Measurements of the Microwave Surface Resistance of $Bi_2Sr_2CaCu_2O_x$ Superconductor on Silver Substrate Using a Half-Wave Coaxial Cavity Resonator

Ichiro MIURA, Eisuke MINEHARA*, Yasuko MASHIMA**,
Shuji YOSHIZAWA**, Ryohji NAGAI*, and Manabu TAKEUCHI

Dept. Electr. Eng. Ibaraki Univ.,
Dept. Phys. Tokai JAERI*,
The 4th Dept. Central Research Laboratory, Dowa Mining Co., Ltd.**

We have measured the microwave surface resistance of $Bi_2Sr_2CaCu_2O_x$ superconductor on silver substrate. The measurements were made around 2.8GHz between 15K and 300K using a half-wave coaxial cavity resonator. The surface resistance of 0.44mΩ, which is lower than that for high purity copper (7N), was obtained at 2.76GHz and 10.5K for the $Bi_2Sr_2CaCu_2O_x$ (Tc=85K) superconductor . The lower value of the resistance shows that the $Bi_2Sr_2CaCu_2O_x$ superconductor on silver substrate is more suitable for high-frequency applications at low temperature than the high purity copper.

KEYWORDS: $Bi_2Sr_2CaCu_2O_x$ superconductor, silver substrate, microwave surface resistance, a half-wave coaxial cavity resonator, Q value

INTRODUCTION

Since the discovery of high-Tc oxide superconductors[1], their investigations have been promoted extensively in the world. A measurement of the microwave surface resistance (Rs) for the superconductors has been known as one of the most sensitive characterization methods. The Rs of the superconductors depends on a number of physical parameters, such as coherence length, energy gap, mean free path, and penetration depth, as well as defects on the superconductors. Thus, the measurements of the Rs as a function of the temperature and frequency yield fundamental information about the superconductors. The Rs also plays a significant role for applications in microwave devices, for examples, cavity resonator, filter, transmission line, wave guide and antenna. It has been reported that the Rs of pellets and thick films made by the $YBa_2Cu_3O_{7-\delta}$ superconductors were decreased by silver-adding[2]. In this paper, the microwave surface resistance of the $Bi_2Sr_2CaCu_2O_x$ (Tc=85K) superconductor[3] on silver substrate was measured and compared with the Rs of high purity copper at low temperature.

EXPERIMENT

As shown in Fig.1, an experimental set-up used in this work consists of a half-wave coaxial cavity resonator, cryostat, microwave measurement instrument (vector network analyzer, HP-8720A), and a work-station (HP-9000-300).

A half-wave cavity resonator, which is resonant in the fundamental TEM (transverse electromagnetic) mode, has a center of a sample (superconductor or normal conductor) and outer conductor of normal conducting metal (coaxial resonator method). As shown in fig.2, a wire-shaped sample is supported in the half-wave coaxial cavity resonator, and inside a cylindrical outer conductor using the quartz tube and wool. A length of the sample corresponds to one half-wavelength of the fundamental resonance frequency. The Rs of the sample was calculated by measuring a Q value of the cavity resonator at differed temperatures from a relationship,

(1) $$Rs_{sample} = \frac{b\omega\mu_0 \ln S}{Q_u S} - \frac{Rs_{cavity}}{S}$$

where Rs_{sample} is the surface resistance of sample, b is an inner radius of outer conductor (35.1mm), ω is a resonant angular frequency, μ_0 is permeability of free space, $S=b/a$, a is a radius of sample, Q_u is an unloaded Q value of the half-wave coaxial cavity resonator, Rs_{cavity} is a surface resistance of the outer conductor. The Q values were measured using the microwave measurement instrument. A cryostat has a He gas closed loop refrigerator and a vacuum pumping system. The He gas closed loop refrigerator can keep the half-wave coaxial cavity resonator at any temperatures in the temperature from 10K to 300K. The microwave measurement instrument is controlled by the work-station.

The samples measured here were the $Bi_2Sr_2CaCu_2O_x$ superconductor printed on silver substrate and the high purity copper (7N). The $Bi_2Sr_2CaCu_2O_x$ superconductor on silver substrate has a length of 50mm, a thickness of 0.6mm, and a width of 5mm. The effective radius of the samples was estimated from thickness and width. The copper has a length of 50mm, and a radius of 0.5mm.

The Rs of $Bi_2Sr_2CaCu_2O_x$ superconductor on silver substrate calculated by Eq.(1) included the Rs of silver substrate, and so the Rs of the superconductor was estimated by

(2) $$Rs_{BSCCO} = \frac{Rs_{sample} - sRs_{Ag}}{1-s}$$

where Rs_{BSCCO} is the intrinsic Rs of the superconductor, Rs_{sample} is the Rs calculated by Eq.(1), Rs_{Ag} is the Rs of the silver substrate, s is surface fraction of silver. The Rs of silver was measured independently using a half-wave coaxial cavity resonator.

RESULTS AND DISCUSSION

Figure 3 shows a temperature dependence of Rs_{BSCCO} and the Rs of the copper (7N). The filled and open circles represent results for Rs_{BSCCO} and the Rs of the copper (7N), respectively. The Rs_{BSCCO} increased between 300K and 80K because of impurity on boundary of the superconductor and silver substrate. The Rs_{BSCCO} decreased sharply at 80K becomes lower than the Rs of copper (7N) below 20K, and 0.44mΩ at 10.5K. This result shows that the $Bi_2Sr_2CaCu_2O_x$ superconductor on silver substrate is more suitable for high-frequency application at the low temperature than the high purity copper.

In order to compare with the Rs of niobium at 4.2K, and the copper and Rs_{BSCCO} at 10.5K and 79.8K were plotted as a function of frequency in Fig.4. The Rs_{BSCCO} at 10.5K and 2.8GHz was 100 times higher than the Rs of niobium at 4.2K and the same frequency. This was explained by that $Bi_2Sr_2CaCu_2O_x$ is polycrystal. If the Rs_{BSCCO} depends quadratically on the frequency, the Rs_{BSCCO} should be lower than the copper at 293K around and below 10GHz. These results show that $Bi_2Sr_2CaCu_2O_x$ superconductor on silver substrate is more suitable for high-frequency application than the high purity copper.

CONCLUSION

In conclusion, we have demonstrated that the surface resistance for the $Bi_2Sr_2CaCu_2O_x$ superconductor on silver substrate exhibits less than that for high purity copper (7N) around 2.8GHz and below 20K. From this result, $Bi_2Sr_2CaCu_2O_x$ superconductor on silver substrate is more suitable for high-frequency applications at low temperature than the copper.

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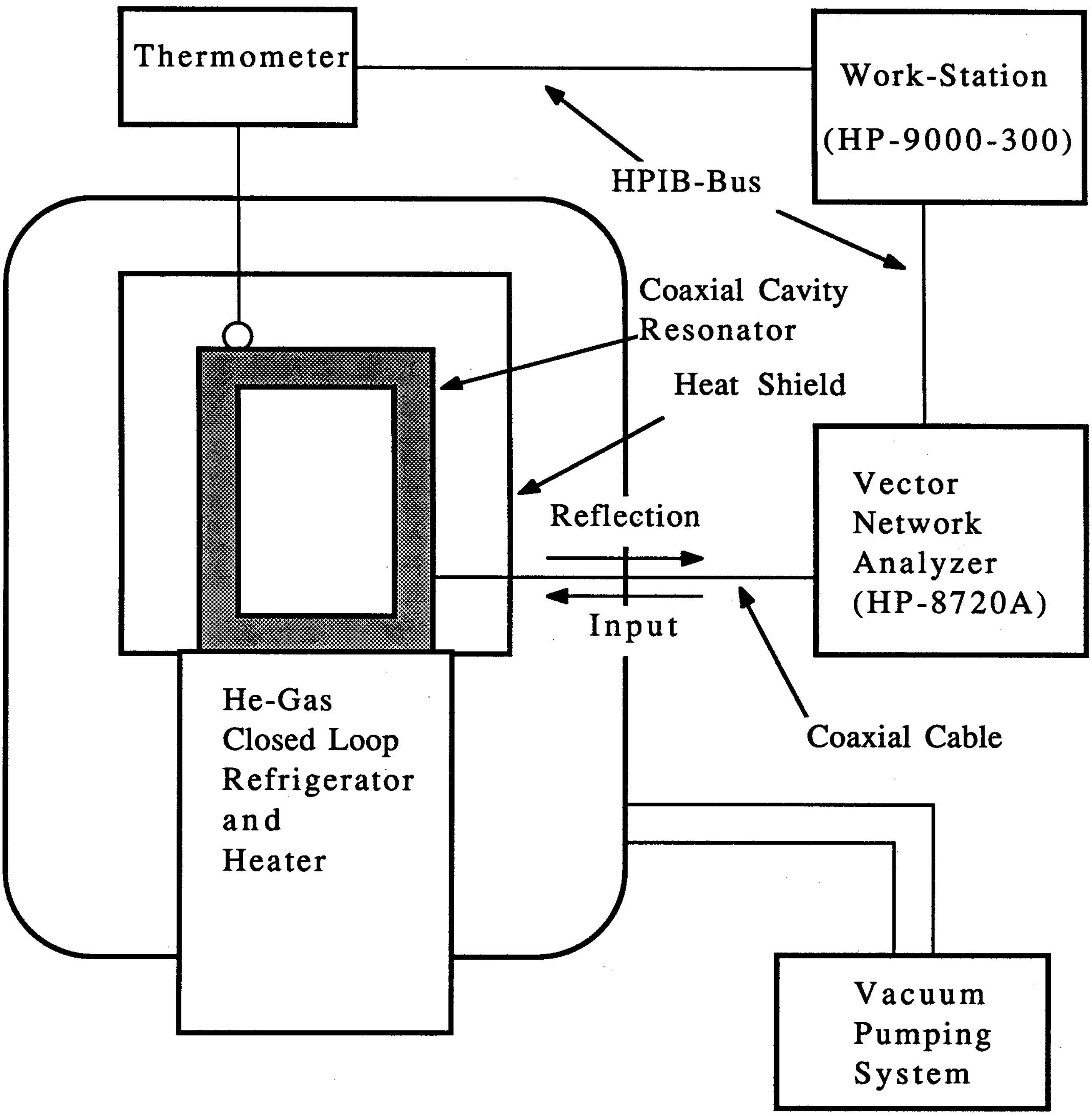

Fig.1 Schematic diagram of the experimental setup

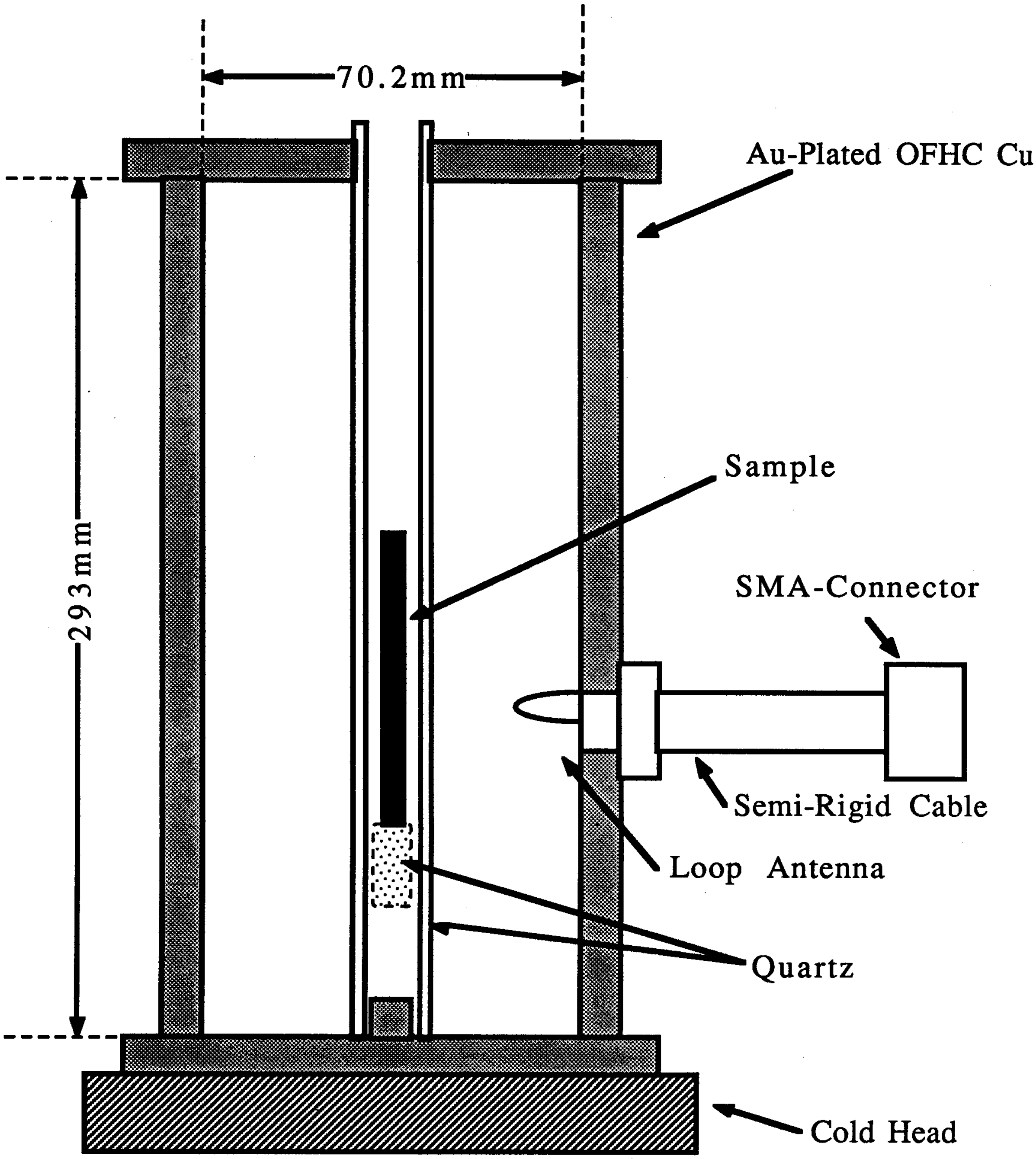

Fig.2 A half-wave coaxial cavity resonator

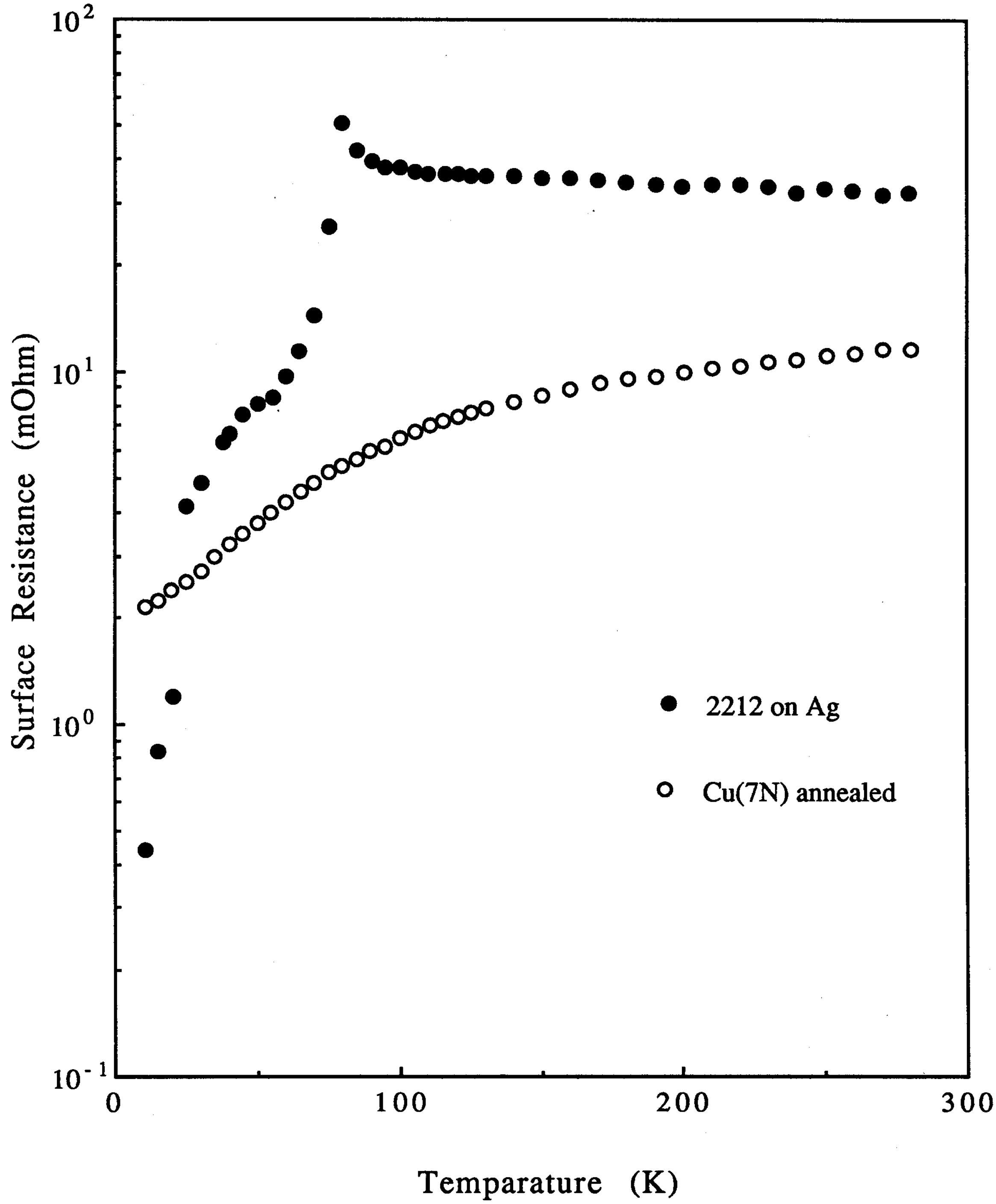

Fig.3 Surface resistance vs. temperature for BSCCO on Ag and Cu(7N) around 2.2GHz

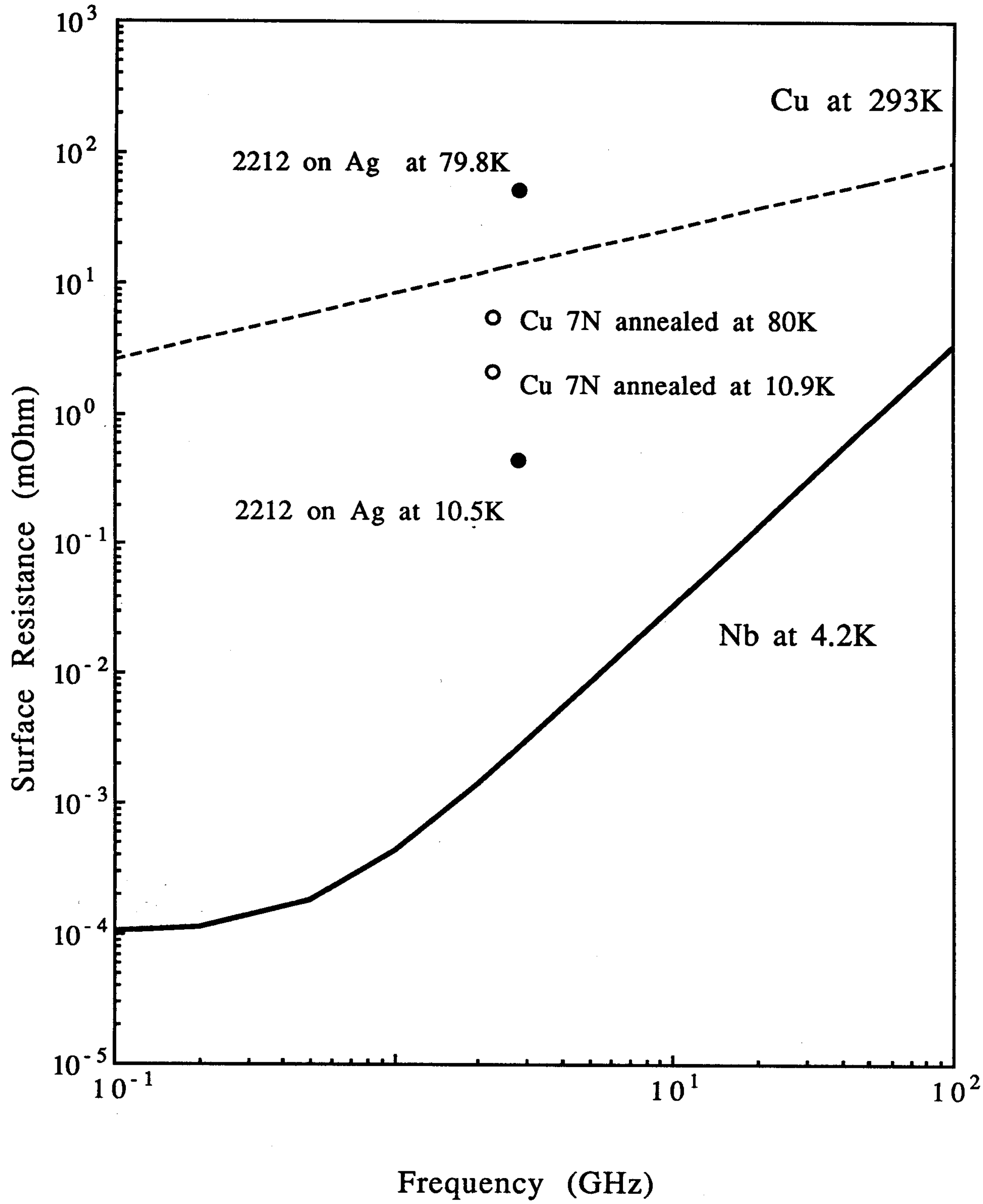

Fig.4 Surface resistance vs. frequency for BSCCO on Ag and Cu(7N) around 10 and 80K