PCP4-7

Effects of Point Defects Introduced by Co-doping and Proton Irradiation in $CaKFe_4As_4$

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Introduction of defects to superconductors enhances their critical current density (J_c). Recently, a new iron-based superconductor, $CaKFe_4As_4$, with a new type of structure is found [1], and its J_c is evaluated to be ~2 MA/cm^2 at 2 K and self-field [2].

To enhance J_c in $CaKFe_4As_4$, we introduced point defects by chemical and physical methods. In the chemical method, we have grown high-quality single crystals in which a part of Fe is replaced by Co up to 9 %. Co-doping is believed to make the inherently overdoped $CaKFe_4As_4$ closer to optimally doped one. Figure 1 shows J_c -H properties of $CaK(Fe_{1-x}Co_x)_4As_4$ up to $x = 0.09$ at $T = 5$ K. A relatively strong magnetic field dependence of J_c in the pristine $CaKFe_4As_4$ is weakened by modest Co-doping ($0.03 < x < 0.07$), leading to large J_c at high fields. It clearly demonstrates that the introduced Co work as point defects.

In the physical method, 3 MeV protons are irradiated into $CaKFe_4As_4$, which are known to produce point defects. In order to compare effects of two different kinds of point defects on J_c and get some insight into the effect of coexisting point defects, the pristine, 3% Co-doped, and 7% Co-doped crystals are irradiated. Figure 2 shows the irradiation dose dependence of J_c of these three crystals at $T = 5$ K and $H = 4$ T. J_c of all these three crystals is enhanced by the introduction of point defects by protons up to 0.1×10^{16} ions/cm^2. It means that proton-induced point defects cooperatively pin vortices with chemically induced point defects. Quantitative comparison shows that 7 % Co-doping has nearly the same effect as that induced by 0.1×10^{16} ions/cm^2 proton irradiation.

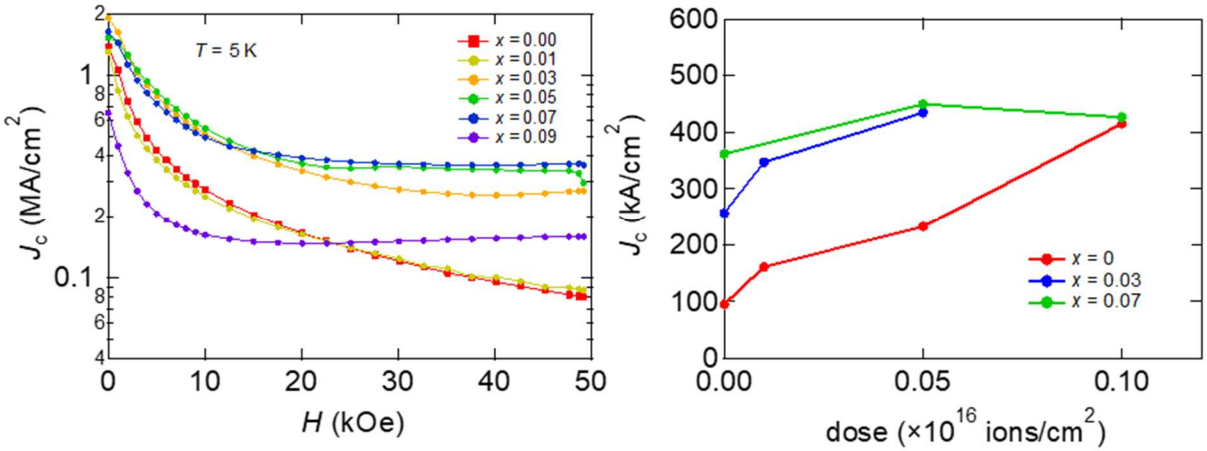

Figure 1: Magnetic field dependence of J_c in $CaK(Fe_{1-x}Co_x)_4As_4$ at $T = 5$ K.
Figure 2: Proton irradiation dose dependence of J_c in $CaK(Fe_{1-x}Co_x)_4As_4$ at $T = 5$ K and $H = 4$ T.

[1] A. Iyo *et al.*, J. Am. Chem. Soc. **138**, 3410 (2016).

[2] S. Pyon *et al.*, Phys. Rev. B **99**, 104506 (2019).

Keywords: Iron-based superconductor, critical current density, particle irradiation, point defects