Enhancement of Critical Current Density in Ion irradiated Ba(Fe,Co)2 As_2 Thin Film

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1.Abstract

The effect of 600 keV He^+ ion irradiation on the temperature and magnetic field dependence of the critical current density J_C of high quality $BaFe_{1.84}Co_{0.16}As_2$ (Co-doped Ba122 type) thin films is investigated. The films are prepared by pulsed-laser-deposition on CaF_2 substrates. The irradiation dosage is varied between $1x10^{13}$ to $1x10^{16}$ ions/cm^2 at room temperature. Upon irradiation, the critical temperature T_C drops slightly from 25 K for the un-irradiated sample to about 20 K for the sample with the highest irradiation level. The maximum J_C value at 4.5 K temperature is enhanced up to 2.4 MA cm^{-2} under 1 T field. The analysis of pinning force dependence on magnetic field shows that the pinning behavior is not changed in the irradiated samples suggesting more pinning centers of similar nature to those of presented in the un-irradiated samples are introduced by the irradiation process. The results indicate that the irradiation of light element ions He^+ with relatively low energy could increase the critical current density in iron based superconductors.

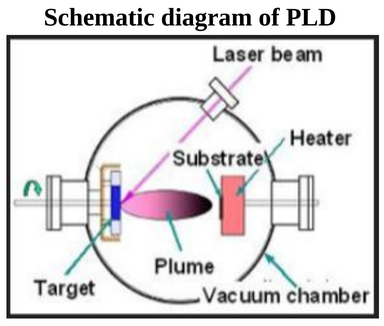
2.Introduction

In many applications, it is essential to carry large current in high magnetic field. The presence of structural defects can 'pin' the quantized magnetic vortices, which are important to the magnitude and field dependence of the critical current density J_C. Various techniques have been successfully developed and employed to enhance the high field performance of J_C by introducing flux pinning centers. Among them, irradiation with neutrons or heavy ions is an effective way. However, there have been report that irradiation with ions of much lower energy can also improve the superconducting properties (enhancement of J_C as well as critical field) [1]. We noticed in the literature that the high energy proton irradiation on iron based superconducting thin films has significant effect on J_C improvement and T_C suppression [2,3,4]. Here, we have studied the effect of low energy He^+ ion irradiation on the critical current density and flux pinning properties of iron based superconductor thin films.

3.Experimental procedure

- $BaFe_{1.84}Co_{0.16}As_2$ thin films were deposited at 850^0 C on CaF_2(001) substrates by PLD with a base pressure about 10^{-7} torr.
- Laser energy density was set to be 1.4 Jcm^{-2} with a repetition of 9Hz frequency.
- Target of nominal composition $BaFe_{1.84}Co_{0.16}As_2$ with T_C = 24.5 K was prepared by the solid state reaction method and was put 40 mm away from the sample.
- A KrF excimer laser of wavelength λ = 248 nm was used for PLD.
- The films were cooled down to room temperature at a rate of 10^0 Cmin^{-1} after deposition.
- Samples with name of IRR_1, IRR_2, IRR_4, IRR_5 and IRR_6 were irradiated with different dosages $1x10^{16}$, $5x10^{15}$, $5x10^{14}$, $1x10^{14}$ and $5x10^{13}$ ions/cm^2 at room temperature respectively.
- Magnetization measurements were performed at temperatures from 4.5 to 17.5 K and applied fields up to 9 T perpendicular to the thin film plane.

Schematic diagram of PLD



4.Results and discussion

- **Field dependence of the Critical current density:**

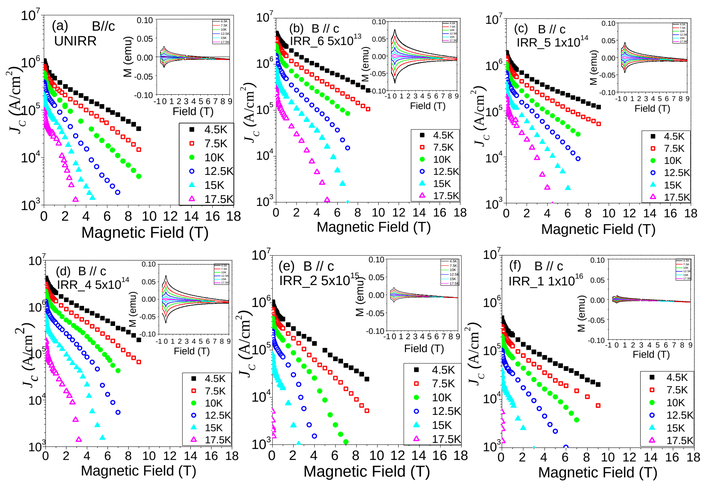


Fig.1 Dependence of critical current density J_C on the magnetic field applied perpendicular to thin films plane at different temperatures. Inset: Magnetic hysteresis loop at different temperatures. From Left to right UNIRR and all others irradiated with different dosages.

The critical current density is calculated from the Bean critical model. For the rectengular shape thin film samples, the following formula is used:

$$J_C(Am^{-2}) = \frac{\Delta M}{b(1-b/3a)}$$

$\Delta M(Am^{-1})$ is the difference in magnetization for increasing and decreasing field, and a(m) and b(m) (a > b) are the widths along two directions in the film plane respectively.

- **Critical current density as a function of temperature & irradiation influence rate:**

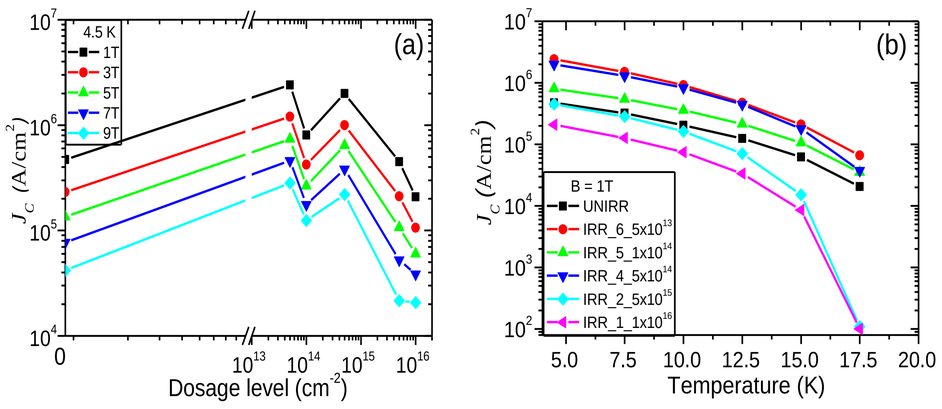


Fig.2 (a) J_C as a function of irradiation dosage rates for field H = 1, 3, 5, 7, 9 T at fixed temperature 4.5 K, (b) J_C as a function of temperature at low field 1 T for given samples are plotted.

- **$J_C^{0.5}B^{0.25}$ versus Magnetic field:**

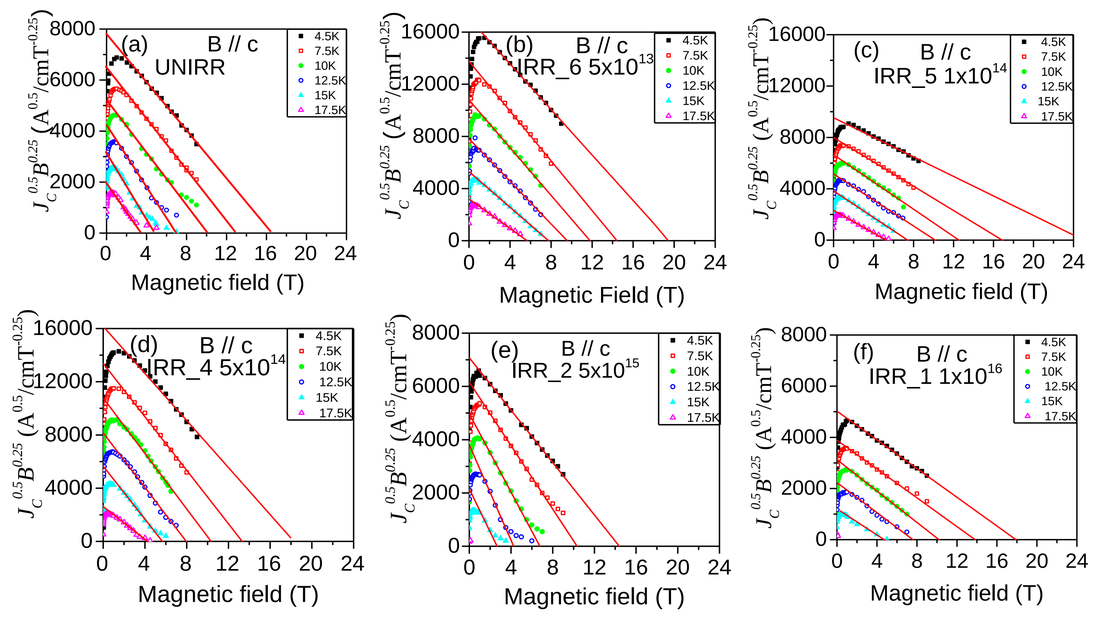


Fig.3 Kramar Plots: $J_C^{0.5}B^{0.25}$ versus magnetic field graphs for all samples at different temperatures. The linear extrapolations of red sold lines give the estimation of irreversibility fields.

- **Flux pinning force effect:**

The scaling behavior between the reduced pinning force f = F_p/F_{pmax} and the reduced magnetic field b = B/B_{irr}. Here F_{pmax} is the maximum value of the pinning force density $F_p = J_CB$ and B_{irr} is the irreversibility field which is determined using a Kramer plot.

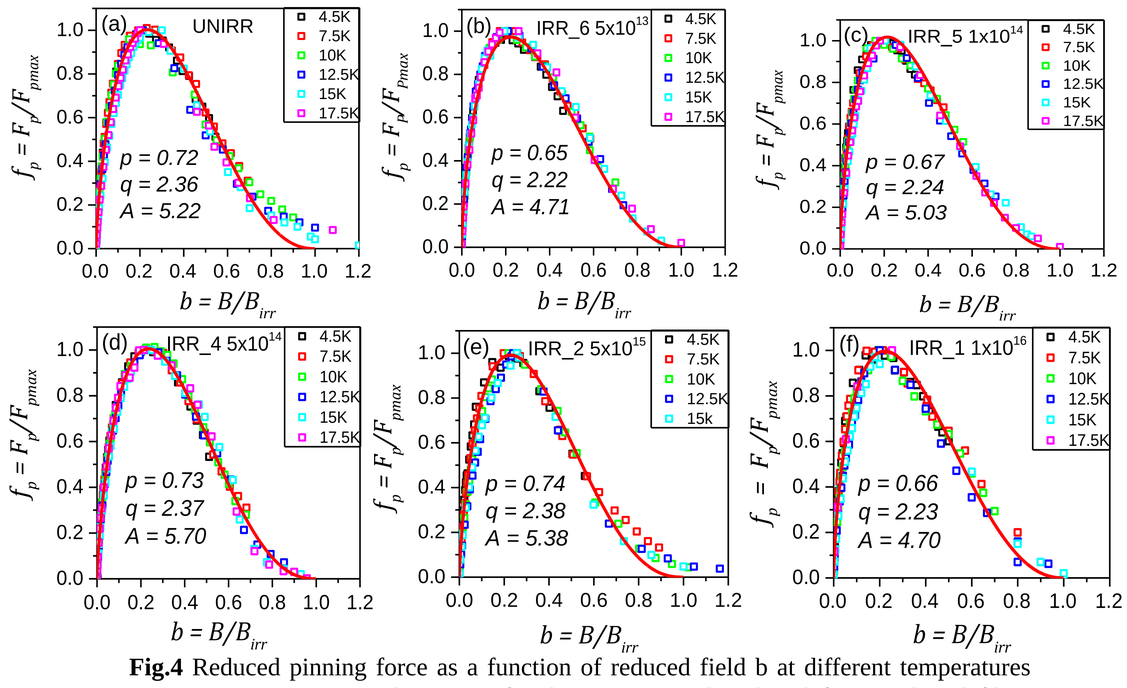


Fig.4 Reduced pinning force as a function of reduced field b at different temperatures (4.5, 7.5,10, 12.5, 15 and 17.5 K) for the one un-irradiated and five irradiated films respectively. The magnetic field is perpendicular to the film plane. The solid lines show the scaling theoretical curve using the expression $f(b)= Ab^p(1-b)^q$. Where "p" and "q" are constants depending on the nature and density of pinning.

5.Conclusion

We have presented experimental results regarding the irradiation effect of 600 keV He^+ ions on the superconducting properties of $BaFe_{1.84}Co_{0.16}As_2$ thin films grown on CaF2(00l)substrates. We found that the critical temperature T_C changes slightly from 25 K for the un-irradiated sample to about 20 K for the sample with the highest irradiation level. The J_C value is raised to 2.4 MA cm^{-2} at 1 T field and 4.5 K temperature for a sample with irradiation dose 5×10^{13}cm^{-2}. Moreover, the scaling behavior of the flux pinning force data revealed that the nature of the pinning centers is similar after irradiation in all samples. Our results suggest that low energy 600 keV He^+ ions could improve the flux pinning and critical current prop-erties in Co doped Ba122 type thin films.

6.References

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