test cavity consists of two parts: a cylindrical half-cell made of bulk niobium (Nb) and a flat Nb or Nb-coated sample disc. The two parts can be thermally and electrically isolated via a vacuum gap, whereas the electromagnetic fields are constrained through the use of RF chokes. Both parts are conduction cooled and suspended in vacuum during operation. The RF test provides simple cavity Q-factor measurements and can also be set up for calorimetric measurements of the RF losses on the sample.

The test cavity itself is described in [8]. It is succinctly a cylindrical pillbox-type cavity, operated in the TM_{010} mode at 7.8 GHz (see Fig. 1).

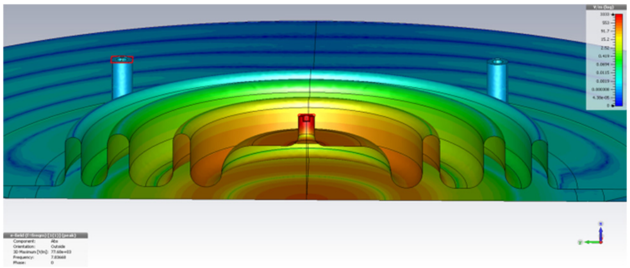

Figure 1: E-field distribution on the surface of the three choke cavity (top) and sample plate (bottom) simulated using CST.

The resonance is induced through a straight RF probe connected to a micrometer allowing variable coupling to the cavity body. The cavity frequency choice is primarily defined by the available sample size which dictates the maximum extent of the chokes. A lower frequency cavity, less affected by BCS resistance, requires larger samples. The advantage of this method is the combination of a compact cavity with a simple planar sample, avoiding the need for welding.

PVD SAMPLE TEST RESULTS

A HiPIMS (High Power Impulse Magnetron Sputtering) deposited sample first tested at Cornell University [7] was placed on the sample-holder.

The sample was deposited at 500°C on a 3 mm thick copper plate. The plate was unfortunately deformed prior to our test, and had a convex dome shape. Despite that, the chokes performed correctly at room temperature and we decided to run the cold test.

The cavity was previously tested using a bulk Nb plate [9] in place of the sample and the surface resistance is calculated from the geometry factor. The Q factor can be directly measured using a VNA due to the large bandwidth of the cavity at 7.8 GHz. Future experiments will utilise a phase locked loop to ensure that the results are not affected by microphonics. For the first test the cavity was not re-etched which may cause a higher surface resistance.

The bulk Nb plate was then replaced by the sample and the Q factor was again measured. CST simulation results were used to calculate the magnetic flux on the cavity and the sample separately. It was assumed that the surface resistance of the cavity is identical to the previous measurement, allowing the determination of the surface resistance of the sample.. However, without temperature mapping we cannot be certain that the original cavity resistance measurement wasn't perturbed by the niobium sheet, Therefore, a DC-RC compensation measurement on the sample disk will be utilised in future runs.

The results are shown in the following figure, which we compare to the bulk Nb sample results taken earlier. The surface resistance is much higher than expected, however there are possible reasons for this. If the cavity became contaminated when changing the sample, the method used would give the appearance of a much larger sample resistance due to the smaller surface area. The system has no magnetic shielding which while unlikely to be an issue at this frequency and temperature, it is possible that a very dirty sample may be affected by this.

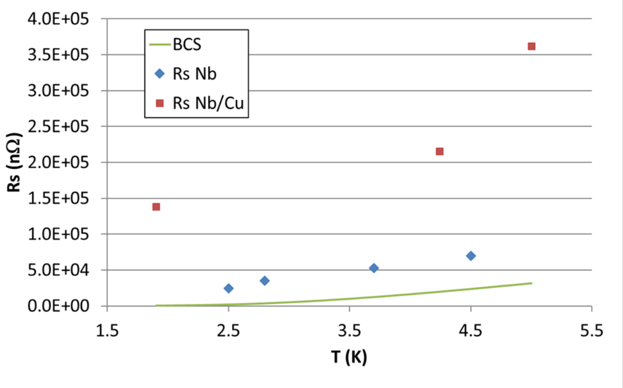

Figure 2: Surface resistance results for the bulk Nb plate (blue) and the Nb deposited sample on copper (Red) compared to BCS (green).

Future tests with an etched cavity, magnetic shielding, a PLL and a DC-RF compensation method will likely provide more accurate results.

CRYOCOOLER

In an effort to simplify the testing procedure, an additional cryostat is currently being assembled. It is cooled with a closed-cycle refrigerator in order to simplify the cooling process (Fig. 3). Details of the cryocooler can be found in [10].

The experimental set-up aims to duplicate the functionality of the LHe cryostat, with a tunable RF coupler acting on a fixed cavity. The sample plate holder is designed to be as simple as possible to remove. The cavity, the sample film and holding assembly is thermally attached to the 2nd stage of the cooler with a base temperature of ~4K.

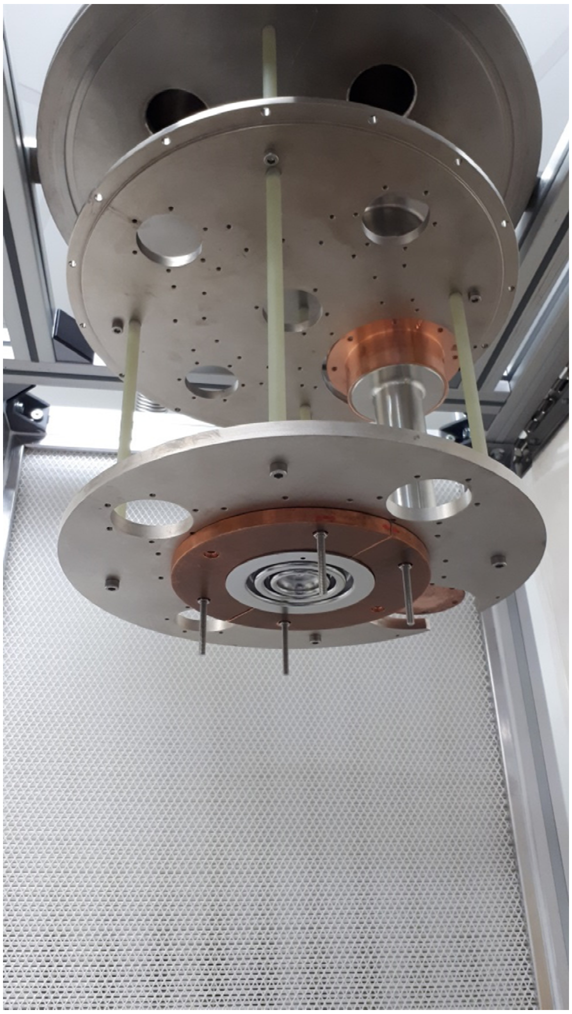

Figure 3: Picture of the cryostat insert showing the Nb cavity fixed on the second stage of the cryocooler. The sample plate can be attached to the rods. Consistent spacing is insured by the use of spacers placed between the cavity and sample plate. The HEPA filter is visible in the background.

As previous efforts in the LHe cryostat were likely limited by particulate contamination, every effort will be made to minimise this risk. The cryostat is mounted on a frame with an integrate HEPA filter unit. Access to the cavity and sample plate is achieved by removing the outer vacuum shield, then the radiation shield (the latter mounted on the first stage of the cryostat).

Attention will be paid to making the thermometry resilient and simple to reattach when changing a sample plate. Procedures have also been defined to make these operations as particulate free as possible.

The vacuum system is one volume, which will require careful handling to avoid contamination. Vacuum levels near the cavity are expected to be reasonable due to cryopumping. The system is only designed for low power operation so we do not expect issues related to field emission. Furthermore, it is common to operate quarter wave cavities in a common vacuum achieving low surface resistances and large surface magnetic and electric fields.

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CONCLUSION

The first cryogenic RF test on a sample showed some degradation in performance compared to the bulk niobium sample. Low power Q-factors for the Nb on Cu sample plate were measured over a temperature range between 1.9 and 5 K, leading to calculated Rs values between 150 and 350 μΩ. These values are quite high and need to be verified. This will be achieved using the closed-circuit refrigerator cooled cryostat currently being assembled. The aim of that cryostat is to simplify the operation and sample change procedures to enable a faster turn-around.

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REFERENCES

[1] S. Wilde *et al.*, "Physical Vapour Deposition of NbTiN Thin Films for Superconducting RF Cavities", in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, paper MOPVA104.

[2] P. Pizzol, J.W. Roberts, J. Wrench, O.B. Malyshev, R. Valizadeh and P. Chalker, "Atomic Layer Deposition of Niobium Nitride from Different Precursors", in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, paper MOPVA100.

[3] P. Pizzol *et al.*, "CVD deposition of Nb based materials for SRF cavities", in *Proc. IPAC'16*, Busan, Korea, May 2016, p. 2241.

[4] S. Wilde *et al.*, "High power impulse magnetron sputtering of thin films for superconducting RF cavities", in *Proc. SRF'15*, Whistler, BC, Canada, Sept. 2015, paper TUPB040, p. 647.

[5] L. Gurran *et al.*, "Superconducting thin film test cavity commissioning", in *Proc. SRF'15*, Whistler, BC, Canada, Sept. 2015, paper TUPB064, p. 731.

[6] O. B. Malyshev *et al.*, "First Results of Magnetic Field Penetration Measurements on Multilayer S-I-S Structures", in *Proc. IPAC'16*, Busan, Korea, May 2016, p. 2245.

[7] J.T. Maniscalco, D.L. Hall, M. Liepe, O.B. Malyshev, R. Valizadeh and S. Wilde, "New Material Studies in the Cornell Sample Host Cavity", in *Proc. IPAC'16*, , Busan, Korea, May 2016, p. 2338.

[8] P. Goudket *et al.*, "Test Cavity and Cryostat for SRF Thin Film Evaluation", in *Proc. IPAC'15*, Richmond, VA, USA, May 2015, paper WEPHA052, p. 3232.

[9] P. Goudket *et al.*, in *Proc. SRF'17*, paper TUPB104, p. 644.

[10] O.B. Malyshev et al., "Design, Assembly and Commissioning of a New Cryogenic Facility for Complex Superconducting Thin Film Testing", presented at IPAC'18, Vancouver, Canada, Apr.-May 2018, paper THPAL089, this conference.