Synthesis and physical properties of perovskite \( \text{Sm}_{1-x}\text{Sr}_x\text{NiO}_3 \) \((x = 0, 0.2)\) and infinite-layer \( \text{Sm}_{0.8}\text{Sr}_{0.2}\text{NiO}_2 \) nickelates

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Abstract. Recently, superconductivity at about 9-15 K was discovered in \( \text{Nd}_{1-x}\text{Sr}_x\text{NiO}_2 \) \((\text{Nd}-112, x \approx 0.125-0.25)\) infinite-layer thin films, which has stimulated enormous interests in related rare-earth nickelates. Usually, the first step to synthesize this 112 phase is to fabricate the \( R\text{NiO}_3 \) \((R\text{-113}, R: \text{rare-earth element})\) phase, however, it was reported that the 113 phase is very difficult to be synthesized successfully due to the formation of unusual \( \text{Ni}^{3+} \) oxidation state. And the difficulty of preparation is enhanced as the ionic radius of rare-earth element decreases. In this work, we report the synthesis and investigation on multiple physical properties of polycrystalline perovskites \( \text{Sm}_{1-x}\text{Sr}_x\text{NiO}_3 \) \((x = 0, 0.2)\) in which the ionic radius of \( \text{Sm}^{3+} \) is smaller than that of \( \text{Pr}^{3+} \) and \( \text{Nd}^{3+} \) in related superconducting thin films. The structural and compositional analyses conducted by X-ray diffraction and energy dispersive X-ray spectrum reveal that the samples mainly contain the perovskite phase of \( \text{Sm}_{1-x}\text{Sr}_x\text{NiO}_3 \) with small amount of \( \text{NiO} \) impurities. Magnetization and resistivity measurements indicate that the parent phase \( \text{SmNiO}_3 \) undergoes a paramagnetic-antiferromagnetic transition at about 224 K on a global insulating background. In contrast, the Sr-doped sample \( \text{Sm}_{0.8}\text{Sr}_{0.2}\text{NiO}_3 \) shows a metallic behavior from 300 K down to about 12 K, while below 12 K the resistivity exhibits a slight logarithmic increase. Meanwhile, from the magnetization curves, we can see that a possible spin-glass state occurs below 12 K in \( \text{Sm}_{0.8}\text{Sr}_{0.2}\text{NiO}_3 \). Using a soft chemical reduction method, we also obtain the infinite-layer phase \( \text{Sm}_{0.8}\text{Sr}_{0.2}\text{NiO}_2 \) with square \( \text{NiO}_2 \) planes. The compound shows an insulating behavior which can be described by the three-dimensional variable-range-hopping model. And superconductivity is still absent in the polycrystalline \( \text{Sm}_{0.8}\text{Sr}_{0.2}\text{NiO}_2 \).

1. Introduction

The discovery of high critical temperature superconductivity (HTS) in cuprates in 1986 [1] created a new era for research of superconductivity. However, after great efforts by many scientists, there are still a lot of puzzlings about the superconducting mechanism.
of cuprates [2]. One of the effective ways to resolve these puzzlings is to explore other new superconductors which are isostructural and isoelectronic to the cuprates [3, 4]. Considering the proximity of nickel and copper in the periodic table, it is natural to raise the question that whether the cuprate-like electronic structure or even superconductivity could be realized in nickelates. If so, this would help to understand the nature of HTS in cuprates. Early theoretical studies proposed that layered nickelates with square planar NiO$_2$ sheets and the Ni$^{1+}$ oxidation state (supposed to give an S = 1/2 magnetic moment) may be analogous to the parent phase of cuprates. By doping holes into the system, superconductivity like that in cuprate superconductors may be realized in nickelates [5, 6]. And this has come true experimentally in Nd$_{1-x}$Sr$_x$NiO$_2$ (0.125 < x < 0.25) [7, 8, 9] and Pr$_{0.8}$Sr$_{0.2}$NiO$_2$ [10] thin films deposited on SrTiO$_3$ substrates with transition temperatures at about 9-15 K and 7-12 K, respectively. Since the superconductivity in the infinite-layer nickelates was discovered in thin films, it is of great interest to know whether it can be realized in bulk form. However, the recent transport measurements on bulk Nd$_{1-x}$Sr$_x$NiO$_2$ samples show insulating behaviors at both ambient and high pressures [11, 12]. Thus the key question is to know what makes the results in thin films and in bulk samples so contradictory. Since the Nd$_{1-x}$Sr$_x$NiO$_2$ and Pr$_{0.8}$Sr$_{0.2}$NiO$_2$ thin films were grown on SrTiO$_3$ substrates, one plausible explanation is that the substrates may play a crucial role in the emergence of superconductivity [13, 14, 15]. As mentioned by Li et al. [7], the films experience compressive strain on the SrTiO$_3$ substrates. And the smaller lattice constant may be more conducive to superconductivity [16]. Following this idea, it may be a good way to simulate the strain effect of substrates on the films by replacing Nd$^{3+}$ or Pr$^{3+}$ with smaller rare-earth cation Sm$^{3+}$.

Looking back to literatures, it is found that the RNiO$_3$ perovskites have been intensively studied [17, 18, 19, 20, 21, 22, 23] due to their metal-insulator (MI) transitions and paramagnetic-antiferromagnetic transitions. Except for LaNiO$_3$ which has a different crystal structure (rhombohedral) from other RNiO$_3$ and is a paramagnetic metal in the whole measured temperature range [24], RNiO$_3$ perovskites are paramagnetic metals at high temperatures, while they are in an insulating and antiferromagnetic state at low temperatures [25]. For R = Pr and Nd, the MI transition temperature ($T_{MI}$) is the same as the paramagnetic-antiferromagnetic transition temperature ($T_N$) [26]. However, for R = Sm or smaller rare-earth ions, $T_{MI}$ is usually higher than $T_N$. In the region between $T_{MI}$ and $T_N$, RNiO$_3$ are paramagnetic insulators. The value of $T_{MI}$ is strongly dependent on the ionic radius of the rare-earth ions [27]. As the ionic radius decreases, the tolerance factor for stabilizing a regular perovskite structure becomes smaller. The decreased tolerance factor further lead to the reduction of Ni-O-Ni bond angle. Thus the bandwidth which is composed of Ni-3$d$ and O-2$p$ orbitals [28] is also reduced. In this case, the physical properties of RNiO$_3$ can be tuned by a variety of methods such as the displacement of rare-earth elements, chemical doping, pressure, temperature, and so on. For SmNiO$_3$, it has been reported that $T_{MI}$ and $T_N$ are 403 K and 225 K, respectively [19]. And crystal symmetry changes
from the high-temperature orthorhombic structure (space group: Pbnm) to the low-
temperature monoclinic structure (space group: P2\textsubscript{1}/n) [15, 29, 30]. High pressure
studies have shown that the pressure is beneficial to the metallic state and drives the
MI transition temperature to a lower value [31, 32]. Furthermore, due to the difficulty
in the fabrication of bulk samples, previous researches mainly focused on thin films and
heterostructures [15, 25]. To our knowledge, there is no study on the doping effect of
bulk SmNiO\textsubscript{3}. Therefore, it is interesting to know whether it will show some novel
physical properties upon doping in bulk samples.

Motivated by the reasonings above, in this paper, we report the synthesis
and investigation on multiple physical properties of Sm\textsubscript{1−x}Sr\textsubscript{x}NiO\textsubscript{3} (x = 0, 0.2)
and Sm\textsubscript{0.8}Sr\textsubscript{0.2}NiO\textsubscript{3} polycrystalline samples. The powder X-ray diffraction (XRD)
measurements have confirmed the perovskite structures for Sm\textsubscript{1−x}Sr\textsubscript{x}NiO\textsubscript{3} (x = 0, 0.2)
and infinite-layer structure for Sm\textsubscript{0.8}Sr\textsubscript{0.2}NiO\textsubscript{2}. The compositional analyses show that
the Ni occupancy is slightly lower than the nominal value in all three samples and
there is a certain strontium distribution in Sm\textsubscript{0.8}Sr\textsubscript{0.2}NiO\textsubscript{3} and Sm\textsubscript{0.8}Sr\textsubscript{0.2}NiO\textsubscript{2}. For
SmNiO\textsubscript{3}, the paramagnetic-antiferromagnetic transition appears at about 224 K on an
insulating background. Upon Sr doping, Sm\textsubscript{0.8}Sr\textsubscript{0.2}NiO\textsubscript{3} exhibits a metallic behavior
accompanied with a resistivity upturn at low temperatures, which seems to be fitted
fairly well by the picture concerning magnetic Kondo scattering. The magnetization
curves of Sm\textsubscript{0.8}Sr\textsubscript{0.2}NiO\textsubscript{3} show paramagnetic behaviors with a possible spin-glass state
below 12 K. After doing soft chemical reduction from Sm\textsubscript{0.8}Sr\textsubscript{0.2}NiO\textsubscript{3}, we successfully
synthesize Sm\textsubscript{0.8}Sr\textsubscript{0.2}NiO\textsubscript{2} samples. The Sm\textsubscript{0.8}Sr\textsubscript{0.2}NiO\textsubscript{2} shows an insulating behavior
which can be well fitted with three-dimensional (3D) variable-range-hopping (VRH)
model (lnρ ∝ T\textsuperscript{−1/4}) in the whole measured temperature range. There is no sign of
superconductivity above 2 K in the polycrystalline Sm\textsubscript{0.8}Sr\textsubscript{0.2}NiO\textsubscript{2}.

2. Experimental methods

Polycrystalline samples of Sm\textsubscript{1−x}Sr\textsubscript{x}NiO\textsubscript{3} (x = 0, 0.2) were successfully synthesized
under high pressure and high temperature by solid-state reaction method. First, the
precursors Sm\textsubscript{2−2x}Sr\textsubscript{2x}NiO\textsubscript{4} (x = 0, 0.2) were prepared by calcining stoichiometric
amounts of Sm\textsubscript{2}O\textsubscript{3} (99.9%, Alfa Aesar), NiO (99.0%, Alfa Aesar) and SrO (99.9%,
Strem Chemicals) at 1200 °C for 24 h. Then the precursors Sm\textsubscript{2−2x}Sr\textsubscript{2x}NiO\textsubscript{4}, NiO and
KClO\textsubscript{4} (99.0%, Alfa Aesar) were weighed in a molar ratio of 1:1:2, mixed and ground
thoroughly in an agate mortar. Subsequently, the mixture was pressed into pellets and
sealed in a gold capsule. These procedures were carried out in a glove box filled with
purified Ar gas (H\textsubscript{2}O, O\textsubscript{2} <0.1 ppm). The gold capsule with the mixed compounds was
then placed in a BN capsule and heated up to 1000 °C and kept at this temperature for
2 h under the pressure of 2 GPa in a piston-cylinder high pressure apparatus (LPC 250-
300/50, Max Voggenreiter). Then the samples were rapidly cooled to room temperature
in 1 min followed by the release of pressure. The obtained samples were washed with
distilled water to dissolve KCl and unreacted KClO\textsubscript{4}, and then dried.
Figure 1. Powder X-ray diffraction patterns (black circles) and Rietveld refinement fitting curves (red lines) of (a) SmNiO$_3$ and (b) Sm$_{0.8}$Sr$_{0.2}$NiO$_3$. The insets of (a) and (b) show the schematic crystal structures of SmNiO$_3$ and Sm$_{0.8}$Sr$_{0.2}$NiO$_3$, respectively.

The sample Sm$_{0.8}$Sr$_{0.2}$NiO$_2$ was obtained by reacting Sm$_{0.8}$Sr$_{0.2}$NiO$_3$ with CaH$_2$ (98.5%, Aladdin) through a soft chemical reduction method. Appropriate amounts of Sm$_{0.8}$Sr$_{0.2}$NiO$_3$ and 0.1 g of CaH$_2$ powder were pressed into pellets respectively and then sealed in an evacuated quartz tube. Note that the Sm$_{0.8}$Sr$_{0.2}$NiO$_3$ and CaH$_2$ pellets were placed at different positions in the quartz tube to avoid direct contact. The quartz tube was heated to 340 °C at a rate of 10 °C/min and sustained at this temperature for 10 h. We have also tried to reduce SmNiO$_3$ with CaH$_2$ in order to obtain SmNiO$_2$, but failed probably because of the instability of Ni$^{1+}$ oxidation state [12].

The phase identification of the prepared samples was carried out by powder XRD (Bruker D8 Advance) with Cu-Kα radiation and the TOPAS 4.2 software [33] was used to refine the crystal structures by Rietveld analysis [34]. Micrographs of the samples were taken by a scanning electron microscopy (SEM) (Phenom ProX, Phenom World) and the chemical composition analyses were done with an energy dispersive X-ray spectrum (EDS) which is an option of the SEM. The dc magnetization was collected on a vibrating sample magnetometer (PPMS-VSM 9T, Quantum Design). The electrical resistivities of the samples were measured by the standard four-probe method using the physical property measurement system (PPMS 16T, Quantum Design).

3. Results and discussion

3.1. Sm$_{1-x}$Sr$_x$NiO$_3$ (x = 0, 0.2)

3.1.1. Sample characterization Figure 1 shows the powder XRD patterns of (a) SmNiO$_3$ and (b) Sm$_{0.8}$Sr$_{0.2}$NiO$_3$ polycrystalline samples with Rietveld refinements. Except for several minor peaks of NiO impurities, all other peaks belong to the perovskite SmNiO$_3$ and Sm$_{0.8}$Sr$_{0.2}$NiO$_3$ phases which can be well indexed with an orthorhombic unit cell (space group: Pbnm). Their schematic crystal structures have been illustrated
Table 1. Crystallographic data of SmNiO$_3$ and Sm$_{0.8}$Sr$_{0.2}$NiO$_3$ at room temperature.

| formula     | SmNiO$_3$       | Sm$_{0.8}$Sr$_{0.2}$NiO$_3$ |
|-------------|-----------------|-------------------------------|
| space group | $Pbnnm$         | $Pbnnm$                       |
| $a$ (Å)     | 5.3241(6)       | 5.3641(8)                     |
| $b$ (Å)     | 5.4282(2)       | 5.3564(8)                     |
| $c$ (Å)     | 7.5594(7)       | 7.5675(8)                     |
| $V$ (Å$^3$) | 218.4743(9)     | 217.4405(1)                   |
| $\rho$ (g/cm$^3$) | 7.815           | 7.469                         |
| $R_{wp}$ (%)| 4.80            | 3.24                          |
| $R_p$ (%)   | 3.77            | 2.55                          |
| GOF         | 1.10            | 1.11                          |

in the insets of Fig. 1(a) and Fig. 1(b), where the yellow/green, blue and red spheres represent the Sm/Sr, Ni and O atoms, respectively. The perovskite structure is distorted because of the relative small ionic radius of Sm$^{3+}$ cation, and the NiO$_6$ octahedra are tilted for optimizing the Sm-O distances. The corner-sharing octahedra are arranged along three directions of the crystal and Sm$^{3+}$ cations occupy the space between these NiO$_6$ octahedra. The cell parameters obtained from Rietveld refinement profiles are $a = 5.3241(6)$ Å, $b = 5.4282(2)$ Å, $c = 7.5594(7)$ Å for SmNiO$_3$ and $a = 5.3641(8)$ Å, $b = 5.3564(8)$ Å, $c = 7.5675(8)$ Å for Sm$_{0.8}$Sr$_{0.2}$NiO$_3$, which are consistent with previous studies [21, 35, 36]. It can be seen that the lattice constant $c$ expands slightly after Sr doping, which is reasonable since the ionic radius of Sr$^{2+}$ (118 pm) is larger than that of Sm$^{3+}$ (95.8 pm) [37]. The crystallographic parameters and the reliability factors have been listed in Table 1. The small values of $R_{wp}$ and $R_p$ indicate that the fittings are considerably good.

Figure 2 presents the SEM images of (a) SmNiO$_3$ and (b) Sm$_{0.8}$Sr$_{0.2}$NiO$_3$ samples. It can be seen clearly that both samples contain two types of grains, which are the major part of the grains with argentous color and a small amount of dark gray ones. Then we perform EDS analyses to get a deeper understanding of the element composition. We measure 18 spots for both samples randomly, which have been marked by the red crosses in the two images. Note that we prepared the samples in stoichiometry. However, by analyzing the Sr content and Ni occupancy normalized by the concentration of Sm for SmNiO$_3$ and (Sm+Sr) for Sm$_{0.8}$Sr$_{0.2}$NiO$_3$, we find that both of them deviate slightly from the nominal values. Namely, the argentous grains correspond to the composition of SmNi$_{1-\delta}$O$_3$ for SmNiO$_3$ and Sm$_{1-y}$Sr$_y$Ni$_{1-\delta}$O$_3$ for Sm$_{0.8}$Sr$_{0.2}$NiO$_3$, respectively. And the small amount of dark gray grains are NiO, which is consistent with the XRD results. Fig. 2(c) presents the Ni occupancy of different spots for SmNiO$_3$ and Sm$_{0.8}$Sr$_{0.2}$NiO$_3$. 
The Ni occupancy changes slightly and the mean values are about 0.97(4) for SmNiO$_3$ and 0.95(3) for Sm$_{0.8}$Sr$_{0.2}$NiO$_3$. Both values are slightly lower than the nominal one. Note that R. Jaramillo et al. [38] did EDS measurements on SmNiO$_3$ thin films and found the ratio of Sm to Ni is around 1.1 with an error of 0.1 but without the indication of Ni deficiency. Since the accuracy of EDS measurement depends on the calibration of the system, sample morphology and the actual location of the energy spectrum from the calculated elements, there are experimental errors in EDS analysis. Thus, whether there is Ni deficiency in the samples requires further experiments. Fig. 2(d) shows the compositional distribution of Sr content with Gaussian fitting for Sm$_{0.8}$Sr$_{0.2}$NiO$_3$. The Sr content is randomly distributed in Sm$_{0.8}$Sr$_{0.2}$NiO$_3$ and the average value obtained from the fitting is 0.135±0.027, which is close to the nominal value and implies the successful doping of Sr. In addition, the full width at half maximum (FWHM) of the XRD peak at around 26° for Sm$_{0.8}$Sr$_{0.2}$NiO$_3$ is 0.24, which is larger than the value of 0.15 for SmNiO$_3$. The broader peak indicates smaller grains in Sm$_{0.8}$Sr$_{0.2}$NiO$_3$ or the Sr concentration has a distribution in the grains. Since the spot number in Fig. 2(c) is sorted by the increase of Sr content, there is no apparent correlation between Sr content and Ni occupancy among different spots.

3.1.2. Magnetic and electrical transport properties

Figure 3(a) displays the temperature dependences of magnetic moment at the field of 1 T in zero-field-cooling (ZFC) and field-cooling (FC) modes for SmNiO$_3$. As we can see, the magnetic moment increases smoothly with decreasing temperature from 300 K to about 224 K and a small kink is observed at 224 K (see the enlarged ZFC curve in the inset of Fig. 3(a)).
After Sr doping, the magnetic moment of Sm$^{0}$ is unsaturated up to the field of 5 T, which rules out the possibility of ferromagnetic behavior. The small magnetic hysteresis demonstrates a weak ferromagnetic behavior. The weak ferromagnetic behavior at low temperatures seen in $M$-$H$ curves has been also observed in BiNiO$_3$ [28] and PbNiO$_3$ [39], and has been attributed to the canted spins or the magnetic impurity phases. Combined with $M$-$T$ and $M$-$H$ results in Sm$_{0.8}$Sr$_{0.2}$NiO$_3$, the low-temperature magnetization behaviors observed here are more likely related to a spin-glass state. Similar behaviors have been found in Ca-doped Lu$_{1-x}$Ca$_x$MnO$_3$ single crystals.

Figure 3. Temperature dependences of magnetic moment measured in both ZFC and FC modes at 1 T for (a) SmNiO$_3$ and (c) Sm$_{0.8}$Sr$_{0.2}$NiO$_3$. The insets of (a) and (c) show the enlarged view around the paramagnetic-antiferromagnetic transition for SmNiO$_3$ and temperature dependences of magnetic moment in ZFC and FC modes at 100 Oe for Sm$_{0.8}$Sr$_{0.2}$NiO$_3$, respectively. Magnetization hysteresis loops measured at 4 K and 300 K for (b) SmNiO$_3$ and (d) Sm$_{0.8}$Sr$_{0.2}$NiO$_3$. The inset of (d) shows the zoom-in view of the loops at low fields for Sm$_{0.8}$Sr$_{0.2}$NiO$_3$. The small magnetic hysteresis demonstrates a weak ferromagnetic behavior. The weak ferromagnetic behavior at low temperatures seen in $M$-$H$ curves has been also observed in BiNiO$_3$ [28] and PbNiO$_3$ [39], and has been attributed to the canted spins or the magnetic impurity phases. Combined with $M$-$T$ and $M$-$H$ results in Sm$_{0.8}$Sr$_{0.2}$NiO$_3$, the low-temperature magnetization behaviors observed here are more likely related to a spin-glass state. Similar behaviors have been found in Ca-doped Lu$_{1-x}$Ca$_x$MnO$_3$ single crystals.
Figure 4. Temperature dependences of resistivity for (a) SmNiO$_3$ and (b) Sm$_{0.8}$Sr$_{0.2}$NiO$_3$. The inset of (b) shows the logarithmic temperature dependence of resistivity at low temperature for Sm$_{0.8}$Sr$_{0.2}$NiO$_3$.

crystals [40], Mn-doped CaNiGeH [41] and KCr$_3$As$_3$ [42]. But we can not exclude the possibility that the behaviors in our samples are caused by impurities or the canted spins. Further study is needed in order to clarify the origin of the low-temperature magnetization behaviors in Sm$_{0.8}$Sr$_{0.2}$NiO$_3$.

Figure 4 shows the comparison of the temperature dependences of resistivity for (a) SmNiO$_3$ and (b) Sm$_{0.8}$Sr$_{0.2}$NiO$_3$. SmNiO$_3$ exhibits an insulating behavior in the whole measured temperature range from 2 K to 300 K, which is consistent with previous reports [25, 19]. In order to better understand the transport behavior of SmNiO$_3$, we have tried to fit the data with several models, such as the band-gap model ($\ln \rho \propto 1/T$), small-polaron-hopping (SPH) model ($\ln(\rho/T) \propto -1/T$) and 3D VRH model ($\ln \rho \propto T^{-1/4}$) [43], but all failed. We should note that the oxygen nonstoichiometry usually occurs in $RNiO_3$ nickelates due to the instability of Ni$^{3+}$ oxidation state [44]. And the oxygen deficiency in the sample plays an important role in transport properties, just like the cases in cuprates and other nickelates [45, 46, 47, 48]. Furthermore, since the pellets used for resistivity measurements were pressed by powder, the grain boundary is another nonnegligible factor which can affect the transport properties [49]. These factors may lead to the exotic scattering in SmNiO$_3$ polycrystals which can not be understood by present models and is different from that in thin films, in which the insulating behavior can be fitted by the VRH model [50]. In contrast, Sm$_{0.8}$Sr$_{0.2}$NiO$_3$ shows a metallic behavior above 12 K with a resistivity upturn at lower temperatures. As we can see in Fig. 4(b), the $\rho - T$ curve is roughly linear between 12 K and 300 K,
so we attempt to fit the data using the formula $\rho(T) = \rho_0 + AT$ and the fitting result has been depicted by the red line. The fitting result yields $\rho_0 = 12.21 \text{ m}\Omega \text{ cm}$ and $A = 3.68 \times 10^{-2} \text{ m}\Omega \text{ cm K}^{-1}$. The metallic behavior observed here may be caused by hole doping through Sr substitution, and has also been observed in bulk Nd$_{0.8}$Sr$_{0.2}$NiO$_3$ [12]. The low-temperature resistivity upturn can be fitted well by the logarithmic function, namely $\rho \propto \ln T$ (see the inset in Fig. 4(b)), which can be attributed to the magnetic Kondo scattering. In this scenario, partial localized Ni-3d electrons carry magnetic moments which serve as the Kondo-scattering centers and thus result in the scattering of conducting electrons [51, 52, 53]. In addition, the grain boundary may also result in the low-temperature resistivity upturn, since the pellets used for resistivity measurements were pressed by powder.

3.2. Sm$_{0.8}$Sr$_{0.2}$NiO$_2$

3.2.1. Sample characterization Using a soft chemical reduction method, we successfully obtain the Sm$_{0.8}$Sr$_{0.2}$NiO$_2$ polycrystalline samples from the prepared perovskite Sm$_{0.8}$Sr$_{0.2}$NiO$_3$. Figure 5(a) displays the powder XRD pattern of Sm$_{0.8}$Sr$_{0.2}$NiO$_2$ sample with Rietveld refinement. And the inset presents the schematic crystal structure. Except for 2-3 minor peaks of Ni impurities, all other peaks correspond to the infinite-layer Sm$_{0.8}$Sr$_{0.2}$NiO$_2$ phase which can be well indexed with a tetragonal unit cell (space group: P4/mmm). Analogous to the case in our reported Nd$_{0.8}$Sr$_{0.2}$NiO$_3$ samples [11], the low crystallinity (inferred from the relatively low intensity of the XRD peaks) is observed in Sm$_{0.8}$Sr$_{0.2}$NiO$_2$, which is a common feature of soft chemical reduction method [54]. And

Figure 5. Powder X-ray diffraction pattern (black circles) and Rietveld refinement fitting curve (red line) for Sm$_{0.8}$Sr$_{0.2}$NiO$_2$. The inset shows the crystal structure of Sm$_{0.8}$Sr$_{0.2}$NiO$_2$. (b) SEM image of Sm$_{0.8}$Sr$_{0.2}$NiO$_2$. (c) Ni occupancy and (d) compositional distribution of Sr concentration with Gaussian fitting for Sm$_{0.8}$Sr$_{0.2}$NiO$_2$. 
in Fig. 6(b), provide further information about the magnetic behavior. The tail was observed at low temperatures. The magnetization hysteresis loops, shown from the behavior of bulk Nd$_{1}$ T and 3 T. And the two curves are roughly parallel to each other. This is different T. The magnetic moment increases almost linearly with the decrease of temperature at depends on the magnetic moment measured in ZFC mode under the fields of 1 T and 3 T. 3.2.2. Magnetic and electrical transport properties relationship between the Ni occupancy and Sr content. average value obtained from the fitting is 0.165± for Sm$_{0}$[11]. Fig. 5(d) shows the compositional distribution of Sr content with Gaussian fitting profile are $a_{0}$=3.8885(3) Å, $b_{0}$=3.2572(0) Å. The reliability factors and the goodness of fit are $R_{wp}$ = 3.46%, $R_{p}$ = 2.75% and GOF = 1.09. The lattice constants are smaller than those of bulk Nd$_{0.8}$Sr$_{0.2}$NiO$_{2}$, which is reasonable due to the smaller ionic radius of Sm$^{3+}$ than that of Nd$^{3+}$. Fig. 5(b) shows the SEM image of Sm$_{0.8}$Sr$_{0.2}$NiO$_{2}$, which contains the main Sm$_{1-x}$Sr$_{x}$Ni$_{1-8}$O$_{2}$ grains and a small amount of Ni impurities from the EDS analyses. Using the same way as that for Sm$_{1-x}$Sr$_{x}$NiO$_{3}$ ($x$ = 0, 0.2) to analyze the EDS data, we display the Ni occupancy of 18 spots in Fig. 5(c). The mean value of Ni occupancy is 0.96(6), which is close to that in bulk Nd$_{0.8}$Sr$_{0.2}$NiO$_{2}$ [II]. Fig. 5(d) shows the compositional distribution of Sr content with Gaussian fitting for Sm$_{0.8}$Sr$_{0.2}$NiO$_{2}$. The Sr content is randomly distributed in Sm$_{0.8}$Sr$_{0.2}$NiO$_{2}$ and the average value obtained from the fitting is 0.165±0.040. Once again, there is no direct relationship between the Ni occupancy and Sr content. 3.2.2. Magnetic and electrical transport properties Figure 6(a) shows the temperature dependences of magnetic moment measured in ZFC mode under the fields of 1 T and 3 T. The magnetic moment increases almost linearly with the decrease of temperature at 1 T and 3 T. And the two curves are roughly parallel to each other. This is different from the behavior of bulk Nd$_{0.8}$Sr$_{0.2}$NiO$_{2}$ [III], in which a paramagnetic Curie-Weiss tail was observed at low temperatures. The magnetization hysteresis loops, shown in Fig. 6(b), provide further information about the magnetic behavior. The $M-H$
curves show clear S-shaped hysteresis loops, indicating a weak ferromagnetic component in the paramagnetic background. As in bulk Nd_{0.8}Sr_{0.2}NiO_2 [11], the ferromagnetic and paramagnetic component can be attributed to the segregated Ni impurities and the main Sm_{0.8}Sr_{0.2}NiO_2 phase, respectively. The different behaviors of magnetic properties between Sm_{0.8}Sr_{0.2}NiO_2 and Nd_{0.8}Sr_{0.2}NiO_2 may be attributed to the different proportion of Ni impurities in the two samples or the intrinsic properties originated from Sm_{0.8}Sr_{0.2}NiO_2. In current situation, the ferromagnetic moment contributed by the Ni impurity seems to be close to that of the bulk Nd_{0.8}Sr_{0.2}NiO_2, while the low temperature Curie-Weiss term seems to be much smaller, suggesting a smaller paramagnetic contribution in Sm_{0.8}Sr_{0.2}NiO_2. Further study is needed to clarify the origin of the magnetic behaviors in Sm_{0.8}Sr_{0.2}NiO_2.

Figure 6(c) shows the temperature dependence of electrical resistivity for Sm_{0.8}Sr_{0.2}NiO_2. Clearly the sample Sm_{0.8}Sr_{0.2}NiO_2 exhibits an insulating behavior. We have also tried to fit the data using different models in order to reveal the nature of its insulating behavior and find that the \( \rho(T) \) curve can only be well fitted in the whole measured temperature range by the 3D VRH model (shown in Fig. 6(d)), which has also been observed in bulk Nd_{0.8}Sr_{0.2}NiO_2 [11], NdNiO_3 thin films [55] and Nd_{1.67}Sr_{0.33}NiO_4 polycrystals [56]. The VRH conduction indicates a strong localization behavior and usually occurs in disordered or correlated systems [57]. The VRH conduction observed here suggests the existence of disorder and/or strong correlation effect in Sm_{0.8}Sr_{0.2}NiO_2. The insulating behavior may get reasons from grain boundary scattering and disorders in the synthesized samples. There is still no sign of superconductivity in Sm_{0.8}Sr_{0.2}NiO_2.

4. Conclusions

In summary, we have successfully synthesized the perovskite Sm_{1-x}Sr_xNiO_3 (x = 0, 0.2) and infinite-layer Sm_{0.8}Sr_{0.2}NiO_2 polycrystalline samples. From XRD and EDS analyses, the Ni occupancy in all the three samples deviates slightly from the nominal value and the Sr content is unevenly distributed in Sm_{0.8}Sr_{0.2}NiO_3 and Sm_{0.8}Sr_{0.2}NiO_2. The sample SmNiO_3 undergoes an antiferromagnetic transition at about 224 K on an insulating background. However after Sr doping, Sm_{0.8}Sr_{0.2}NiO_3 becomes a metal and a possible spin-glass state is observed below 12 K from the magnetization measurements. The Sm_{0.8}Sr_{0.2}NiO_2 sample exhibits an insulating behavior and superconductivity is still absent in the present compound. These results provide some useful information of the Sm derivative nickelates, and also clues for the realization of superconductivity in bulk nickelates.

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