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High field (14 T) magneto transport of Sm/PrFeAsO

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Abstract

We report high field magneto transport of Sm/PrFeAsO. Below spin density wave transition (T_{SDW}), the magneto-resistance (MR) of Sm/PrFeAsO is positive and increasing with decreasing temperature. The MR of SmFeAsO is found to be 16%, whereas it is 21.5% in the case of PrFeAsO, at 2.5K under applied magnetic field of 14 Tesla (T). In the case of SmFeAsO, the variation of isothermal MR with field below 20 K is nonlinear at lower magnetic fields (3.5 T). On the other hand, PrFeAsO shows almost linear MR at all temperatures below 20 K. The anomalous behavior of MR being exhibited in PrFeAsO is originated from Dirac cone states. The stronger interplay of Fe and Pr ordered moments is responsible for this distinct behavior. PrFeAsO also shows a hump in resistivity (R-T) with a possible conduction band (FeAs) mediated ordering of Pr moments at around 12 K. However, the same is absent in SmFeAsO even down to 2 K. Our results of high field magneto-transport of up to 14 T brings about clear distinction between ground states of SmFeAsO and PrFeAsO.

Keywords

field, 14, t, magneto, transport, sm, high, prfeaso

Disciplines

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High field (14 T) magneto transport of Sm/PrFeAsO

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temperature. The MR of SmFeAsO is found to be 16%, whereas it is 21.5% in the case of PrFeAsO,
at 2.5 K under applied magnetic field of 14 Tesla (T). In the case of SmFeAsO, the variation of
isothermal MR with field below 20 K is nonlinear at lower magnetic fields (<2 T) and it is linear at
moderately higher magnetic fields ($H \geq 3.5$ T). On the other hand, PrFeAsO shows almost linear
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I. INTRODUCTION

Iron based superconducting pnictides have attracted a
lot of interest due to the interplay of multi-band structure of
Fermi surface and anti-ferromagnetism being mediated by
the magnetic Fe ions.[1] To understand the framework of
whether or not Fe pnictides are strongly correlated systems
like cuprates, more needs to be addressed. Since density-
functional theory (DFT) calculations have indicated that the
electron-phonon interaction is too weak to account for high
transition temperatures,[2,3] the strength of the Coulomb corre-
lations could give some information related to the pairing
mechanism in these compounds.[4] Almost each REFeAsO
exhibits a structural phase transition followed by an anti-
ferromagnetic spin-density wave (SDW) magnetic ordering
(T_{SDW}) at around 150 K.[5,6] It is known that the MR is a very
powerful tool to investigate the electronic scattering and the
topology of the Fermi surface. For example, in MgB_2, a large
MR was found which is closely related to the multiband
property.[7] The magnetoresistance can provide information
about Dirac cone states. The Dirac cone state is a novel elec-
tronic state with ideal massless fermion character. It is theo-
retically predicted that Dirac cone states exist in iron
pnictide superconductors via special band folding below the
antiferromagnetic transition temperature[8–10] and is experi-
mentally confirmed in $BaFe_2As_2$.[11–13] Very high transport
mobility leads to a linear relationship between momentum
and energy. This is due to the zero effective mass and the
long relaxation time of the conduction electrons regardless

of impurities and/or various many-body effects.[14] Landau
level (LL) splittings of the Dirac cone states are proportional
to the square root of the external magnetic field H
[$\Delta_n = \pm v_F(heH|n|/\pi)^{1/2}$, where v_F is the Fermi velocity].
Behavior of Dirac fermions under magnetic field is discussed
in Ref. 15 and the energy scale associated with the Dirac fer-
mions is rather different from the ordinary 2D electron gas.
Thus energy scaling makes the LL states thermally stable
even in moderate fields ($H \leq 10$ T).[15] Consequently the low
energy properties of discrete LL states become accessible to
conventional experimental probes, especially in MR
measurements.

It is reported that MR of PrFeAsO and $BaFe_2As_2$ is
linear at lower temperature ranges and at low field,[13,16]
whereas NdFeAsO does not show any linearity.[17] Abrikosov
interpreted the phenomenon of linear MR by considering a
quantum limit where all of the carriers in the Dirac cone
states occupy only the zeroth LL.[18] This situation can be real-
ized in two specific conditions: (1) When Fermi energy E_F of
the system is lower than the LL splitting $\Delta_1 = \pm v_F(heH/\pi)^{1/2}$
between the first and the zeroth LLs. This means that when H
is higher than a critical value $H^*(0)$ at 0 K, all the carriers
can occupy only the zeroth LL. (2) at the finite temperature,
thermal fluctuation (k_BT) should not exceed Δ_1. In such a
quantum limit, MR can no longer be described within the
conventional framework of Born scattering approximation.[13]
Instead MR is directly proportional to $(N_i/en^2)H$. In this sit-
uation the electron density n (Dirac carriers) and the scatter-
ing centers N_i determine the MR.[18] Thus the resulting MR is
linear in relation to H.

In pnictides of *1111* family the phenomena of linear MR
is only observed in PrFeAsO.[16] This shows that the ground
state of PrFeAsO is something different than other members

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of *1111* family.[17] In the present study we tried to investigate the cause behind it. Pr orders anti-ferromagnetically at 12 K in PrFeAsO, whereas Sm orders at around 5 K in SmFeAsO. Earlier, muon-spin relaxation measurements had been made on *RE*FeAsO (*R* = La, Ce, Pr, and Sm) compounds. In case of CeFeAsO considerable interaction between the *RE* and Fe magnetism below the ordering of Fe moments ($T = 140$ K) was found.[19] The resonant scattering experiments showed strong interplay between Fe and Sm magnetism in SmFeAsO.[20] The neutron diffraction studies showed a delicate interplay of Fe and Pr moments in PrFeAsO.[21] In the case of NdFeAsO, a change from *AFM* to *FM* arrangement along the *c* direction below 15 K, accompanied with the onset of Nd *AFM* order below T_{Nd} 6 K, is observed in neutron diffraction study.[22] Thus it is clear that the magnetism of *RE*FeAsO is complex.[19–22]

In the present article we studied the ground state magneto transport properties of arsenides (Sm/PrFeAsO) to unearth some of their complex magnetic peculiarities. Our results of high field (14 T) magneto transport bring out clear distinction between ground states of superconducting arsenides (Sm/PrFeAsO). The details of synthesis conditions are reported in Ref. 6.

II. RESULTS AND DISCUSSION

Figure 1 shows the resistivity versus temperature plots of synthesized SmFeAsO and PrFeAsO samples in zero field. The resistivity decreases slowly down to 200 K, indicating near metallic behavior. A broad turn is observed at around 150 K with a sharp metallic step, which is associated with both the structural phase transition from tetragonal to orthorhombic symmetry and the *SDW* magnetic transition (T_N) of Fe moments.[1] Another broad turn near 70 K is observed which may be due to the impurity phase of RE_2O_3 ($\sim 4\%$). The lower inset of Fig. 1 shows the possible antiferromagnetic ordering of Pr at around 12 K (T_N^{Pr}) in PrFeAsO, which is seen more clearly in its $d\rho/dT$ [see upper inset of Fig. 1]. Interestingly, the same (resistivity step/anomaly) is absent in SmFeAsO down to lowest studied temperature of 2 K.

Figures 2(a) and 2(b) show the dependence of *MR%* with field for SmFeAsO and PrFeAsO, respectively, at various temperatures below 200 K. *MR* is a very powerful tool to investigate the electronic scattering process and the information about the Fermi surface. *MR* is defined as

$$MR\ (H) = \Delta\rho/\rho(0), \qquad (1)$$

where, $\Delta\rho = \rho(H) - \rho(0)$, $\rho(H)$ is the resistivity in applied field H, and ρ_0 is the resistivity at zero field.

The change in *MR* from 200–150 K, is less than 2% even in the magnetic field of 14 T for both samples. With the structural transition and consequent anti-ferromagnetic *SDW* ordering below 150 K, the *MR%* increases rapidly and reaches 16% for SmFeAsO (Fig. 2(a)) and 21.5% for PrFeAsO (Fig. 2(b)) at 2.5 K under applied field of 14 T. In SmFeAsO variation of *MR* with field is non-linear. Though the linearity of *MR* increases with decreasing temperature but at lower fields it remains non-linear even at 2.5 K. The observed variation of *MR* on *H* is linear in H of strength
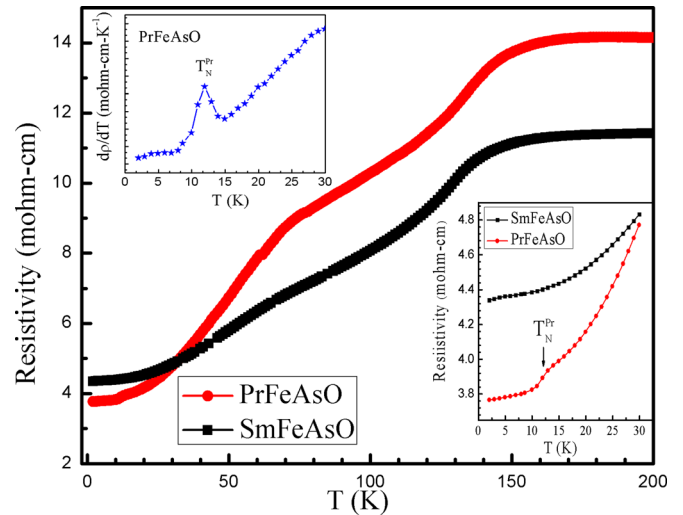

FIG. 1. (Color online) Resistivity curve of the undoped Sm/PrFeAsO samples in zero magnetic field below 200 K. The lower inset shows the resistivity of Sm/PrFeAsO from 30–2 K. The antiferromagnetic ordering of Pr at around 12 K (T_N^{Pr}) in PrFeAsO can be seen. Upper inset shows $d\rho/dT$ of PrFeAsO from 30–2 K.

($|H| \geq 3.5$ T), but changed from a linear to a quadratic relation ($MR \propto H^2$) in lower fields ($|H| \leq 1.0$ T) [Fig. 3(a)] at 2.5 K. Similar behavior of *MR* is observed in $BaFe_2As_2$ but in a different field range.[13]

On the other hand, non-linearity of PrFeAsO disappears below 40 K and a linear variation of *MR* is reported with field.[16] We also found similar behavior in our PrFeAsO sample with maximum *MR* change of 21.5% at 5 K and 14 T. The *MR* versus *H* curve develops a weak negligible
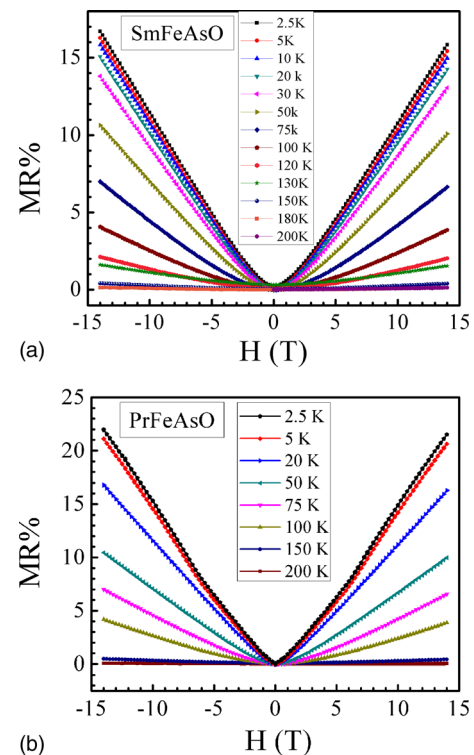

FIG. 2. (Color online) Variation of *MR* with magnetic field (0–14 T) at different temperatures in (a) SmFeAsO. (b) PrFeAsO.

curvature in the low-field region, which indicates a crossover to a quadratic behavior as $H \to 0$. The dependence of *MR* on *H* is linear in field strength $|H| \geq 1.5$ T and changed from a linear to quadratic ($MR \propto H^2$) for lower *H* values ($|H| \leq 0.5$ T) [Fig. 3(b)] at 20 K. The *MR* at 5 and 2.5 K increases linearly at both below and above 6 T but with slightly different slopes [Fig. 3(c)]. This behavior signals a weak metamagnetic transition.[16,23] The linear *MR* for PrFeAsO at lower temperatures can be explained as the inherent quantum limit of the zeroth Landau level (*LL*) of the Dirac cone states in accordance with Abrikosov's model of a quantum *MR*.[13,16,18] It is worthwhile to mention that impurities and/or various many-body effects do not have any impact on this behavior.[14] Our results also support this fact as having almost equal amount of impurities, PrFeAsO shows quantum *MR* while the same is absent in SmFeAsO. Thus it is inherent property of particular compound. In the parent compound of
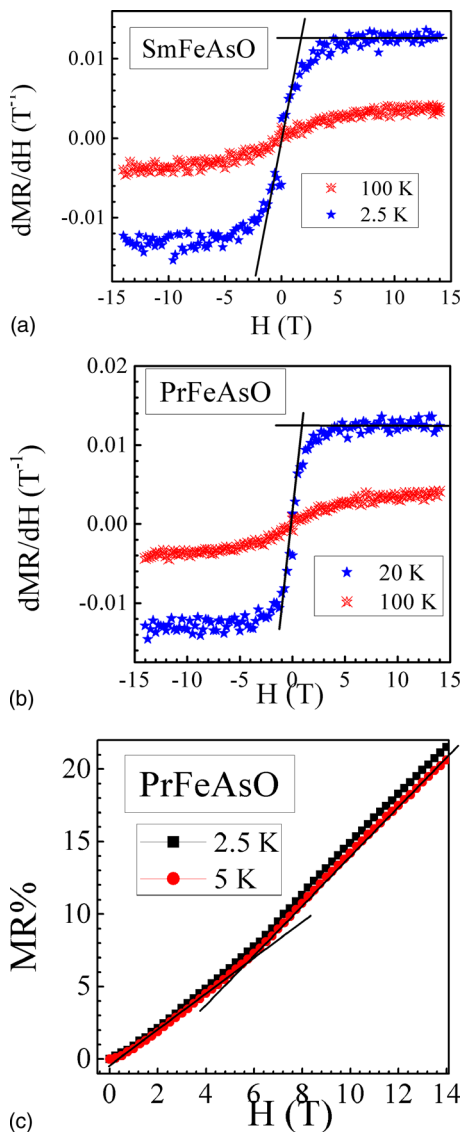
pnictides, a Dirac surface state is created due to the *SDW* band reconstruction and the apex of the Dirac dispersion intersects the Fermi energy, giving rise to electron and hole pockets. In Ref. 13 it is argued that, for PrFeAsO, the carrier density may be high enough to induce the existence of small pocket on the Fermi surface satisfying the quantum condition.

The *MR* behavior of Sm/PrFeAsO below 40 K shows a clear distinction between ground states of different superconducting arsenides. Besides linear *MR*, slightly different slopes are also observed below and above 6 T at 5 and 2.5 K in PrFeAsO [Fig. 3(c)]. The distinct behavior of PrFeAsO can be interpreted with the help of the neutron diffraction data below 40 K of Ref. 21 It is reported that the ordering of Fe moments along the *a* axis starts at around 85 K and reaches a maximum at $\sim$40 K, below which an anomalous expansion of the *c* axis sets in. This expansion results in a negative thermal volume expansion of 0.015% at 2 K. It was proposed that this effect, which is absent in superconducting samples, is driven by a delicate interplay between Fe and Pr ordered moments.[21] The *RE* and Fe moments interplay is also observed in SmFeAsO and NdFeAsO.[20,22] The interaction between two magnetic sublattices is observed at $\sim$110 K for SmFeAsO with $T_N^{Sm} \sim 5$ K and for NdFeAsO ~ 15 K with $T_N^{Nd} \sim 6$ K.[20–22] However T_N^{Pr} is 12 K in case of PrFeAsO. It seems interplay of Fe and Pr ordered moments is stronger than interplay of Fe and Sm/Nd. This interplay leads to a negative thermal volume expansion of PrFeAsO (Ref. 21) and the same is absent in Sm/NdFeAsO. It is argued that some materials behave as a gapless semiconductor at a proper "tuning," e.g., by pressure or doping at a random point in the reciprocal space.[18,24] This leads to a linear energy (momentum) spectrum with the contact of valence band to the conduction band, or slight hybridization of both, leading to the quantum magneto-resistance. Linear *MR* is observed below $\sim$40 K with the occurrence of negative thermal volume expansion in PrFeAsO. The effect is obviously missing in case of SmFeAsO due to lack of negative thermal expansion.

FIG. 3. (Color online) (a) *dMR/dH* at 2.5 K and 100 K; at 2.5 K *MR* exhibits linear *H* dependence for $H \geq 3.5$ T. (b) *dMR/dH* at 20 and 100 K; at 20 K *MR* exhibits linear *H* dependence for $H \geq 1.5$ T. (c) *MR* at 5 and 2.5 K which shows linear increase with *H* up to 6 T and it follows a steeper slope above this field.

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