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Magneto-optical observation of the influence of an artificial periodic magnetic pattern on the pinning of a $YBa_2Cu_3O_{7-\delta}$ thin film

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In a recent paper [1], it has been shown from transport measurements that artificial reversible pinning can be created by the application of a magnetic tape on the surface of a thin superconducting film.

We study the influence of a periodic array of magnetic stripes, generated from a signal pre-recorded on a magnetic tape, on the pinning of vortices. With our high resolution magneto-optical technique [2], we visualize in two dimensions the penetration of the flux in a thin $YBa_2Cu_3O_{7-\delta}$ film partially covered by such a magnetic tape. In particular, we investigate the evolution of flux entry in the superconducting strip under and next to the magnetic tape. We present results obtained for various temperatures and various applied fields.

1. INTRODUCTION

In a recent paper [1], Yuzhelevski and Jung have shown by current-voltage measurements on a YBCO film that the critical current can be changed due to the presence of a pre-recorded magnetic tape, the signal of which is expected to pin vortices. In order to study the change in the flux penetration quantitatively, we have made some magneto-optical observations of a sample with and without a tape, in various conditions of field and temperature. In this paper, we present clear evidence that the flux is pinned stronger by the magnetic tape.

2. EXPERIMENTAL PROCEDURE

The studied sample is a $YBa_2Cu_3O_{7-\delta}$ film deposited on a (100) $SrTiO_3$ substrate by pulsed laser deposition (PLD). The thickness is 150 nm and the critical temperature is 88.5 K. The sample is patterned in stripes of 0.5 mm wide and 9 mm long, using conventionnal photolithography and chemical etching.

The magnetic tape used is a high resolution Sony commercial tape HF90, type I. The pre-recorded signal is a 1 kHz sinusoidal signal. At the writing speed of 3.75 cm/s, the period is 37.5 μm, which has been verified magneto-optically.

The tape is put perpendicular onto the strip in order to have the lines of constant field parallel to the edges of the superconducting strip (see fig.1) along which superconducting currents are flowing.

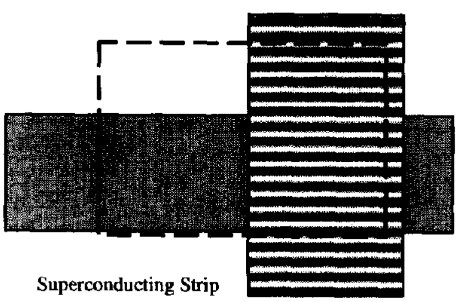

Fig. 1. Sample geometry : a magnetic tape with a pre-recorded signal is placed in close contact with a superconducting strip. Dashed line (see fig.2).

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The local magnetic field in the magneto-optical (MO) experiments is detected using Bi-doped YIG films [2] with in-plane anisotropy, which exhibit a large Faraday effect (typically 0.06 degrees/mT) and can be used for a broad range of temperatures, from 1.5 K up to 300 K. The magnetic resolution is better than 0.1 mT.

The indicator is placed on top of the sample plus tape and the assembly is mounted in our home-built cryogenic polarization microscope [3], which is in the variable temperature insert of an Oxford Instruments 1 Tesla Magnet system. The applied magnetic field is parallel to the c- axis of the sample and perpendicular to the indicator. By using two crossed polarizors the spatial variation of the perpendicular component of the local induction B_z at the sample is visualized as an intensity pattern. From the intensity images, the local field H_z is determined using the calibration $I = \beta f(H_z^2)$, where I is the intensity and β is a proportionality constant [4].

In order not to destroy or damage the pre-recorded signal, we have never applied a field larger than 100 mT, since a field of 200 mT was found to erase partially but irreversibly the signal of the tape. Therefore, the pre-recorded signal is constant during all the experiments.

3. RESULTS AND DISCUSSION

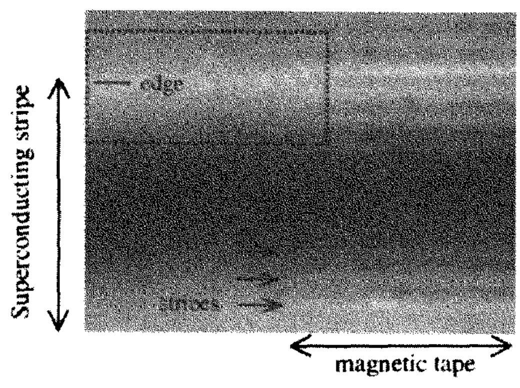

Fig. 2. Magneto-optical image at T = 4.2 K and B_a = -30 mT. The magnetic tape signal is on the right of the picture. The image corresponds to the region enclosed by the dashed line in fig.1. Dotted line (see fig.5).

To correct for possible uneven illumination, images obtained for different fields and temperatures are divided by an illumination image, obtained after zero-field cooling the sample. A typical magneto-optical image in an applied field of -30 mT is shown in fig.2. Note the stripe pattern of the tape on the right-hand side, and the edge of superconductor at the top.

3.1. Magneto-optical image of the field distribution

From the corrected intensity images and using the calibration mentioned above, the H_z field was calculated. As shown in fig.3, we clearly see the influence of the tape by the lower value of the field in the middle of the sample at the position of the tape, and also by the deviation of the flux entry oustide the tape.

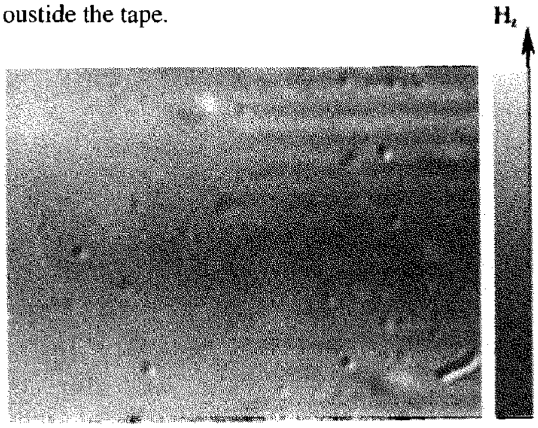

Fig. 3. Magneto-optical image of the absolute value of the field H_z in greyscale at T = 40 K and B_a = 10 mT. The highest values are in bright and the lowest in dark, see scale at the right of the picture.

3.2. Effect of the temperature

To enhance the visibility of differences in flux penetration due to the tape, we use very slightly uncrossed polarizors (such that the flux front appears at slightly different position depending on the sign of the field) and calculate the ratio between images obtained at applied fields $+H_a$ and $-H_a$. With this procedure, see fig.4, we obtain slightly different intensity images and the flux front becomes clearly visible as a peak if these are divided. In addition, by dividing these two images, we get rid of any illumination artefacts.

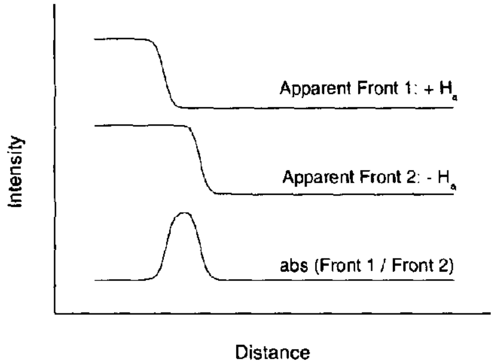

Fig. 4. Enhancing the visibility of front position by dividing two images at + H_a and − H_a with very slightly uncrossed polarizors.

By a threshold procedure, we can now determine the position of the front and study its evolution with temperature (see Fig.5).

Fig.5. Penetration of flux in the sample for T = 4.2 K, 15 K and 40 K, at B_a = 10 mT. This is an enlargement of dotted area of fig. 2.

We observe that the position of the front exhibits a deviation, which is not the same for all temperatures and which increases with increasing distance from the magnetic tape, see fig.5. In the present field of view, surprisingly, the front is rather well described by a straight line making an angle with the sample edge.

We can determine from a linear fit the deviation angle, and plot it as a function of temperature (see fig.6).

The obtained angles are increasing with the temperature, which is a clear evidence of the pinning effect due to the presence of the tape. The flux is more pinned near the artificial periodic array and penetrates more easily when the distance from the tape increases. This effect is larger when the temperature increases and is consistent with the observations made at liquid nitrogen temperature by Yuzhelevski and Jung [1].

3.3. Effect of the field

We have also determined the deviation angles for other applied fields, from 5 to 20 mT, in steps of 5 mT. We present in fig. 6 the obtained values as a function of temperature.

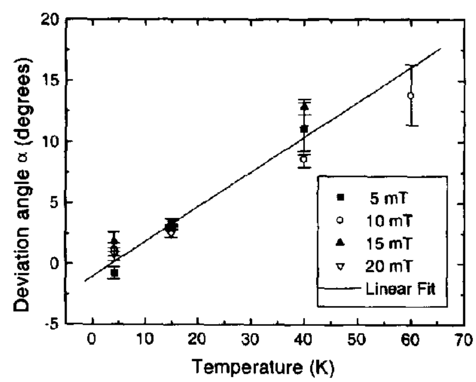

Fig. 6. Temperature dependence of the deviation angle α at B_a = 10 mT.

We observe that no important change in the deviation angle occurs as a function of field (in the present range). However, the increase of the angle with temperature seems to be roughly linear, with a slope of 0.3 deg/K.

4. CONCLUSIONS

From magneto-optical images, we have shown that an artificial magnetic array on a magnetic tape has a significant pinning effect on a YBCO film. This effect is clearly seen as a deviation of the flux front with an angle that increases with temperature.

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