Physica C 507 (2014) 35–40

Contents lists available at ScienceDirect

Physica C

journal homepage: www.elsevier.com/locate/physc

Doping dependence of the upper critical field, superconducting current density and thermally activated flux flow activation energy in polycrystalline $CeFeAsO_{1-x}F_x$ superconductors

S.V. Chong [a,b,*], G.V.M. Williams [b,c], S. Sambale [a,c], K. Kadowaki [d]

[a] Robinson Research Institute, Victoria University of Wellington, PO Box 33436, Lower Hutt 5046, New Zealand
[b] MacDiarmid Institute for Advanced Materials and Nanotechnology, Victoria University of Wellington, PO Box 600, Wellington 6140, New Zealand
[c] School of Chemical and Physical Sciences, Victoria University of Wellington, PO Box 600, Wellington 6140, New Zealand
[d] Division of Materials Science, Faculty of Pure & Applied Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8573, Japan

ARTICLE INFO

Article history:
Received 14 July 2014
Received in revised form 26 September 2014
Accepted 29 September 2014
Available online 22 October 2014

Keywords:
Iron-based superconductors
Quaternary compound
Flux flow activation energy
Critical current density
Maki parameter

ABSTRACT

We report the results from resistivity and magnetic measurements on polycrystalline Ce oxypnictide ($CeFeAsO_{1-x}F_x$) samples where x spans from 0.13 to 0.25. We find that the orbital limiting field is as high as 150 T and it systematically decreases with increasing doping. The Maki parameter is greater than one across the phase diagram and the large Maki parameter suggests that orbital and Pauli limiting effects contribute to the upper critical field. The broadening of the superconducting transition in the resistivity data was interpreted using the thermally activated flux flow (TAFF) model where we find that the TAFF activation energy, $U_0(B)$, is proportional to $B^{-\gamma}$ from 1 T to high fields, and γ does not significantly change with doping. However, U_0 and the superconducting critical current, J_c, are peaked in the mid-doping region ($x = 0.15$–0.20), and not in the low ($x < 0.15$) or high doping ($x > 0.20$) regions. Furthermore, U_0 is correlated with J_c and follows the two fluid model for granular samples.

1. Introduction

The discovery of iron-based compounds with superconducting transition temperatures, T_c's, as high as 56 K, second only to the high temperature superconducting cuprates (HTSCs), has provided us with a new candidate for technological applications using superconducting materials. Iron-based superconductors possess several appealing features which make them a strong candidate for high magnetic field applications at low temperature. With T_c's comparably higher than conventional low-temperature superconductors, such as Nb_3Sn, this new class of superconductors also has a very high upper critical field, B_{c2}, and high critical currents [1]. B_{c2} of the iron-based superconductors was initially reported to be large in the 1111- and 122-Fe arsenides, and subsequently a large B_{c2} (with $dB_{c2}/dT > -5$ T/K) was also reported in the 122- and 11-Fe chalcogenides family [2–4]. For example, a dB_{c2}/dT of -12 T/K was recently reported in Rb-doped $TlFe_{2-\delta}Se_2$ with $B||ab$-plane of the single crystal [5], and a more anisotropic $(Sm_{1-x}Nd_x)$-based 1111 superconductor showed a similar value of -11.2 T/K [6]. The high B_{c2} values found in the iron-based superconductors mean that they have potential device applications and hence it would be particularly useful to know how B_{c2} changes with doping. Furthermore, the doping dependence of the superconducting critical current is also required as well as the important role of flux pinning. One study by Shahbazi et al. on polycrystalline $CeFeAsO_{1-x}F_x$ with $x = 0.10$ and $x = 0.20$ found that the thermally activated flux flow (TAFF) activation energy, U_0, was lower for $x = 0.2$ while the inductive superconducting critical current, J_c, was slightly higher for $x = 0.2$ [7]. Thus, there is a clear need to study how B_{c2}, J_c, and U_0 change with doping.

In this paper we report the results from resistivity and magnetic measurements on $CeFeAsO_{1-x}F_x$ with nominal $x = 0.13$, 0.15, 0.20 and 0.25. We show that B_{c2} systematically decreases with increasing doping and U_0 and J_c are correlated, where J_c has a maximum in the mid-doping region from $x = 0.15$ to $x = 0.20$.

2. Experimental details

A series of $CeFeAsO_{1-x}F_x$ polycrystalline samples was prepared by a two-step solid state reaction as previously described [8,9]. The first step involved reacting a stoichiometric mixture of CeAs, CeO_2, CeF_3 and Fe at 1273 K for 24 h in sealed evacuated quartz

* Corresponding author at: Robinson Research Institute, Victoria University of Wellington, PO Box 33436, Lower Hutt 5046, New Zealand. Tel.: +64 4 463 0072.
E-mail address: shen.chong@vuw.ac.nz (S.V. Chong).

http://dx.doi.org/10.1016/j.physc.2014.09.015
0921-4534/

ampoules. The reacted mixture was then re-ground, compacted into pellets and again sealed in evacuated quartz ampoules for a final sintering at 1453 K for 50 h. Powder X-ray diffraction (XRD) of the resulting samples showed the appearance of impurities such as FeAs, $FeAs_2$ and CeAs which increases with fluoride-doping (F-doping) but the total amount is less than 15% in the highest fluoride-doped sample. The resistivity was measured using a *Quantum Design* Physical Property Measurement System (PPMS) using the four terminal method. The inductive critical current density was determined from magnetization loop (M–B) measurements on rectangular-shaped samples with thickness < width ≪ length on a *Quantum Design* Magnetic Property Measurement System (MPMS).

3. Results and discussion

The temperature-dependent resistivity at different applied magnetic fields (0–8 T) for the F-doped Ce oxypnictide samples is shown in Fig. 1. The increase in T_c is consistent with the doping phase diagram of $CeFeAsO_{1-x}F_x$ reported in literature [10–12], which unlike the cuprates [13] and the electron-doped $BaFe_{2-x}Co_xAs_2$ superconductors [14] do not display a superconducting dome-shape doping phase diagram, and with no downturn in the value of T_c being observed even up to the heavily-doped region ($x = 0.30$) [12].

In the presence of an applied magnetic field the superconducting transition temperature is seen to reduce systematically with increasing magnetic field. Comparing the change in T_c ($\Delta T_c = |T_c^{8T} - T_c^{0T}|$) for all four samples, it is observed in Fig. 1 that ΔT_c increases with increasing F-doping with $\Delta T_c = 1.03$ K for $x = 0.13$ and it increases to 3.90 K for $x = 0.25$. This indicates that there is a change in B_{c2} with doping. The powder averaged upper critical field was estimated from the temperature where the resistivity had decreased to 90% of the normal state resistivity, which is the method used in the literature [2,3,6,7]. The resultant B_{c2} is plotted in Fig. 2(a) where it is apparent that the gradient is largest for the underdoped sample with $x = 0.13$. This is clearer in Fig. 2(b) where B_{c2} is plotted against the reduced temperature, T/T_c. Similar to another study on polycrystalline $CeFeAsO_{1-x}F_x$, we find that B_{c2} is not linear over the entire magnetic field range and it deviates from the high field linearity close to T_c [7]. Thus, we use the average gradient above 1 T to estimate dB_{c2}/dT from the data in Fig. 2, similar

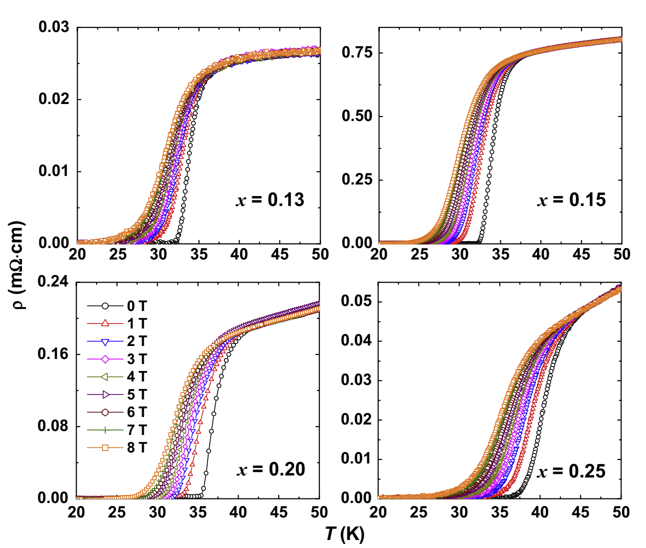

Fig. 1. Temperature-dependent resistivity of $CeFeAsO_{1-x}F_x$ at different applied magnetic fields. The broadening of the transition with increasing applied field indicates thermally assisted flux flow behaviour.

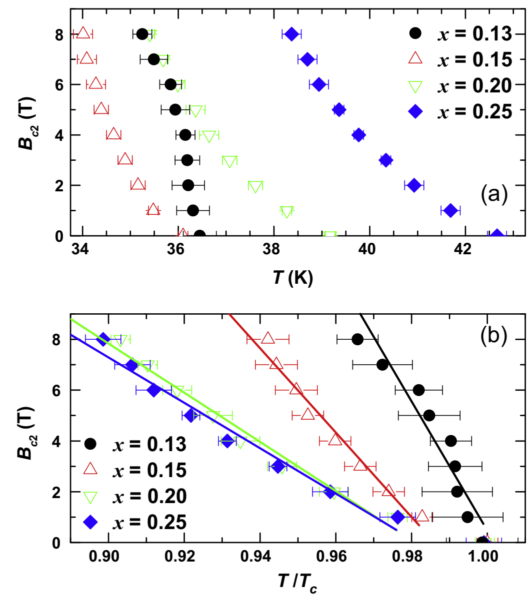

Fig. 2. (a) Plot of the upper critical fields, B_{c2}, against the temperature. (b) Plot of B_{c2} against the reduced temperature, T/T_c. The linear lines in (b) are intended to guide the eye.

to the "linear analysis" used to obtain B_{c2} in the $YBa_2Cu_3O_{7-\delta}$ [15] and MgB_2 [16] superconductors. The resultant dB_{c2}/dT is plotted in Fig. 3(a) against x where we find that dB_{c2}/dT is −6.1 T/K for the 0.13 F-doped sample and decreases to −2.1 T/K for the 0.25 F-doped sample. These estimated slopes are as high as those reported by Shahbazi et al. [7] for the 10% and the 20% F-doped samples where dB_{c2}/dT has values of −5.9 and −2.4 T/K, respectively, but they are overall higher than those reported by Prakash et al. [17] with dB_{c2}/dT values of −3.52 and −1.45 T/K for 10% and the 20% F-doping, respectively.

Similar to other studies [5,17,18], we estimate the orbital limiting field at 0 K, $B_{c2}^{orb}(0)$, using the single-band Bardeen–Cooper–Schrieffer (BCS) Werthamer–Helfand–Hohenberg (WHH) formula

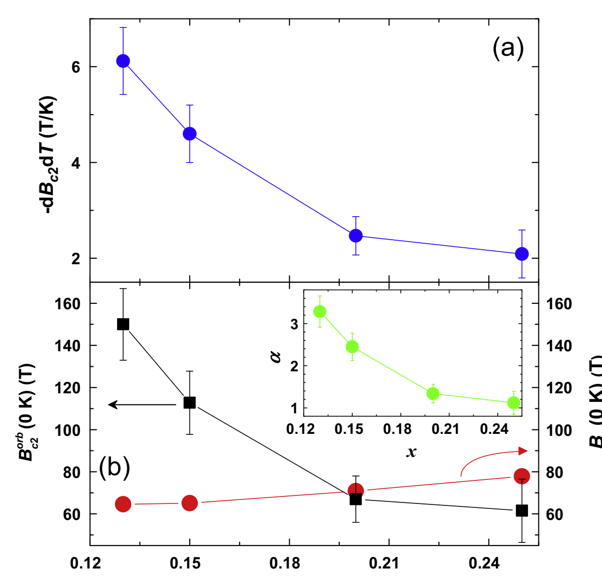

Fig. 3. (a) Plot of $-dB_{c2}/dT$ against the nominal fluoride concentration, x. (b) Plot of the orbital limiting field, $B_{c2}^{orb}(0)$ (filled squares, left axis), and the Pauli limiting field, $B_P(0)$ (filled circles, right axis), against x. The inset shows a plot of the Maki parameter, α, against x.