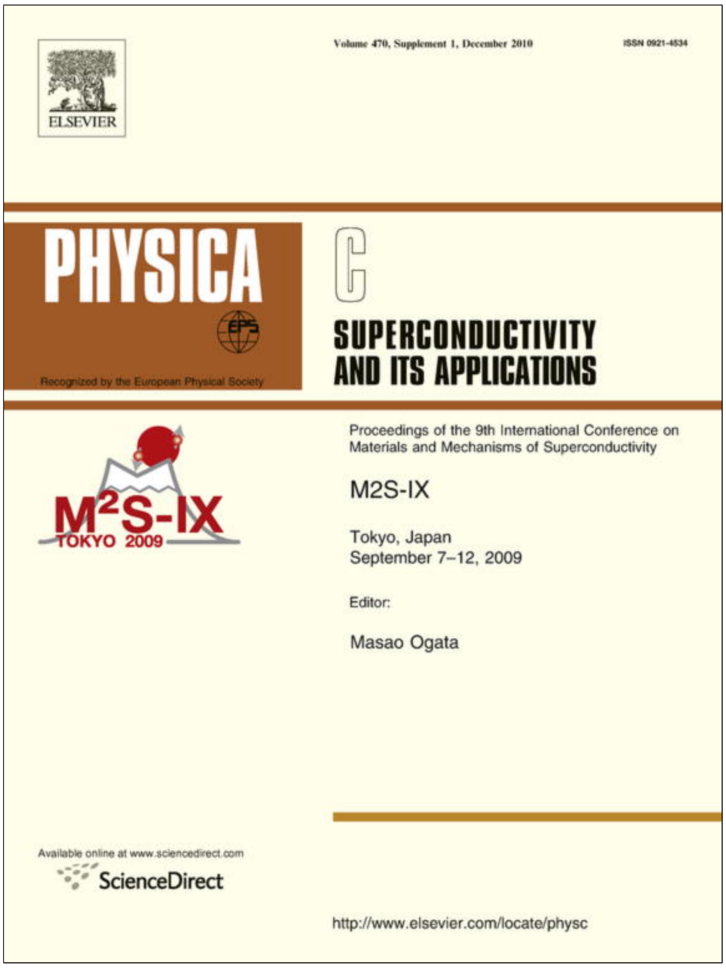

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Two-dimensional superconductivity of $SmFeAsO_{0.85}$ single crystals: A fluctuation-conductivity study

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ABSTRACT

Temperature dependence of the in-plane conductance of a $SmFeAsO_{0.85}$ single crystal is measured in *c*-axis and planar magnetic fields up to 7 T. The conductivity near the superconducting transition is well described by two-dimensional (2D) thermal-fluctuation theory. The 2D superconductivity arises as the *c*-axis coherence length is much shorter than the spacing between neighboring FeAs layers.

Among the new family of REFeAsO (RE = rare-earth elements) [1], fluorine-doped and fluorine-free SmFeAsO compounds present high superconducting transition temperatures ($T_c = 54{-}56$ K) [2–5], strong temperature dependence of the upper critical field H_{c2} near T_c (8–12 T/K) [6–8], and high anisotropy ratios (7–9) [7–9]. All these suggest possible strong thermal fluctuation effect in the materials, which is quantified by the Ginzburg fluctuation parameter [10], $Gi = 10^{-9}\left[\kappa^4 T_c^2 \gamma^2 / H_{c2}(0)\right]$. Here $\kappa = \lambda/\xi$ is the Ginzburg–Landau parameter (λ is the London penetration depth and ξ is the coherence length) and $\gamma = m_c/m_a$ is the mass anisotropy ratio. The value of *Gi* estimated for SmFeAsO is about $8 \times 10^{-3} - 1.3 \times 10^{-2}$ [6,7], which is comparable to $\sim 10^{-3} - 10^{-2}$ of high-T_c cuprates but is larger than $\sim 10^{-5}$ of conventional superconductors. Thus, as the value of H_{c2} is extracted from magnetoconductance data, the region around T_c should be excluded to avoid the influence of significant fluctuation effect.

Moreover, analysis of fluctuation effects on the conductivity, magnetization, and thermoelectricity, etc., reveals the dimensionality of superconductivity of the system. Recently, it was reported that the temperature dependence of the fluctuation conductivity (σ_{fl}) of $SmFeAsO_{1-x}F_x$ polycrystals follows the two-dimensional (2D) scaling behavior [11] for the magnetic fields higher than ~8 T [6]. This is the single available report on the $\sigma_{fl}(T)$ scaling for $REFeAsO_{1-x}F_x$. Also, for polycrystals, the alignment of the field with respect to the crystal direction is not clear. Thus, further examination of the fluctuation-conductance effect in this family of iron-pnictide materials is required by adopting high-quality single crystals with well-defined field direction.

In this work, we investigate $\sigma_{fl}(T)$ of a $SmFeAsO_{0.85}$ single crystal by measuring the magnetoresistance at various fields below 7 T. Comparing to the previous result of polycrystalline $SmFeAsO_{1-x}F_x$, our $SmFeAsO_{0.85}$ crystal reveals that the 2D scaling [11] is valid for a wider field range below 7 T.

$SmFeAsO_{0.85}$ single crystals with nominal compositions were grown under high temperatures and high pressure. Details of the single-crystal growth are described elsewhere [5]. In-plane resistive transition of crystals with dimensions of $\sim 80 \times 50 \times 10\ \mu m^3$ was measured using the standard four-probe technique (see the inset of Fig. 1b). Temperature dependence of the resistance $[R(T)]$ was measured in *c*-axis $(H_{\parallel c})$ and planar $(H_{\parallel ab})$ magnetic fields up to 7 T while maintaining 1 mA bias current normal to the fields.

Fig. 1a and b shows $R(T)$ of the $SmFeAsO_{0.85}$ single-crystal sample in $0\ T \leqslant H \leqslant 6.9$ T for $H_{\parallel c}$ and $H_{\parallel ab}$, respectively. The zero-field T_c is ~50.5 K, determined by the deviation of $R(T)$ from a linear relation above T_c. The narrow transition width of ~0.5 K, determined by the criterion of 10–90% of the normal-state resistance, indicates good quality of our crystals. Upon increasing *H*, the resistive transition in $H_{\parallel c}$ becomes broader and T_c is lowered. However, the decrease of T_c is much less for $H_{\parallel ab}$ (Fig. 1b). This behaviors of $R(T)$ is similar to what was previously observed in $REFeAsO_{1-x}F_x$ (RE = Sm and Nd) [6–8,12,13]. In high-T_c superconductors, it is well known that the fluctuation effect is responsible for broadening of the resistive transition in magnetic fields [11].

The fluctuation effect on the conductivity of our crystal is analyzed by using the scaling theory proposed by Ullah and Dorsey [11]. Based on the time-dependent Ginzburg–Landau theory, the scaling function of the fluctuation conductivity $[\sigma_{fl}(T)]$ is obtained

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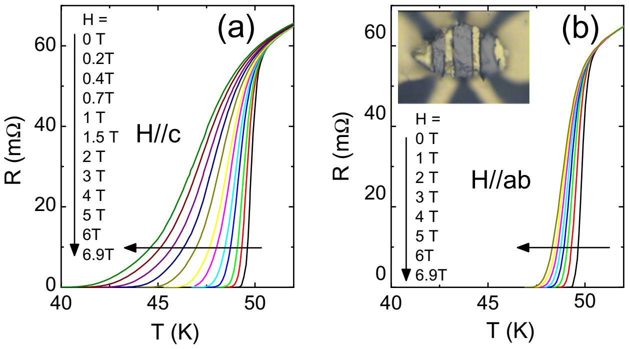

Fig. 1. Temperature dependence of the resistance $R(T)$ of SmFeAsO$^{0.85}$ single crystal measured in various fields from 0 to 6.9 T for (a) $H_{\parallel c}$ and (b) $H_{\parallel ab}$. The upper inset of (b) shows the microscopic images of the four-probe patterned crystals used for the transport measurements.

within the Hartree approximation. $\sigma_{fl}(T)$ for $H_{\parallel c}$ is scaled to the form

$$\sigma_{fl}\left(\frac{H}{T}\right)^{1/2} = F_{2D}\left[\frac{T - T_c(H)}{(TH)^{1/2}}\right] \text{for 2D,} \tag{1}$$

and

$$\sigma_{fl}\left(\frac{H}{T^2}\right)^{1/3} = F_{3D}\left[\frac{T - T_c(H)}{(TH)^{2/3}}\right] \text{for 3D.} \tag{2}$$

Here, $T_c(H)$ is the single free parameter for the fit and the accurate determination of $T_c(H)$ is utterly important to obtain a high-quality scaling. Field dependence of T_c is accurately obtained by the relation $T_c(H) = T_{c0} - H/|dH_{c2}/dT|_{T_{c0}}$, along with the measured zero-field transition temperature T_{c0} and $dH_{c2}/dT|_{T_{c0}}$. For a good analysis of the fluctuation effects on σ, the normal-state resistivity $\rho_n(T)$ should be accurately obtained because $\sigma_{fl}[=1/\rho(T) - 1/\rho_n(T)]$ is determined by the measured resistivity $\rho(T)$ and the extrapolated $\rho_n(T)$. Since the fluctuation effect appears in the temperature range of $\sim\frac{1}{2}T_c < T < \sim 2T_c$, $\rho_n(T)$ is extrapolated above T_{c0} using the relation $\rho_n(T) = \rho_0 + AT$, where A is a constant.

The trial 2D and 3D scalings of σ_{fl} of SmFeAsO$_{0.85}$ are presented in Fig. 2a and b, respectively. Excellent scaling behavior of the fluctuation conductivity is obtained for the 2D case although the scaling becomes somewhat worse for 1 and 2 T. In comparison, the 3D scaling does not work. The parameters in this analysis are $T_{c0} = 50$ K and $dH_{c2}/dT|_{T_{c0}} = -2.6 \pm 0.1$ T/K. The value of slope $dH_{c2}/dT|_{T_{c0}}$ is in good agreement with that determined from the measured data $H_{c2}(T)$ [14]. One may forcibly bring the 3D scaling better, but only with unphysical parameters. By contrast, σ_{fl} of SmFeAsO$_{1-x}$F$_x$ polycrystals showed the 2D scaling only for $H > 8$ T where $H \sim 8$ T was suggested as the 3D-to-2D crossover field. The 2D nature of SmFeAsO$_{0.85}$ even for $H < 7$ T arises from the c-axis coherence length ($\xi_c(0) \approx 3.6$ Å) [14] that is much shorter than the spacing between the neighboring superconducting FeAs-planes ($s \approx 8.4$ Å).

In summary, we measured the in-plane resistance of SmFeAsO$_{0.85}$ single crystals in various fields below 7 T for $H_{\parallel c}$ and $H_{\parallel ab}$. Scaling of the fluctuation conductivity for $H_{\parallel c}$ indicates that the 2D nature of superconductivity of SmFeAsO$_{0.85}$ is valid in a wider field range of $H < 7$ T than reported for polycrystalline SmFeAsO$_{1-x}$F$_x$ crystals. The 2D superconductivity of SmFeAsO$_{0.85}$ arises from $\xi_c(0) < s$.

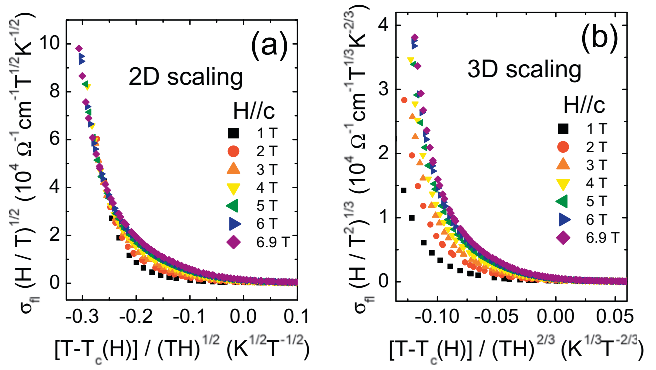

Fig. 2. (a) 2D scaling and (b) 3D scaling of the fluctuation conductivity based on Eqs. (1) and (2) [11], respectively, for $H \| c$.

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