# Effects of asymmetrically-introduced splayed columnar defects on the peak effect in $(Ba, K)Fe_2As_2$

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Iron-based superconductors (IBSs) are intensively studied from both fundamental and applied aspects. In particular, to make these materials practically appealing, the enhancement of critical current density, $J_c$, is indispensible. Columnar defects (CDs) introduced by heavy-ion irradiation are known to be very effective to enhance $J_c$.[1] The effects of heavy-ion irradiation have been demonstrated in 122-type IBSs.[2–4] Compared with heavy-ion irradiated $Ba(Fe, Co)_2As_2$, the $J_c$. in heavy-ion irradiated $(Ba, K)Fe_2As_2$ has been enhanced up to $\sim$ 15 MA/cm$^2$. To further enhance $J_c$. in $(Ba, K)Fe_2As_2$, we have introduced heavy ions in a splayed manner, where CDs are introduced symmetrically from two directions ($\pm\ \theta_{CD}$) from the $c$-axis with the same dose (Fig. 1(a)). We confirmed that $J_c$ in $(Ba, K)Fe_2As_2$ can be enhanced by $\sim 30\%$ by choosing $|\theta_{CD}| = 5°$.[5] In the course of these studies, we discovered an anomalous peak effect in $(Ba, K)Fe_2As_2$ when the CDs are introduced at angles of $|\theta_{CD}| > 15°$.[5] The anomalous peak of $J_c$ as a function of magnetic field appeared near $1/3B_\Phi$ ($B_\Phi = n\Phi_0$, $n$: density of CDs, $\Phi_0$: flux quantum).

As described above, all splayed CDs have been introduced symmetrically with respect to the $c$-axis. Therefore, in this study, we introduced asymmetries to the splayed CDs and measured its effect on the anomalous peak. All irradiations were done using a 2.6 GeV U beam at the RI Beam Factory at RIKEN Nishina Center at a total dose of $B_\Phi = 8$ T ($n = 4\times10^{11}$ cm$^{-2}$). Three types of asymmetries were introduced. (1) We changed the average direction of two the types of CDs from the $c$-axis, $\theta_{CD} = 20° \pm 15°$ (Fig. 1(b)). (2) Instead of changing the direction of two types of CDs, we made different doses for the two directions while maintaining the total dose, $B_\Phi = 2$ T and 6 T for $\theta_{CD} = -15°$ and $+15°$, respectively (Fig. 1(c)). (3) The splay plane is tilted, so that it will have an angle $\phi_{CD}$ from the $ac$ plane (Fig. 1(d)). $J_c$-$H$ at 20 K with various configurations of splayed CDs are compared with the symmetric splayed CDs. It is obvious that the introduction of asymmetry strongly suppresses the anomalous peak effect near $1/3B_\Phi$.

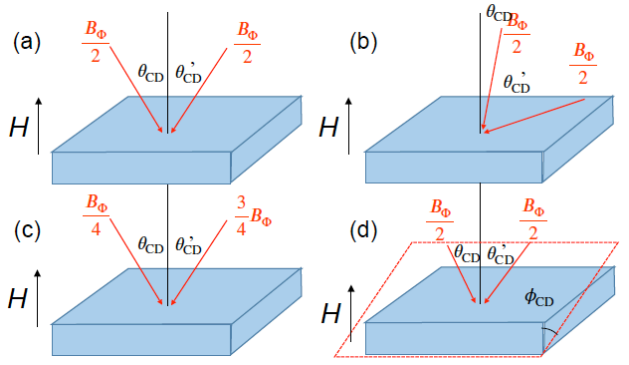


Fig. 1. (a) Standard splayed CDs. (b) Asymmetric splayed CDs with the average direction away from the $c$-axis. (c) Splayed CDs with asymmetry in doses. (d) Asymmetric splayed CDs with splay plane tilted away from the $ac$-plane.

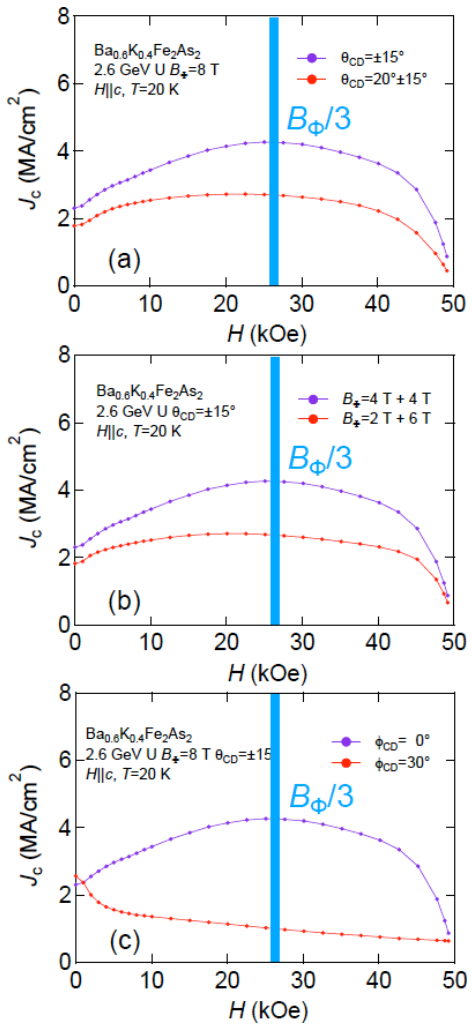


Fig. 2. $J_c$-$H$ at 20 K with various configurations of splayed CDs; (a) Comparison of (a) and (b) in Fig. 1, (b) Comparison of (a) and (c) in Fig. 1, and (c) Comparison of (a) and (d) in Fig. 1.

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