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Competing flux pinning of columnar defects in different directions for high-T_c superconductors

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We studied competing effect for flux pinning between columnar defects (CDs) along the *c*-axis and crossing at $\pm\theta_i$ relative to the *c*-axis in high-T_c superconductors, through the angular behaviors of critical current density J_c in $YBa_2Cu_3O_y$ thin films with the CDs installed by heavy-ion irradiations. A large enhancement of J_c centered at $B \mid\mid c$ occurs for the CD-configurations composed of CDs along the *c*-axis and with $\theta_i \leq \pm 60°$: the angular region where J_c is enhanced by CDs is more expanded for the CD-configuration with larger crossing angle $\pm\theta_i$, whereas the enhancement of J_c at $B \mid\mid c$ is slightly weakened. A J_c peak at $\pm\theta_i$, however, cannot be seen even for the film including CDs with $\theta_i = \pm 60°$. These results demonstrate that the synergy effect of flux pinning between CDs along the *c*-axis and with $\theta_i \leq \pm 60°$ can occur in angular range from $-\theta_i$ to θ_i, since the trapping angle of CDs along the *c*-axis is about 60°. In the vicinity of $B \mid\mid ab$, on the other hand, CDs in any direction hardly contribute to flux pinning for the CD-configurations with $\theta_i \leq \pm 60°$. For the CD-configuration composed of CDs along the *c*-axis and with $\theta_i = \pm 80°$, by contrast, the J_c drastically enhances around $B \mid\mid ab$: the J_c peak emerges at the two irradiation angles $\theta_i = \pm 80°$ and the value of J_c increases even at $B \mid\mid ab$ where the J_c shows not a peak but a dip behavior. The appearance of the J_c peak at $\theta_i = \pm 80°$ means that the CDs crossing at $\theta_i = \pm 80°$ contribute to the flux pinning independently from CDs along the *c*-axis, since the crossed CDs exist out of the trapping angle of CDs along the *c*-axis. On the other hand, there is a little enhancement of J_c with no peak around $B \mid\mid c$ even though the CDs are also installed along the *c*-axis: CDs in closer directions to the *ab*-plane induce sliding motion of flux lines along the CDs at $B \mid\mid c$, leading to the deterioration of flux pinning by CDs along the *c*-axis.

Keywords: high-Tc superconductors, critical current density, anisotropy, columnar defects