Superconductivity in SmFe1-xCoxAsO (x=0.0-0.30)

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Abstract
We report synthesis, structural details, and magnetization of SmFe$_{1-x}$Co$_x$AsO with x ranging from 0.0 to 0.30. It is found that Co substitutes fully at Fe site in SmFeAsO in an isostructural lattice with slightly compressed cell. The parent compound exhibited known as the spin density wave (SDW) character is below at around 140 K. Successive doping of Co at Fe site suppressed the SDW transition for x=0.05 and later induced superconductivity for x=0.10, 0.15, and 0.20, respectively, at 14, 15.5, and 9 K. The lower critical field as seen from magnetization measurements is below 200 Oe. The appearance of bulk superconductivity is established by wide open isothermal magnetization M(H) loops. Superconductivity is not observed for higher content of Co, i.e., x >= 0.30. Clearly the Co substitution at Fe site in SmFe$_{1-x}$Co$_x$AsO diminishes the Fe SDW character, introduces bulk superconductivity for x between 0.10 and 0.20 and finally becomes nonsuperconducting for x above 0.20. The Fe$^{2+}$ site Co$^{3+}$ substitution injects mobile electrons to the system and superconductivity appears; however direct substitution introduces simultaneous disorder in superconducting FeAs layer and thus superconductivity disappears for higher content of Co.

Keywords
Superconductivity, smfe1, xcoxaso

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Superconductivity in SmFe_{1-x}Co_xAsO (x=0.0–0.30)

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II. EXPERIMENTAL DETAILS

Polycrystalline SmFe_{1-x}Co_xAsO; x=0.0, 0.15, 0.20, and 0.30 samples were synthesized by single step solid-state reaction method, details are given in Ref. 11.

The x-ray diffraction (XRD) pattern of the compound was taken on Rigaku mini-flex II diffractometer. The resistivity measurements were carried out by conventional four-probe method on a Quantum Design Physical Property Measurement System (PPMS). Heat capacity measurements Cp(T) were also carried out on the same PPMS. The magnetization measurements were carried out on Quantum Design Magnetic Property Measurement System (MPMS).

III. RESULTS AND DISCUSSION

The room temperature XRD pattern for SmFe_{1-x}Co_xAsO samples with x=0.0, 0.15, 0.20, and 0.30 along with their Rietveld analysis are shown in Fig. 1(a). The structure of SmFe_{1-x}Co_xAsO at room temperature for all compositions of x was refined with the tetragonal space group P4/nnm (space-group no. 129). Both Sm and As atoms are located at Wyckoff positions 2c, O is situated at 2a, and Fe/Co are shared at site 2b. Good fits to the reported structural model are observed. It is observed that all main peaks can be well indexed based on the space group P4/nnm, indicating that the studied samples are essentially single phase. Some extra peaks at around 30° and 43° having very low intensity are also seen in the XRD pattern of pure SmFeAsO and...
SmFe_{0.85}Co_{0.15}AsO sample, which are due to the minor presence of SmAs. Another small peak at around 34.5° shows the minute presence of CoAs for SmFe_{0.70}Co_{0.30}AsO sample. The exact final compositions of all the studied samples are not determined. Detailed compositional, structural, and microstructural analysis on these samples is already underway and will be reported later.

The Lattice parameters for SmFe_{0.9}Co_{0.1}AsO are found to be \( a = 3.9398(7) \) Å and \( c = 8.4639(4) \) Å, while for the parent compound the lattice parameters are \( a = 3.9375(6) \) Å and \( c = 8.5021(4) \) Å. Clearly, Co doping leads to decrement in the c-axis lattice, while the a-axis remains nearly unaltered [Fig. 1(b)]. The decrease in c lattice parameter suggests toward the successful chemical substitution of Co in the trivalence Co^{3+} state at the place of Fe^{2+}. The shrinkage of c-axis suggests the strengthening of interlayer Coulomb attraction, implying the increase in density of negative charge in FeAs layers by the Co doping. The incorporation of Co in the Fe site reduces the cell volume due to contraction of the c-axis lattice constant.

Figure 2(a) shows the temperature dependence of the dc magnetization measured under zero-field-cooled (ZFC) and field-cooled (FC) conditions at 10 Oe for SmFe_{0.85}Co_{0.15}AsO; \( x = 0.10, 0.15, \) and 0.20 samples. The susceptibility becomes negative (diamagnetic) below temperature 14, 15.5, and 9 K for \( x = 0.10, 0.15, \) and 0.20, respectively. This shows that \( x = 0.15 \) possess the highest transition temperature \( T_c \) among the three superconducting samples. The SmFe_{0.70}Co_{0.30}AsO does not show superconductivity in magnetization measurement. The inset of Fig. 2(a) shows M versus H at \( T = 2 \) K for the same. (b) Temperature dependence of magnetic susceptibility M(T) in FC and ZFC conditions for SmFe_{0.85}Co_{0.15}AsO sample. Inset (i) shows the complete magnetization loops M(H) at 2 K for the same and inset (ii) shows the first quadrant of M(H) loop at 2, 5, 7, and 9 K for SmFe_{0.85}Co_{0.15}AsO sample.
Temperature dependence of dc susceptibility of highest $T_c$ SmFe$_{0.85}$Co$_{0.15}$AsO sample is further shown in Fig. 2(b) separately and its magnetization loops at various temperatures of 9, 7, 5, and 2 K are depicted in insets of the same figure. Although transition is broad, the compound undergoes into superconducting state at below 15.5 K. Upper inset shows the first quadrant of M(H) loop at temperature 9, 7, 5, and 2 K for SmFe$_{0.85}$Co$_{0.15}$AsO, where linear response of the Meissner state up to less than 180 Oe is followed by a decrease in magnitude of M with increasing H, as is typical of flux penetration in the vortex state of a type-II superconductor. This gives the lower critical field $(H_c1)$ of around 180 and 50 Oe at 2 and 9 K, respectively. As expected, the $H_c1$ decreases with increase in temperature from 2 to 9K. Lower inset shows the complete M(H) loops for SmFe$_{0.85}$Co$_{0.15}$AsO at 2, 5, and 9 T field in applied fields of 2000 to 2000 Oe. Although wide open loops are seen right up to 9 T field, but with a positive background, which arise from paramagnetic contributions from Sm$^{3+}$, Fe$^{2+}$, and Co$^{3+}$ spins.

The temperature dependence of electrical resistivity $\rho(T)$ in zero field is shown in main panel of Fig. 3 for SmFe$_{0.85}$Co$_{0.15}$AsO sample and inset of Fig. 3 shows the variation in resistivity under magnetic field $\rho(T)$H up to 9 T field. At room temperature the resistivity value is 3.8 m$\Omega$ cm and it decreases with temperature as expected for metallic behavior. Finally at 14 K, the SmFe$_{0.85}$Co$_{0.15}$AsO sample becomes superconducting. The superconducting transition temperature being determined from resistivity measurements as $\rho=0$ is at 14 K; though the diamagnetic transition temperature $(T_{c\text{dia}})$ is slightly higher at 15.5 K, see Fig. 2(a). This is because $T_{c\text{dia}}$ coincides roughly with the superconducting onset. The parent compound SmFeAsO does not show superconductivity and the same rather exhibits the SDW characteristic at around 140 K. $\rho(T)$H measurements reveal that the resistive transitions for this superconducting composition shift to lower temperatures by applying a magnetic field. The transition width for the sample becomes wider with increasing H. If we focus on the temperature at which resistivity becomes negligible ($\rho \rightarrow 0$) we find that rate of decrease in transition temperature with applied magnetic field is 1 K/T {d$T_{c\text{dia}}$/dH ~ 1 K/T} for Co substituted SmFe$_{0.85}$Co$_{0.15}$AsO sample. This value is far less than that of YBCO {d$T_{c\text{dia}}$/dH ~ 4 K/T} and MgB$_2$ {d$T_{c\text{dia}}$/dH ~ 2 K/T} samples; it suggests toward a high value of upper critical field $(H_{c2})$ in these compounds. We can say that oxypnictides are emerging as a new class of high field superconductors surpassing the $H_{c2}$ of Nb$_3$Sn, and MgB$_2$. In fact, FeAs seems surpassing the 100 T field benchmarks of the high-$T_c$ cuprate superconductors.

We observed that by doping the magnetic ion Co$^{3+}$ in the conducting Fe–As plane of SmFeAsO, the SDW state of Fe$^{2+}$ is suppressed and superconductivity is induced by induction of mobile electron carriers in the system. This is unlike the cuprate superconductors, in which substitution of Cu with its neighbors in the periodic table (Ni, Zn, Co, Fe, etc.) in CuO$_2$ plane severely destroys the superconductivity.

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