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Characterization of $GdBa_2Cu_3O_{7-x}$ superconducting thin films by a new optical interference fringe method

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$GdBa_2Cu_3O_{7-x}$ superconducting thin films, grown on yttrium-stabilized ZrO_2 (YSZ) and $LaAlO_3$ (LAO) substrates, were investigated by a new optical interference fringe method. The results show that (i) two sets of interference fringe pattern are observed on the samples grown on LAO substrates when the film thickness is less than 250 nm, one of them coming from the thin film and the other from the substrate; (ii) the fringe patterns vary slightly on different regions of the samples, which means that the perfection of the thin films is non-uniform; and (iii) defects such as grain boundaries and twin lamellae are observed in some samples. The relationship between the fringes and the degree of perfection of the sample is discussed according to the experimental results.

1. Introduction
Owing to applications of high-T_c superconducting thin films, non-contacting and non-destructive characterization methods are required for improving the quality of the thin films. However, conventional light-scattering techniques are not sufficient to detect defects in the epilayers and the interfaces since the thickness of the epilayers is usually a few micrometres or less [1, 2].

Recently, a new type of interference fringe induced by an extremely thin film with a thickness even less than the wavelength of light has been discovered by some of the present authors [3, 4]. Based on the principle of light scattering and interference, the quality of thin films and the state of their interfaces can be characterized. In this paper, we report some experimental results for $GdBa_2Cu_3O_{7-x}$ (GBCO) superconducting thin films by the new interference fringe method.

2. Experimental procedure
The GBCO thin films were grown by d.c. magnetron sputtering using stoichiometric targets prepared from GdO_2, $BaCO_3$ and CuO powders on (1 0 0) $LaAlO_3$ (LAO) and yttrium-stabilized ZrO_2 (YSZ) substrates. The approximate thicknesses of the films grown on the LAO substrates were 100, 250, 600 and 650 nm, and on the YSZ 200 nm. The superconducting transition temperature of the samples was measured by a.c. susceptibility to be about 90 K. Details of the preparation and superconducting properties of the GBCO thin films have been presented elsewhere [5, 6].

The optical interference fringe experiments were performed with equipment described elsewhere [3]. A laser beam with wavelength 900 nm was focused and obliquely impinged upon the surface of the thin films so as to set a spot of 1.5 mm in diameter at the surface

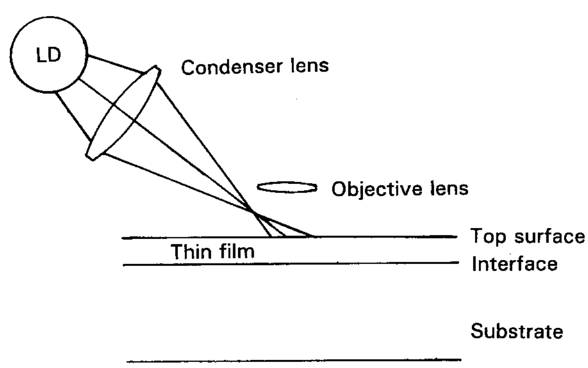

Figure 1 Schematic diagram of optical arrangement to obtain the new interference fringes.

of the sample (Fig. 1). The interference fringes were observed by an optical microscope system with an i.r.-TV camera which was connected to an image processor system for improvement of weak images and quantitative measurements.

3. Results and discussion

Fig. 2 shows an interference fringe pattern of a sample with a film thickness of 100 nm. Similar interference fringe patterns were observed for all samples. It is evident that the fringes are concentric oval rings because of the inclined illumination of the i.r. laser beam. They consist of many tiny bright spots and look discontinuous under high magnification. The rings become more and more narrow and the intervals between two adjacent rings closer and closer as their diameters become smaller. Moreover, each ring is composed of several finer rings, for example nine finer rings in the outermost ring of Fig. 2. This configuration is different from that of Haidinger fringes.

Two sets of interference fringe were observed from the samples grown on LAO substrates with film thicknesses of 100 and 250 nm, one of them from the film (A in Fig. 2) and the other from the substrate (B in Fig. 2). It is found that the distances between these two sets of fringe patterns on the surface are related to the film thickness, measured from Fig. 2 to be about 0.14 mm for the film with a thickness of 100 nm and 0.1 mm for that of 250 nm, respectively. The ratio of the intensities of the fringes from the substrates for the sample with the film thickness of 100 nm to that of 250 nm is about 5:1. For the samples with film thickness 600 and 650 nm, only one set of fringes was observed. This is because of the strong absorption of the thin films.

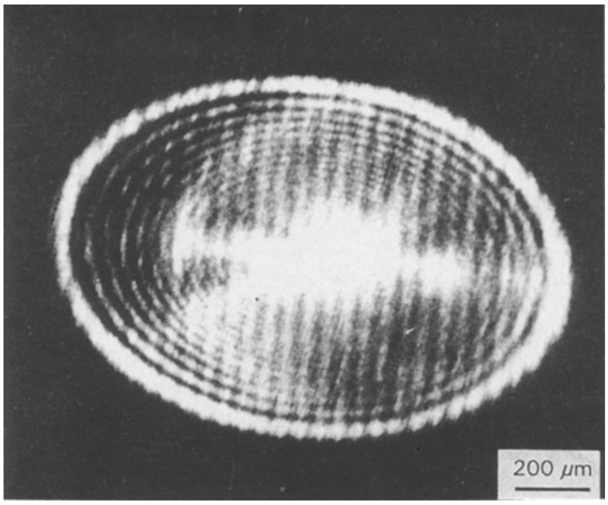

Figure 3 Interference fringe pattern with parallel lines.

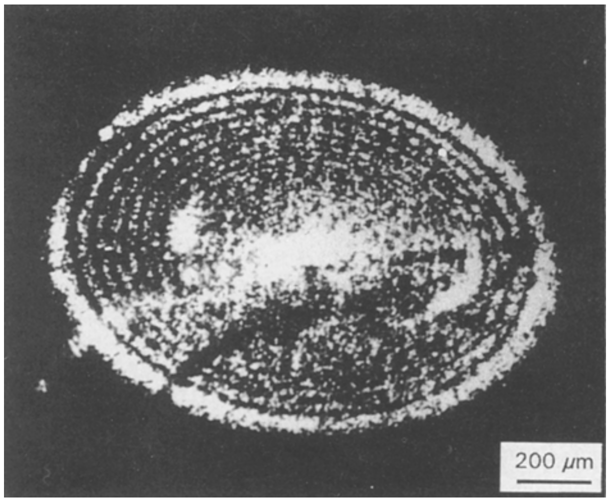

Figure 4 Defect images in an interference fringe pattern.

Fig. 3 is an interference fringe pattern observed from a sample grown on a YSZ substrate. One can see parallel lines superimposed on the fringes. This phenomenon was also observed by differential interference contrast microscopy. They are proposed to be twin lamellae in the thin films. Twin boundaries were also found in the thin films. This indicates that the GBCO epilayer is a single-crystalline thin film.

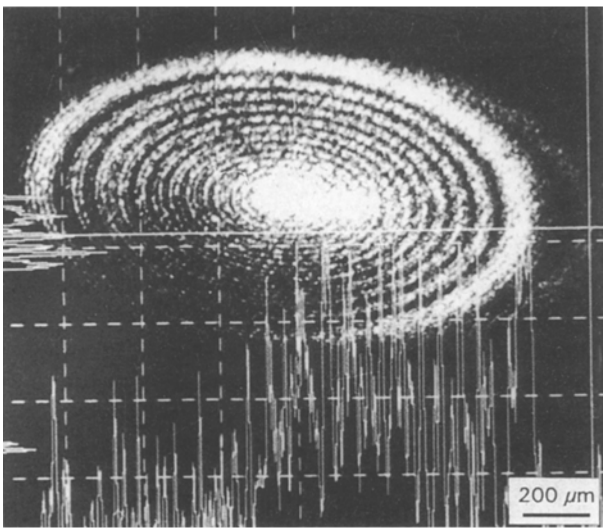

Figure 2 Interference fringe patterns of GBCO thin film grown on the LAO substrate. The film thickness is 100 nm.

Fig. 4 shows some irregular lines and relatively bright spots in some regions of the sample grown on a YSZ substrate. They are images scattered from optically imperfect structures due to lattice defects, such as dislocations and inclusions etc., in the thin films. This indicates that the new interference fringe method is an efficient method to characterize structural perfection in the thin films.

Comparing the surface micrographs of the thin films with the fringe patterns, it was found that the morphology of a fringe pattern is strongly dependent on the surface roughness. The concentric-ring fringe patterns can only be observed on the regions where the surface is smooth. The variation in intensity of the fringe patterns was usually observed in most of the samples examined. This means that the present method is very sensitive to the perfection of thin films.

The interference fringes could be explained to be an interference phenomenon between the light reflected from the top surface of the thin film and that scattered from the interface between the thin film and the substrate. The fine structure of the fringes reflects the quality of the thin film. Further investigations are in progress to explain the interference fringes quantitatively, and also to determine the refractive index and the absorption coefficient of the thin films by developing a new optical interference theory.

4. Conclusion

The new interference fringe method provides an efficient method to characterize non-destructively and in a non-contacting manner the quality of superconducting thin films and the interfaces between the films and their substrates. Two sets of interference fringes were observed on samples grown on LAO substrates, but only when the film thickness was less than 250 nm. The interference fringes consist of many tiny spots and show relatively higher visibility in some regions of the samples. Defects such as grain boundaries and twin lamellae are also detected.

Acknowledgements

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