Effects of columnar defects introduced by 2.6 GeV U-ion irradiation on J_c characteristics of 2H-$NbSe_2$

T. Tamegai,[*1] W. J. Li,[*1] S. Pyon,[*1] A. Takahashi,[*1] Y. Kobayashi,[*1] A. Yoshida,[*2] T. Kambara,[*2] and A. Ichinose[*3]

One of the most salient features of superconductors is the zero-resistance state. Although the presence of such a state may be obvious in superconductors without a magnetic field, a motion of quantized vortices can destroy this useful state. The introduction of defects that function as pinning centers for vortices is known to be a practical method to restore the ideal zero-resistance state under strong magnetic fields, leading to the enhancement of the critical current density (J_c) in superconductors. The irradiation of heavy ions on superconductors can create columnar defects (CDs) by destroying the crystal structure of superconductors. CDs are ideal pinning centers for vortices because they can trap vortices along their full length. The effectiveness of CDs in enhancing J_c was demonstrated in high-temperature superconductors[1] and also in iron-based superconductors.[2] However, the effect of heavy-ion irradiation on conventional superconductors has attracted much less attention to date. Only very recently, systematic work has been conducted on 2H-$NbSe_2$ irradiated at an angle of 30° from the c-axis with a dose-equivalent matching field (B_Φ) of 3 T. In this paper, the presence of the peak effect of J_c is reported. We investigated the effect of 2.6 GeV U-ion irradiation on the J_c characteristics of 2H-$NbSe_2$.

Single crystals of 2H-$NbSe_2$ with $T_c \sim 7.2$ K were grown using the iodine transport method. 2.6 GeV U ions were irradiated on 2H-$NbSe_2$ at various angles, θ_{CD}, from the c-axis and at various B_Φ values up to 16 T. The dependence of J_c on B_Φ and θ_{CD} were studied.

Figure 1 shows scanning transmission electron microscope (STEM) image of 2H-$NbSe_2$ irradiated by 2.6 GeV U-ions from the directions of $\theta_{CD} = \pm 15°$. It is clear that continuous CDs with diameters of ∼7–10 nm were created.

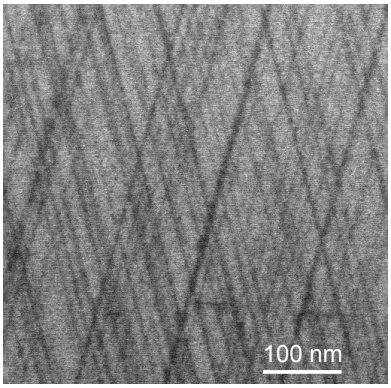

Fig. 1. Columnar defects created by 2.6 GeV U-ion irradiation ($\theta_{CD} = \pm 15°$) in single-crystal 2H-$NbSe_2$.

*1 Department of Applied Physics, The University of Tokyo
*2 RIKEN Nishina Center
*3 Central Research Institute of Electric Power Industry

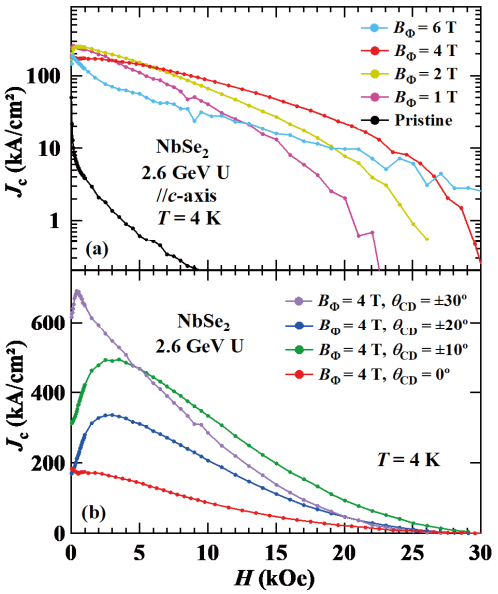

Fig. 2. Effects of 2.6 GeV U-ion irradiation on J_c-H in 2H-$NbSe_2$: (a) pristine and irradiated samples with $B_\Phi = 1, 2, 4$, and 6 T (//c) and (b) samples irradiated with $\theta_{CD} = 0°$, ±10°, ±20°, and ±30° at $B_\Phi = 4$ T.

Figure 2(a) shows Jc as a function of the magnetic field $H(//c)$ at 4 K for a pristine sample of 2H-$NbSe_2$ and samples irradiated at $B_\Phi = 1$, 2, 4, and 6 T along the c-axis. In all cases, J_c decreases monotonically with H. Compared with the pristine sample, J_c at 1 kOe is enhanced by a factor of more than 10 even at $B_\Phi = 1$ T. Figure 2(b) shows J_c as a function of H at 4 K for 2H-$NbSe_2$ irradiated from the directions of $\theta_{CD} = \pm 10°$, ±20°, or ±30° at $B_\Phi = 2$ T + 2 T Shown as a reference is the sample with $B_\Phi = 4$ T at $\theta_{CD} = 0°$. In all cases, the magnetic field H is applied along the c-axis (the average direction of CDs). It is remarkable that, in samples irradiated with $\theta_{CD} = \pm 10°$ and ±20°, J_c shows a broad peak at $H = 2$–3 kOe, which is less than 10% of the total B_Φ. Such a peak effect is similar to the one observed in a sample with tilted CDs.[3] It should also be noted that similar broad peaks were observed in $(Ba, K)Fe_2As_2$ irradiated at $\theta_{CD} \sim \pm 15°$. In this case, however, the peak appears at $H \sim 1/3B_\Phi$. At a larger $|\theta_{CD}|$, the broad peak is suppressed and replaced by a sharp drop of J_c below $H \sim 0.3$ kOe. The origin of the broad peak in J_c-H in 2H-$NbSe_2$ with splayed CDs is not known yet. More systematic studies on 2H-$NbSe_2$ with different configurations of CDs are required.

References

1) L. Civale *et al.*, Phys. Rev. Lett. **67**, 648 (1991).
2) Y. Nakajima *et al.*, Phys. Rev. B **80**, 012510 (2009).
3) S. Eley *et al.*, Sci. Rep. **8**, 13162 (2018).
4) A. Park *et al.*, Phys. Rev. B **97**, 064516 (2018).