Contrasting physical properties of the trilayer nickelates \( \text{Nd}_4\text{Ni}_3\text{O}_{10} \) and \( \text{Nd}_4\text{Ni}_3\text{O}_8 \)

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We report the crystal structures and physical properties of trilayer nickelates \( \text{Nd}_4\text{Ni}_3\text{O}_{10} \) and \( \text{Nd}_4\text{Ni}_3\text{O}_8 \). Measurements of magnetization and electrical resistivity display contrasting behaviors in the two compounds. \( \text{Nd}_4\text{Ni}_3\text{O}_{10} \) shows a paramagnetic metallic behavior with a metal-to-metal phase transition \( (T^*) \) at about 162 K, as revealed by both magnetic susceptibility and resistivity. Further magnetoresistance and Hall coefficient results show a negative magnetoresistance at low temperatures and the carrier type of \( \text{Nd}_4\text{Ni}_3\text{O}_{10} \) is dominated by hole-type charge carriers. The significant enhancement of Hall coefficient and resistivity below \( T^* \) suggests that effective charge carrier density decreases when cooling through the transition temperature. In contrast, \( \text{Nd}_4\text{Ni}_3\text{O}_8 \) shows an insulating behavior. In addition, this compound shows a paramagnetic behavior with the similar magnetic moment as that of \( \text{Nd}_4\text{Ni}_3\text{O}_{10} \) derived from the Curie-Weiss fitting. This may suggest that the magnetic moments in both systems are contributed by \( \text{Nd}^{3+} \) ions. By applying pressures up to about 49 GPa, the insulating behavior is still present and becomes even stronger under a high pressure. Our results suggest that the different Ni configurations (\( \text{Ni}^{1+}/2^+ \) or \( \text{Ni}^{2+}/3^+ \)) and the changes of coordination environment of Ni sites may account for the contrasting behaviors in trilayer nickelates \( \text{Nd}_4\text{Ni}_3\text{O}_{10} \) and \( \text{Nd}_4\text{Ni}_3\text{O}_8 \).

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1 Introduction

Transition metal oxides with quasi-two-dimensional layered structures often attract special attention in searching for superconductors with high critical temperature (high-\( T_C \) SCs). The inspiration comes from the discovery of high temperature superconductivity in the copper oxide perovskite \( \text{La}_{2−x}\text{Ba}_x\text{CuO}_4 \) by Bednorz and Müller [1]. Later efforts have led to some success, for example, superconductivity with unconventional properties has been observed in \( 3d/4d \) transition metal oxides \( \text{Na}_x\text{CoO}_2·y\text{H}_2\text{O} \) (\( x \sim 0.35, y \sim 1.3 \)) [2], \( \text{Sr}_2\text{RuO}_4 \) [3] and so on. To find new high-\( T_C \) SCs, one strategy is to design materials in which electronic and structural features are analogous to cuprates [4,5]. Nickel-based oxides have been studied for a long time since nickel and copper are adjacent elements in the periodic table. Theoretical and experimental efforts have been done to search superconductivity in those materials, such as mixed-valent \( \text{Ni}^{1+}/\text{Ni}^{2+} \) nickelates and \( \text{LaNiO}_3/\text{LaMO}_3 \) heterostructures [6,7]. Recently, the observation of superconductivity in Sr-doped \( \text{NdNiO}_2 \) films has been reported [8]

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and many theoretical works have followed up on this issue [9-16]. Although the observation of superconductivity in bulk samples is still lacking up to now [17], the related investigation on layered nickelates, especially on the materials containing Ni$^{1+}$ (3$d^8$) valence state, becomes an important issue in condensed matter physics [12-15].

Rare-earth nickelates with the chemical formula $R_{n+1}Ni_yO_{3n+1}$ ($n = 1, 2, 3$ and $\infty$) belong to the Ruddlesden-Popper (RP) series compounds [18,19]. The structure can be described as the stacking of perovskite blocks ($RNiO_3$)$_n$ and rock salt ($R-O$) layers. In general, the electronic properties of RP-type nickelates are highly dependent on the $n$ values and oxygen nonstoichiometry [20-23]. Among them, the $n = 3$ compounds, namely $R_3Ni_2O_8$ ($R = La, Pr$ and Nd; denoted as: $R4310$) [24-26], have attracted much attention due to the metallic ground state and density-wave-like transition at intermediate temperatures. $R4310$ have been reported to undergo a metal-to-metals transition at temperatures varying from 140 to 165 K with pronounced peak or kink features on the temperature dependences of specific heat, resistivity, and magnetization [22,23,27-29]. The phase transitions at $T^*$ [30] in $R4310$ have been attributed to the charge-density-wave instability [31,32], but the origin is still unclear, and more experimental evidences are needed to distinguish the density-wave-like transition in $R4310$. Moreover, another layered nickelate phase $R_3Ni_2O_8$ ($R = La, Pr$ and Nd; denoted as $R438$) can be obtained by oxygen reduction from perovskite $R4310$ phase [6,33-37]. Each unit cell of $R438$ (Tetragonal; space group: I4/mmm) consists of three-square-like NiO$_2$ planes separated by $R^+$ cations, which results in a structural arrangement similar to that of some cuprates, like La$_2$Ca$_2$Cu$_2$O$_{8}$ [38]. Unlike $R4310$, the physical properties of $R438$ vary greatly with different rare-earth elements. For example, La$_2$Ni$_2$O$_8$ exhibits insulating behavior and undergoes a semiconductor-insulator transition at about 105 K [36]. NMR study reveals the presence of antiferromagnetic order below 105 K [39]. Some theoretical works have been put forward to explain the electronic and magnetic behaviors of La$_2$Ni$_2$O$_8$, but the origin of the transition is still unsettled [6,36,40,41]. However, another $R438$ series compound $Pr_3Ni_2O_8$ was reported to have a metallic ground state without the feature of phase transition from crystal structure and specific heat measurements [33]. Nonetheless, the detailed studies on other $R438$ type compounds, such as Nd$_2$Ni$_2$O$_8$, are still lacking. More importantly, the averaged valence of Ni in $R438$ is +1.33, which is very close to the valence state of Ni in the reported superconducting nickelate Nd$_{1-x}$Sr$_x$NiO$_2$ thin films [8]. Thus, it is interesting to know whether the superconductivity can also be realized in $R438$, especially Nd$_2$Ni$_2$O$_8$.

In this paper, we focus on the structures and physical properties of the trilayer nickelates Nd$_4$Ni$_2$O$_{10}$ (Nd4310) and Nd$_2$Ni$_2$O$_8$ (Nd438). By using a high temperature solid state reaction and subsequent low temperature topochemical reduction method, we successfully synthesize the title compounds. The magnetic susceptibilities of both samples show a Curie-Weiss behavior. In Nd4310, hole-type charge carriers are confirmed from Hall effect measurements and a significant reduction of carrier concentration below the transition temperature ($T^*$) around 162 K is observed. However, Nd438 exhibits an insulating behavior without any clues of phase transition, which is different from the reported La$_2$Ni$_2$O$_8$ and Pr$_2$Ni$_2$O$_8$ [33,36]. The study of electrical resistance under high pressures indicates absence of superconductivity up to 49 GPa above 2 K, but an enhancement of insulating behavior under high pressures is observed.

2 Materials and methods

Polycrystalline samples of Nd$_4$Ni$_2$O$_{10}$ were synthesized by a two-step solid state reaction at high temperatures with flowing oxygen. First, a stoichiometric mixture of high-purity Nd$_2$O$_3$ (Aladdin; purity: 99.99%) and NiO (Aladdin, purity: 99.9%) were weighed and ground thoroughly in an agate mortar under argon atmosphere. Then we pressed the mixture into pellets and sintered the pellets at 1000°C for 24 h. At last, the sintered pellets were reground, pelletized, and sintered at 1100°C for one week with several intermediate regrounding and pressing processes, and eventually the single phase Nd$_4$Ni$_2$O$_{10}$ samples are obtained. Note that all sintering processes were performed in an oxygen atmosphere with an oxygen pressure of about 0.1 MPa. The samples of Nd$_2$Ni$_2$O$_8$ were prepared via a topochemical reduction process from Nd$_4$Ni$_2$O$_{10}$ using CaH$_2$ as a reducing agent. Three molar additions of CaH$_2$ and one molar of Nd$_2$Ni$_2$O$_8$ were ground and pelletized in a glove box, and sealed in an evacuated quartz tube. The total mass of the pellet is about 0.1 g. The sealed tube was slowly heated to 280°C and maintained for 20 h. Then the final phase of Nd$_2$Ni$_2$O$_8$ was obtained by washing the CaO byproduct and the residual CaH$_2$ out of the samples with saturated NH$_4$Cl in anhydrous ethanol. The obtained Nd$_2$Ni$_2$O$_8$ samples were in powder form. For resistivity measurements, the powder samples were pressed into a pellet and heat treated at 180°C for 10 h together with another separately placed pellet of CaH$_2$ in an evacuated quartz tube.

The room temperature powder X-ray diffraction (XRD) patterns were collected using the Bruker D8 Advance diffractometer with Cu-K$_\alpha$ radiation. The scan rate was 0.01°/step in the range of 2θ from 10° to 90°. Rietveld refinement fitting [42] was performed by using the TOPAS 4.2 software [43]. The magnetic properties were measured with a SQUID-VSM-7T (Quantum Design). The electronic resistivity was measured with a Physical Property Measurement System (PPMS, Quantum Design), and a standard four-probe
method was used for the ambient pressure resistivity measurements. The Hall resistivity was measured using a six-probe method. The high-pressure electric transports were measured via a four-probe van der Pauw method [44] in a diamond anvil cell (cryo-DACPMS, Almax easyLab), and the ruby fluorescence method was used to determine the values of pressure [45].

3 Results and discussion

3.1 Sample characterization

Figure 1(a) illustrates the crystal structures of Nd4310 (left) and Nd438 (right). Nd4310 crystallizes in the monoclinic symmetry (space group: $P2_1/a$) with distorted NiO$_6$ octahedra in perovskite (NdNiO$_3$) blocks and rock-salt Nd-O layers. The compound Nd438 can be obtained by removing the oxygen atoms from the Nd-O layers in the vertex of NiO$_6$ octahedra and performing structural rearrangement from RP type Nd4310, and crystallizes in the tetragonal structure (space group: $I4/mmm$) [35]. The structure can be described as intergrowth of three corner-sharing square NiO$_2$ planes and $R$$_2$O$_2$ fluorite-type layers, stacking along the c axis. The powder XRD data and relevant Rietveld refinements of Nd4310 and Nd438 are shown in Figure 1(b) and (c). The purity of the Nd4310 and Nd438 phases is confirmed by indexing of all the observed diffraction peaks from XRD data. Two tiny impurity peaks which may arise from segregation phases nickel and NdNi alloy are observed in Nd438, which are shown in Figure 1(c). The impurity phases in Nd438 should originate from the decomposition of Nd4310 or residual NiO which is a common feature in the low temperature reduction process [17,46]. The results of Rietveld fitting and cell parameters of both samples are summarized in Table 1, which are in a good agreement with those in previous reports [29,35,47]. All of these show that our samples are of good quality.

During the reduction process, the apical oxygen atoms of NiO$_6$ octahedra in Nd4310 have been removed or shifted. The removal of apical oxygen will cause the change of the valence state of Ni in Nd438. Thus, we perform bond valence calculations to get more information about the cationic valence or possible charge ordering state. The bond valence sum (BVS) values [48] can be calculated from the equation: $V = \sum \exp[(r_0 - r_i)/B]$, where $r_i$ is the bond length, $r_0$ is 1.654 Å for Ni$^{2+}$–O bonds, 1.574 Å for Ni$^{3+}$–O bonds and 2.105 for Nd$^{3+}$–O bonds, and $B$ is an empirical parameter which is usually determined to be 0.37. The calculated BVS values of Nd4310 and Nd438 are summarized in Table 2. Note that the Ni/Nd site-notations in Table 2 are the same as that in previous reports [29,35]. The BVS results yield that the averaged oxidation state of Ni is +2.57 in Nd4310, which is close to the expected value (+2.6) and consistent with the previous report [29]. However, the averaged oxidation state Ni$^{1.42+}$ in Nd438 is higher than its expected value (+1.33, assuming Nd is +3). Note that from the ref. [37], two different types of defects have been observed in Nd438 through the transmission electron microscopy (TEM) study, which may lead to a slight increase of valence state of Ni in Nd438. Meanwhile, the BVS calculations on the rare earth cation of both materials (2.75 and 2.79 for Nd4310 and Nd438, respectively) reveal the averaged oxidation states of Nd are slightly lower than the formal oxidation state +3. The relatively low valence state for Nd seems to be a common feature especially in the nickelates with infinite-layer structure. The origin of such deviation may be attributed to the development of bonding character upon reduction or strain related effect as proposed in ref. [35]. By the way, a charge inhomogeneity is evident between the inner layer (Ni1/Ni2) and outer layer (Ni3/Ni4) in Nd4310, where the averaged Ni valence in the inner layer is higher than that of the outer layer. However, we do not find any indications for charge

Table 1 Crystallographic data of Nd$_4$Ni$_3$O$_{10}$ and Nd$_4$Ni$_3$O$_8$ at room temperature

| Compound      | Nd$_4$Ni$_3$O$_{10}$ | Nd$_4$Ni$_3$O$_8$ |
|---------------|----------------------|-------------------|
| space group   | $P2_1/a$             | $I4/mmm$         |
| $a$ (Å)       | 5.3614(2)            | 3.9142(9)        |
| $b$ (Å)       | 5.4497(5)            | 3.9142(9)        |
| $c$ (Å)       | 27.399(8)            | 25.296(7)        |
| $\beta$ (°)  | 90.309(3)            | 90               |
| $V$ (Å$^3$)   | 800.57(3)            | 387.58(2)        |
| $\rho$ (g/cm$^3$) | 4.680               | 4.546            |
| $R_{wp}$ (%)  | 4.92                 | 4.45             |
| $R_p$ (%)     | 3.86                 | 3.50             |
| GOF           | 1.04                 | 1.06             |
ordering of Ni\(^{3+}\)–Ni\(^{2+}\)–Ni\(^{3+}\) in Nd4310 and Ni\(^{1+}\)–Ni\(^{2+}\)–Ni\(^{1+}\) in Nd438 from room temperature BVS calculations.

### 3.2 Magnetic and electrical transport properties

In Figure 2(a), we show the data of magnetization and resistivity of Nd4310 to characterize the phase transition at about 162 K. As we can see, the temperature dependence of magnetic susceptibility and resistivity curves indicate a paramagnetic metallic behavior in a wide temperature range and a transition-related anomaly at about 162 K in \(\rho-T\) curve (as shown by the black arrow), which are consistent with previous reports \([24,29]\). It is worth noting that a magnetic susceptibility kink can also be observed as inferred from the \(d\chi/dT\) curve shown in the inset of Figure 2(a), which is consistent with the transition in the \(\rho-T\) curve. We perform the magnetization hysteresis (\(M-H\)) measurements for Nd4310 at temperatures of 10 and 300 K, and present the data in Figure 2(b). The \(M-H\) curves show linear dependence and the magnetization is unsaturated up to \(H=5\) T. The results indicate that the title compound is paramagnetism in nature and do not contain the ferromagnetic component in the measured temperature range. Then we fit the temperature dependence of the magnetic susceptibility curve by the Curie-Weiss (C-W) law \(\chi = \chi_0 + C / (T + T_K)\) in the low temperature (3-40 K) region. The fitting values of Pauli paramagnetism \(\chi_0\) and Curie constant \(C\) are 0.0349 emu mol\(^{-1}\) Oe\(^{-1}\) and 2.62 emu K mol\(^{-1}\) Oe\(^{-1}\), respectively. The effective magnetic moment (\(\mu_{\text{eff}}\)) determined through the fitting is about 4.58 \(\mu_B\) f.u. in Nd4310.

To get a deeper understanding of the density-wave-like transition around 162 K, we show the data of Hall coefficient \(R_{H}\) of Nd4310 at various temperatures in Figure 2(c). The inset of Figure 2(c) shows the raw data of the transverse resistivity \(\rho_{xy}\) at different temperatures. The linear positive values of \(\rho_{xy}\) indicate hole type carriers in whole temperature range. Furthermore, the Hall coefficient \(R_{H}\) around the temperature about 162 K changes significantly. For temperatures below 162 K, the clear temperature dependence of Hall coefficient may be attributed to the multi-band conduction of the charge carriers. The almost constant Hall coefficient (about \(6\times10^{-10}\) m\(^2\) C\(^{-1}\)) above 162 K may correspond to a dominating single band property. Taking all the experimental evidences about the phase transition at \(T^*\) into consideration, including the step-like changes of the cell parameters and specific heat peaks reported by Li et al. \([29]\), the transition around 162 K may be a first-order transition with possible reconstruction of the Fermi surface. The transition in Nd4310 might originate from intertwined spin- and charge-density waves, similar to the case in La\(_2\)Ni\(_3\)O\(_8\) \([49]\). Figure 2(d) shows the field dependence of \(MR\) for Nd4310 at different temperatures. With the application of a magnetic field, a negative \(MR\) is visible below 10 K. The negative \(MR\) increases with decreasing temperature and reaches its maximum \(\Delta\rho/\rho_0 = -1.7\%\) at 2 K with \(H = 5\) T. The sensitive magnetic field dependence of negative \(MR\) may be due to the delocalization or suppression of the Kondo-like scattering, which can lead to the decrease of resistivity under the

![Figure 2](Color online) (a) Magnetic susceptibility and resistivity of Nd\(_3\)Ni\(_2\)O\(_8\) as a function of temperature. Inset shows the enlarged view of \(\chi-T\) curve and the corresponding \(d\chi/dT\) curve from 150 to 175 K. (b) Magnetization hysteresis loops of Nd\(_3\)Ni\(_2\)O\(_8\) at 10 and 300 K. (c) Hall coefficient \(R_{H}\) of Nd\(_3\)Ni\(_2\)O\(_8\) as a function of temperature. Inset shows the \(\rho_{xy}-H\) curves at different temperatures. (d) Magnetoresistance \(\Delta\rho/\rho_0\) as a function of the magnetic field at different temperatures.
magnetic field. These pictures are basically consistent with the resistivity turnup below 50 K in our $\rho$-$T$ data. Note that the low-temperature negative $MR$ behaviors in the present material are different from the reported La$_3$Ni$_3$O$_{10}$ and Pr$_3$Ni$_3$O$_{10}$ [27,28], in which a positive $MR$ is observed below 10 K. Thus, it is possible that the $MR$ behavior in these materials is associated with the magnetism of Nd$^{3+}$ or oxygen nonstoichiometry.

For comparison, we present the temperature dependence of magnetization hysteresis curves for Nd438 under different magnetic fields (1 and 3 T) in Figure 3(a). The magnetization increases with decreasing temperature and demonstrates a para-magnetic behavior in the whole temperature region. Combining the magnetization hysteresis curves measured at different temperatures shown in Figure 3(b), we can separate a ferromagnetic component from the paramagnetic background which should come from the ferromagnetic impurity of nickel. Then we use a similar method as described in the previous report [17] to derive the inherent magnetization of Nd438 by subtracting the $M$-$T$ curve of 1 T from that of 3 T. The derived curve is presented in the inset of Figure 3(a). The C-W like temperature dependence of susceptibility curve is similar to its parent compound Nd4310, but different from the brother compound La$_3$Ni$_3$O$_{10}$ in which a field dependent sharp drop of magnetization at low temperatures is observed. We also use the C-W law to fit the $\chi_T$ curve in low temperature region (3-40 K) to analyze the magnetic behavior of Nd438. The fitting values of Pauli paramagnetism $\chi_0$ and Curie parameter $C$ are 0.0466 emu mol$^{-1}$ Oe$^{-1}$ and 1.95 emu K mol$^{-1}$ Oe$^{-1}$, respectively. And the effective magnetic moment ($\mu_{eff}$) determined through the fitting is about 3.95 $\mu_B$/f.u. in Nd438. The fitting result of Nd438 is similar to that of parent compound Nd4310. The relatively large value of $\mu_{eff}$ may suggest that the magnetic moments in both systems are contributed by the Nd$^{3+}$ ions.

Figure 3(c) presents the resistivity of Nd438 as a function of temperature at zero field. The result reveals an insulating behavior in the temperature range from 2 to 300 K, with a room temperature resistivity about 3.4 $\Omega$ cm. Note that the absolute resistivity of Nd438 is similar to Pr$_3$Ni$_3$O$_{10}$ but the electrical transport behaviors are very different. For Pr$_3$Ni$_3$O$_{10}$, the $\rho$-$T$ curve exhibits metallic behavior in the temperature range of 2-300 K [33]. Then we try to fit the electrical transport data to analyze the conduction type of the insulating behavior. Neither band gap model nor variable range hopping model could be used to fit the insulating behavior. Surprisingly, the transport behavior can be well described by a $\log_2\rho-\log T$ relationship in the whole temperature region we measured. To our knowledge, the linear $\log_2\rho-\log T$ behavior can be classified as the multi-phonon hopping (MPH) conduction model [50,51], which indicates that carriers are coupled with both acoustic and optical phonons. As for the origin of insulating behavior in Nd438, it remains unclear yet. The band structure calculations indicate that the material should be a metal [12], but the insulating behavior may be attributed to the possible buckling of the NiO$_2$ square-planar or a hidden antiferromagnetic order inducing band-gap opening at the Fermi level, similar to the case in La$_3$Ni$_3$O$_{10}$ [40,52]. Although the electrical resistivity measurements show an insulating behavior in Nd438, some of the external factors may also affect the resistance behavior and even lead to extrinsic insulating behavior of the sample. One of the causes here is the grain boundary effect, which is always the case in the fragile samples with low density. Another possibility is the incomplete oxygen reduction of the sample during the reduction process with CaH$_2$. In this case, the apical oxygen atoms in the NiO$_6$ octahedra may not be completely removed and a possible intermediate phase of Nd$_3$Ni$_3$O$_{10-x}$ is formed. Moreover, the insulating behavior may also be caused by the topotactic intercalation of hydrogen in Nd438, in which the phase of Nd$_3$Ni$_3$O$_{10-x}$ may be formed during the CaH$_2$ reduction reaction. However, we want to emphasize that, the insulating behavior in our Nd$_3$Ni$_3$O$_{10}$ sample seems to be intrinsic, which is suggested by the missing of any Drude component as inferred from our recent optical reflectance data (not shown here). The field dependence of $MR$ for Nd438 is shown in Figure 3(d). It is evident that the value of $MR$ for Nd438 at 2 K (about $-9\%$ at 5 T) is much larger than that of Nd4310. The larger negative $MR$ in the present Nd$_3$Ni$_3$O$_{10}$ material may be caused by the de-localization of the low-dimensional correlated oxides or Kondo-like scattering.

Figure 4(a)-(c) display the resistance and normalized resistance ($R/R_{300K}$) in semi-logarithmic scale as a function of...
temperature of Nd438 sample from 2 to 300 K at various pressures. The absolute resistance values at room temperature (R_{300K}) decrease continuously with the increase of applied pressure up to 49 GPa as shown by the blue arrowed line in Figure 4(a) and (b). And the R_{300K} as a function of pressure are plotted in Figure 4(d). For pressures below 15.1 GPa, the low temperature resistance (R_{2K}) also decreases with increasing pressure. The pressure-induced enhancement in conductivity at room temperature may be attributed to the modification of the grain boundaries or the narrowing of hopping distance under compression. When the pressure is increased further (above 18.7 GPa), the insulating behavior is still existing and becomes even stronger. Carefully checking the resistance at low temperatures, a crossover of resistance values at different pressures is observed below 50 K. The abnormal upturn trend of resistance at low temperature may indicate that the insulating behavior becomes much stronger when applying a high pressure. We present the curves of normalized resistance versus temperature at various pressures in Figure 4(c) and summarize R_{2K}/R_{300K} versus pressure curves in Figure 4(d). One can see that, the value of R_{2K}/R_{300K} first decreases slightly with the increase of pressure and then increases sharply. At the highest pressure (49.0 GPa) reached in our measurements, the compound Nd438 becomes a strong insulator with the ratio R_{2K}/R_{300K} of about 943. The enhanced insulating behavior of the sample under high pressure above 18.7 GPa may be attributed to the pressure-induced lattice distortions, which is particularly the case for materials with relatively strong spin-orbit interactions. Moreover, pressure-induced structural transition may also be the reason of the unusual increase of R_{2K}/R_{300K} above 18.7 GPa in Nd438. Note that in La$_3$Ni$_2$O$_8$, a structural transition was observed for pressures above 21 GPa [53]. Anyway, our high-pressure resistance measurements reveal the enhancement of insulating behavior in Nd438. However, superconductivity has not been observed in Nd438 under pressures up to 49 GPa.

4 Conclusions

To summarize, we successfully synthesize the trilayer nickels Nd$_4$Ni$_3$O$_{10}$ and Nd$_4$Ni$_3$O$_8$, and conduct detailed experimental investigations through magnetization and resistivity measurements. The magnetization and resistivity data for Nd$_4$Ni$_3$O$_{10}$ indicate paramagnetic metal behavior with a phase transition at about 162 K. A hole-type feature of charge carriers with obvious change of $R_{H}$ around $T^*$ is observed from Hall resistivity measurements. The significantly reduced carrier concentration and strong temperature dependence of $R_{H}$ below $T^*$ indicate a possible reconstruction of the Fermi surface around $T^*$. By using a low temperature topochemical reduction method, we obtained the compound Nd$_4$Ni$_3$O$_8$ with square NiO$_2$ planes. The magnetization and electrical transport measurements reveal a Curie-Weiss like paramagnetic feature and an insulating behavior. The intrinsic electrical resistivity behavior of this compound may still need further check due to the possible grain boundary effect, incomplete oxygen reduction or unexpected Nd$_4$Ni$_3$O$_8$H$_x$ phase. The high-pressure study on electrical resistance of Nd438 shows the robust insulating behavior, and no superconductivity is observed up to 49 GPa above 2 K.

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