Elemental analysis and the impact of Sr substitution on magnetic properties of Nd_{(1-x)}Sr_{(x)}MnO₃ (x = 0; 0.5 and 1) perovskite manganite

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Abstract. The series sample of Nd_{(1-x)}Sr_{(x)}MnO₃ (x = 0; 0.5 and 0.1) has been prepared with sol-gel method. The elemental compound or chemical characterization of Nd_{(1-x)}Sr_{(x)}MnO₃ (x = 0; 0.5 and 0.1) were obtain using Energy Dispersive X-Ray Spectroscopy (EDS). The EDS results show that the elements were all presents in the sample, which also verified that the sample has successfully synthesized. The Vibrating Sample Magnetometer (VSM) was used to measure the magnetic properties of the sample under room temperature. The results show that the material is all soft magnetic with the magnetization decrease as the temperature decrease.

1. Introduction
The research in substituted perovskite structure of rare-earth manganite with general formula A_{1-x}B_xMnO₃ (A = rare-earth and B = alkaline earth) have been investigated extensively due to their unique properties such as critical behavior, magnetoresistance and magnetocaloric effect [1, 2]. Currently, some reports explore the properties of Nd_{(1-x)}Sr_{(x)}MnO₃ perovskite-type manganites with various amounts of substitution [3]. The characteristic of the magnetic behavior of rare-earth perovskite manganite such as NdMnO₃ is also being studied generally [4]. It has attracted much attention because it potentially being the candidate for several technology applications with a lot of advantages such as easy to fabricate, cheap, high in resistivity and chemical stability which bring the possibility to the material to become the magnetic refrigeration in a room temperature [5, 6].

Changing the temperature of heat treatment sample preparation or giving the variant amount of substitution on A-site could tune the magnetic properties of the material [7]. Partially substituting strontium in the parental compound leads to a ferromagnetic phase under room temperature [8]. Divalent alkaline metal such as Sr impacts the magnetic behavior of the perovskite material, which influenced by the double exchange interaction between Mn³⁺ and Mn⁴⁺ [9]. The different value of Curie temperature (Tₖ) was also obtain from Nd_{(1-x)}Sr_{(x)}MnO₃ material [10]. The high value of Tₖ will
be obtained as the amount of substitution increase in the sample [11]. It is also interesting to note that varying the applied magnetic field could also influence the value of $T_C$ [12]. The research still continues to investigate the correlation between the morphology and the properties of the material. In this work, we present a study of elemental and magnetic properties of $Nd_{1-x}Sr_xMnO_3$ ($x = 0; 0.5$ and $1$) that were prepared using sol–gel method.

2. Method

Sol-gel method was used to prepare the sample of $Nd_{1-x}Sr_xMnO_3$ ($x = 0; 0.5$ and $1$). $Sr(NO_3)_2$ (purify ≥ $99.0$ %), $Nd_2O_3$ (purify ≥ $99.0$ %), and $Mn(NO_3)_2.4H_2O$ (purify ≥ $98.5$ %) and $C_6H_8O_7.H_2O$ were used as precursors. All of the materials were calculated by stoichiometry and weighted by digital balance. Before continuing the sol-gel process, neodymium oxide needs to be converted into neodymium nitrate ($Nd(NO_3)_3$) by reacting it with the nitric acid solution. Next, all precursors were dissolved using double distilled water and mixed into the beaker glass with constant stirring and heat treatment until it reached 80 ºC. Ammonium solution was added into the solution to get pH = $7$. The solution were mixed using magnetic stirrer under constant temperature until it changed into gel form. Samples were dried at $110$ ºC and calcined at $600$ ºC, each sample was mashed into powder using a mortar and compacted into a pellet form with 10 tons of pressure for $2$ minutes. Last, sample was sintered for $6$ hours at $1200$ ºC to grow a crystal bonds. The crystal structural and morphological property of the sample was examined using a Scanning Electron Microscope (SEM), Energy Dispersive X-Ray Spectroscopy (EDS) and Vibrating Sample Magnetometer (VSM).

3. Results and Discussion

The samples were characterized by Scanning Electron Microscope (SEM) to identify the morphology of the sample. The grain size of the sample was able to identify using $5.10^3$ magnification. The morphology of the sample obtained from SEM was shown in figure 1, it can be seen that the sample with Sr substitution has the smallest grain among all. It is also in good agreement with previous research [13]. To prove the existence of Nd, Sr, and Mn, the EDS result was shown in figure 2.

![Figure 1](image1.png)

*Figure 1. SEM image at $5.10^3$ magnification of (a) $NdMnO_3$, (b) $Nd_{0.5}Sr_{0.5}MnO_3$ and (c) $SrMnO_3$."

![Figure 2](image2.png)

*Figure 2. The results of EDS Spectra (a) $NdMnO_3$ and (b) $Nd_{0.5}Sr_{0.5}MnO_3$."
The measurement of the composition using EDS was presented in Table 1. It shows the amount of each element that exists in the sample. Every element that was used in the synthesis process were present in the table, it could be stated that the sample has successfully synthesized. Even the results show a different amount of element, at $x = 0.5$ the atomic ratio of Nd was 9.96% and Sr was 8.21% indicated that the amount of strontium successfully substituted into Nd. The different results obtain from EDS results due to its function as semi-quantitative analysis, even the state of the sample itself could not be seen, the different amount of substitution could influence the magnetic properties of the sample.

| Concentration | Element | Weight ratio (wt%) | Atomic ratio (at%) | Total (%) |
|---------------|---------|--------------------|-------------------|-----------|
| $x = 0$       | Nd      | 23.78              | 17.25             | 100       |
|               | Mn      | 55.84              | 16.53             |           |
|               | O       | 20.38              | 66.22             |           |
|               | Nd      | 33.85              | 9.96              |           |
|               | Sr      | 16.95              | 8.21              |           |
| $x = 0.5$     | Mn      | 25.92              | 20.03             | 100       |
|               | O       | 23.28              | 61.79             |           |
|               | Sr      | 43.57              | 18.15             |           |
| $x = 1$       | Mn      | 29.00              | 19.26             | 100       |
|               | O       | 27.43              | 62.59             |           |

The magnetic properties of the sample were identified using Vibrating Sample Magnetometer (VSM). The measurement was performed under room temperature. The results was shown in figure 3, it could be seen that the graph shows decreasing phenomena due to the amount of strontium that was substituted to the NdMnO$_3$.

Figure 3. The graph magnetization in magnetic field ($M$ vs $H$) of Nd$_{1-x}$Sr$_x$MnO$_3$ ($x = 0; 0.5$ and $0.1$) with inset (a) is magnetization of Nd$_{0.5}$Sr$_{0.5}$MnO$_3$, which all performs under the room temperature.

The hysteresis loop of the sample was shown in figure 4. It shows that the material is soft magnetic as the small value coercivity and remanence. The parameter was shown in table 2. Due to limit of VSM equipment then the magnetic saturation of the sample can not be seen under room temperature. All the samples are paramagnetic which in good agreement with the previous results [15, 16].
Figure 4. The hysteresis loop (M vs H) behavior of of Nd\textsubscript{(1-x)}Sr\textsubscript{x}MnO\textsubscript{3} (x = 0; 0.5 and 0.1) and inset (a) is hysteresis loop of Nd\textsubscript{0.5}Sr\textsubscript{0.5}MnO\textsubscript{3}. The measurement are perform under the room temperature.

Table 2. Results of VSM analysis of Nd\textsubscript{(1-x)}Sr\textsubscript{x}MnO\textsubscript{3} (x = 0; 0.5 and 0.1).

| x   | Coercivity (Oe) | Remanence (emu/g) | Magnetization (emu/g) |
|-----|----------------|-------------------|-----------------------|
| 0   | 88.17          | 5.3 × 10^{-2}    | 1.37                  |
| 0.5 | 66.22          | 3.0 × 10^{-2}    | 10.10                 |
| 1   | 288.51         | 6.6 × 10^{-3}    | 0.18                  |

4. Conclusions
The investigation of elemental analysis and magnetic properties sample of Nd\textsubscript{(1-x)}Sr\textsubscript{x}MnO\textsubscript{3} (x = 0; 0.5 and 0.1) has been done on the sample. The sample was successfully synthesized as the results of EDS shows that all the element were presented in the sample. The morphology of the sample that was measured by SEM shows that each sample has a different size of grain which could lead to the different properties of the sample. The magnetic properties of the sample were measured using VSM shows that the sample has a small value of remanence and coercivity which shows that the sample is soft magnetic under room temperature.

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