Analysis Perovskite Material Absorber Based on $Nd_{0.6}Sr_{0.4}Mn_xFe_{1/2(1-x)}Ti_{1/2(1-x)}O_3$ (x = 0, 0.1, 0.2) by Sol-Gel Method

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Abstract. The purposes of this research is to synthesis $Nd_{0.6}Sr_{0.4}Mn_xFe_{1/2(1-x)}Ti_{1/2(1-x)}O_3$ (x = 0. 0.1, 0.2) materials as electromagnetic wave absorber using the sol-gel method. Materials characterized using X-Ray Diffraction (XRD) to determine the phase formed and Vector Network Analyzer (VNA) to determine the ability or strength of absorption of electromagnetic waves. The result of XRD material has a structure orthorhombic with space group P b n m (62-3), the substitution of Mn^{+3} ions on Fe^{+3} ions and Ti^{+4} ions causes a phase change of the material from when x =0 in the absence of Mn^{+3} ions 2 phases are formed, while when Mn^{+3} is substituted 1 phase is formed. The result of VNA with a frequency range of 8 – 12 GHz shows that the material has the ability to absorb electromagnetic waves up to 98,22% at a frequency of 9,5 GHz when x = 0.2. Thus, the material synthesis $Nd_{0.6}Sr_{0.4}Mn_xFe_{1/2(1-x)}Ti_{1/2(1-x)}O_3$ has been successfully synthesized and has the ability to absorb electromagnetic waves.

Keywords: Perovskite, absorber electromagnetic wave, sol-gel.

1. Introduction

Electronic devices used in everyday life can work with high frequencies contained in signal amplifiers with the possibility of having problems with high frequency radiation noise, one example of which is electromagnetic wave interference. To reduce the frequency radiation that occurs, a material that can absorb electromagnetic waves is needed. A modified ferrite-based magnetic material is being developed to be used as an absorber material (Manaf & Adi, 2014)(Nursanni, Putra, & Nastiti, 2021).

Perovskite materials are currently interesting to study because of their unique electrical and magnetic properties. A lot of engineering has been done by substituting an ion in the perovskite material with the aim of getting a material that can be applied to absorb electromagnetic waves (Al-Rabi, Tjahjono, & Saptari, 2020). Perovskite material has the

general formula ABO_3 where A is filled with rare earth elements with a +3 charge such as La^{+3}, Pr^{+3}, Nd^{+3} while B is filled with transition metal ions such as Mn^{+3}, Fe^{+3}, Ti^{+3} (Rizwan et al., 2020)(Angappane, Pattabiraman, Rangarajan, & Sethupathi, 2004)

Electromagnetic wave absorbing materials have been investigated by various materials to find high absorption and wide absorption capacity. Current research focuses on electromagnetic waves in the 8-12Ghz range (Liu, Feng, & Qiu, 2011). As an electromagnetic wave absorbing material, the material needed is a material that has a high permeability and permittivity value so as to produce a material that has a strong absorption. Thus, perovskite material with magnetic material allows it to be used as an absorber material because it has a fairly high saturation value and can be absorbed over a wider frequency range (Ramprecht & Sjöberg, 2007).

Wisnu Ari Adi et al in their research with materials $La_{0.8}Ba_{0.2}Fe_xMn_{1/2(1-x)}Ti_{1/2(1-x)}O_3$ states that the addition of the value of x to the element Fe reduces the resistivity value and reduces the strength of absorption of electromagnetic waves (Adi, Manaf, & Ridwan, 2017). In this research, structural engineering of the perovskite material was carried out by modifying the composition of the material with the aim of knowing how the Nd and Sr if the absorber test. So it can be expected that this Mn doping can affect the increasing permittivity properties (Yunasfi, Rachmawati, Mashadi, Adi, & Arofah, 2018)(Handoko et al., 2018). The synthesis process used in this study used the sol-gel method. The materials was then characterized by using XRD to determine the crystal structure and its parameters and VNA characterization to determine the absorption of electromagnetic waves.

2. Experimental

$Nd_{0.6}Sr_{0.4}Mn_xFe_{1/2(1-x)}Ti_{1/2(1-x)}O_3$ was synthesized by using the sol-gel method. The materials were precursor Nd_2O_3, $Sr(NO_3)_2$, $Mn(NO_3)_2.4H_2O$, Fe_2O_3, TiO_2 by being dissolved each with aquabidest, except Nd_2O_3, Fe_2O_3 and TiO_2 were dissolved with nitric acid (HNO_3) to convert oxide to nitrate. Then all the precursors are mixed together to become a homogeneous solution. The precursor mixture was then stirred and heated on a hotplate to a temperature of 80ºC then the solution was added with ammonia solution until pH value reaching 7 by maintaining a stable temperature and magnetic bar speed, the solution was left for approximately 2 hours so that the water content was reduced. With reduced water, the mixture coagulates to form a gel.

The materials were then dehydrated at 150ºC for 2 hours until the dried gel was obtained. The resulting dried gel was calcined at 600ºC for 6 hours and sintered at 900ºC for 12 hours. The materials were characterized using X-Ray Diffraction (XRD) to determine the base formed and see the crystal microstructure. The XRD data were analyzed using the Rietveld refinement method on GSAS-EXPGUI software with the outputs of phases, crystal structures, lattice parameters, and volumes.

The materials were characterized using Vector Network Analyzer (VNA) to determine the absorption strength of electromagnetic waves. The value of the reflection loss obtained from the VNA test can then be calculated to get the Through Power value, which is the value of the strength of a material to be able to absorb electromagnetic waves.

Calculation of the absorption strength of electromagnetic waves can be calculated using equations (1) and (2).

$$\Gamma = 10^{\left(\frac{-reflection\ loss}{20}\right)} \quad (1)$$

$$Through\ Power\ (\%) = 100\ (1 - \Gamma^2) \quad (2)$$

3. Results and Discussion

3.1. XRD Characterization

Figure 1 shows the material $Nd_{0.6}Sr_{0.4}Mn_xFe_{1/2(1-x)}Ti_{1/2(1-x)}O_3$ was characterized using XRD. The XRD characterization produces a diffraction pattern that shows various phases at each x value.

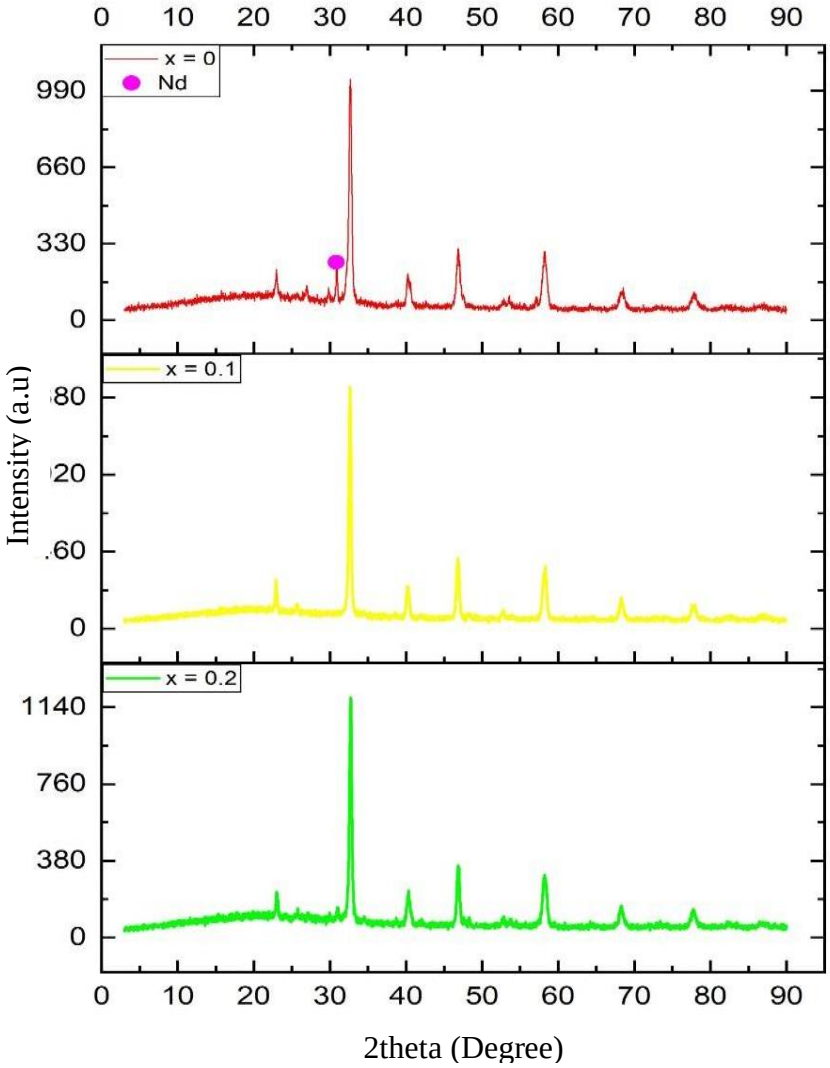

Figure 1. XRD pattern on the material $Nd_{0.6}Sr_{0.4}Mn_xFe_{1/2(1-x)}Ti_{1/2(1-x)}O_3$ (x = 0, 0.1, 0.2)

Figure 1 shows XRD characterization resulted of the diffraction pattern indicating the presence of another phase, namely the Nd phase with a variation of x = 0 according to entry data 96-153-8699 and Nd_2O_3 phase with a variation of x = 0.2 according to entry data 96-101-0280. For x = 0.1 single phase is formed phase $Nd_{0.6}Sr_{0.4}Mn_{0.1}Fe_{0.45}Ti_{0.45}O_3$.

The value of weight fraction for each phase when x = 0 is 99.751% for $Nd_{0.6}Sr_{0.4}Fe_{0.5}Ti_{0.5}O_3$ and 0.249% for Nd, x = 0.2 is 98.161% for $Nd_{0.6}Sr_{0.4}Mn_{0.2}Fe_{0.4}Ti_{0.4}O_3$ and 1.839% for Nd_2O_3.

Table 1. Result of Structure Parameter materials $Nd_{0.6}Sr_{0.4}Mn_xFe_{1/2(1-x)}Ti_{1/2(1-x)}O_3$

Structure Parameters	x = 0	x = 0.1	x = 0.2
Space Group	P b n m (62-3)	P b n m (62-3)	P b n m (62-3)
Structure Crystal	Orthorhombic	Orthorhombic	Orthorhombic
a (Å)	5.48182	5,481009	5,481322
b (Å)	5.53700	5,519561	5,522760
c (Å)	7.76548	7,745495	7,738376
Volume (Å^3)	235.7043	234,323	234,256
Bond Length (Å)	2.095153	1,96148	1,9597
Bond Angle (^{o})	161.688	161,644	161,627
Wt. Fraction	99.751	100	98.161
Average Crystallite Size (nm)	20.8746	21.7720	19.8506
Discrepancy Factors			
Rwp (%)	12.09	11.05	11.54
Rp (%)	9.56	8.78	9.12
Chi Square (χ^2)	1.187	1.023	1.049
Goldschmidt	0.826254	0.78220	0.82299
Phase	$Nd_{0.6}Sr_{0.4}Fe_{0.5}Ti_{0.5}O_3$	$Nd_{0.6}Sr_{0.4}Mn_{0.1}Fe_{0.45}Ti_{0.45}O_3$	$Nd_{0.6}Sr_{0.4}Mn_{0.2}Fe_{0.4}Ti_{0.4}O_3$

Table 2. Structure Parameters of Phase II

Structure Parameters	x = 0	x = 0.2
Space Group	P 63/m m c	P 3 2 1
Crystal Structure	Hexagonal	Hexagonal
a (Å) = b (Å)	3.76464	3.820093
c (Å)	12.35837	5.993174
Volume	151.683818	75.256
Wt. Fraction	0.249	1.839
Phase	Nd	Nd_2O_3

The results of the Table 1 above explain that the material formulation $Nd_{0.6}Sr_{0.4}Mn_xFe_{1/2(1-x)}Ti_{1/2(1-x)}O_3$ (x = 0, 0.1 , 0.2) has an orthorhombic crystal structure indicated by the space groups are Pbnm (62-3). Based on Table 1 the increase of Mn content as a doping ion for Fe and Ti sites did not alter the basic structure . Based on Table 1 the occurrence of substituted Mn^{+3} on materials did not change the basic crystal structure (Saptari, Tjahjono, Winarsih, Prasetyo, & Kurniawan, 2017). The result was supported by the Goldschmidt tolerance factor (t_G) calculated when Mn^{+3} substitution on the Fe and Ti site caused reduction in Mn^{+3} content according to equation (3).

$$t_G = \frac{0.6\, r_{Nd^{+3}} + 0.4\, r_{Sr^{+2}} + r_{O^{-2}}}{\sqrt{2}\,[\,(0.6-x)\, r_{Mn^{+3}} + 0.4\, r_{Mn^{+4}} + x\, r_{Fe^{+3}} + x\, r_{Ti^{+3}} + r_{O^{-2}}]} \quad (3)$$

Debye-Scherrer equation used to calculate the resulting crystallite size in equation (4):

$$D = \frac{0.9\,\lambda}{\beta cos\theta} \quad (4)$$

Where D, λ, and β are crystallite size at the angle of θ, the wavelenght of X-Rays used, the widening of the curve (FWHM) (Saptari et al., 2017). Based on the crystal size of 20.8746 nm for variation x = 0, 21.7220 for variations of x = 0.1, and 19.8506 for

variations of x = 0.2 there is a change in crystal size caused by the addition of Mn elements. According to Azwar Manaf and Wisnu Ari Adi who stated that a good refinement result has a chi-square value between 1-1,3. The chi-square values of 1.187, 1.050, and 1.044 indicate that the results of the refinement have a good match (Manaf & Adi, 2014).

3.2. VNA Characterization

The samples were characterized using a Vector Network Analyzer to determine the strength of the absorption of electromagnetic waves using the frequency of the X band at frequency between 8.0 – 12.0 GHz. Characterization using VNA occurs in the form of S_{11} (reflection coefficient) and S_{21} (transmission coefficient) data from electromagnetic wave sources, but this research only takes the value from S_{11}. The value of RL (Reflection loss) is obtained which describes the ability of a material to absorb electromagnetic waves, as shown in Figure 4.

A very significant increase in absorption strength was obtained because each sample had a wide absorption peak resulting from magnetic resonance. In addition, the increase was caused by an increase in the addition of Mn elements. The results of the deepest peak and the width of the absorption peak can be seen in Table 3. The calculate is through power using equation (1) and (2) .

Table 3. The ability of absorption of electromagnetic waves on the material $Nd_{0.6}Sr_{0.4}Mn_xFe_{1/2(1-x)}Ti_{1/2(1-x)}O_3$

x	*Reflection Loss* (dB)	Frequency (GHz)	Through Power (%)
0	-6.947674	10.86	79.64
0.1	-9.391217	10.96	88.5
0.2	-17.5	9.5	98.22

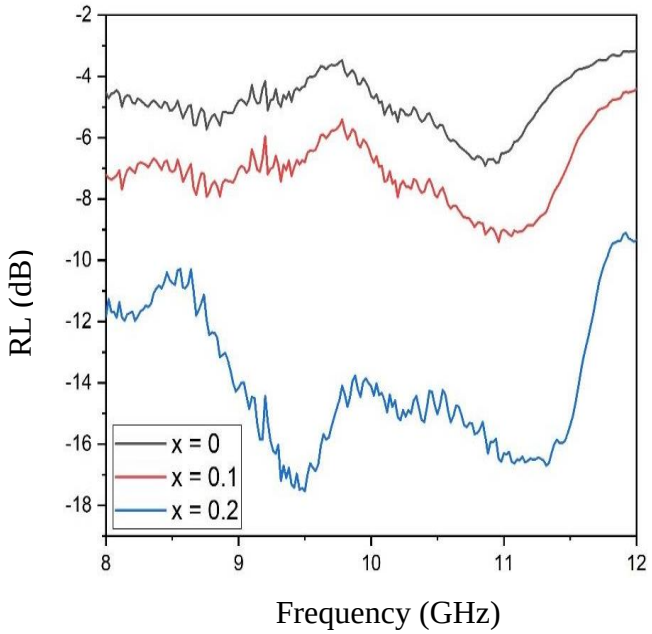

Figure 2. Electromagnetic Wave Absorption Curve on Material

Based on the combined graph of each sample depicted in Figure 3, it is clear that the increase in reflection loss between one sample and another is clearly visible. With the absorption peak width, also known as broadband frequency, there is a great opportunity that the material can be applied as a candidate for absorbing electromagnetic wave materials.

The Figure 4. shows the frequency of microwave absorbing properties of $Nd_{0.6}Sr_{0.4}Mn_xFe_{1/2(1-x)}Ti_{1/2(1-x)}O_3$ with the same thickness, d = 2 mm, for three different samples with (x = 0, 0.1, and 0.2). The reflection loss spectra of materials $Nd_{0.6}Sr_{0.4}Mn_xFe_{1/2(1-x)}Ti_{1/2(1-x)}O_3$ (x = 0, 0.1, and 0.2) in the frequency range of 8 - 12 GHz.

Based on Table 3 reveals the microvabe absorption properties of the $Nd_{0.6}Sr_{0.4}Mn_xFe_{1/2(1-x)}Ti_{1/2(1-x)}O_3$ (x = 0, 0.1, and 0.2). The materials had the highest microwave absorption performance at the reflection loss was -17.5 dB at matching frequency 9.5 GHz with 98.22% through power or microwave. The addition of Mn+3 ions has an effect on the increase in magnetic properties, with one of the requirements for a good electromagnetic wave absorbing material is a material that has high magnetic and electrical properties. This increase in magnetic properties explains that the ability of this material to absorb electromagnetic waves is increasing (Adi, Indro, & Kusumastuti, 2017). The absorption ability is caused by several factors, that is the interaction of double exchange, permeability, and permittivity in the materials.

4. Conclusion

Material $Nd_{0.6}Sr_{0.4}Mn_xFe_{1/2(1-x)}Ti_{1/2(1-x)}O_3$ has been successfully prepared using the sol gel method. Refinement results on XRD characterization show that the material $Nd_{0,6}Sr_{0,4}Mn_xFe_{1/2(1-x)}Ti_{1/2(1-x)}O_3$ has two phases for the sample x = 0 with phase Nd and x = 0.2 with phase Nd_2O_3 but x = 0.1 has single phase. In addition, the material has an orthorhombic structure with a space group P b n m(62-3) which has been adjusted to the calculation of the Goldschmidt tolerance. The results of the VNA characterization showed an increase in the value of the absorption strength due to the addition of Mn elements and the value of the largest absorption strength of the material was found in the sample x = 0.2 with through power is 98.22%.

5. Suggestion

In the next research, it's expected to test using VSM to determine the magnetic properties of the material, using FPP to determine the electrical properties, and using SEM to determine morphology.

References

Adi, W. A., Indro, M. N., & Kusumastuti, A. A. (2017). Effect of Manganese Addition on the Structure , Magnetic Properties and Microwave Absorption of Effect of Manganese Addition on the Structure , Magnetic Properties and Microwave Absorption of La0.8Ba0.2MnxFe1/2(1-x)Ti1/2(1-x)O3. *IOP Conf. Series: Earth and Environmental Science*, *58*, 1–8. doi: 10.1088/1755-1315/5

Adi, W. A., Manaf, A., & Ridwan. (2017). ABSORPTION CHARACTERISTICS OF THE ELECTROMAGNETIC WAVE AND MAGNETIC PROPERTIES OF THE La0.8Ba0.2FexMn1/2(1-x)Ti1/2(1-x)O3 (x= 0.1-0.8) perovskite system. *International Journal of Technology*, *5*, 887–897. doi: http://doi.org/10.14716/ijtech.v8i5.871

Al-Rabi, M., Tjahjono, A., & Saptari, S. A. (2020). Analisis Fasa , Struktur Kristal dan Sifat Kemagnetan Material Komposit Berbasis Nd0.6Sr0.4MnO3 / Fe2O3. *Journal of Materials Science, Geophysics, Instrumentation and Theoritical Physics*, *3*(II), 114–122. doi: http://doi.org/10.15408/fiziya.v3i2.17638

Angappane, S., Pattabiraman, M., Rangarajan, G., & Sethupathi, K. (2004). Electron magnetic resonance study in a single crystal of the colossal magnetoresistance manganite Nd0.5Sr0.5MnO3. *The American Physical Society*, *69*, 1–8. doi: http://doi.org/10.1103/PhysRevB.69.094437

Handoko, E., Sugihartono, I., Fahdiran, R., Jalil, Z., Saptari, S. A., & Mangasi, A. M. (2018). Effects of sintering temperature on structure , magnetic and dielectric properties of La0.5Sr0.5Fe0.9Mn0.05Ti0.05O3 material. *MATEC Web of Conferences*, *197*(02008), 1–5. doi: http://doi.org/10.1051/matecconf/201819702008

Liu, J., Feng, Y., & Qiu, T. (2011). Journal of Magnetism and Magnetic Materials Synthesis , characterization , and microwave absorption properties of Fe – 40 wt % Ni alloy prepared by mechanical alloying and annealing. *Journal of Magnetism and Magnetic Materials*, *323*(23), 3071–3076. doi: 10.1016/j.jmmm.2011.06.073

Manaf, A., & Adi, W. A. (2014). Structural Investigation and Microwave Characteristics of (Ba0.2La0.8)Fe0.2Mn0.4Ti0.4O3 Absorbing Materials. *4th International Conference on Mathematics and Natural Science (ICMNS 2012)*, *252*, 249–252. doi: 10.1063/1.4868793

Nursanni, B., Putra, K. P., & Nastiti, G. (2021). Sintesis dan Karakterisasi Penyerapan Gelombang Mikro pada Komposit PANi - Barium Heksaferrit Tersubstitusi Mn dan Ti - CFO. *Jurnal Pendidikan dan Teknologi Otomotif*, *1*(1), 1–7.

Ramprecht, J., & Sjöberg, D. (2007). BIASED MAGNETIC MATERIALS IN RAM APPLICATIONS. *Progress In Electromagnetics Research*, *75*, 85–117.

Rizwan, M., Usman, Z., Shakil, M., Gillani, S. S. A., Azeem, S., & Jin, H. B. (2020). Electronic and optical behaviour of lanthanum doped CaTiO 3 perovskite Electronic and optical behaviour of lanthanum doped CaTiO 3 perovskite. *Materials Research Express*, *7*(015920), 1–10.

Saptari, S. A., Tjahjono, A., Winarsih, S., Prasetyo, P., & Kurniawan, B. (2017). Effect of Ni-doping on Structure and Morphology of La0.7Ba0.3Mn1-xNixO3 Compounds by Sol-Gel Method. *International Journal of Basic & Appllied Sciences IJBAS-IJENS*, *7*(06), 12–16.

Yunasfi, Rachmawati, I., Mashadi, Adi, W. A., & Arofah, N. (2018). ANALISIS FASA SISTEM Mn(1-x)NdxFe2O4 SEBAGAI KANDIDAT BAHAN PENYERAP GELOMBANG MIKRO. *METALURGI*, *33*(2), 55–60.