A Facility For Magnetic Field Penetration Measurements on Multilayer S-I-S Structures

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A FACILITY FOR MAGNETIC FIELD PENETRATION MEASUREMENTS ON MULTILAYER S-I-S STRUCTURES

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Abstract

The best-performing superconducting RF cavities made of bulk Nb have reached breakdown fields which sometimes exceed 200 mT and are close to the superheating field for Nb. As it was theoretically shown [1], a multilayer coating can be used to enhance the breakdown field of SRF cavities. In the simplest case, such multilayer may be a superconductor-insulator-superconductor (S-I-S) coating, for example, bulk niobium (S) coated with a thin film of insulator (I) followed by a thin layer of another superconductor (S) which could also be a dirty niobium [2]. To verify such an enhancement under a DC magnetic field at 4.2 K an experimental facility was designed, built and tested in ASTeC. The details of experimental setup and first results of the measurements are presented here.

METHOD

A number of well-known techniques such as RRR measurements, DC magnetization in parallel and perpendicular magnetic field and AC susceptibility studies have been used to study the superconducting properties of thin films. These methods are useful for the characterization of the films; however, they are not very suitable to select the best coating material in the superconductor-insulator-superconductor (S-I-S) coating, which would provide the higher breakdown field in the SRF cavities. There are several reasons for that:

(1) The most interesting case corresponds to the magnetic field parallel to the surface; however, as the film samples are usually small, then their alignment parallel to the magnetic field is difficult.

(2) These small samples would only represent a small fraction of total surface area of a larger sample, not representing the whole area.

(3) The samples are exposed to the magnetic field from both sides of the film, so in the case of S-I-S coating the magnetic field can easily penetrate between the layers from the open edges.

To address the problems listed above, the following method was suggested by A. Gurevich and implemented by ASTeC at STFC Daresbury Laboratory to study and compare various superconducting materials under DC magnetic field. A short superconducting magnetic coil is placed in the middle of a relatively long sample tube made of or coated with superconducting material with a large aspect ratio. Two magnetic field strength sensors (e.g. Hall-effect sensor/probe) are placed in on the central plane of the magnet: one inside the tube and the other outside as shown in Figure 1.

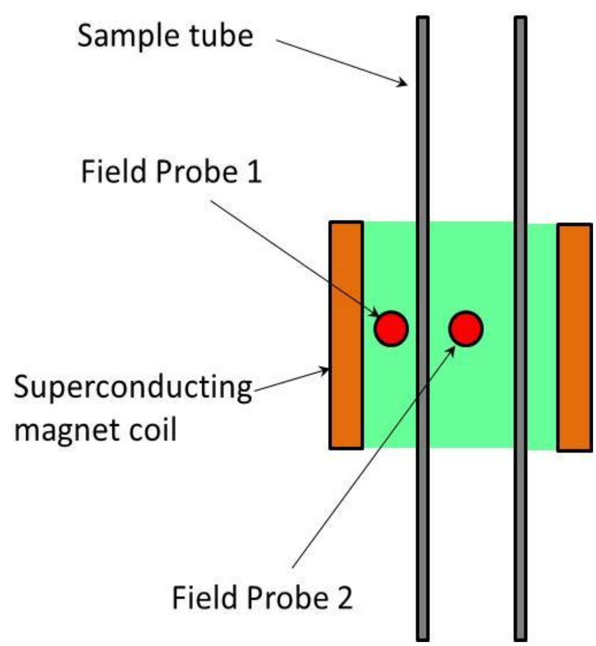

Figure 1: A schematic layout of magnetic measurements with tubular superconducting samples.

In this geometry the maximum magnetic field in the middle plane of the coil is uniform over the cross section of the bore. In the middle of the magnet, the magnetic field is the strongest and tangential to the sample tube walls. The magnetic field decreases with a distance from the middle plane of the coil and is no longer tangential. So, when Hall probes are placed in the middle of the magnet, Probe 1 measures the maximum magnetic field of the coil and Probe 2 measures the field that penetrates through the superconductor sample tube walls.

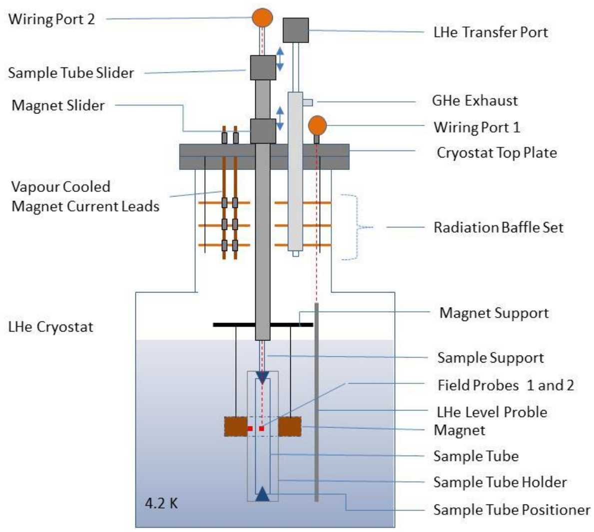

Figure 2: A detailed layout of the magnetic penetration facility.

A detailed layout of the magnetic penetration facility is shown in Figure 2. In this facility the tubular sample, magnetic field probes and superconducting magnets are placed in LHe bath, therefore all measurements are performed at 4.2 K.

Figure 3: An image of the magnetic penetration facility.

Figure 3 shows the facility built at ASTeC cryogenic laboratory in the STFC Daresbury Laboratory site. Magnetic field of the superconducting magnet can be varied between 0 and +/–1.7 T. The magnet and magnet field probes can move up and down +/–12 cm from the middle of the tube. Two Hall probes were mounted to be always in the central plain of the magnet and move together with it. One probe is inside the tube and the other is outside. Magnetic field sensitivity of the Hall probes is 10^{-4} T.

SAMPLES

Four samples have been prepared for the measurements.

Sample 1: The tube was manufactured from niobium with RRR=384 by Niowave Inc. [3]. The tube was 230 mm long and had the outer diameter of 12 mm and the inner diameter of 7.5 mm. No chemical treatment was done after fabrication.

Three other samples were Nb films deposited on a polished copper tube which was 240 mm long and had the outer diameter of 12 mm and the inner diameter of 10 mm. Sample 2 was a ~1 µm thick Nb film. Sample 3 was a ~100 nm thick Nb film. Sample 4 was a S-I-S structure with ~1 µm thick Nb film, ~10 nm thick AlN insulation layer and ~100 nm thick Nb film. The detailed characterization of the films is ongoing.

EXPERIMENTAL

Experiments with Sample 1

For the measurement two experimental procedures were developed.

Experimental procedure 1:

- Magnet held stationary.
- Magnet current is stepped up slowly and turned off between steps.
- The lower critical field H_{C1} was measured at first indication of residual magnetisation detected outside the Nb tube with Probe 1 when magnet current is turned off between the steps measured with magnet off, i.e. with zero external field.
- The full penetration field in the Bean model defined as $H_P = d\,J_c$, where J_c is the critical current density due to pinning of vortices and d is the wall thickness, was measured with two techniques:
  - when the magnetic field first detected inside the Nb tube with Probe 2
  - when residual magnetisation is first measured with magnet off, i.e. with zero external field.
- The upper critical field H_{C2} was defined as a field of complete penetration through the Nb tube, so that Probes 1 and 2 detect the same field.

Based on the Experimental procedure 1, the following critical magnetic fields of Nb were obtained:

$$H_{C1} \approx 1.15\times10^5\ \mathrm{Am^{-1}}\ \text{or}\ B_{C1}\approx 0.145\ \mathrm{T}$$
$$H_P \approx 2.11\times10^5\ \mathrm{Am^{-1}}\ \text{or}\ B_P\approx 0.264\ \mathrm{T}$$
$$H_{C2} \approx 3.74\times10^5\ \mathrm{Am^{-1}}\ \text{or}\ B_{C2}\approx 0.470\ \mathrm{T}$$

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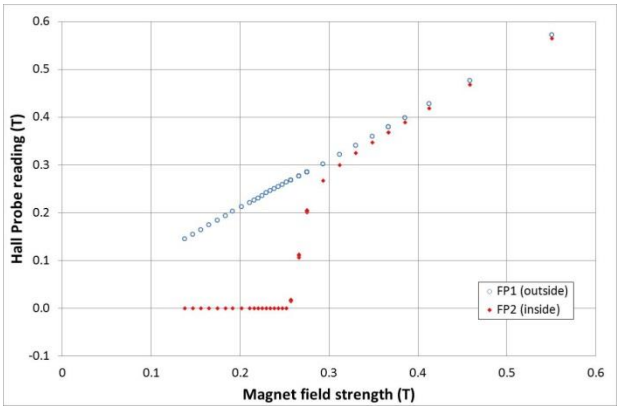

Figure 4: Field penetration measurements with Sample 1 (bulk Nb tube).

Experimental procedure 2:

- Magnet current stepped up to 1.7 T.
- Then magnet was switched off: field remains trapped in tube.
- Probes moved up and down to scan through trapped field profile.

The results are show in Figure 5. The initial position of the centre of magnet and probes is zero. One can see that the residual field is almost constant at +/- 2 cm from the centre of magnet, but as the distance along the magnet further increases beyond, +/-6 cm from the centre, the field reduces rapidly to below the sensitivity level. That means that the magnetic field was below H_{c1} for distances greater than 6 cm away from the centre of magnet. This leads to a conclusion that in such a geometry of magnet and a sample tube a sample of ~12 cm long is sufficient. For practical application this means that our standard 24-cm long sample of can contain two different ~12-cm long coating, i.e. two samples can be measured in one experiment.

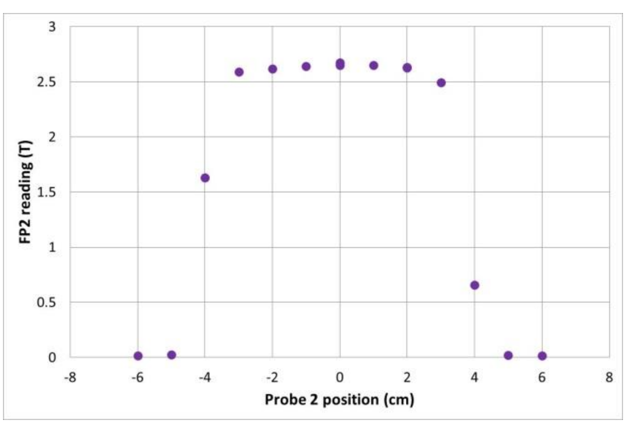

Figure 5: Trapped field measurements after exposure to the magnetic field of 1.7 T.

Experiments with Sample 2

Sample 2 was intended to be studied with Experimental procedure 1:

- Magnet held stationary
- Magnet current was stepped up slowly up to ~1 T, and turned off between steps.

The results are presented in Figure 6. Because the loss of data in this experiment, the first point in the measurements with a magnetic field of H = 0.136 T was obviously above both H_{C1} and H_P because Probe 2 detected magnetic field inside the tube. Then in whole range of measurements the magnetic field between two probes was different by a factor 2.0. When the external magnetic field was set to zero, both Hall probes measure zero field.

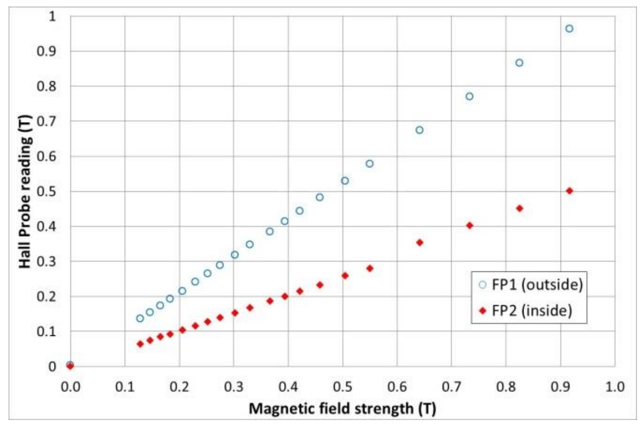

Figure 6: Field penetration measurements with Sample 2 (~1 µm thick Nb film on copper tube).

CONCLUSIONS AND FUTURE PLANS

The new magnetic field penetration facility was built at STFC Daresbury Laboratory. It was tested with a bulk Nb tube and demonstrated the critical field results comparable with one from the literature. The 1-µm thick Nb film deposited on Cu tube exhibited the reduction of magnetic field by a factor of 2, demonstrating that the new facility is capable for studying various samples such as bulk tubes, thin films deposited on Cu tubes and the S-I-S structures.

These results are very preliminary; the experiments with more detailed automatized data acquisition will be performed in near future with four prepared samples and other samples.

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