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Effect of swift heavy ion irradiation on surface resistance of $DyBa_2Cu_3O_{7-\delta}$ thin films at microwave frequencies

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Abstract. We report the observation of a pronounced peak in surface resistance at microwave frequencies of 4.88 GHz and 9.55 GHz and its disappearance after irradiation with swift ions in laser ablated $DyBa_2Cu_3O_{7-\delta}$ (DBCO) thin films. The measurements were carried out in zero field as well as in the presence of magnetic fields (up to 0.8 T). The films were irradiated using 90 MeV oxygen ions at Nuclear Science Centre, New Delhi at a fluence of 3×10^{13} ions/cm^2. Introduction of point defects and extended defects after irradiation suppresses the peak at 9.55 GHz whereas no suppression is observed at 4.88 GHz. These results and the vortex dynamics in the films at microwave frequencies before and after irradiation are discussed.

Keywords. Microwave surface resistance; superconductors; peak effect; ion irradiation.

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1. Introduction

The properties of the flux line lattice (FLL) in the presence of magnetic fields in type II superconductors has been the subject of intense research during the past few years [1,2]. The dynamic behavior of such vortex phases can be studied by high frequency methods where the vortex response at very low currents are probed when the vortices undergo reversible oscillations and are less sensitive to flux creep. In low frequency measurements, such as ac susceptibility, a peak in the critical current density (J_c) near the transition temperature T_c is observed in the J_c vs. $T(H)$ plots. This phenomena is known as peak effect (PE) [3,4]. This peak, associated with the order–disorder transition of the FLL, is rationalized within the Larkin–Ovchinnikov scenario [5] where the effective pinning force on the FLL is given by $BJ_c(H) = (n_p\langle f^2\rangle / V_c)^{1/2}$ where n_p is the density of pinning centers, f the elementary pinning force parameter and V_c the Larkin volume over which the FLL maintains its spatial order. We have shown in an earlier communication [6] the observation of PE in surface resistance (R_s) in thin films of $DyBa_2Cu_3O_{7-\delta}$ (DBCO) at subcritical currents at microwave frequencies for the first time. The dynamics of the vortices at microwave frequencies can be described by the Gittleman and Rosenblum equation of motion [7] which is defined as

$$\eta \dot{x} + \kappa x = \phi_0 J \tag{1}$$

where η is the Bardeen–Stephen viscous drag coefficient, k the pinning constant, $\varphi_0 J$ is the external force on the vortex and ϕ_0 the flux quantum given as $hc/2e$. Within the collective pinning scenario, the total external force per unit volume is $F = n\varphi_0 J$ whereas the total restoring force is the same as in eq. (1) and therefore $\kappa \propto (n_p \langle f^2 \rangle / V_c)^{1/2}$.

This will have the same temperature and field variation as J_c and will show a peak-like feature close to T_c. Pinning of magnetic flux lines due to either inherent material disorder or due to defect sites introduced artificially dramatically changes the dynamics of the FLL. In this paper, we report the microwave response of 'DBCO' thin films at 4.88 and 9.55 GHz before irradiation and after irradiating them with 90 MeV oxygen ions at a fluence of 3×10^{13} ions/cm^2.

2. Experimental

Laser ablated DBCO ($T_c = 92$ K) thin films (thickness 2500 Å) were grown on twinned $LaAlO_3$ substrates. The films were patterned into linear microstrip resonators of width 175 μm and length 9 mm. Details of the microwave measurements and determination of R_s have been described earlier [8]. dc magnetic field varying from 0.2 T up to 0.8 T was applied perpendicular to the film plane (parallel to the c-axis of the film) using a conventional electromagnet. Irradiation was carried out using the 15 UD Pelletron accelerator at Nuclear Science Centre, New Delhi using 90 MeV O^{+7} ions at a fluence of 3×10^{13} ions/cm^2. The films were tilted by $5^\circ \pm 1^\circ$ away from the c-axis to avoid ion channeling. At this ion energy and for this fluence, irradiation by oxygen ion creates point defects and other extended defects.

3. Results and discussion

The variation of R_s with temperature at 4.88 GHz (fundamental excitation of the microstrip), measured at various magnetic fields before and after irradiation with 90 MeV O ions is shown in figure 1. For clarity, the variation of R_s with T for 0.4 T and 0.8 T, before and after irradiation is shown in two separate insets of figure 1. The peak in R_s at 4.88 GHz arises from depinning of flux lines from random defects, and as explained earlier, is associated with the crossover from elastic to plastic motion of the FLL. The peak is found to shift to lower temperatures with increasing field. Earlier we had proposed a model [6] where within the collective pinning scenario, since η varies smoothly with temperature, the depinning frequency, $\omega_p (=k/\eta)$, will also show a minimum followed by a peak at the order–disorder transition. Hence, R_s exhibits a dip followed by a peak close to T_c. Irradiation with 90 MeV O ions at a fluence of 3×10^{13} ions/cm^2 leads to the creation of random uncorrelated point defects. These defects created by oxygen ion irradiation are found to have no effect on the peak at 4.88 GHz. However, disorder increases and this is

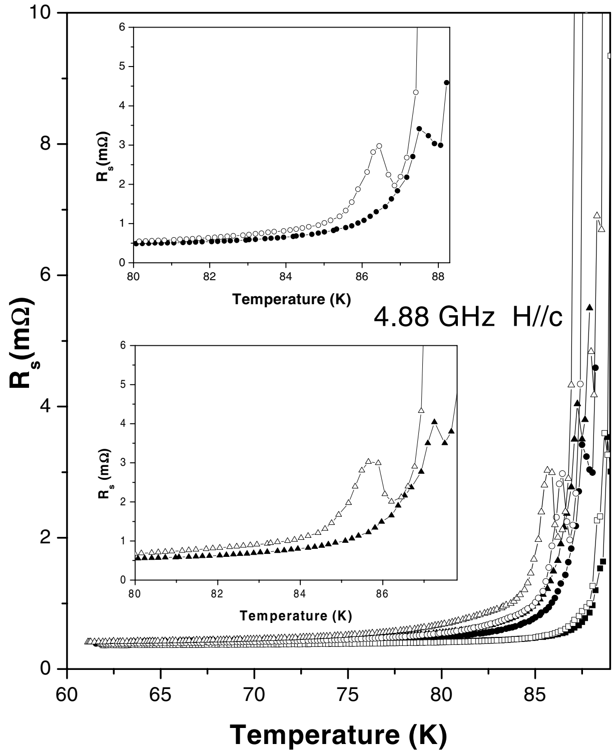

Figure 1. R_s vs. T plots at 4.88 GHz for various applied fields ($\| c$) for both pristine (filled points) and irradiated (open points) films. The two insets separately show R_s vs. T plots for 0.4 T (upper) and 0.8 T (lower).

manifested in the increase in the value of R_s at this frequency. However, as the measurement frequency is increased to 9.55 GHz (first harmonic excitation of the microstrip), it is seen (figure 2 and insets) that the peaks are suppressed at higher fields. Although the uncorrelated point defects and extended defects created after oxygen ion irradiation are incapable of pinning flux lines at 4.88 GHz, it appears that at 9.55 GHz, the cumulative action of these irradiation-induced defect centers along with inherent growth defects brings about some correlation, which enhances their pinning strength and prevents a flux line to be depinned from such sites at this frequency. Hence, at 9.55 GHz the peaks are found to be somewhat suppressed. Irradiation-induced disorder causes R_s to increase and also shifts the order–disorder transition temperature to lower values as seen in figure 1.

4. Conclusion

We have studied PE phenomena at 4.88 GHz and 9.55 GHz in the presence of dc magnetic field, in DBCO thin films for $H \| c$ before and after irradiation with 90 MeV O ions. The peak is attributed to an order–disorder transformation of the FLL as the temperature or

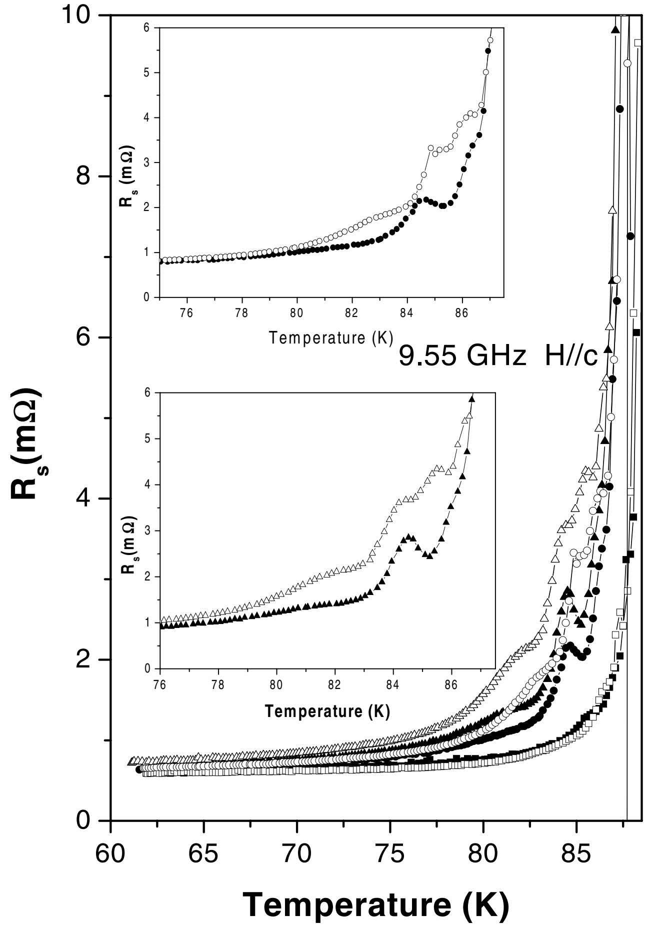

Figure 2. R_s vs. T plots at 9.55 GHz for various applied fields ($\| c$) for both pristine (filled points) and irradiated (open points) films. The two insets separately show R_s vs. T plots for 0.4 T (upper) and 0.8 T (lower).

field is increased. The defects created by 90 MeV O ion irradiation are uncorrelated random point defects or extended defects. At 4.88 GHz these defect centers are incapable of pinning the flux lines. However, it appears that at 9.55 GHz some correlation is established between these irradiation-induced defect centers and inherent growth defects which then effectively pins the flux lines at this frequency.

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