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FIRST FULL CRYOGENIC TEST OF THE SRF THIN FILM TEST CAVITY

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Abstract

A test cavity that uses RF chokes, rather than a physical seal, to contain the field is a promising method of SRF sample testing, especially in thin films research where the rate of sample production far outstrips that of full SRF characterisation. Having the sample and cavity physically separate reduces the complexity involved in changing samples - major causes of low throughput rate and high running costs for other test cavities - and also allows direct measurement of the RF power dissipated in the sample via power calorimetry. Choked test cavities operating at 7.8 GHz with three RF chokes have been designed and tested at Daresbury Laboratory. As part of the commissioning of this system, we performed the first full SRF test with a bulk Nb sample and we verified that the system would perform as required for future superconducting thin film sample tests.

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].

To achieve testing of planar samples, the cavity was designed, built, and commissioned 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 no radiation could be produced.

This paper reports on the first full cryogenic test of the thin film test cavity design which was carried out with a bulk niobium sample plate.

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 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 hence the cavity halves are suspended in vacuum during operation. The flat disc can be replaced with a sample, such as a Cu disc coated with a film of niobium or any other superconducting material. The RF test provides simple cavity Q-factor measurements and can also be set up for calorimetric measurements of the 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). 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 a primarily defined by the available sample size which dictates the maximum extent of the chokes. A lower frequency cavity which might be less affected by BCS resistance would require larger samples. The advantage of this method is the combination of a compact cavity with a simple planar sample.

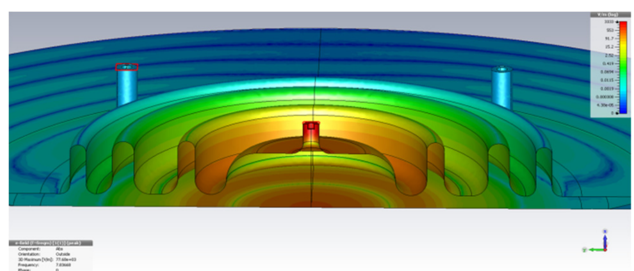

Figure 1: E-field distribution on the surface of the three choke cavity (top) and sample plate (bottom) simulated using CST.

CRYOGENIC FACILITY

The cryogenic set-up was reported on in previous papers [8] and shown in Fig. 2 for completeness. The steel sample chamber is constructed to have a long neck leading to warm ports for the RF cables and thermometry wiring. This is surrounded by concentric LHe and LN_2 chambers. The cradle assembly holding the test cavity and sample is bolted onto the bottom face of the LHe reservoir.

The outer insulation vacuum and sample chambers are pumped separately. By pumping He vapour from the LHe chamber, cavity and sample temperatures down to 2 K can be reached. As the sample is only weakly thermally coupled to the cold plate, cool-down is generally ensured by 3 mbar He gas convection in the sample chamber.

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Cavity and sample temperatures can be controlled through the use of heaters attached to both cavity and sample support plates.

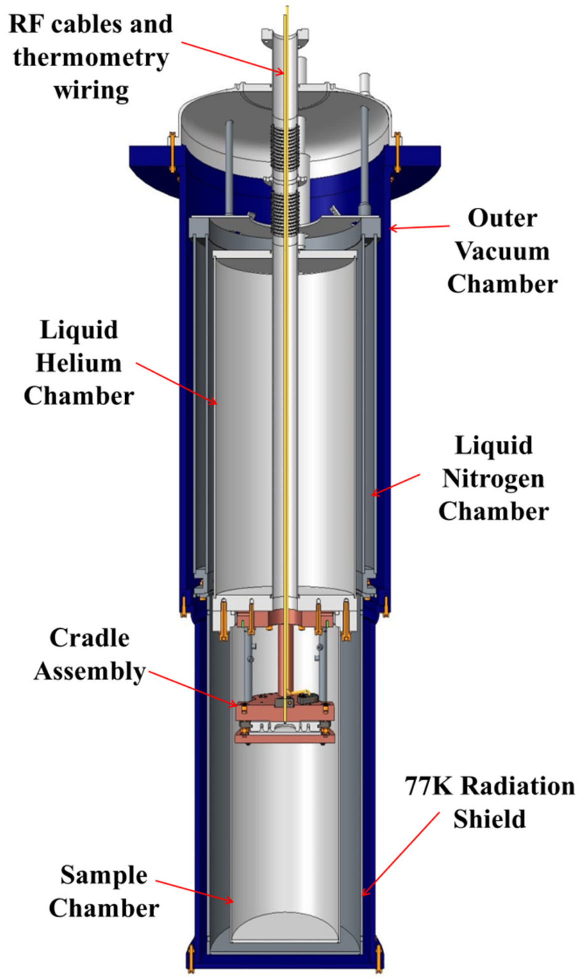

Figure 2: Schematic of the test cryostat and cradle assembly.

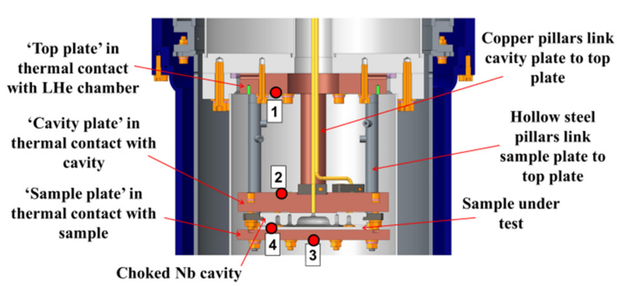

Figure 3: Detailed schematic of the cavity cradle with temperature sensors marked 1-4.

In the cradle assembly (see Fig. 3), the thermal contact was provided through the use of indium foil at all joins between metal parts.

RF COLD TEST

RF measurements were taken using a vector network analyser connected to the input probe. The input power was restricted to 100 mW due to radiation limits in the testing area. This allowed us to take low power measurements only.

All measurements were taken in matched conditions using the adjustable input coupler. The loaded Q was measured from the S11 trace, the results being shown in Fig. 4.

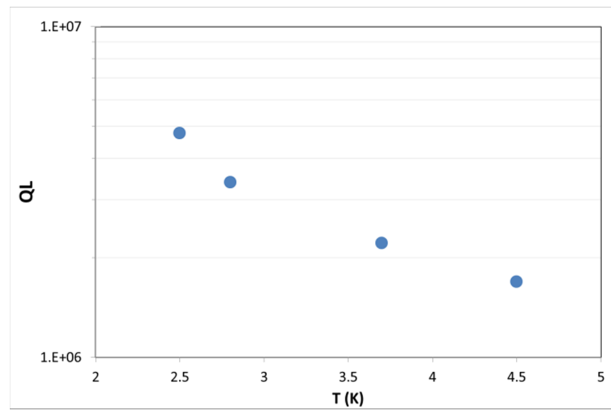

Figure 4: Loaded Q as a function of the temperature of the cavity and sample.

The measured Q varies between $2x10^6$ at 4.5 K and $5x10^6$ at 2.5 K. In the assumption that $Q_0 = 2\ Q_L$, which is true in matched conditions where there is no additional source of loss such as RF leakage through the gaps, coupling apertures or past the chokes, the calculated R_s is shown in Fig. 5.

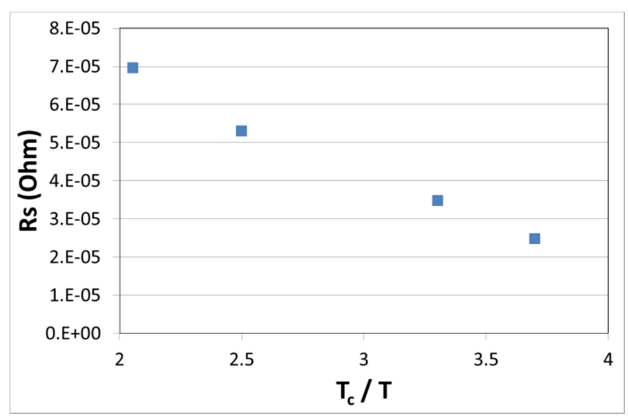

Figure 5: Surface resistance as a function of T_c / T.

DISCUSSION AND FUTURE PLANS

The first RF test successfully demonstrated that the leakage through the chokes/apertures has a Q-factor greater than 5×10^6 (the highest measured value if one assumes no losses in the cavity). The shape of the R_s curve suggests that the leakage Q is somewhat greater than 1.1×10^7.

The R_s values calculated from the results are higher by slightly over an order of magnitude than one would

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expect for bulk niobium in these conditions [9]. This may well be due to a number of factors, such as the cavity was not etched/polished as would normally be applied to a SRF cavity. Furthermore, due to operational conditions, less attention was paid in the preparation of this test to proper cleanroom conditions than would ideally have been required. This leads to the possibility that the true performance of the cavity system may well be in excess of the reported values. Further tests carried out in improved conditions are planned.

In order to calculate the residual resistance we subtract the theoretical BCS resistance from the measured resistance: $R_{res} = R_s - R_{BCS}$, as shown in Fig. 6.

The residual resistance is somewhere between 20-40 μΩ which is rather high. Previous studies have shown that residual resistance does have a frequency dependence to the power of somewhere between 1 and 2 [9], but even if we account for this, in the worst case the resistance should only be 20 times larger than at L-band. While there could be some other effect that has a larger effect at higher frequencies, it is more likely that this is due to the fact that the main cavity body has not had the damage layer removed by BCP or high pressure rinsed, hence there may be many contaminants on the surface. Another possibility is that the losses are artificially increased by the RF losses radiated via the choke. If the losses are due to normal conducting losses on the cavity body or RF losses via the choke then this will not affect future results using calorimetry on the sample plate. The only effect will be to limit the achievable gradient for a given RF input power.

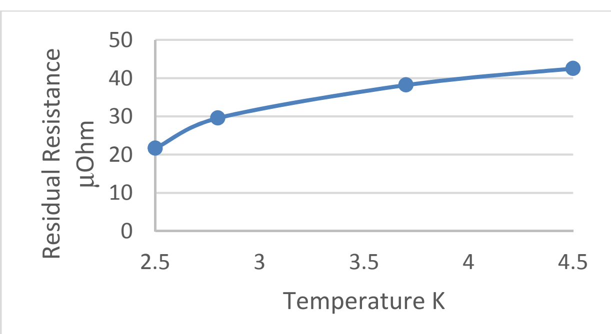

Figure 6: Calculated residual resistance from the measured resistance and the BCS resistance.

CONCLUSION

The first cryogenic RF test demonstrated that the cryostat and RF instrumentation operated as designed. Low power Q-factors for the bulk Nb sample plate were measured over a temperature range between 2.5 and 4.5 K, leading to calculated Rs values between 10 and 30 μΩ. Further studies are required to completely explain these results, and are planned later this year.

ACKNOWLEDGMENT

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