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Microwave bulk properties of melt-textured high-T_C $YBa_2Cu_3O_{7-\delta}$ superconductors

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Abstract
Bulk properties of a melt-textured YBCO superconductor have been studied using the grazing incidence microwave reflectivity technique. A correlation of the obtained results in the superconducting state with the results in the normal state at room temperature has been found. This shows the possibility of monitoring the quality of the melt-textured samples at room temperature without cooling to critical temperature. Also, the correlation with distribution of a trapped magnetic flux at $T = 77$ K has been shown.

1. Introduction

The progress in the manufacture of the bulk melt-textured $YBa_2Cu_3O_{7-\delta}$ high-temperature superconductors allows one to produce devices for different applied purposes, for example, in high-power networks [1]. Here, it is important to have a fast and nondestructive method for monitoring the properties of HTSs suitable for applied purposes. The known testing methods (e.g. a method based on analysis of the levitation force in magnetic field or the trapped magnetic flux) require carrying out the measurements at temperatures lower than T_C. As a result, complication of the measurements takes place. Naturally, a technique that allowed us to perform the monitoring of the samples at room temperature would be more suitable.

Recently [2], we have reported on the results of the measurements of microwave (MW) absorption on the top, bottom and sides of bulk melt-textured $YBa_2Cu_3O_{7-\delta}$ at $T =$ 77 and 300 K. Based on these results, we have arrived at the conclusion on correlation of the measurement results in the superconducting (S) and normal (N) states. The grazing incidence microwave reflectivity technique has been used for the above mentioned measurements [3, 4] (the microwave waveguide section is shown in figure 1(a)).

In the present work, the dependence of microwave absorption in the *a–b* plane on the height of the sample is investigated in the temperature range $T = 77$–130 K and the obtained results are compared with the data of the trapped magnetic flux measurements.

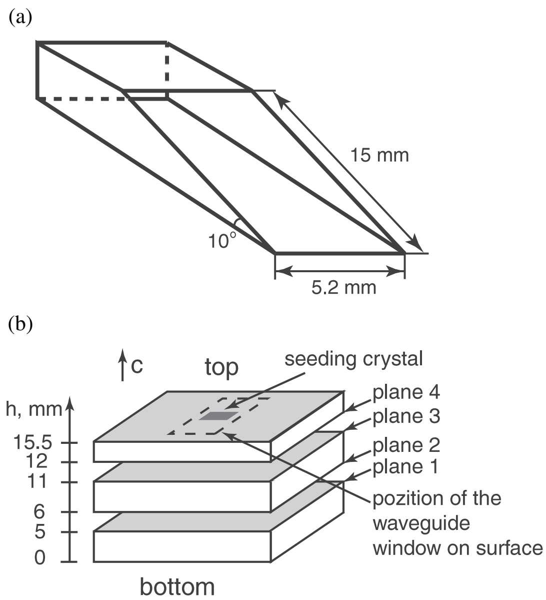


Figure 1. The measuring waveguide window (a) and the sample under study (b). The position of the waveguide measuring window on the sample surface is showed by the dashed line.

2. Samples and measurement technique

One of the three samples (PT22) investigated in [2], with dimensions 21×21 mm $h^{-1} \times 15.5$ mm of melt-textured

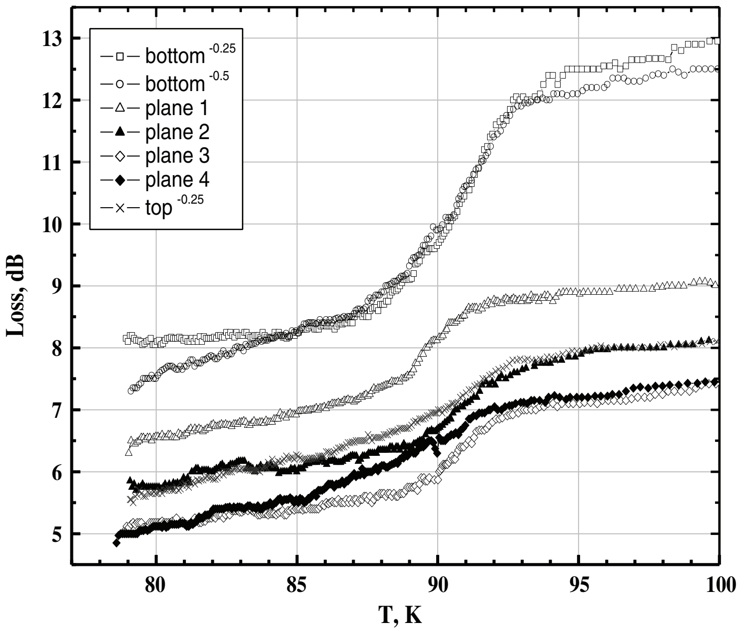


Figure 2. Temperature dependence of the microwave losses at planes 1–4, top plane polished by 0.25 mm (top$^{-0.25}$), bottom plane polished by 0.25 mm (bottom$^{-0.25}$) and bottom polished by 0.5 mm (bottom$^{-0.5}$).

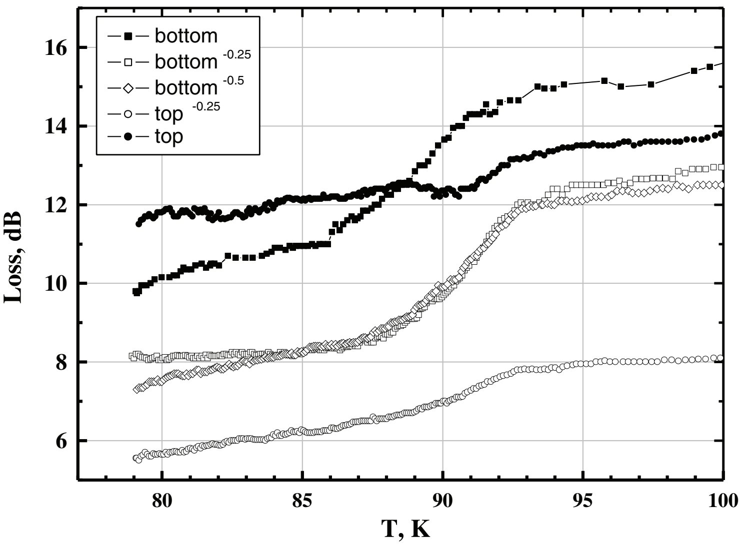


Figure 3. Temperature dependence of the microwave losses on the top non-polished plane (top), top plane polished by 0.25 mm, bottom non-polished plane (bottom), bottom plane polished by 0.25 mm (bottom$^{-0.25}$) and bottom plane polished by 0.5 mm (bottom$^{-0.5}$), showing degradation of the sample.

Y123 material, was chosen for the present study. These samples were prepared in special batch-processing. For the standard composition of $Y_{1.5}Ba_2Cu_3O_{7-\delta}$ a commercial prereacted $YBa_2Cu_3O_{7-\delta}$ powder with an excess of Y_2O_3 was used. Up to 1 wt% CeO_2 is added for the refinement of Y_2BaCuO_5 inclusions. A batch consisting of a number of cylindrical or cuboid YBCO blocks can be prepared in one box furnace run. Seeding by a melt-textured $SmBa_2Cu_3O_x$ crystal produces a single-domain material. After the melt-texturing process the quality of the block is tested by non-destructive levitation force measurement (0.41 T SmCo magnet, 25 mm in diameter and 15 mm in thickness) measured 0.5 mm above the block [5]. The integral levitation force and field mapping measurements were carried out for the top and bottom of the samples (the top plane is determined by the placing of seeding crystal; see figure 1(b)), where the top and bottom planes are perpendicular with respect to the HTS *c*-axis. To perform the temperature measurements of MW absorption, the sample has been cut in a direction perpendicular to the *c*-axis for four plates (figure 1(b)). Microwave standing-wave-ratio (SWR) measurements at room temperature were performed before cutting. To decrease the influence of the cutting process on the sample properties the process was performed by a thin disc with a diamond covering at low rotation speed with air cooling. In order to remove the damaged surface layer, the sample was polished after cutting.

The measurements were carried out at $T = 77$ K (the integral levitation force and field mapping measurements), in the temperature range $T = 77$–130 K (the microwave absorption measurements using the grazing incidence reflectivity technique [2–4] at frequency $f = 41$ GHz) and at 300 K (the SWR measurements using the same technique). The dimensions of the sample testing area, determined by dimensions of the inclined open ended waveguide window, is short-circuited by the sample surface, are 15×5.2 mm^2 (figure 1(a)), therefore the results are averaged over this area. The microwave measurements in the temperature range were carried out at the central part of the sample plane surfaces (planes 1–4, top and bottom; see figure 1(b)) and the SWR measurements at room temperature (in normal state) at different positions of the waveguide window on the sample surfaces.

3. Experimental results

Temperature dependences of MW absorption are shown in figure 2 for all planes of the sample, obtained after the cutting process. There is a decrease in absorption in the direction from the bottom plane polished by 0.5 mm (bottom$^{-0.5}$) to the top one polished by 0.25 mm (top$^{-0.25}$), caused by improvement of sample properties approaching the seeding crystal and a small increase at the top plane. Since in this case a central part of the sample surface has been measured, the increase in absorption is conditioned by the properties of the $SmBa_2Cu_3O_X$ seeding crystal deposited in the central part of the surface of the top plane (figure 1(b)). The increase of absorption in the centre of the top plane was also shown in [2] at room temperature (in normal state).

Degradation of the sample near the surface boundary with time (more than six months) has been found. We can make a conclusion on the presence of a thin degraded layer with a higher level of MW absorption. Figure 3 shows a sharp decrease in absorption on the top and bottom planes after removing the 0.25 mm thick surface layer (bottom$^{-0.25}$, top$^{-0.25}$) from the corresponding surfaces. Further polishing of the surface (from bottom$^{-0.25}$ to bottom$^{-0.5}$ in figure 3) has a small effect on absorption.

The most remarkable feature is a good correlation of MW absorption L_S in the S state with absorption L_N in the N state in the measuring plane. This correlation also occurs for the planes with degraded layers (first and last points in figure 4). The dependence of values $SWR = (R + 1)/(R - 1)$ on the distance from the bottom was recorded for the plane parallel to the c-axis (side of the sample), where R is the reflection coefficient (figure 4), before performing the cutting process. The waveguide measuring window in this case was placed at the side of the sample moving step by step from the bottom plane to the top one. The higher SWR, the lower absorption L. SWR increases with increasing h (figure 1(b)). Therefore, the quality of the sample improves along this direction. Here we should note that the measurements on the c-plane were carried out at room temperature. One can see a correlation of the MW temperature results (decreasing losses from bottom to top plane of the sample and thus increasing sample quality) with SWR results at room temperature (increasing SWR from bottom to top plane of the sample and thus increasing sample quality as well).

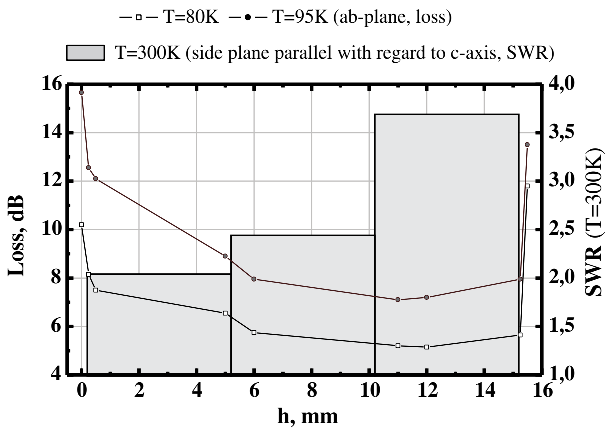


Figure 4. Dependence of the microwave losses in superconducting ($T = 80$ K) and normal ($T = 95$ K) states on distance from the bottom (ab-plane, lines), measured on the planes obtained by cutting the sample and comparison with SWR data at room temperature (in normal state on the side of the sample before cutting the sample) on the plane parallel to the c-axis (c-plane, bars) [2].

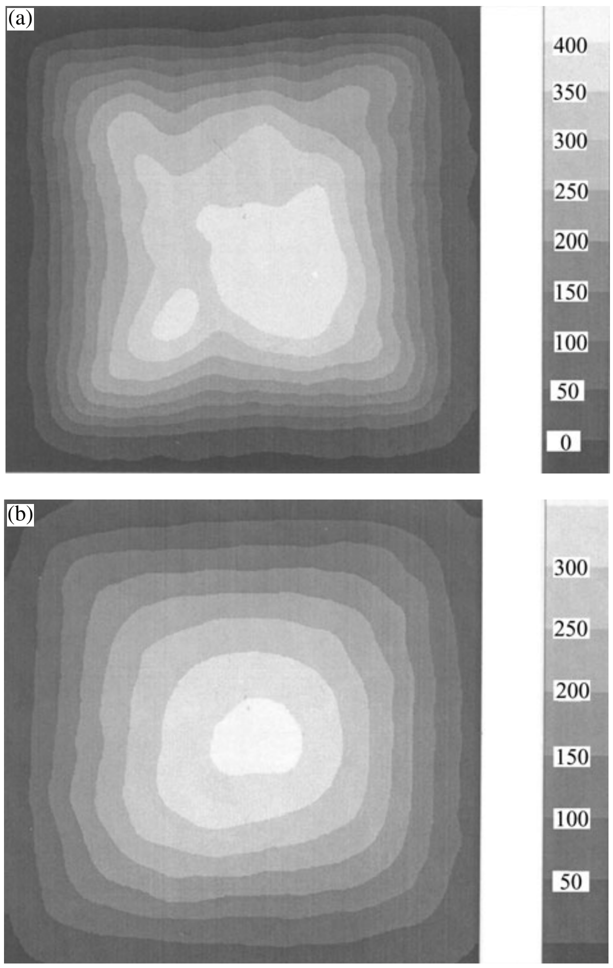
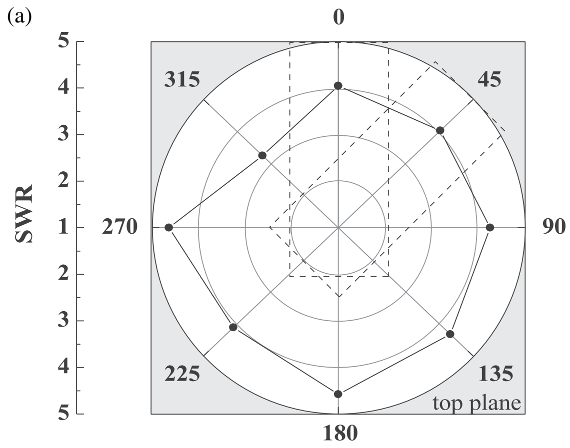


Figure 5. Distribution of the trapped magnetic flux for top (a) and bottom (b) planes.

The discovered feature can be explained by the presence of the defects which deteriorate the impedance properties of the sample in S and N states. In this case, the microwave properties of the sample surface layer can be characterized by effective



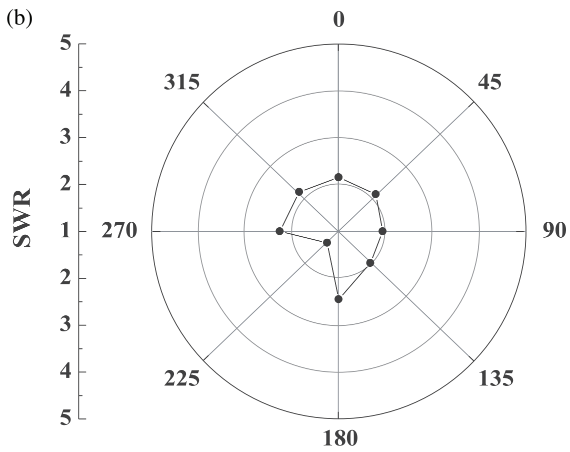


Figure 6. Dependence of the standing wave ratio (SWR) for the top (a) and bottom (b) planes on rotation angle of the waveguide window. Schematic positions of the measuring waveguide window on the sample surface for 0° and 45° are shown in (a) by dashed lines.

surface resistance $R_S^{eff} = R_S + R_{SD}$, where R_S is the surface resistance of the defectless (clear) part of the sample and R_{SD} is the surface resistance caused by the defects and quality of the surface (here we neglect the influence of the thickness because it is much greater than magnetic penetration depth). The values of R_S^{eff} measured at $f = 36$ GHz are equal to 35.3 mΩ at $T = 77$ K and to 2.2 Ω at $T = 300$ K. On the other hand, R_S^{eff} of thin YBCO films at the same frequency is 6–8 mΩ at $T = 77$ K. The sample surface resistance measurements have been carried out using a quasi-optical sapphire resonator [6].

It is known that usually for the determination of the sample quality measurements of the trapped magnetic flux at $T = 77\ \mathrm{K} < T_C$ are used. For sample PT22 the trapped magnetic flux distribution for the top and bottom planes has been measured (figures 5(a) and (b)). The dependences of standing wave ratio SWR at $T = 300$ K on rotation angle of the waveguide window (step 45°) at the sample surface have also been determined for the top and the bottom in the *a*–*b*-plane (figures 6(a), (b)). Here one can see that the sample is fairly homogeneous for both magnetic measurements at $T = 77$ K and SWR angle measurements at $T = 300$ K. We can also see a correlation of the absolute values of the magnetic measurement and SWR angle measurement results both for the top (higher values of trapped magnetic flux and higher SWR thus higher quality of the sample surface) and for the bottom (lower values of trapped magnetic flux and lower SWR thus lower quality of the sample surface). Some violation of the angle homogeneity of the SWR data in comparison with magnetic measurements can be conditioned by incidental inhomogeneities of the sample surface properties. Note should be taken that it is possible to increase the monitoring resolution on the sample plane coordinates in a certain way by decreasing the waveguide window.

4. Conclusion

Thus, the MW absorption in the melt-textured YBCO samples in the *a*–*b*-plane depending on the temperature and different distances from the bottom plane has been studied. The measured sample surface resistance is about or somewhat better than the resistance of copper. The results obtained in the S state correlate very well with the results obtained in the N state. There is also a good correlation of these results with the results obtained from room-temperature SWR measurements made on the plane parallel to the *c*-axis of the sample. In addition, the correlation of MW absorption with the distribution of the trapped magnetic flux at $T = 77$ K is shown. The results show an increase in quality of the sample in the direction from the bottom plane to the top one (the latter contains a seeding crystal). The present work shows a possibility of monitoring the quality of the melt-textured samples at room temperature, which makes the monitoring process fairly simple and inexpensive.

Acknowledgments

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