Anomalous peak effect in 122-type iron-based superconductors

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Iron-based superconductors (IBSs) have attracted considerable attention due to their potential for high-field applications. In such applications, the critical current density, J_c, has to be reasonably large even under strong magnetic field. Introduction of artificial pinning centers in terms of heavy-ion irradiation, which creates columnar defects (CDs), is one of the promising ways to enhance J_c.[1)] The effects of heavy-ion irradiation have been studied in 122-type IBSs.[2–4)] The first attempt to create CDs in $Ba(Fe,Co)_2As_2$ made its J_c more than five times larger compared with unirradiated crystals.[2)] J_c has been enhanced to ~15 MA/cm^2 in $(Ba,K)Fe_2As_2$ by irradiating various kinds of heavy ions.[3)] Theoretically, it is predicted that further enhancement of J_c is possible by dispersing the direction of CDs, thereby suppressing the motion of kinks and promoting flux entanglements. In fact, we have confirmed that J_c in $(Ba,K)Fe_2As_2$ can be enhanced by ~30% by dispersing the direction of CDs.[5)] In the course of such studies, we discovered an anomalous peak effect in $(Ba,K)Fe_2As_2$ when CDs are introduced at angles of $\theta_{CD} = 15°$ or more.[5)] The peak of J_c as a function of magnetic field appears at about 1/3 of the matching field B_Φ ($= n\Phi_0, n$: density of CDs, Φ_0: flux quantum).

In the present experiment, we studied how the anomalous peak effect shows up in another IBSs, $Ba(Fe_{0.93}Co_{0.07})_2As_2$ ($T_c \sim 24$ K). U ion irradiation of 2.6 GeV has been performed at the RI Beam Factory at RIKEN Nishina Center at a total dose of $B_\Phi = 8$ T. U ions are irradiated from two directions at $\pm\theta_{CD}$ with $\theta_{CD} = 0°$ to 30°. J_c is evaluated by measuring the magnetization of the sample with the help of the extended Beam model.

Figure 1(a) shows the magnetic field dependence of J_c at 25 K in $(Ba_{0.6}K_{0.4})Fe_2As_2$ ($\theta_{CD} = \pm 15°$) for the field angle from the c-axis, θ_H, from 0° to 20.6°. As we have mentioned above, an anomalous peak effect shows up at around $H \sim 1/3B_\Phi$. It should be noted that the anomalous peak is strongly suppressed when the direction of the magnetic field is away from the average direction of CDs. The magnetic field dependence of J_c in $Ba(Fe_{0.93}Co_{0.07})_2As_2$ ($\theta_{CD} = \pm 15°$) from $T = 2$ K to 20 K with the field parallel to the c-axis is shown in Fig. 1(b). Unlike the case of $(Ba_{0.6}K_{0.4})Fe_2As_2$, no anomalous peaks are observed at $H \sim 1/3B_\Phi$ at any temperature. The weak anomalies observed below 5 kOe are due to the self-field effect as we have discussed in Ref. 4). In order to reveal the origin of the difference in the J_c behavior between the two materials, scanning transmission electron microscopy (STEM) observations

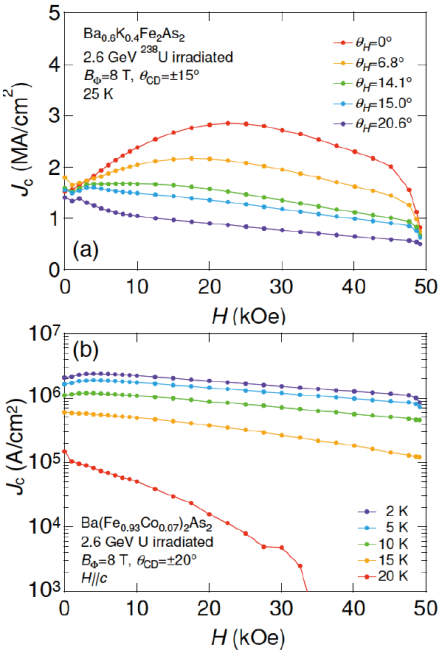

Fig. 1. Magnetic field dependence of J_c in (a) $(Ba_{0.6}K_{0.4})Fe_2As_2$ ($T = 25$ K, $B_\Phi = 8$ T, $\theta_{CD} = \pm 15°$) and (b) $Ba(Fe_{0.93}Co_{0.07})_2As_2$ ($B_\Phi = 8$ T, $\theta_H = 0°$, $\theta_{CD} = \pm 20°$).

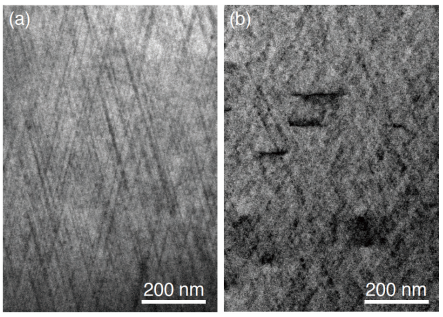

Fig. 2. STEM images of CDs created by 2.6 GeV U irradiation ($B_\Phi = 8$ T) in (a) $(Ba_{0.6}K_{0.4})Fe_2As_2$ ($\theta_{CD} = \pm 20°$) and in (b) $Ba(Fe_{0.93}Co_{0.07})_2As_2$ ($\theta_{CD} = \pm 30°$).

have been made. Figures 2(a) and (b) show STEM images for $(Ba_{0.6}K_{0.4})Fe_2As_2$ and $Ba(Fe_{0.93}Co_{0.07})_2As_2$. The defects created by 2.6 GeV U irradiation are almost continuous CDs in the case of $(Ba_{0.6}K_{0.4})Fe_2As_2$, while they are strongly discontinuous in $Ba(Fe_{0.93}Co_{0.07})_2As_2$. Such discontinuity of CDs are believed to make the effect of splay insignificant in $Ba(Fe_{0.93}Co_{0.07})_2As_2$, leading to the suppression of the anomalous peak effect.

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