Study of vortex configuration in the mixed state of a-W/Si multilayers

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Abstract

Configuration of vortices in highly tilted fields have been studied on amorphous W/Si multilayers with strong (3D) and weak (quasi-2D) layer coupling through the simultaneous measurements of electric fields in the film plane, E_x and E_y, as a function of current density J, where x||J. We observe in the 3D sample the vortices move as the tilted lines around the glass transition and gradually change the configuration to the kinked lines with decreasing temperature. In the quasi-2D sample, only the dynamics of 2D pancake vortices has been observed at low J.

Key words: vortex line configuration; crossing lattice; W/Si multilayer; current-voltage characteristics

Recent studies on the mixed state of high T_c superconductors have made significant progress in understanding the novel vortex states. Especially, for the magnetic fields H inclined from the c axis, a variety of vortex configurations have been proposed, such as tilted line [1], kinked line [1,2], and crossing (combined) lattice [1,3]. Since the peculiar configurations originate from the layered crystal structure, it is possible to apply these concepts to the vortices in multilayer superconductors, which have an advantage of controlling the anisotropy.

In this work, we have studied the vortex motion and configuration in W/Si superconducting multilayers with strong (3D) and weak (quasi-2D) interlayer coupling by the measurements of electric field - current density (E-J) characteristics for two components under a special condition of inclined H as shown below [4]. The variation of the vortex configuration with degree of anisotropy is demonstrated.

Figure 1 shows the directions of J and H used in the measurements, where J is along the x axis and H = (H_0, H_0, δH_0) with δ ∼ 0.15. In this condition, Lorentz force F_L = μ_0(0, −δJH_0, JH_0) moves the vortices with a velocity v = (0, −v_y, v_z), which yield the electric field E = (E_x, E_y) = μ_0(v_zH_0 + δv_yH_0, −v_zH_0). Here v_y, v_z > 0. When the vortices enter the sample as tilted lines along H, they move along F_L and E_x ≈ −E_y would be observed because v_z becomes the main part of the motion. On the other hand, when v_z is suppressed by the strong layer pinning (intrinsic pinning), −E_y becomes smaller than E_x. In the 2D case, only the motion of pancake vortices would result in E_y = 0. Therefore, the simultaneous measurements of E_x and E_y give us a direct information about the motion of vortices, reflecting the vortex configuration.

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Amorphous W/Si multilayers were fabricated by an UHV evaporation method on oxidized Si(100) substrates [5]. Two kinds of samples, \([W/Si(2nm/1nm)]_{30}\) (WS21) and \([W/Si(2nm/4nm)]_{22}\) (WS24), were prepared. The interlayer coupling between the W layers is strong for WS21 (3D) and very weak for WS24 (quasi-2D) from our previous work [5]. The superconducting transition temperatures for the samples are 3.0 K and 2.0 K for WS21 and WS24, respectively. For the measurements of \(E_x(J)\) and \(E_y(J)\) characteristics, the samples were patterned into six-point configuration as shown in Fig. 1 with 700 \(\mu m\) in length and 200 \(\mu m\) in width.

Figure 2 shows two typical sets of \(E(J)\) characteristics of WS21 for \(E_x\) and \(-E_y\) in \(H = 2.5\ T\). Similar types of \(E_{x,y}(J)\) curves are observed in all \(H\) studied. With decreasing \(T\), the curvature of \(E_x(J)\) on log-log plots changes from positive to negative one below \(T_g\) (dashed line in Fig. 2). This is the standard behavior regarded as the vortex glass transition [6,7]. It is noted that the trace of \(-E_y(J)\) become close to that of \(E_x(J)\) around \(T_g\). This implies that the vortices move along \(P_L\) across the film plane. Thus, the vortices form correlated lines, which is tilted nearly along \(H\), around \(T_g\) in WS21. In the inset of Fig. 2, we plot the ratio of \(-E_y/J_x\) at \(J = 1\times10^{-1}\ V/m\) as a function of \(T\). The ratio shows the peak at \(T_g\) and decreases with decreasing \(T\). The peak corresponds to the development of tilted vortex line with diverging of correlation length \(\xi_k \sim |T - T_g|^{-\nu}\) with \(\nu\) the static exponent [6]. The reduction of the ratio can be explained by the effect of the intrinsic pinning that becomes remarkable at low \(T\). The gradual change in the vortex configuration from the tilted line to the kinked one occurs.

In Fig. 3, \(E_{x,y}(J)\) curves for WS24 in \(H = 0.5\ T\) are shown. As well as the case of WS21, the curvature change in \(E_x(J)\) in log-log scale is observed. However, the sign of correlated motion is not found in \(E_y(J)\), which is very small and even has positive values at a low current region as shown in the inset of Fig. 3. The positive value cannot arise from the motion of in-plane vortex component, but be ascribed to the velocity drift of out-of-plane vortex component (pancake) due to the Magnus force. Thus, \(E_x(J)\) and \(E_y(J)\) at low \(J\) mainly result from the easy motion of pancake vortices. At high current region, the negative \(E_y\) emerges although the absolute value is still much smaller than \(E_x\). This indicates the existence of the in-plane vortex component, which is hard to move along the \(z\) direction due to the layer structure. Considering these results, it may be natural that the vortex configuration in WS24 may consist of in-plane and out-of-plane vortices, which move separately as in crossing (combined) lattice state [1,3].

In conclusion, different kinds of vortex motions are observed in the W/Si multilayers with strong and weak interlayer coupling. These reflect the contrastive vortex configurations, the correlated line and the separation of in-plane and out-of-plane vortices.

References