ELABORATION AND CHARACTERIZATION OF A HIGH TEMPERATURE SUPERCONDUCTING MICROSTRIP ANTENNA OPERATING AT 38 GHz .

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Introduction

The High Tc Superconductors (HTS) are very promising for applications in passive devices : experimental investigations such as delay-lines, resonators, and filters at X-band frequencies have shown that HTS films provide a substantial loss reduction over metallic (silver, gold or copper) devices [1].

HTS materials can improve antenna efficiency by reducing the losses in both the feed network and the radiating elements. The prospects for the use of High Tc Superconductors to miniaturize antenna systems have been theoretically evaluated [2-4].

Here, we have experimentally investigated the properties of HTS and compared them with normal metal (silver) in Ka-band with a single element microstrip patch antenna on a (100) MgO substrate. We report here on our home-made measurement set-up working at 80 K and 38 GHz. Measurements from the antennas, including input impedance and gain are presented.

Modelization

We selected a single rectangular patch with a width W and a lengh l. The feed network uses a 50 ohms line. The relative dielectric constant of MgO (9.9 at 300 K and 9.6 at 80 K in a broad frequency band including microwaves [5]) results in a microstrip line width of 360 µm for this geometry which feeds directly the patch through a notched input. For the calculation of the patch resonance frequency and the patch impedance, we used two electromagnetic C.A.D. softwares : Saphir v1.0 (developed by CNES, INSA de Rennes, IPSIS) and Ensemble (developed by Boulder Microwave Technologies, Inc). From Saphir modelization, calculated values are width W=1800 µm and length l=1020 µm for a resonance frequency of 38 GHz and a return loss equal to 34.5 dB. With Ensemble v3.2 software, we find, with the above geometry, a resonance frequency at 39.6 GHz and a return loss equal to 16.5 dB. The difference between the results obtained from the two softwares could be due to the high permittivity of MgO.

HTS antenna realization

The $YBa_2Cu_3O_7$ thin film has been in situ deposited by pulsed laser ablation from a home made stoichiometric target (density > 90 %) as reported in reference [6]. The 340 nm thick $YBa_2Cu_3O_7$ thin film used in this work has been deposited on a 10x10x0.5 mm^3 (100) MgO single crystal substrate at 740 °C under an oxygen pressure of 0.4 mbar and has been cooled down to room temperature under atmospheric pressure of O_2 without any further treatment.

Due to the large mismatch between MgO and $YBa_2Cu_3O_7$ unit-cell parameters (9 %), some amount of the c-axis domains was rotated by 45° with respect to substrate axes ($c_{\perp 45}$ notation) [7,8], so inducing high angle grain boundaries. The rate of desoriented domains for the here used film is 2 %. A low ratio of such mixture is needed in order to achieve the lowest surface resistance (figure 1a) [9]. In the same way, we find a strong correlation between inductive losses characterized by $S(\chi'')$ (χ'' peak surface normalized by the amplitude of χ' signal from inductive measurements at 119 Hz) and the rate of misoriented grains (figure 1b). So, there is a clear relation between the microwave and the low frequency losses.

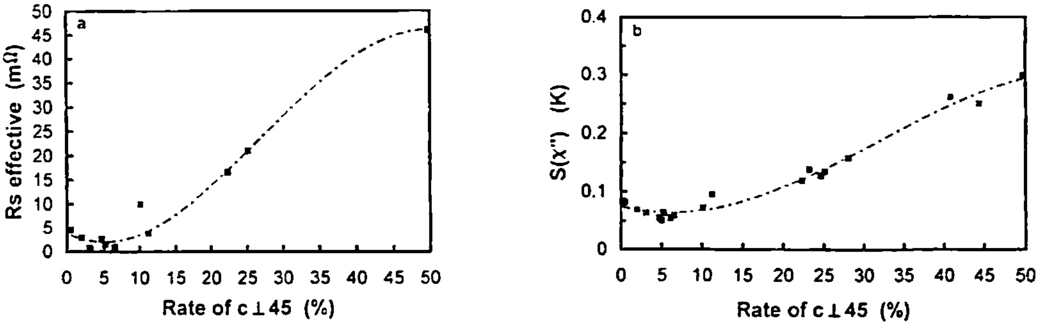

Figure 1 : Evolution vs. the fraction of 45° misalignment grains of : (a) R_S eff at 77 K and 10 GHz ; (b) $S(\chi'')$, normalized by dividing by the amplitude of the χ' transition, so in K.

The critical temperature Tc of the film has been determined from d.c resistive measurements in a four probe configuration : zero resistance is found at 85.7 K. This critical temperature is not the highest obtainable but it has been clearly evidenced that the optimal conditions for the best microwave properties are not systematically the same for optimum Tc [10]. The pertinent parameter to choose a thin film in view of microwave applications is the surface resistance Rs. This parameter has been measured at 10 GHz and at 77 K on, by a dielectric resonator method described elsewhere [11]. A value of 3 mΩ has been obtained, which is significantly lower than that of Ag (15 mΩ at 10 GHz and 77 K).

In order to compare HTS material with normal metal, a 300 nm thin film of silver has been deposited by evaporation on MgO substrate. A 1.5 µm Ag ground plane was deposited on the back side of both HTS and silver antennas. The films have been patterned by standard contact lithography and ion milling operations using a rather low energy Ar ion beam to design the antenna patch element. No modification of the superconducting properties has been observed after $YBa_2Cu_3O_7$ material patterning.

Measurements, results and discussion

The resonance frequency and S coefficients were measured by using a home made vacuum set-up for microwave measurements at low temperature (figure 2). The antenna is fixed with silver paint on a sample-holder (photo 1). The whole is pasted on the plate with silver paint in order to ensure a good thermal contact. The antenna is cooled down to 80K under a pressure of 6.10^{-3} mbar.

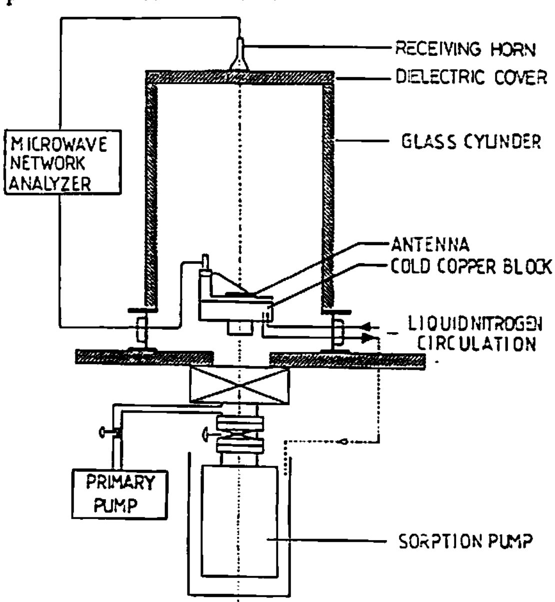

Figure 2 : Set-up for antenna measurements at low temperature

Photo 1 : HTS antenna fixed on a sample-holder with a standard K connector

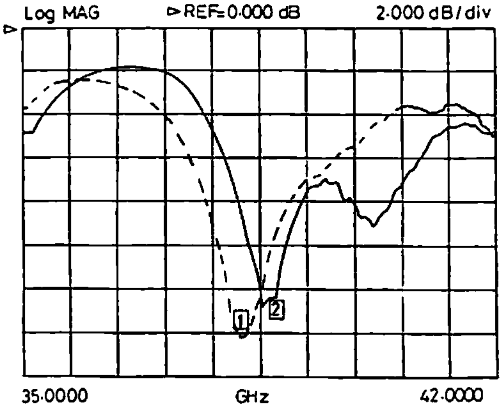

Figure 3: Reflection coefficient (S_{11}) of the silver antenna, (1) at 300 K, (2) at 80 K. Note the shift in frequency due to the variation of substrate's permittivity

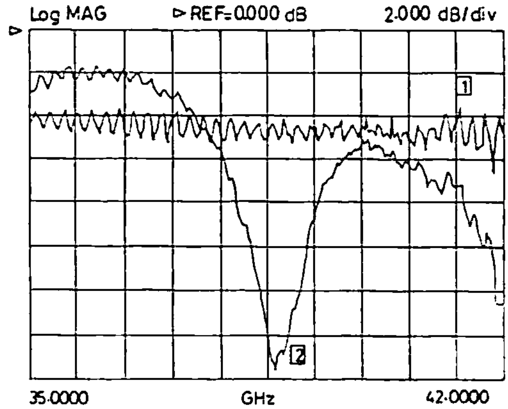

Figure 4 : Reflection coefficient (S_{11}) of the HTS antenna, (1) at 300 K, (2) at 80 K.

Calibration of the here used Wiltron network analyzer was carried out by employing Wiltron's coaxial calibration standards (SOLT) at 300 K. We checked, at room temperature and with silver antenna, that the set-up dielectric cover (figure 2) does not perturb the return loss but transmission coefficient measured by the horn is found to be reduced by 1 dB at room temperature.

For the silver antenna, we note a frequency variation of 0.3 GHz for the S_{11} coefficient when the temperature decreases from 300 K to 80 K (figure 3). This is due to the decrease of MgO's permittivity. We note also a variation in the values of the return loss when the temperature decreases ($|S_{11}|$ = -14.2 dB at 38.3 GHz and 300 K to -12.7 dB at 38.6 GHz and 80 K).

On the other hand, the HTS antenna exhibits no resonance at room temperature (figure 4) due to high surface resistance above the superconducting transition temperature. In contrast, when Tc is reached and the working temperature continues to decrease, the HTS antenna matching improves ($|S_{11}|$ = -15.8 dB at 38.6 GHz and 80 K) (figure 4).

The gains of the HTS and silver antennas are deduced from the measurement of the reflected (S_{11}) and transmitted (S_{21}) coefficients for the antenna under test. The antenna is used as transmitting element in the presence of a receiving horn. With all other factors being the same for the two antennas, we express the antenna gains, G, in terms of the usual S parameters using the Friis formula :

$$G_{(i)} = \frac{\left|S_{21(i)}\right|^2}{\left(1 - \left|S_{11(i)}\right|^2\right) \times G_{HORN} \times \frac{\lambda^2}{16\pi^2 r^2}}$$

with : G_{HORN} : horn gain
λ : wavelength
r : distance between the receiving horn and transmitting antenna
(i): corresponding to the silver or HTS antennnas

The gain of both antennas are presented in the following table :

ANTENNA	G (dBi) at 300K and 38.3 GHz	G (dBi) at 80K and 38.6 GHz
SILVER	5.7	6.7
HTS	/	7.9

In conclusion, a superconducting microstrip antenna on (100) MgO operating at 38 GHz has been studied using a home made vacuum set-up. The use of $YBa_2Cu_3O_7$ thin film does not change the antenna design and resonance frequency compared to a normal metallic one. The HTS antenna gain at 80 K, over silver one at 80 K and 300 K, are respectively 1.2 dB and 2.2 dB. The main part of HTS efficiency comes likely from the fact that metal microstrip transmission line has higher ohmic losses, especially at Ka-band.

Next step is to decrease the ripples on the transmission coefficient S_{21} measurement by putting the receiving horn inside the measurement set-up. We hope thus to improve the precision of the gain measurement.

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