SUPERCONDUCTING SURFACE RESISTANCE MEASUREMENTS WITH A TE011 CAVITY

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Abstract

This paper describes the experiments with a TE011 cavity and gives some results, especially the magnetic field dependence on Rs at 4.2 K simulated by thermal effect. The results obtained with several successive removable Nb end plates characterized this cavity as a good tool to measure the RF surface resistance of various superconducting materials.

Introduction

We have constructed a cylindrical TE011 cavity in order to test the RF surface resistance Rs of superconducting bulks as well films on a demountable end plate of the cavity. We study the magnetic field, the temperature and the frequency (measurements on TE011, TE012 and soon TE013 modes) dependences on Rs.

The localization of defects on the removable plate using sensitive thermometers in superfluid helium and the possible further identification of these defects via surface analysis tools (SEM, Auger...) was one of our main goals, as was the case in earlier pioneering works [1].

This test cavity is usefull, not only for the control and optimization of processes in the elaboration of new RF thin films at low field levels but may also serve to study the magnetic thermal breakdown effects on such materials.

Cavity design

The main body of the cavity is made out of high purity Niobium (RRR 180). The diameter of the removable disc, ϕ_e = 126mm, has been choosed to fit our SEM apparatus. The inner diameter of the cavity is then ϕi=110mm; its height is 66mm. An 1mm Pb gasket located in a groove machined in the disc itself has been prefered to an In one, since it gives a better handling and removability, as well as a higher Tc.

The resonance frequencies in liquid helium of the 2 modes on which we operate till now are then: for TE011: F1 = 4.04 GHz; for TE012: F2 = 5.66 GHz.

The corresponding geometric factors for the overall cavity are: G1 = 722 Ω, G2 = 853 Ω. The fractional geometric factors for the end plate are respectively: G'1 = 3298 Ω, G'2 = 2254 Ω.

The maximum magnetic field is situated on the half diameter of the end plate and, for the TE011 mode, simultaneously on the half height of the cylindrical wall.

A peripheric groove in the fixed end plate has been designed to shift away the degenerate TM 111 mode by 50 MHz.

Finally a variable coupling on the incident port with a possible loop displacement of 25mm ($10^5 < Qext < 3 10^{11}$) has been carefully designed, following the method used in [2].

Superfluid helium thermometry

We use sensitive fixed thermometers which have been deviced by the IPN Orsay Group [4] collaborating with us. Forty probes, 10mm in diameter are located and pressed with a thermal bonding agent on the plate under test. The temperature mapping is performed by a scanning technique (HP 3852 scanner) using HP 44705 relay multiplexers - the maximum offset voltage and noise of which is 2 μV - and a HP 3458 voltmeter which gives an accuracy of 0.1 μV and a noise level of 0.2 μV for the 100 mV range with a 20 ms integration time. A particular sensor, giving the bath temperature, is scanned after each of the others in order to reduce the effect of the bath temperature variation on the disc temperature rise measurement.

Experimental results

Tests on RRR 180 Nb discs

The first experiments with discs made out of RRR 180 Nb and chemically treated were carried out in order to test the surface resistance reproductibility of the cavity after disassemblings and reassemblings. Figures 1 and 2 show the results of three successive tests: test n°1 after chemical polishing of the main body cavity, tests n°2 and n°3 without new chemical treatment of the cavity.

For these 3 tests, at low level field:
Rres = 100, 130 and 105 nΩ at 4 GHz;
Rres = 300, 255 and 230 nΩ at 5,7 GHz.

The residual surface resistance remains relatively insensitive to exposure to the atmosphere.

The maximum magnetic field obtained before quench was 50 mT.

A magnetic field dependence on Rs at 4.2 K is observed.

The best plotted fit to the BCS theory using Halbritter's program [5] was obtained with the following parameters:

T_c = 9.2 K; coherent lenght ξ = 500 Å; mean free path l = 3600 Å; London penetration depth Λ =333Å; gap: $\frac{\Delta}{kT_c}$ =1.9 (1)

The figure 3 shows, as an example, the localization of the lossy regions on a Nb plate at 1.6 K. The plotted temperature is the difference between the measured temperatures when the RF is on and off. The resolution in this differential temperature measurement is of the order of 0.1 mK.

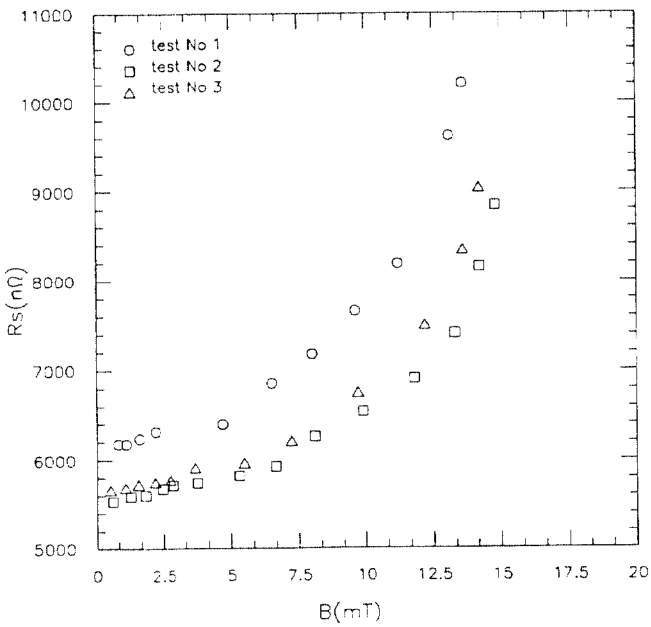

Fig 1. Rs (B) for Nb at T = 4.2K - F = 4 GHz

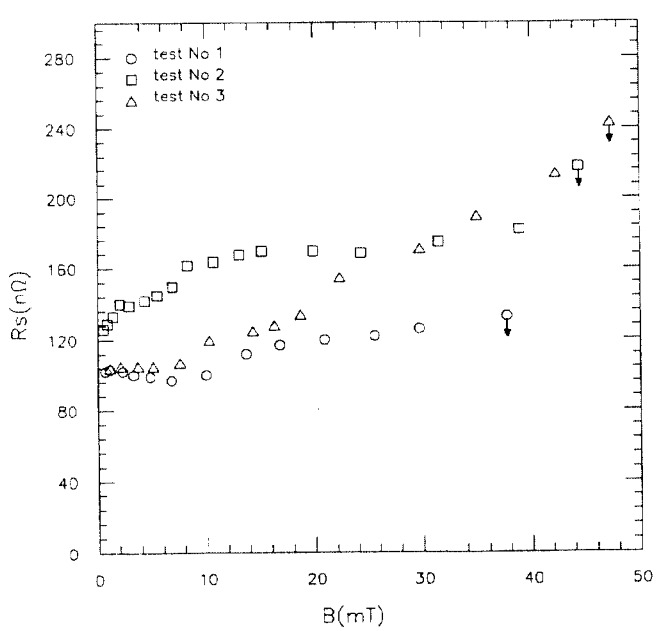

Fig.2. Rs (B) for Nb at T = 1.6K - F = 4 GHz

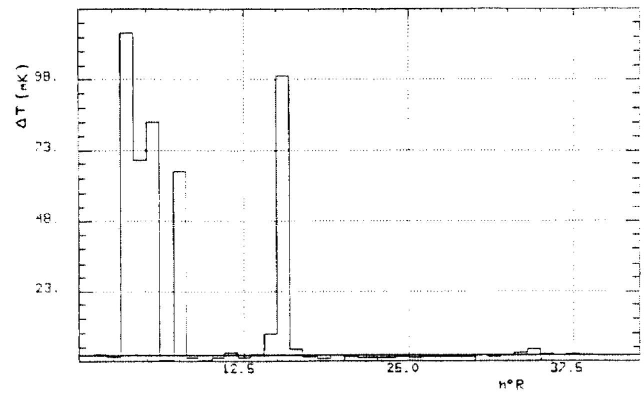

Fig.3. ΔT distribution obtained by 40 probes on a Nb plate for Bmax = 47 mT, Tbath = 1.6 K.

Tests on a Nb Ti (0.54/0.46) alloy disc

The figure 4 shows the strong dependence of magnetic field level on Rs at 4.2 K due to the very bad thermal conductivity of the NbTi alloy.

The main results are:

- At low level field:
Rres # 350 nΩ at 4 GHz
Rres # 1000 nΩ at 5,7 GHz
- At 4.2 K R BCS # 9000 nΩ at 4 GHz and 28000 nΩ at 5,7 GHz
- Breakdown magnetic field: 8 mT

These values are in reasonable agreement with the estimations given in reference [6].

The best fit to the BCS theory for this NbTi plate at 4 GHz gives:
T_c = 9.8K; ξ = 40 Å; l = 10 Å; $\frac{\Delta}{kT_c}$ =1.73; Λ = 1000Å. (2)

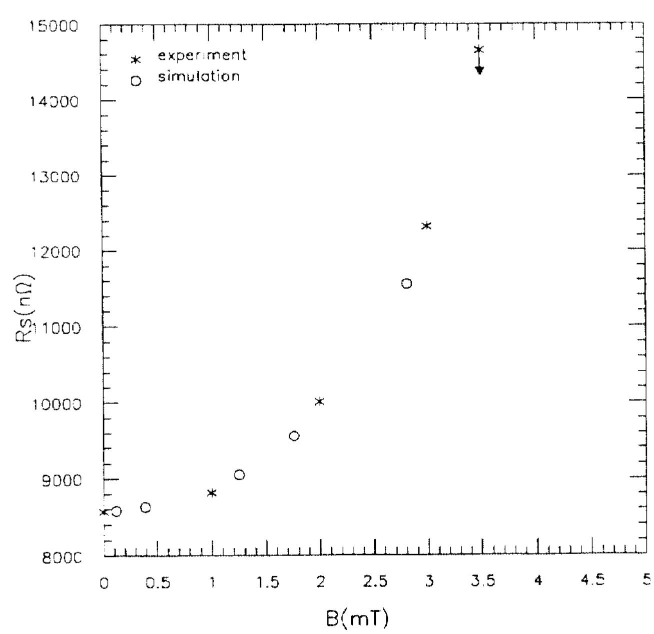

Fig.4. Rs (B) for NbTi at T = 4.2 K. F = 4 GHz

Thermal behaviour of the superconducting material at 4.2 K

In order to know whether the increase of the Rs end plate with the magnetic field level is of thermal origin, a model was used with the following ingredients:

- the superconducting material has uniform properties with a surface resistance Rs = R BCS (T)+ Rres;

- R BCS is calculated using Halbritter's code [5] with the parameters - given above in (1) and (2) - fitting the experimental data at low field;

- the thermal conductivity of the superconducting material has a temperature dependence given by:

λ (T) = -84.75 + 53.42 exp (0.216 T) for Nb (2.76 K $<$ T $<$ 9.2 K), in agreement with independent measurements of λ made in our laboratory for RRR 180 Nb sheets,
and by:
λ = 0.2 W $m^{-1}K^{-1}$ for the NbTi alloy, value independent of T in the temperature range of interest and taken from the reference [6];

- the heat exchange between the disc and the He bath is parametrized by $P = C.\Delta T^n$ where P is the heat flux and ΔT the temperature difference between the wall and the bath with the parameters n = 2 and C = 100 $W.m^{-2}.T^{-2}$ according to the literature ref [7].

Despite its very non linear nature, the one dimensional time independent heat balance equation could be solved without use of a finite element code, giving an equilibrium temperature Teq (B) depending on the magnetic field B at the superconducting surface, and then a surface resistance Rs (Teq).

For the Nb end plate the experimental results for Rs (B) are qualitatively reproduced by the above model. However, the predicted effect is too small, perhaps because additional small size defects, neglected in the calculation, could contribute to the total heating of the surface.

For the NbTi alloy end plate, the calculation reproduces very well the experimental data (Fig 4) probably because the heating of the surface is more effective than for Nb, due to the very poor thermal conductivity of the material.

Conclusion

After the good results obtained in these preliminary experiments, the TE011 test cavity we have deviced, appears to be an excellent tool for the surface resistance study, above 4 GHz, of superconducting films and their behaviour at high level fields. Our next experiments are beginning on our first sputtered NbTiN coatings on Cu substrate.

References

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