Asian J. Adv. Basic Sci.: **2018, 6***(3)*, 73-76
ISSN (Print): 2454 – 7492
ISSN (Online): 2347 – 4114
www.ajabs.org

Thermally Activated Flux Flow and Upper Critical Field of $SmFeAsO_{0.8}F_{0.2}$ Pnictide Superconductor

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(Published 03 Mar, 2018)

ABSTRACT: In this article, we report the superconducting property of $SmFeAsO_{0.8}F_{0.2}$ sample. The compound of interest is crystallized in tetragonal having P4/nmm space group and lattice parameters are a = 3.925(1) Å and c = 8.463(3) Å. From R-T measurement the superconducting transition is found at around 50.9 K. The upper critical field $H_{c2}(0)$ being determined from ρ(T)H measurements with 90% criteria of normalised resistivity, is ~959 Tesla. Flux flow activation energy (U_0/k_B) varies from 3297.03 K to 454.37 K with magnetic field vary from 0 Tesla to 14 Tesla for studied compound $SmFeAsO_{0.8}F_{0.2}$.

Keywords: Granular coupling; Magneto-transport; Pnictide superconductor and Upper critical field.

INTRODUCTION: The extensive research on high T_c cuprates again led towards the study of high T_c superconductivity with discovery of $LaO_{1-x}F_xFeAs$ oxypnictide system [1]. Also, scientifically this layered system has many interesting properties making them able to compete with high T_c cuprates superconductors [2]. The critical temperature, T_c in the pnictide system was observed to vary from 26 K up to 55 K by replacing Lanthanum (La) with other rare earth ions, like Gd, Ce, Nd, Pr and Sm [3-6]. These types of compounds have two layers of FeAs and LaO sheets. Theoretically, superconductivity takes place in FeAs layer, whereas the LaO layer is charge reservoirs when doped with F ions [6], [7]. Due to short coherence length, these materials exhibit a very high upper critical field H_{c2} (over 100 Tesla) [8], [9], [10]. The pure SmFeAsO sample is non-superconducting and shows SDW signal above 55 K. The superconductivity has been induced by creating oxygen vacancy or doping of fluorine ions on oxygen site. Despite having such a high T_c, these types of compounds have a limitation of granularity [11], [12]. Due to this the wires made of this compound can only carry current densities of order 103 Acm^{-2}. This granularity arises as a consequence of non-superconducting phases like FeAs, SmAs and Sm_2O_3. Some elemental doping and addition has been attempted to get better grains connectivity and to achieve high magnetic critical current density (J_c) [13] in the present work.

MATERIALS AND METHODS: The sample of $SmFeAsO_{0.8}F_{0.2}$ was synthesized by solid-state reaction method. High purity (~99.9%) powders of Sm, As, Fe_2O_3, Fe, and FeF_3 in their stoichiometric ratios are properly weighed, mixed and grounded in presence of high purity Ar gas atmosphere in glove box. Then sample was palletized and placed in furnace under heat treatment of 550 ºC for 12 hours, 750 ºC for 12 hours, 950 ºC for 12 hours and then at 1140 ºC for 12 hours with slow heating rate of 120 ºC/hour. Phase purity was verified through XRD. Finally, the sample has been sealed in quartz tube and preceded the sintering process at 1150 ºC for 12 hours to obtain a hard pellet. The sample was then characterized by the X-ray powder diffraction technique using Rigaku X-ray diffractometer (Cu-Kα line) and Rietveld analysis was performed using Fullprof program. Detailed resistivity measurement (ρ-T) under magnetic field of up to 14 Tesla had been carried out on Quantum design- Physical Properties Measurement System (PPMS-14Tesla down to 2K).

RESULTS AND DISCUSSION: Figure 1 shows the Rietveld refined XRD patterns of the studied $SmFeAsO_{0.8}F_{0.2}$ sample. The sample is crystallized in tetragonal structure and having P4/nmm space group. It is very difficult to prepare pure phase of this sample. Some peaks of impurities like FeAs, SmAs and Sm_2O_3 have also been observed together with main phase of the compound, which is marked as *. The lattice parameters from rietveld refinement are found to be a = 3.925(3) ´ , c = 8.463(2) ´ and Volume = 130.41 ´^{3} for $SmFeAsO_{0.8}F_{0.2}$. In the above figure, the permitted planes of the $SmFeAsO_{0.8}F_{0.2}$ system are shown by blue vertical lines between the observed/fitted patterns and their difference in the bottom. These results are in close agreement with that reported earlier [14].

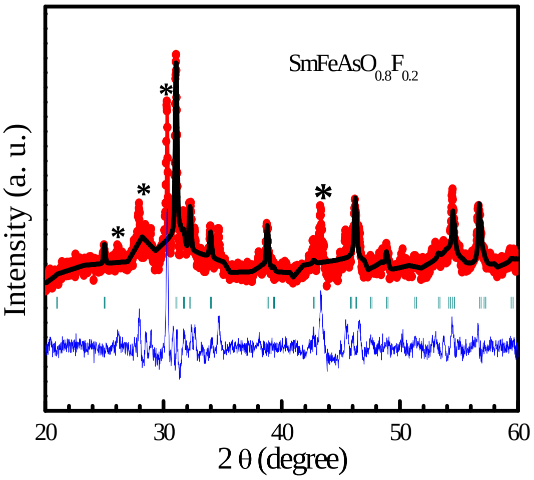

Figure 1: Rietveld refinement using Fullprof fitted room temperature observed X-Ray Diffraction, XRD patterns for $SmFeAsO_{0.8}F_{0.2}$ sample.

Fig. 2 shows the temperature dependence of the normalized resistivity ($\rho/\ \rho_{55}$) under applied magnetic field from 0 to 14 Tesla for $SmFeAsO_{0.8}F_{0.2}$ sample. The superconducting critical temperature is observed at around 50.9 K and T_c^{offset} ($\rho = 0$) is at 46.4 K in 0 field having a transition width of 4.5 K. The T_c^{offset} value shifts to the lower temperature on applying magnetic field.

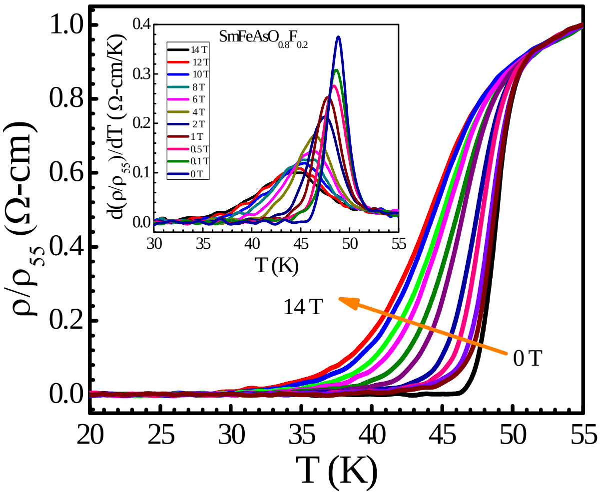

Figure 2: Temperature, T versus Normalized resistivity, ρ/ρ_{55} curve under applied magnetic field up to 14Tesla of $SmFeAsO_{0.8}F_{0.2}$ and inset is the curve between Temperature derivative of normalized resistivity, $d(\rho/\rho_{55})/dT$ and Temperature, T for $SmFeAsO_{0.8}F_{0.2}$.

Although, T_c^{onset} is not much affected to magnetic field and is almost same, but as applying magnetic field the transition width broadens monotonically. The T_c^{offset} decreases to below 30.7 K on applying 14 Tesla magnetic field hence the rate of decrement in T_c^{offset} with magnetic field of the studied sample is found around 1.12 K/Tesla {dT_c/dH = (46.4 K - 30.7 K)/(14 – 0 Tesla)}.

The inset view of fig. 2 shows the temperature derivative of normalized resistivity for $SmFeAsO_{0.8}F_{0.2}$ under magnetic field up to 14 Tesla. In zero magnetic field, due to the good percolation path of superconducting grains, a sharp peak is obtained which is the sign of better connectivity between the grains. On applying the field the transition peak becomes broader with a shift towards the lower temperature. The peak intensity also decreases with increasing applied magnetic field. The broadening of peak with magnetic field implies that the onset part is less sensitive to the magnetic field as compared to the T_c^{offset}. This behaviour is attributed to the thermally activated creeps of vortices [11].

Fig. 3 presents the upper critical field [$H_{c2}(T)$] at zero temperature which has been calculated by extrapolating the data using Ginzburge-Landau (GL) equation. The $H_{c2}(T)$ is calculated by using 90%, 50% and 10% criteria of ρ_N (normal state resistivity). The Ginzburge-Landau equation is

$$H_{c2}(T) = H_{c2}(0) \times \left[\frac{(1-t^2)}{(1+t^2)}\right],$$

where $t = T/T_c$ is the reduced temperature, $T_c = T_c^{onset}$ and $H_{c2}(0)$ is the upper critical field at T = 0 K.

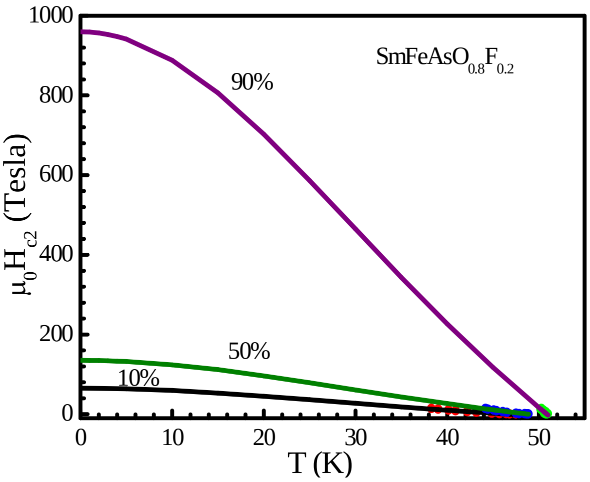

Figure 3: The Ginzburge Landau (GL) fitted variation of H_{c2} with Temperature, T for $SmFeAsO_{0.8}F_{0.2}$ sample at 90% criteria, 50% criteria and 10% criteria.

The H_{c2} versus temperature plot shows that the H_{c2} value of $SmFeAsO_{0.8}F_{0.2}$ is around 959 Tesla, 135 Tesla and 65 Tesla for 90%, 50% and 10% respectively. On considering onset values data the H_{c2} value is observed as high as 959 Tesla but on taking 50% criteria the value of H_{c2} is not equal to the half of the obtained value from 90% criteria. It is found very small i. e. 135 Tesla. Same as found in 10% criteria, the value obtained is only 65 Tesla. This is because of the effect of creeps of vortices at lower resistivity region, thus the ρ(T) dependences are thermally activated and are usually described by the Arrhenius equation [15]

$$\rho(B,T) = \rho_0 \exp\left[-\frac{U_0}{k_B T}\right],$$

where U_0 = Thermally Activation Flux-Flow energy, which is obtained from the slope of linear part of Arrhenius plot. ρ_0 is the field independent preexponential factor, and k_B is Boltzmann's constant.

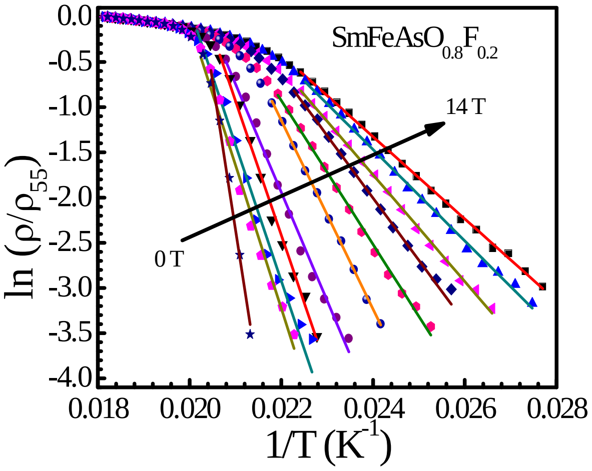

Figure 4: Fitted Arrhenius plot of resistivity for $SmFeAsO_{0.8}F_{0.2}$ sample.

The fitted ln ρ vs. T^{-1} plot to the experimental data shown in Fig. 4 and the calculated values of the activation energy vary from U_0/k_B = 3297.03 K and 454.37 K for $SmFeAsO_{0.8}F_{0.2}$ in the field range of 0 - 14 Tesla which is comparable with the other reported results [14].

CONCLUSION: From the above results, it is concluded that the sample has been successfully prepared from single step solid state reaction method. The obtained value of the upper critical field is found out to be 959 Tesla, which is much higher than other pnictide systems. The values of the activation energy obtained from experimental data ranging down from U_0/k_B = 3297.03 K to 454.37 K for $SmFeAsO_{0.8}F_{0.2}$ in the field range of 0 – 14 Tesla. These results show that the compound of interest is very promising and has high potential as superconductor.

ACKNOWLEDGEMENT: Poonam Rani would like to thank the Jamia Millia Islamia University for the Support to pursue her Ph.D and thanks to CSIR for the SRF as a financial support. The authors like to thank Dr. D. K Aswal, Director, NPL, for his keen interest in this work.

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