

BiS₂ - based superconductivity in F-substituted NdOBiS₂

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Abstract

We have successfully synthesized a new BiS₂-based superconductor NdOBiS₂ with F-doping. This compound is composed of superconducting BiS₂ layers and blocking NdO layers, which indicates that the BiS₂ layer is the one of the common superconducting layers like the CuO₂ layer of cuprates or Fe-As layer of Fe-based superconductors. We can obtain

$\text{NdO}_{1-x}\text{F}_x\text{BiS}_2$ with bulk superconductivity by a solid-state reaction under ambient pressure.

Therefore, $\text{NdO}_{1-x}\text{F}_x\text{BiS}_2$ should be the suitable material to elucidate the mechanism of superconductivity in the BiS_2 -layer.

Quite recently, Y. Mizuguchi et al. reported superconductivity in the novel BiS₂-based superconductor Bi₄O₄S₃ with a superconducting transition temperature (T_c) of 8.6 K [1]. This material has a layered structure composed of superconducting BiS₂ layers and blocking layers of Bi₄O₄(SO₄)_{1-x}, where x indicates the defects of SO₄²⁻ ions at the interlayer sites. The stacking structure of the superconducting and blocking layer is analogous to those of high- T_c cuprates [2-5] and Fe-based superconductors [6-14]. In both systems, their T_c can be enhanced by changing the blocking layers. In order to enhance the T_c of the BiS₂-based superconductor, the investigation of exchanging the blocking layer will be of great interest.

Soon after the discovery of Bi₄O₄S₃, a new BiS₂-based superconductor LaO_{1-x}F_xBiS₂ was reported [15]. This compound consists of the same superconducting layer but with different blocking layers compared to that of Bi₄O₄S₃. Furthermore, the superconductivity shows a relatively high T_c of 10.6 K. This fact suggests that the BiS₂ layer is the common superconducting layer, and the blocking layer contributes to the enhancement of the T_c in this system. LaO_{1-x}F_xBiS₂ shows a small superconducting volume fraction for ambient pressure but achieves bulk superconductivity under high pressure. This result suggests that high pressure would promote F substitution. Therefore, chemical pressure for the exchange of La by Nd possibly induces the promotion of F substitution. Here, we report that a new BiS₂-based superconductor NdO_{1-x}F_xBiS₂ ($x = 0.1 - 0.7$) can be obtained by a solid-state reaction under ambient pressure.

The polycrystalline samples of $\text{NdO}_{1-x}\text{F}_x\text{BiS}_2$ ($x = 0.1 - 0.7$) were prepared by a solid-state reaction. Mixtures of Bi grains, Bi_2S_3 grains, Nd_2O_3 powders, Nd_2S_3 powders, and NdF_3 powders with nominal compositions of $\text{NdO}_{1-x}\text{F}_x\text{BiS}_2$ ($x = 0.1 - 0.7$) were ground, pelletized, and sealed into an evacuated quartz tube. The tube was heated at 800 °C for 10 h. The obtained samples were characterized by X-ray diffraction with Cu-K α radiation using the θ -2 θ method. The temperature dependence of magnetization was measured by a superconducting quantum interface device (SQUID) magnetometer with an applied field of 1 Oe. The resistivity measurements were performed using the four-terminal method from 300 to 2 K. In order to investigate an upper critical field of $\text{NdO}_{1-x}\text{F}_x\text{BiS}_2$, the temperature dependence of resistivity between 10 and 2 K was measured under a magnetic field of up to 7 T.

Figure 1(a) shows the X-ray diffraction profile for the powdered samples of $\text{NdO}_{1-x}\text{F}_x\text{BiS}_2$ ($x = 0.1 - 0.7$). With the exception of a few minor peaks relating to impurity phases, all of the peaks can be characterized to space group $P4/nmm$. The nominal x dependence of the lattice constants a and c is summarized in Fig. 1(b) and (c). These lattice constants were estimated from 2θ values and Miller indices. The a lattice constant exhibits little change with increasing x while the c lattice constant dramatically decreases. The decrease of the lattice parameter c indicates that F substitutes O since the ionic radius of F is smaller than that of O.

Figure 2(a) shows the temperature dependence of magnetic susceptibility for $\text{NdO}_{1-x}\text{F}_x\text{BiS}_2$ ($x = 0.1 - 0.7$). A superconducting transition is observed for all samples. These samples with $x = 0.1 - 0.6$ exhibit a high shielding volume fraction exceeding 90 % (2 K, ZFC), indicating the appearance of bulk superconductivity in those samples. The x dependence of T_c is plotted in Fig. 2(b). The T_c varies like a bell curve with increasing x . The $\text{NdO}_{0.7}\text{F}_{0.3}\text{BiS}_2$ sample exhibits the optimal T_c of all samples.

The temperature dependence of the resistivity for $\text{NdO}_{0.7}\text{F}_{0.3}\text{BiS}_2$ is shown in Fig. 3. Resistivity slightly decreases between 300 and 130 K. Below 130 K, resistivity gradually increases and the superconducting transition appears around 6 K. This behavior, where the resistivity increases with decreasing temperature is also observed in $\text{LaO}_{1-x}\text{F}_x\text{BiS}_2$. The onset and zero-resistivity temperatures are estimated to be $T_c^{\text{onset}} = 5.6$ K and $T_c^{\text{zero}} = 5.2$ K, respectively. Figure 4(a) shows the temperature dependence of the resistivity from 10 to 2 K under a magnetic field. The T_c of $\text{NdO}_{0.7}\text{F}_{0.3}\text{BiS}_2$ decreases with increasing magnetic field. The upper critical field (B_{c2}) and the irreversibility field (B_{irr}) are plotted in Fig. 4(b). The $B_{c2}(0)$ was estimated to be 5.2 T with the data points at $0.4 \sim 2.0$ T using the WHH theory, which gives $B_{c2}(0) = -0.69T_c(\text{d}B_{c2}/\text{dT})|_{T_c}$ [16].

In conclusion, the BiS_2 -based superconductor $\text{NdO}_{1-x}\text{F}_x\text{BiS}_2$ ($x = 0.1 - 0.7$) has been successfully synthesized by a solid-state reaction method. Chemical pressure promotes the F substitution, which originated from the exchange of La by Nd. As a result, $\text{NdO}_{1-x}\text{F}_x\text{BiS}_2$ with

bulk superconductivity can be obtained under ambient pressure. These results demonstrate that the BiS₂ layer is the common superconducting layer. Thus, if we synthesize materials with the stacking structure consisting of the BiS₂ layer and other blocking layers, new superconductors with the BiS₂-layer would be discovered.

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Figure caption

Fig. 1

(a) X-ray diffraction patterns of $\text{NdO}_{1-x}\text{F}_x\text{BiS}_2$ ($x = 0.1 - 0.7$). Filled circles indicate the peaks of the impurity phases. (b) and (c) show the nominal x dependence of the lattice constants a and c , respectively.

Fig. 2

(a) The temperature dependence of the magnetic susceptibility for $\text{NdO}_{1-x}\text{F}_x\text{BiS}_2$ ($x = 0.1 - 0.7$).
(b) The F concentration dependence of the superconducting transition temperature for $\text{NdO}_{1-x}\text{F}_x\text{BiS}_2$ ($x = 0.1 - 0.7$).

Fig. 3

The temperature dependence of resistivity for $\text{NdO}_{0.7}\text{F}_{0.3}\text{BiS}_2$ between 300 and 2 K.

Fig. 4

(a) The temperature dependence of the resistivity from 10 to 2 K under magnetic fields
(b) Magnetic field – temperature phase diagram for $\text{NdO}_{0.7}\text{F}_{0.3}\text{BiS}_2$. The dashed lines are liner fits to the data.

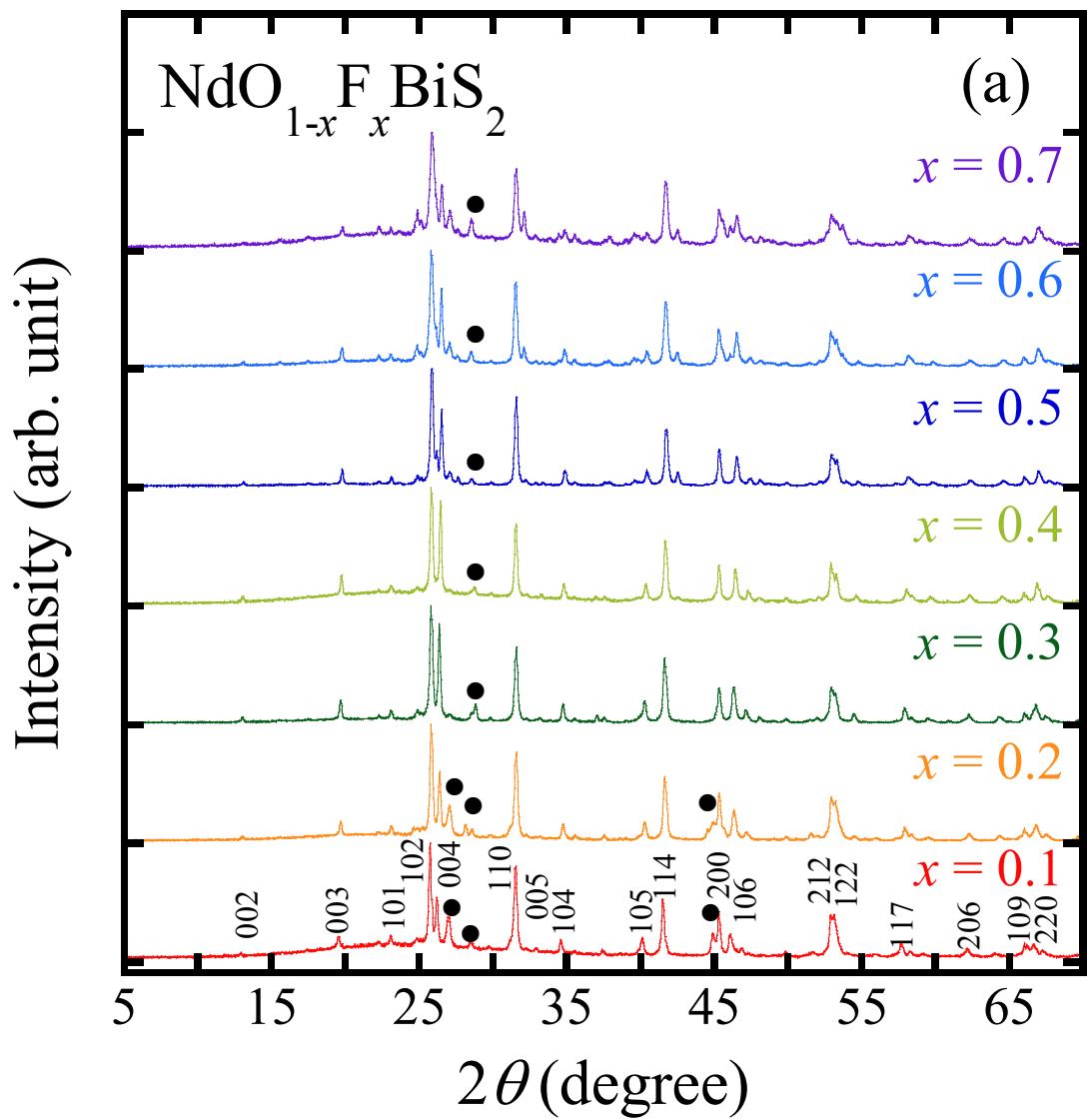


Fig. 1(a). S. Demura

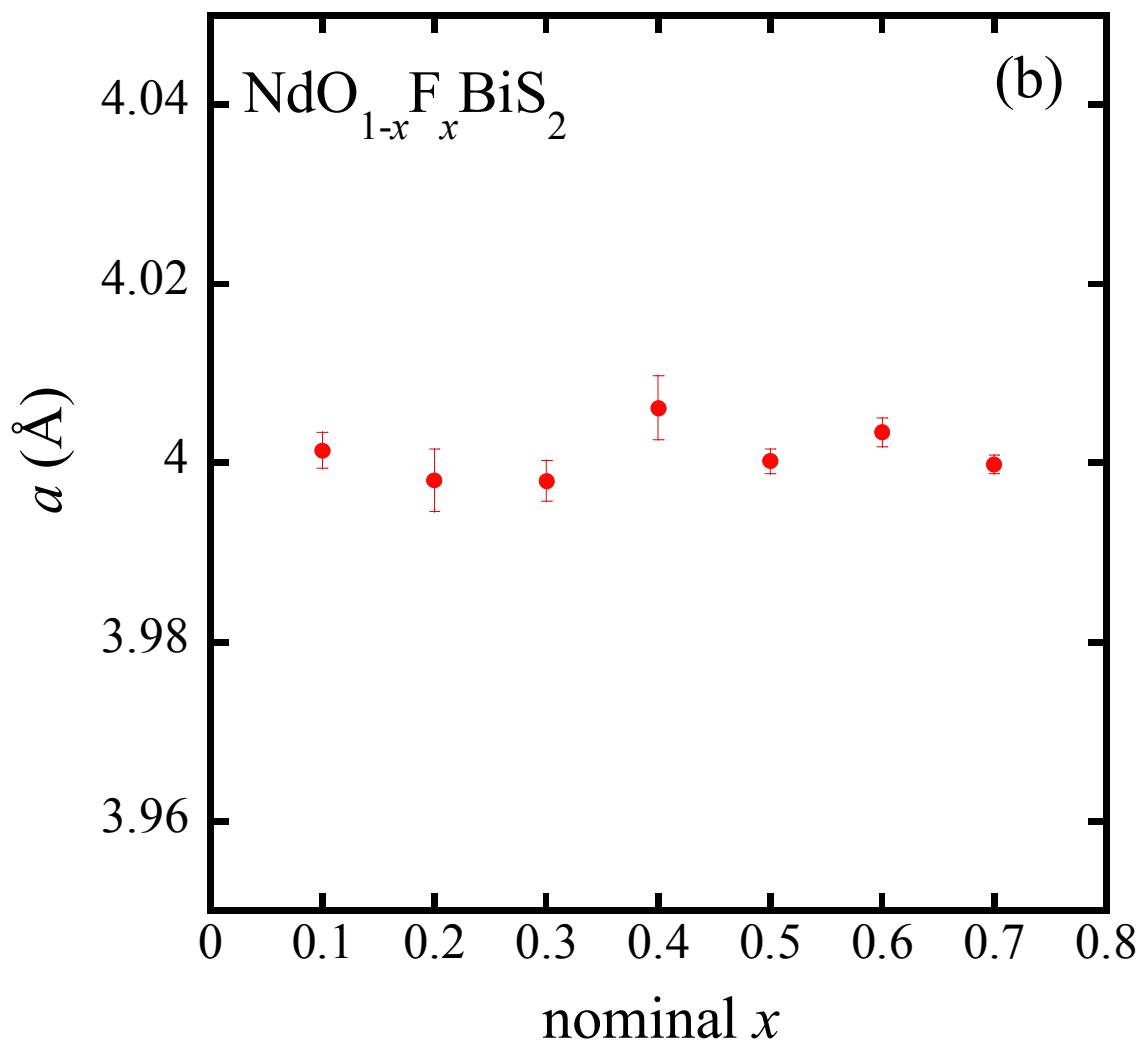


Fig. 1(b). S. Demura

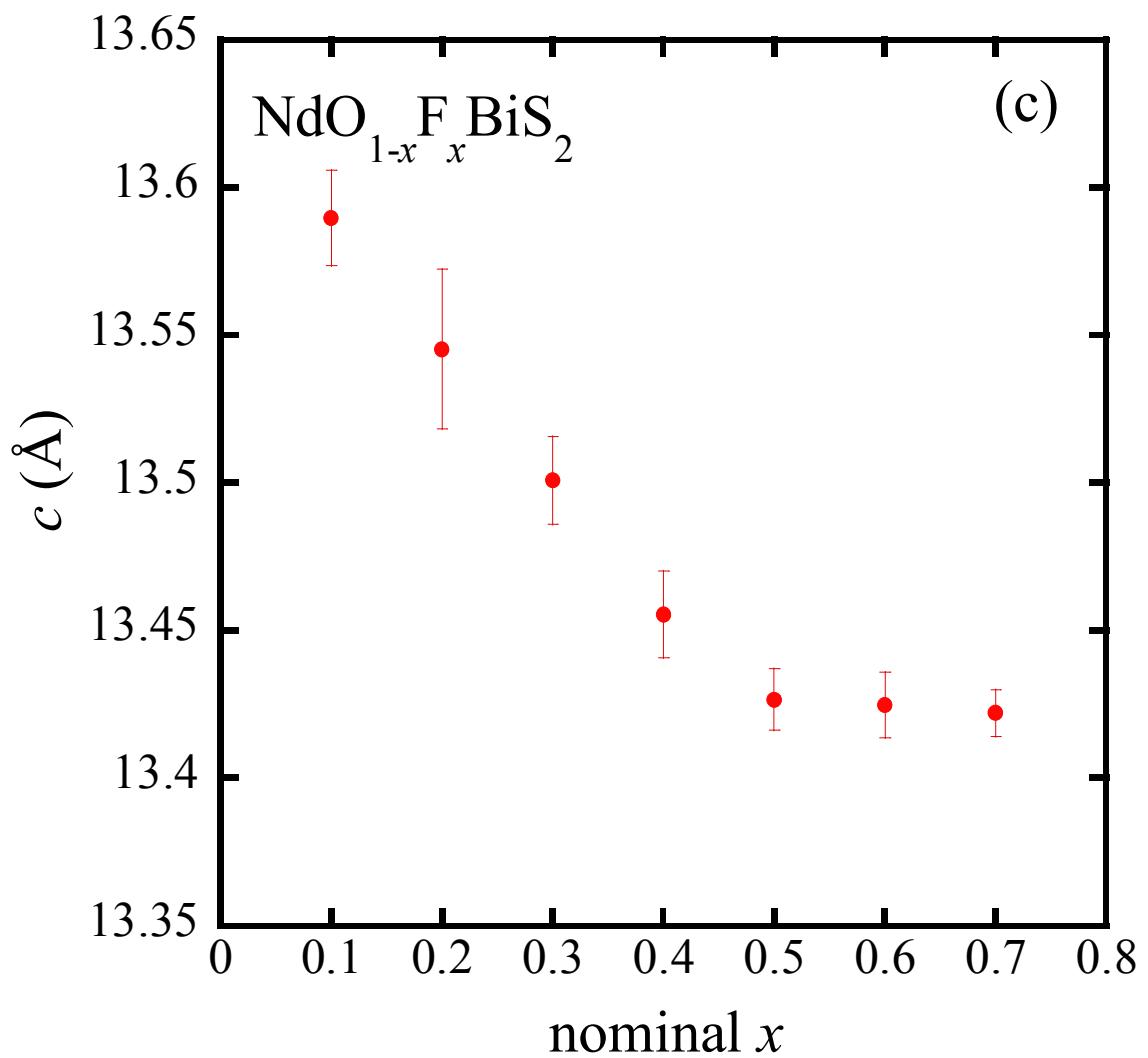


Fig. 1(c). S. Demura

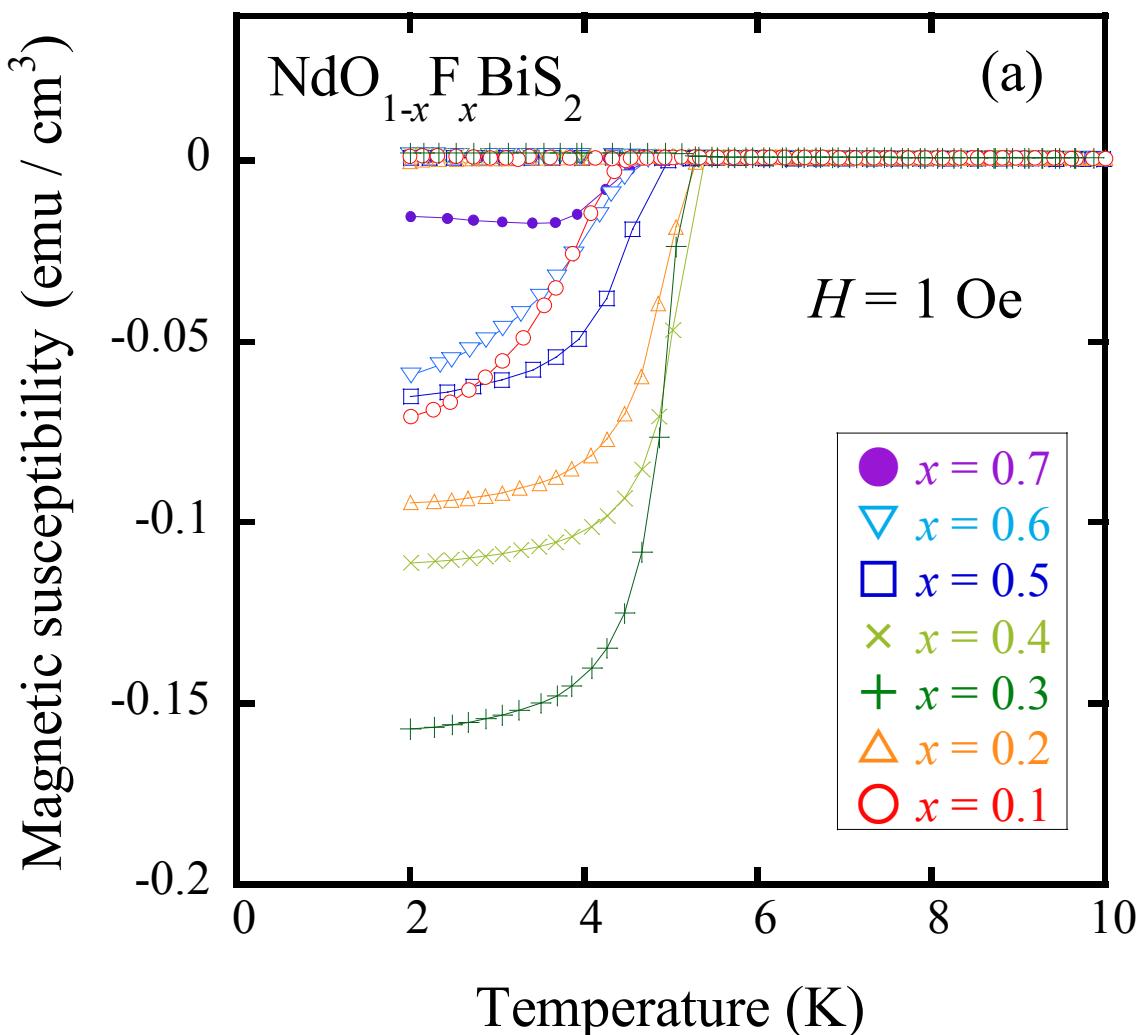


Fig. 2(a) S. Demura

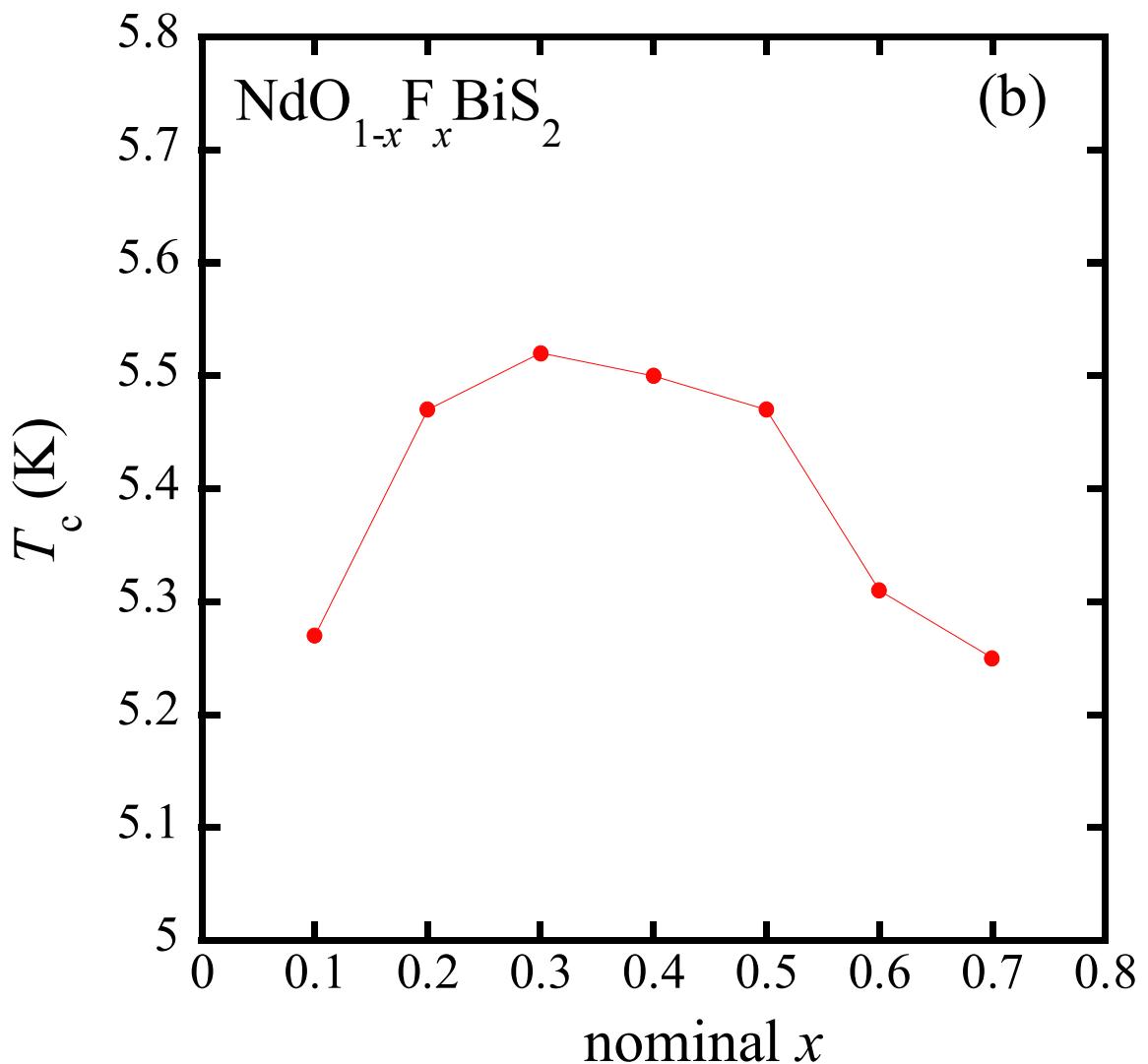


Fig. 2(b) S.Demura

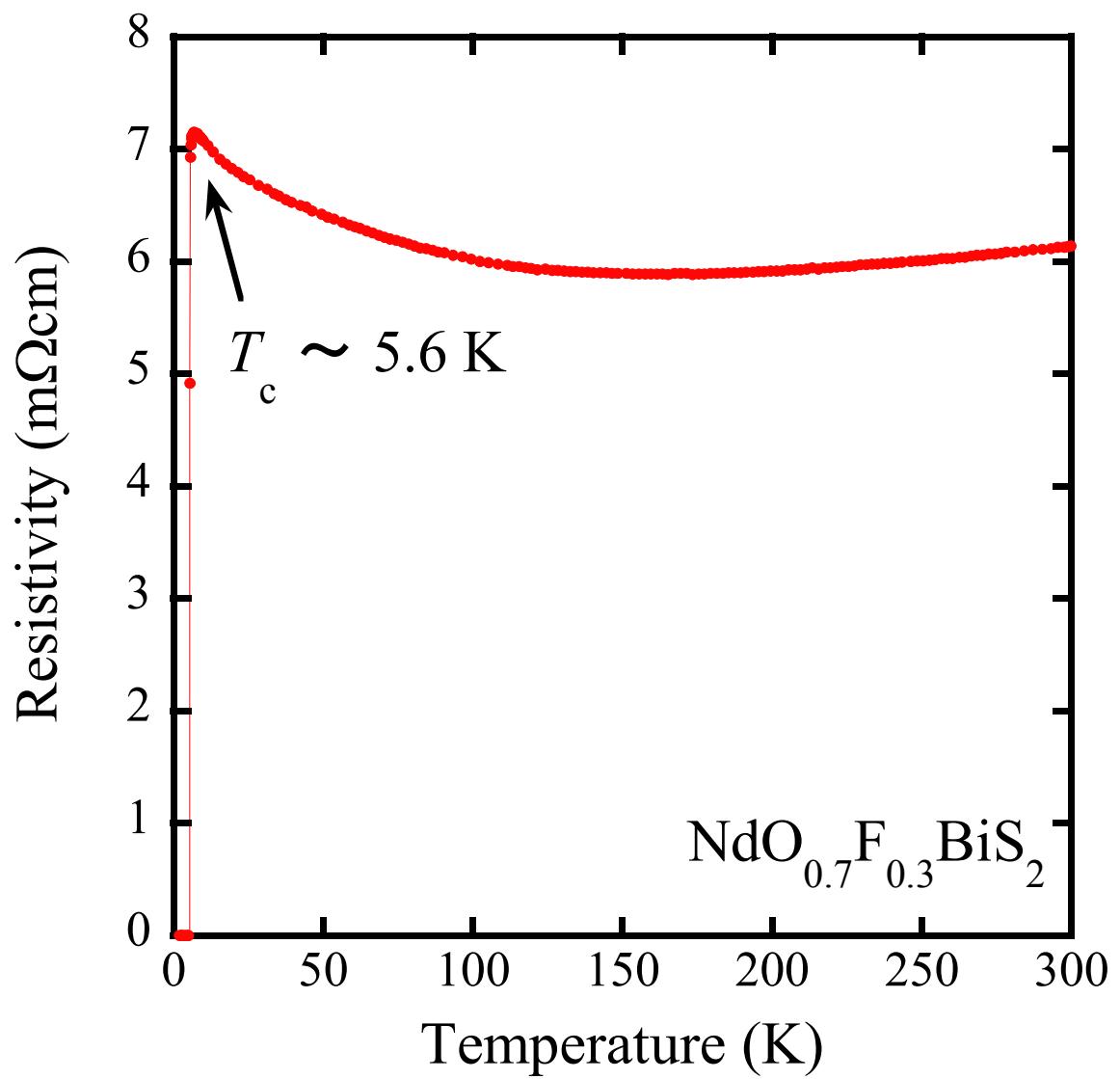


Fig. 3 S. Demura

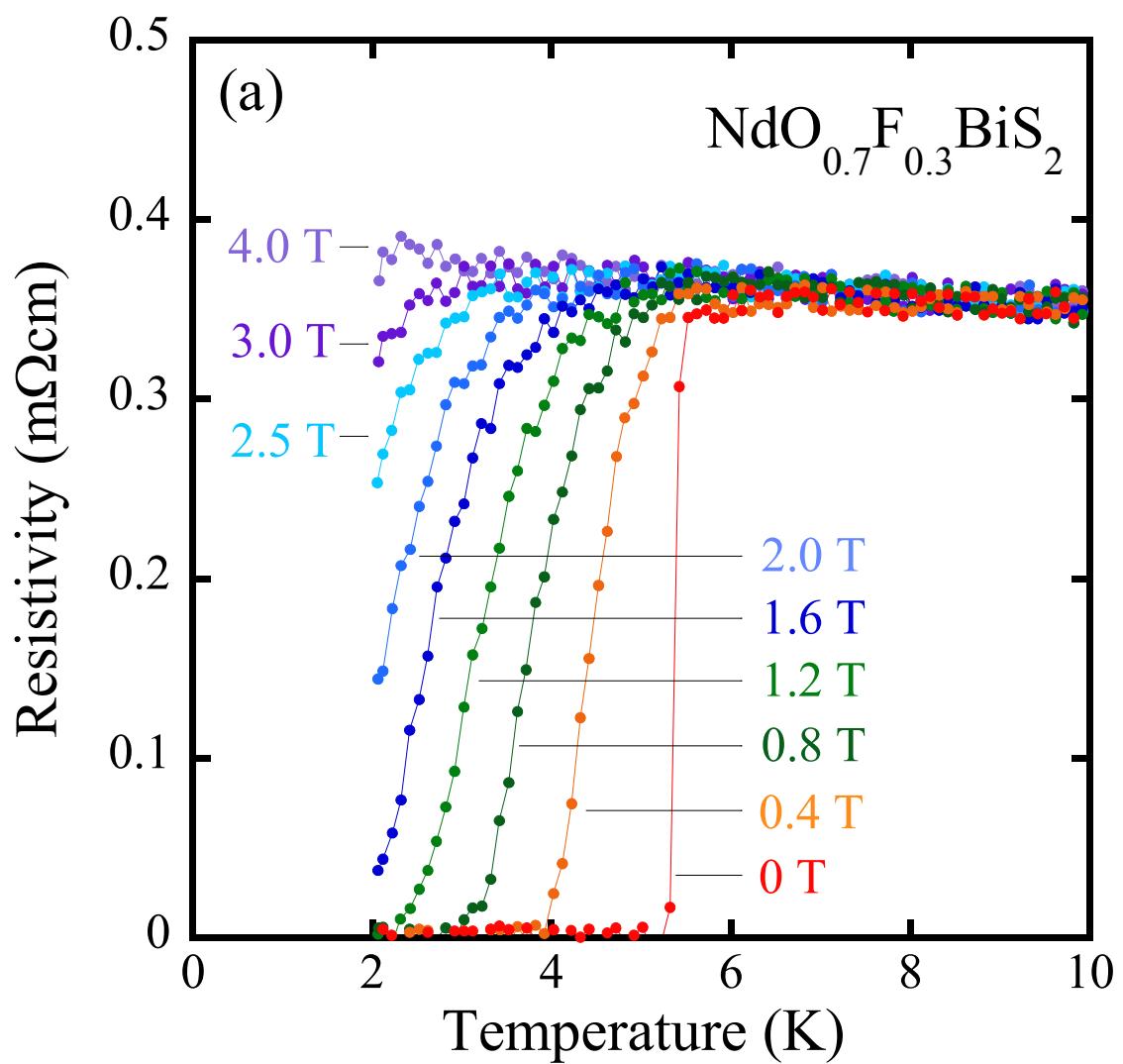


Fig. 4 S. Demura

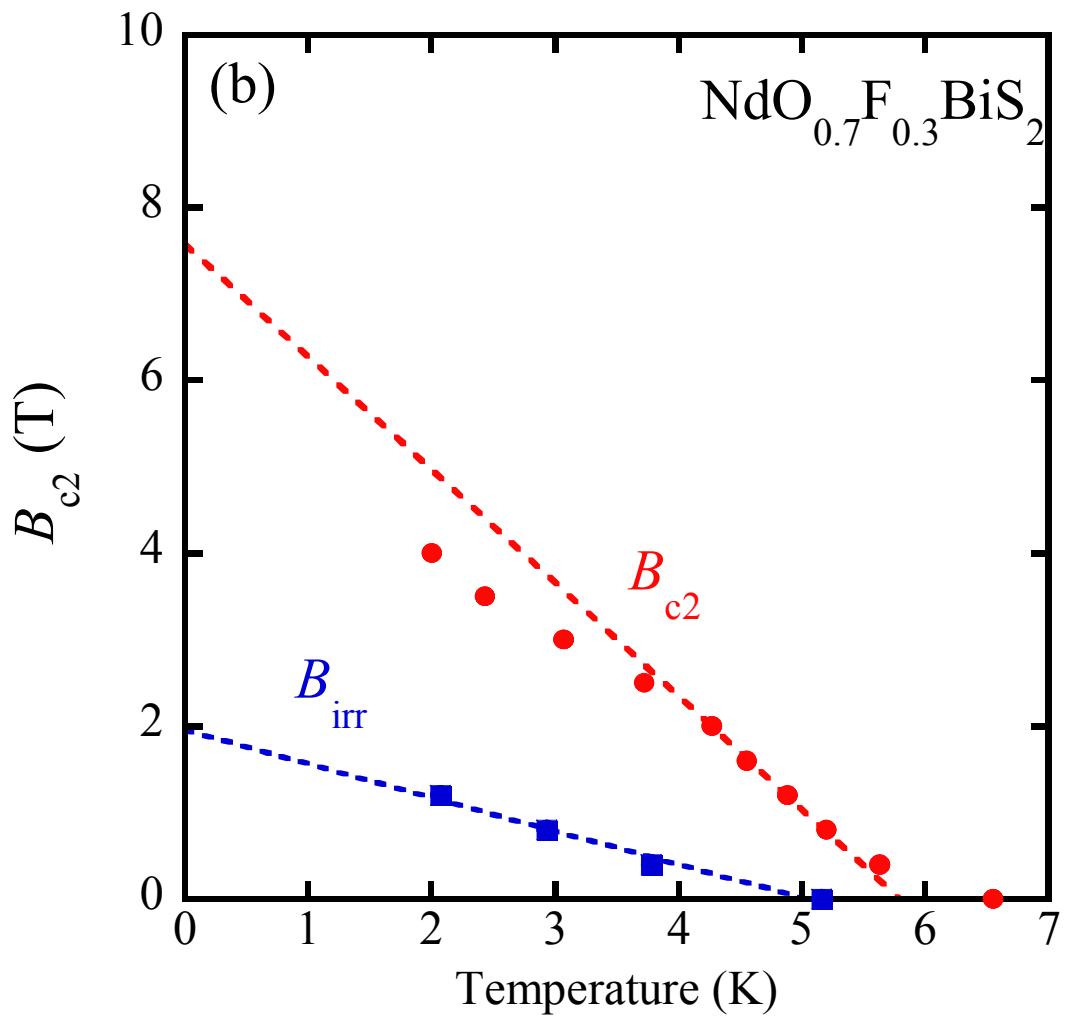


Fig. 4(b) S. Demura