RF SURFACE RESISTANCE MEASUREMENTS OF SUPERCONDUCTING SAMPLES WITH VACUUM INSULATED THERMOMETERS

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Abstract

A cylindrical niobium cavity is used at Saclay for measuring, with a differential RF method, the surface resistance Rs of superconducting thin films (Nb or NbTiN) sputtered on removable copper disks. In order to improve the accuracy, mainly at 4 K**,** we have developed a thermometric method to get, from thermal model calculations, the local and absolute Rs values. Temperature sensors pressed on the back side of the disk are placed in a vacuum chamber ; a heater post on the center of the sample disk allows a power calibration without knowing the sample thermal properties (thermal conductivity, heat transfer coefficient at the LHe interface). The first results obtained by this method are discussed and compared to the data measured by the classical RF method.

1 INTRODUCTION

A cylindrical bulk niobium cavity is used for measuring, with a RF method at two frequencies (4 GHz and 5.6 GHz), the surface resistance of Nb or NbTiN films sputtered on removable copper disks. This differential method requires a comparison to a reference bulk niobium disk and gives a poor accuracy for Rs at 4.2K (±1000 nΩ). In order to improve the accuracy and sensitivity of the measurements, method based on temperature mearurements (called “thermometric method”) is developed to obtain both local and absolute value of surface resistance for bath temperature T_{bath} in the range 1.7 K-4.2 K

2 PRINCIPLE OF THE METHOD

The principle of the method is based on numerical simulation [1] performed with CASTEM 2000 code. In this simulation, the disk sample is only cooled on the outside rim and is either subjected to a static heater power or to RF losses induced by the surface magnetic field Hs. In the case of a 12 mm heater diameter, the numerical simulation results (Fig. 1) show that the temperature profiles ($\Delta T=T-T_{bath}$ vs. r) are very close for the large radii (r>40mm) when the static power equals the global RF losses on the disk sample.

Hence, after a calibration with static heater power, the total dissipated RF power can be deduced from measured temperatures of the outer part of the disk. Assuming a polynomial dependence of Rs vs. Hs, we can then calculate the corresponding coefficients using the least square method.

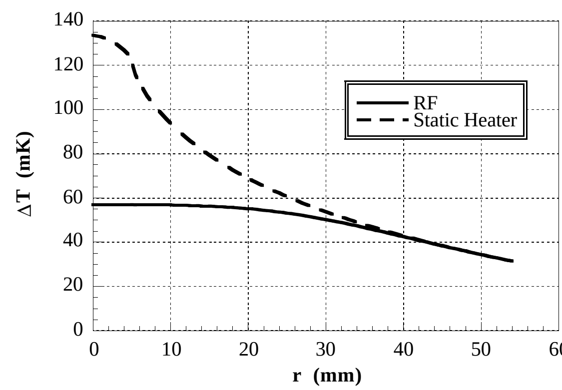

Fig.1 : Radial temperature profile on Nb/Cu subjected to a static heater power or RF magnetic field (T_{bath}=1.715 K ; $P_{stat}=P_{RF}$)

3 EXPERIMENTAL SET-UP AND PROCEDURE

3.1 Description

The test-cell (Fig. 2) consists of the RF part mainly composed by a cylindrical cavity and the thermometric part including a dismountable assembly with a static heater and 24 thermometers (all located in a vacuum insulation jacket). The temperature sensors are mounted on four arms at 90° apart from each other, each arm supporting six thermometers radially distributed with a step Δr=7 mm (starting radius r_{min}=12.4mm). A calibrated thermometer (1.5K-60K) is located on the heater post to control its temperature and hence to deduce the heat leaks to the surrounding Liquid Helium.

3.2 Experimental procedure

The experiment is performed in two steps. First, the thermometers are calibrated in the temperature range 1.6 K-4.5 K by comparison to a reference germanium temperature sensor. To reduce the thermometers self-heating, the power dissipated in the sensors is kept lower than 0.1 µW. Then, the temperature distribution of the disk sample is measured as function of the applied static power (10mW<P_{stat}<2W) and also as function of the magnetic RF field.

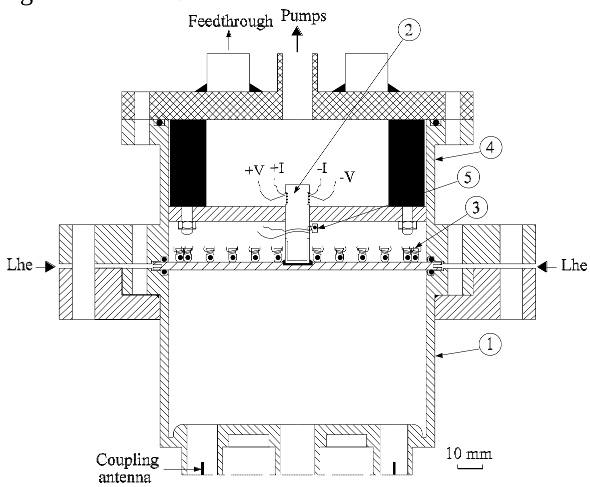

Fig.2 : Experimental set-up (1=cylindrical cavity, 2=static heater, 3=thermometers, 4=vacuum insulation jacket, 5=calibrated thermal sensor)

4 EXPERIMENTAL RESULTS AT 1.7K

Several Nb thin films deposited on copper disks were successfully tested with this method. We present in the following the results obtained with two of these samples (disk#1 at f=5.6 GHz ; disk#2 at f=4 GHz).

4.1 Static heating calibration

The thermal response of the 24 thermometers to a static heater power is systematically measured. All the results confirm a linear dependence of ΔT vs. P_{stat} in the power range studied with a mean deviation lower than 1 mK. From the slope of the experimental temperature profile, since $\Delta T \propto \ln(r)/k_{Cu}$, the thermal conductivity of the disk can be determined with a good accuracy (5%). Typical values obtained in such a way are 750 W/m.K and 850 W/m.K for respectively temperatures of 1.7 K and 2.0 K.

Since $k_{Cu}(T)$ is measured *in-situ*, the Kapitza conductance at Cu-HeII interface remains the only unknown thermal parameter required for simulations. By using a thermal code, its value can be found by adjusting the measured temperature of the most external thermometer ($\Delta T_{ext} = \Delta T_6$) to the computed values. For example, the value of 4000 W/m^2.K determined for a LHe temperature of 1.7 K is in good agreement with other measurements [2]. Moreover, the simulated radial temperature distribution is in good agreement with experimental data (Tab. 1).

P_{stat} (mW)	ΔT_1 (mK)	ΔT_2 (mK)	ΔT_3 (mK)	ΔT_4 (mK)	ΔT_5 (mK)	ΔT_6 (mK)
220*	36.5	29.4	24.4	20.7	17.6	15.1
220**	36.8	29.2	25.3	20.9	17.5	15.1
1990*	320	260.3	218.7	186.6	160.5	138.3
1990**	323	254.6	228.4	187.8	159.2	138.3

Tab. 1 : Simulated (*) and measured (**) radial temperature on disk#1 (T_{bath} =1.715K, f=5.6 GHz)

4.2 RF heating results

- Results with disk#1

In the case of RF heating, the thermal response of the thermometers is not linear with respect to the square magnetic field (Fig. 3). This is mainly due to the dependence of the surface resistance with respect to the magnetic field.

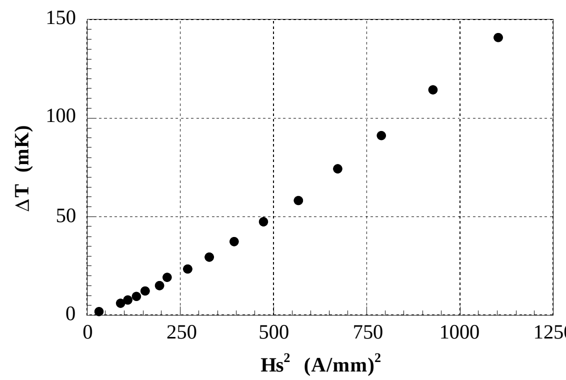

Fig.3 : Temperature variations measured at r=47.4mm (T_{bath} =1.715K, f=5.6 GHz)

Using the Kapitza conductance determined by the calibration with static power heater, we have computed the radial temperature distribution on disk#1. The corresponding numerical results are in good agreement with experimental data (Tab.2).

H_S (A/mm)	ΔT_1 (mK)	ΔT_2 (mK)	ΔT_3 (mK)	ΔT_4 (mK)	ΔT_5 (mK)	ΔT_6 (mK)
14*	25.3	24.8	23.6	21.7	19.2	16.6
14**	21.1	20.4	20.1	18.7	18.5	16.9
33*	209	205.4	195.9	179.6	159	137.9
33**	200.1	194.1	188.3	173.1	162.9	146.9

Tab. 2 : Simulated (*) and measured (**) radial temperature profile (T_{bath} =1.715K, f=5.6 GHz)

For this disk, the surface resistances deduced from thermometric measurements (Rs^{Th}) are close (better than 5% at low magnetic field values) to those obtained by the classical RF method (Rs^{RF}).

- Results with disk#2

In contrast to disk#1, the temperatures measured on the disk#2 at a given radius show an azimuthal temperature gradient for surface magnetic field up to 25 A/mm. The observed variations, which are greater than 20%, can not be attributed to the accuracy of ΔT measurements (see section 4.1). These differences are due to effective inhomogeneities of RF losses on the disk surface.

In this case, the surface resistance deduced from thermometric measurements (Fig. 4) is systematically lower (about 20%) than the average value obtained by the classical RF method.

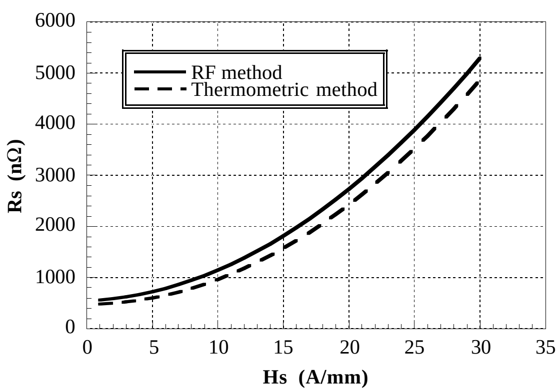

Fig. 4 : Surface resistance vs. surface magnetic field (T_{bath} =1.715K, f=4 GHz)

5 EXPERIMENTAL RESULTS AT 4.2K

5.1 Calibration with the static heater

At T_{bath} = 4.2K, the thermal response is no more linear with the static heater power, due to the power law dependence of the heat transfer coefficient h* between the copper disk and the Liquid Helium bath in nucleate boiling regime : $h^* = C \cdot (T_{Cu} - T_{bath}^n)$

Both the *n* and *C* parameters can however be deduced with the thermal code by fitting the measured temperatures of the most external thermometers to the computed values. With such a method, the value found for the exponent *n* is 1.8 with T_{bath} = 4.23K, which is in good agreement with the literature [2]. Note that only average values of these parameters are obtained, since they can vary with the surface state of the copper disk and the orientation of the Cu-LHe interface.

P (mW)	ΔT_1 (mK)	ΔT_2 (mK)	ΔT_3 (mK)	ΔT_4 (mK)	ΔT_5 (mK)	ΔT_6 (mK)
220*	41.6	38.5	36.4	34.9	33.6	32.5
220**	41.1	38.4	36.5	34.7	33.2	32.5
1990*	206	179.8	161.6	147.7	136.5	127
1990**	206.5	179.6	165.4	148.8	135.7	127.1

Tab. 3 : Simulated (*) and measured (**) radial temperature profile on disk#1 (T_{bath} = 4.235 K)

When using this dependence of h*, the full radial temperature distribution can be computed (Tab. 3), and the results are very close to the experimental data.

5.2 RF heating results

For bath temperature around 4.2 K, the surface resistance of the disks has been measured by the thermometric method at low magnetic fields. These data are in good agreement with those obtained by the classical RF method, but provide a better accuracy (Tab. 4). Moreover, the resistance follows the well-known BCS quadratic dependence with the resonant frequency.

f (GHz)	Rs^{Th} (nOhm)	Rs^{RF} (nOhm)
4*	3200 ± 300	4000 ± 1000
5.6*	6000 ± 300	5200 ± 1000
4**	5200 ± 300	5100 ± 1000
5.6**	9000 ± 300	not measured

Tab. 4 : Surface resistance of disk#1(*) and disk#2 (**) at Hs=1A/mm (T_{bath} = 4.235 K)

5 CONCLUSION

A new thermometric method, for local surface resistance measurements of superconducting samples at 1.7 K and 4.2 K, has been developed. Comparing the corresponding data to those obtained by the classical RF measurements has validated it. With this powerful thermometric method, the variations of the surface resistance of the coatings with the RF magnetic field can be obtained. Though it is not necessary if the only interest is the determination of the resistance, the thermal parameters of the copper disks can also be evaluated.

Some tested disks exhibit an inhomogeneous surface resistance. Further microscopic analysis of highly dissipating areas could provide a correlation between the observed heatings and the microstructure of the film substrate.

We planned to measure the temperature dependence of the resistance at different magnetic fields, and to improve the experimental set-up by increasing the number of thermal sensors on the outer part of the disk.

REFERENCES

[1] S.Chel, DAPNIA/SEA 94-04, internal report (in French), 1994

[2] S.W Van Sciver, "Helium Cryogenics", Plenum press, 1986.