Anomalous peak effects in $Ba_{0.6}K_{0.4}Fe_2As_2$ with splayed and tilted columnar defects

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Introduction of artificial defects by particle irradiations has been known to be a useful tool for suppressing the motion of vortices thus enhance the critical current density (J_c) in superconductors. In particular, heavy-ion irradiation can create linear amorphous tracks in superconductors, which are referred to as columnar defects (CDs), having similar geometry and dimensions to vortices and are considered to be the most effective way to enhance J_c. Significant enhancements of J_c by the introduction of CDs have been demonstrated in cuprate superconductors,[1)] iron-based superconductors (IBSs),[2)] and conventional superconductors such as $NbSe_2$.[3)]

J_c usually decreases monotonically as the applied magnetic field increases. However, an anomalous peak effect (APE), where J_c shows a peak in a certain field range, is observed in superconductors with splayed CDs, which are formed by crossing CDs at a specific angle symmetrically with respect to the *c*-axis.[4)] The APE is observed at 1/3 of the matching field ($B_\Phi = n\Phi_0$, n: density of CDs and Φ_0: flux quantum) when H is applied along the average direction of the splayed CDs. However, a similar non-monotonic behavior of J_c was reported in a recent study on 1.4 GeV Pb-irradiated $NbSe_2$ with CDs tilted from the *c*-axis by 30°, when H was applied along the CDs.[3)] The peak effect occurs at $H \sim B_\Phi/5$, which is close to APE observed in systems with splayed CDs. If APE is observed in superconductors with tilted CDs, we may need to reconsider the mechanism of APE.

In this study, we aimed at clarifying whether APE appears in IBSs with tilted CDs or not. To this end, we irradiated $Ba_{0.6}K_{0.4}Fe_2As_2$ with 2.6 GeV U ions and studied the magnetic field dependence of J_c.

A STEM image of CDs tilted 20° from the *c*-axis created by 2.6 GeV U irradiation in $Ba_{0.6}K_{0.4}Fe_2As_2$ is shown in Fig. 1. Continuous CDs with diameters of ~5 nm are observed.

The magnetic field dependence of J_c at 15 K in $Ba_{0.6}K_{0.4}Fe_2As_2$ with splayed CDs ($B_\Phi = 3T + 3T$, $\theta_{CD} = \pm 20°$) and tilted CDs ($B_\Phi = 3T$, $\theta_{CD} = 20°$) at several field angles are shown in Figs. 2(a) and (b), respectively. In the case of splayed CDs, APE is most pronounced at $H \sim B_\Phi/3$ when H was aligned with the *c*-axis ($\theta_H = 0°$) and it is suppressed as H deviated from *c*-axis as reported in our previous study.[4)] In the case of tilted CDs, anomalous enhancements of

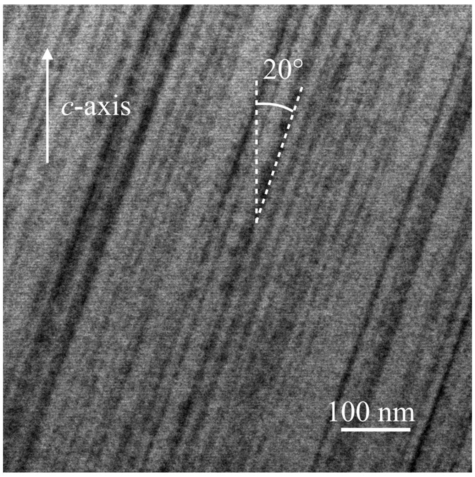

Fig. 1. A STEM image of CDs tilted 20° from the *c*-axis created by 2.6 GeV U irradiation in $Ba_{0.6}K_{0.4}Fe_2As_2$.

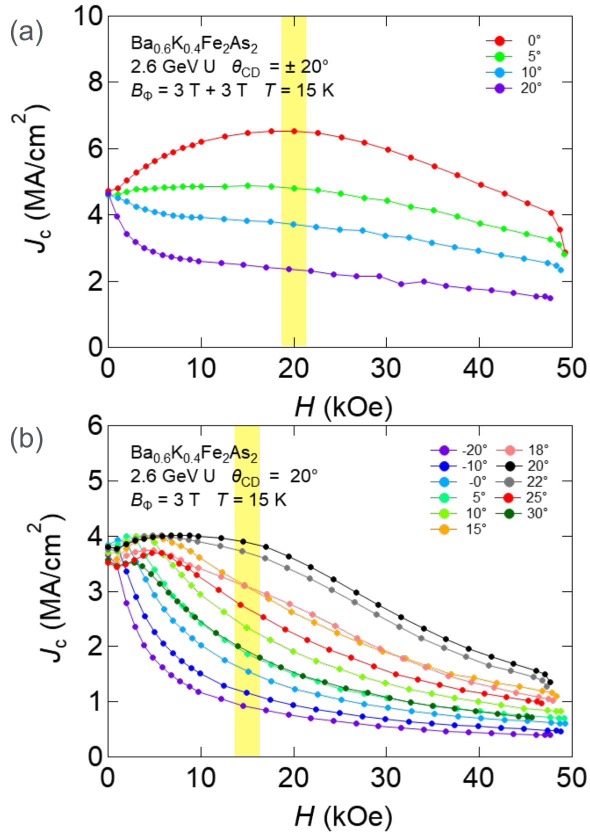

Fig. 2. Magnetic field dependence of J_c at 15 K in $Ba_{0.6}K_{0.4}Fe_2As_2$ with (a) splayed CDs ($B_\Phi = 3T + 3T$, $\theta_{CD} = \pm 20°$) and with (b) tilted CDs ($B_\Phi = 3T$, $\theta_{CD} = 20°$) at various field angles. APEs are observed in yellow hatched regions.

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J_c were observed when H was aligned with the CDs ($\theta_H = \theta_{CD} = 20°$). However, the strongest enhancement of J_c was observed at $H \sim B_\Phi/2$ in contrast to $\sim B_\Phi/3$ in the case of splayed CDs. As H deviated from CDs, the peak position gradually shifted to lower fields. When H was deviated from CDs, such as at $\theta_H = 15°$ and 25°, a small sharp peak remained at $H \sim 5$ kOe. This magnetic field coincides with the calculated self-field of the sample ($B_{sf} \sim J_c \cdot d \sim 4$ kG), where d is the thickness of the sample. It indicates that the sharp peak was caused by the self-field effect due to strong curvature of vortices below the self-field.[5)]

References

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