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Frequency and Temperature Dependence of Permeability and Magnetic Loss Factor of Mg Substituted Ni Ferrite

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Abstract: *The frequency and temperature dependence of complex permeability (μ^*) and magnetic loss factor ($\tan\delta$) of the series $Ni_{1-x}Mg_xFe_2O_4$ have been presented in this work. The frequency dependent initial permeability for all the samples remains unchanged below 20 MHz which increases with increasing Mg content and becomes a maximum at around 60 MHz for $MgFe_2O_4$. The value of Curie temperature is found from the temperature dependence of initial permeability at constant frequency value of 100 kHz, which decreases with increasing Mg content. The temperature dependent initial permeability remains constant up to 400°C, which decreases with increasing Mg content. From the frequency dependent permeability spectra, it is observed that permeability decreases with increasing Mg content, whereas resonance frequency (f_r) increases which confirms the Snoek's relation $f_r\mu_i$ = constant. This means that there is an effective limit to the product of resonance frequency and permeability so that high frequency and high permeability are mutually incompatible. Magnetic loss factor values decrease gradually to a minimum as the frequency increases and then shows a rising trend with increasing frequency.*

Keywords: *Ni-Mg ferrites; Complex permeability; Magnetic loss factor; Frequency and temperature dependence*

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I. Introduction

Investigation on soft spinel ferrites have become an intensive research work in recent years. Due to their frequency-dependent physical properties such as permittivity and permeability, soft spinel ferrites have significant aspects of potential applications in several electromagnetic devices, especially in the radio frequency region. The polycrystalline form of ferrites, in particular, is being used extensively in many electronic devices since these ferrites are of high permeability in the radio frequency region, high electrical resistivity, mechanical hardness, chemical, thermal and environmental stabilities. A number of experimental and theoretical investigations on the frequency dispersion of complex permeability in polycrystalline ferrite have been reported [1–6]. In last few years, due to the advent of ferrites, important new possibilities such as higher Q's, smaller sizes and also lower costs are among the advantages these new magnetic materials offer. Growing interest in magnetic memory, square loop and microwave applications demands a fundamental understanding and further investigations of Ni-Mg ferrites. However, the selection criteria of a ferrite material for a particular application mainly depend on the basic constituents of its composition and synthesizing techniques. The complex permeability spectra of polycrystalline ferrites depend on both the chemical composition of the ferrite as well as the post sintering density and the microstructure such as grain size, porosity and intra or intergranular pores. These are attributed to the fact that the permeability of polycrystalline ferrite can be described by the superposition of two different magnetizing processes: spin rotation and domain wall motion [1, 6, 7]. In addition, there exists a natural resonance due to the effective anisotropy field which results in magnetic losses. Thus, some limitations (like a threshold frequency) arise in the application of polycrystalline ferrite to radio frequency device. This effect is known as the Snoek’s limit [8]. This limitation rule, as per the available reported works in our reach, has only been qualitatively or semi-quantitatively considered, whereas, the reported works on quantitative studies on the Snoek’s limit is rather rare. Magnesium ferrite ($MgFe_2O_4$) is one of the most important ferrites. It has a cubic structure of normal spinel-type and is a soft magnetic n-type semiconducting material, which finds a number of applications in heterogeneous catalysis, adsorption, sensors and in magnetic technologies [2]. It was found that the permeability dispersion consisted of two different magnetizing mechanisms: domain wall motion resonance and spin rotational relaxation and it was successfully separated using the dispersion parameters according to a numerical method. Domain wall motion resonance was sensitive to both the microstructure of the polycrystalline ferrite (ferrite grain size) and the volume loading of the ferrite (the post sintering Density). The spin rotational relaxation, playing a major role in the frequency range above hundreds of MHz, depended only on the volume loading of the ferrite and the dispersion parameters provided which corresponded to Snoek's law [9]. But it is thought that further studies would be required for more detailed discussion on Snoek's law and the limitations of spinel ferrite in high-frequency devices.

The basic composition of $Ni_{1-x}Mg_xFe_2O_4$ has been selected into which the divalent paramagnetic magnesium ions are doped to study the influence on the complex permeability and magnetic loss factor values. The variations in these values with increasing frequency ranging from 100 kHz–100MHz have been presented in this paper. Moreover, the study of frequency dependence of complex permeability helps to understand the magnetic spectrum of these ferrites with a spinel structure. Some typical compositions of nickel-magnesium ferrites are found to be useful in deflection yokes, switching devices and microwave applications.

II. Experimental

$Ni_{1-x}Mg_xFe_2O_4$ ferrites with x=0.2, 0.4, 0.6, 0.8, 1.0 were prepared using the usual standard double sintering ceramic technique. The used pure oxides NiO, MgO and Fe_2O_3 were mixed according to the compositions $Ni_{1-x}Mg_xFe_2O_4$ and ground in an agate mortar in order to obtain a very fine powder. The powder is calcined at 1100^0C for 3 hours and quenched to room temperature as described in [1]. The pre-sintered ferrite powders were crushed and the resulting powders were mixed with 1 wt.% polyvinyl alcohol (PVA) as a binder and uniaxially pressed into toroid shape at a pressure of 25 kN. The grain density of the samples was found to be 3.05±0.05 g/cc. The compacted toroids were sintered in static air at 1250^0C for 3.5 hours and slowly cooled to room temperature.

The initial permeability, μ_i, calculated from the inductance values measured by an Agilent Impedance Analyzer at room temperature on coil wound toroidal samples with an ac driving field of $\approx 10^{-3}$ Oe. The Curie temperature of the samples was determined from the temperature dependence of initial permeability at a constant frequency (100 kHz) of a sinusoidal wave. Initial permeability of toroid samples having an outer diameter (OD) of 15 mm, inner diameter (ID) of 9 mm and thickness of 3 mm approximately was determined using the experiment described by Heck [10]. About 5 turns of 30 SWG enameled copper wire were wound on the toroids and the inductance, L; was measured at various frequencies (ranging from 100 kHz to 100 MHz) using an Agilent Impedance Analyzer LCR Meter Bridge Model 4294A. The initial permeability was calculated using the relation,

$$\mu_i = \frac{L}{L_0}\text{, where}$$

$$L_0 = 4.6N^2 d\log\left(\frac{OD}{ID}\right)\times 10^{-9}\,H$$

Lo is the air-core inductance, N is the number of turns and d is the thickness of the toroid. All the measurements were carried out at temperature ranges from $27C600^0$ ot pu C^0.

III. Results and discussion

3.1. Complex initial permeability

Fig.1 shows the real and imaginary permeability spectra for $Ni_{1-x}Mg_xFe_2O_4$ samples with x=0.2, 0.4, 0.6, 0.8, 1.0 respectively. The real part of initial permeability value decreases with increasing Mg content in $Ni_{1-x}Mg_xFe_2O_4$ ferrite. The initial permeability as a function of frequency in the range 100kHz-100MHz (upper portion) remains almost constant until the frequency is raised to a certain value, and then began to decrease at higher frequency. For all the samples, the initial permeability remains unchanged below 20 MHz which increases with increasing Mg content and becomes maximum at around 60 MHz for $MgFe_2O_4$. The imaginary part of the permeability (as in lower portion of Fig.1) initially decreases to a minimum value, then gradually increases with frequency, and is reached a broad maximum at a certain frequency, where the real permeability is rapidly decreased, this feature is well known as the natural resonance.

In the magnetic spectra of ferrites, in general, it is observed that the initial permeability remains almost constant up to certain lower range of frequency after which the initial permeability increases to a maximum value in the frequency range 50 to 60 MHz and then decreases rapidly to a very low value. This phenomenon, known as dispersion of initial permeability, is attributed to either domain wall displacements or domain rotation or both of these contributions.

3.2. Relative Quality Factor (RQF)

From the loss factor, the relative quality factor (or Q factor) was calculated for the compositions, as shown in Fig.2. It is seen that the peak value of RQF decreases with increasing Mg content, but all samples show the similar trend in variation with frequency and get a peak at around 10 MHz. For inductors used in filters applications, the quality factor is often used as a measure of performance. According to Snoek's law, the relation between resonance frequency f_R and the initial permeability μ_i for Ni–Zn ferrites may be expressed as,

$f_R = (1/\mu_i)\times 3\times 10^9$ Hz [9]. This indicates that the lower the permeability values, the higher will be the frequencies at which resonance phenomenon occurs. Moreover, the permeability values and hence the resonance frequency depend on the amount and type of dopant ions and the sintering conditions of these samples [11, 12].

3.3. Variation of the initial permeability with temperature

Fig. 3 shows the variation of the initial permeability ($\mu^{/}_{i}$) with temperature T (^{0}C) for all samples. It is found that the curves are typical of multi domain grains showing a sudden drop in at the Neel temperature (T_N). It is determined by drawing a tangent for the curve at the rapid decrease of $\mu^{/}_{i}$. The intersection of the tangent with T-axis determines T_N. It was reported that the sharp decrease of $\mu^{/}_{i}$ with temperature at T_N reflects the homogeneity of the sample which can be expressed as the slope of the linear part ($\partial\mu^{/}_{i} /\partial T$) at T_N.

3.4. Variation of T_N with Mg concentration

The dependence of the Neel temperature (T_N) on the Mg-concentration are shown in Fig. 4. It is clear that the Neel temperature (T_N) of $Ni_{1-x}Mg_xFe_2O_4$ samples decreases with increasing Mg-concentration.

For all the samples except (which is independent up to 200^{0}C) x = 1.0, the real part of permeability is mostly independent of temperature up to 380 ^{0}C. It is observed that the permeability falls sharply when the magnetic state of the ferrite samples changes and after that the permeability becomes smaller i.e. the paramagnetic character. We can precisely say that the transition takes place from ferrimagnetic to paramagnetic at the Neel Temperature (T_N). The vertical drop of the permeability at the Curie point indicates the degree of homogeneity in the sample composition [13, 14]. Further increasing temperature permeability becomes smaller and independent of temperature i.e. paramagnetic behavior. Our samples have showed an excellent degree of homogeneity. Measurement of the initial permeability as a function of temperature can therefore be used as a material characterization of that composition.

IV. Conclusions

The present work has provided a systematic study of dynamic initial permeability, relative quality factor and ferrimagnetic to paramagnetic transition temperature (Neel temperature, T_N) of Mg substituted Ni ferrites. It is observed that with increasing Mg content the limit of high frequency applications increased. Though the T_N decreased with Mg content, it is high enough for $MgFe_2O_4$, T_N = 442 ^{o}C.

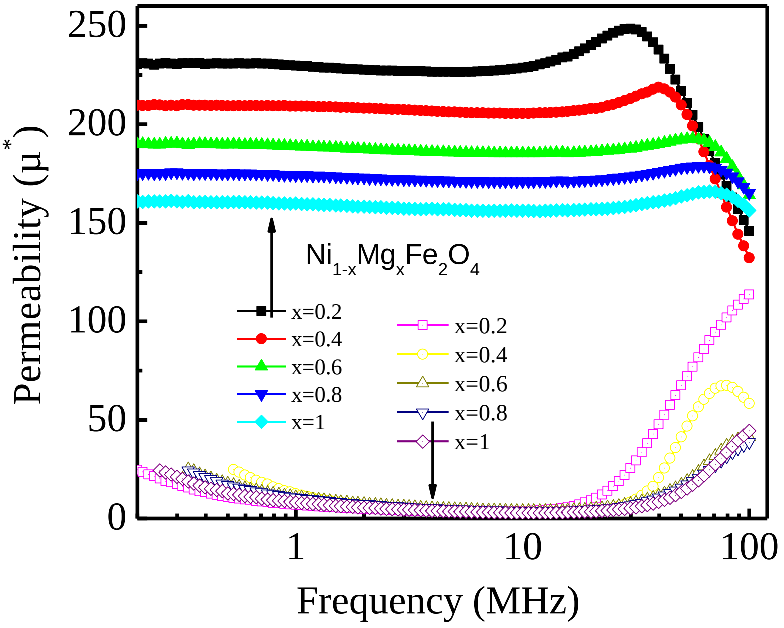

Fig. 1. Variation of μ_i' (upper) and μ_i'' (lower) with frequency for $Ni_{1-x}Mg_xFe_2O_4$.

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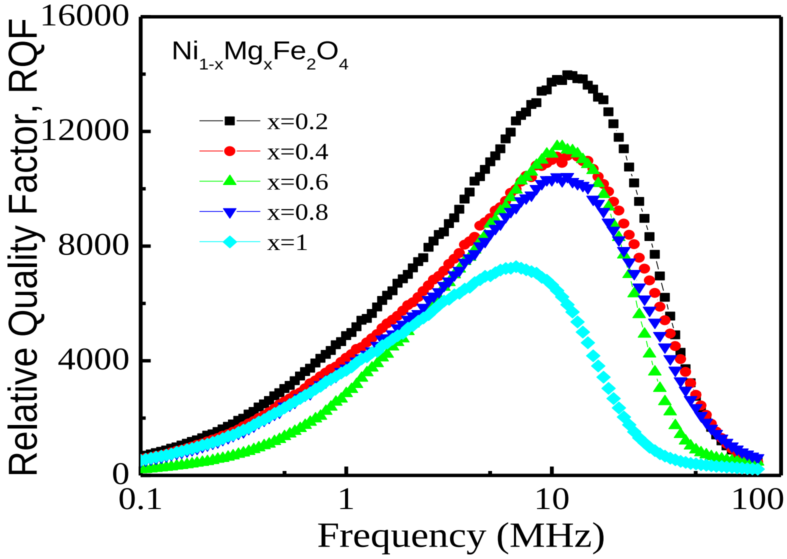

Fig. 2. Variation of RQF with frequency for $Ni_{1-x}Mg_xFe_2O_4$.

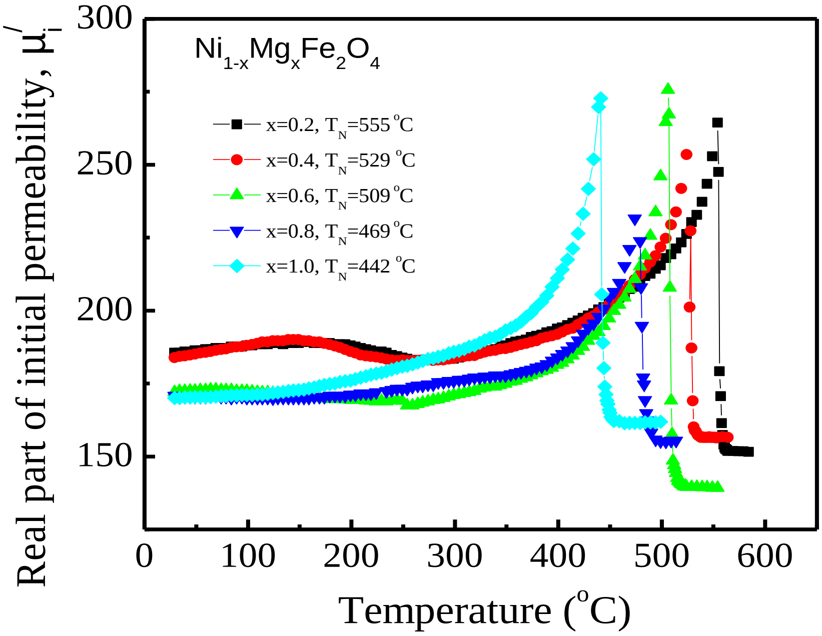

Fig.3. Variation of μ_i' with temperature for $Ni_{1-x}Mg_xFe_2O_4$.

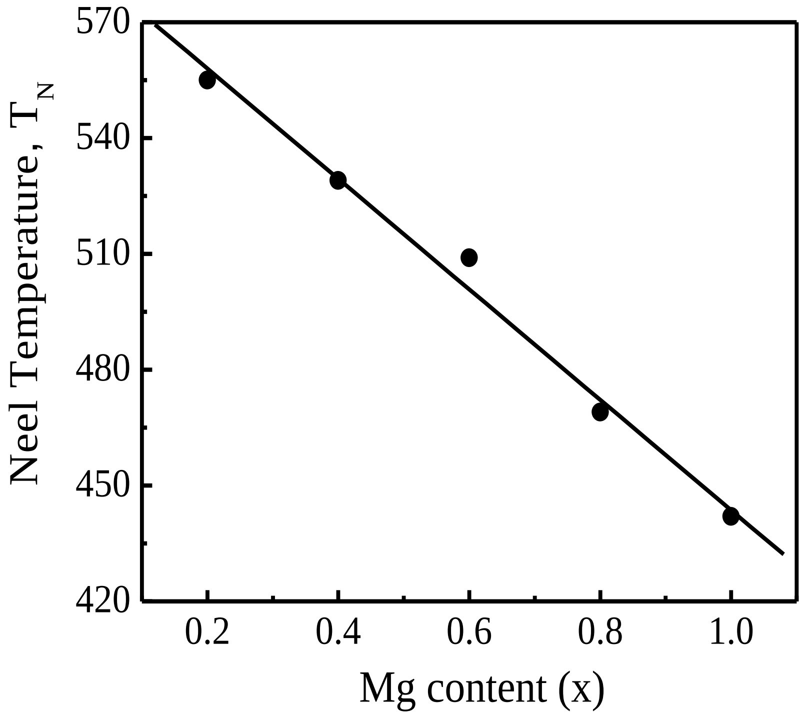

Fig. 4. Variation of T_N with Mg content.

References

[1]. G. T. Rado, Magnetic Spectra of Ferrites, Rev. Mod. Phys. **25**, 81 (1953).

[2]. D. Polder and J. Smit, Resonance Phenomena in Ferrites, Rev. Mod. Phys. **25**, 89 (1953).

[3]. J. Smit and H. M. J. Wijn, *Ferrites* (Phillips Technical Library, Eindhoven, The Netherlands, 1959).

[4]. E. Schloemann, J. Appl. Phys. **41**, 204 (1970).

[5]. A. Globus, J. Phys. France. Colloq. **C1**, 1 (1977).

[6]. J. P. Bouchaud and P. G. Zerah, J. Appl. Phys. **67**, 5512 (1990).

[7]. G.T. Rado, R.W. Wright, W.H. Emerson, Phys. Rev. 80 (1950) 273

[8]. Y. Naito, Proceedings of 1st International Conference on Ferrites, Tokyo, Japan, 1970, p. 558.

[9]. J. L. Snoek, Physica (Amsterdam) **4**, 207 (1948).

[10]. C. Heck, Magnetic Materials and their Applications, Butterworths, London, 1974.

[11]. R.J. Willey, P. Noirclerc, G. Busca, Chem. Eng. Commun. 123, 1 (1993). doi:10.1080/00986449308936161

[12]. Tatsuya Nakamura, J. App. Phy. 88, 1 (2000), p. 348-353

[13]. A. Lakshman, K.H. Rao, R.G. Mendiratta, J. Magn. Magn. Mater. 250 (2002) 92.

[14]. A. Lakshman, Magnetic, electrical, and mossbauer studies of indium and chromium substituted magnesium–manganese ferrites, Ph.D. Thesis, Andhra University, Vishakapatnam, 1996.

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