Pakistan Journal of Applied Sciences 2(11): 1029-1031, 2002

Low Magnetic-Energy Loss Antannae for High Operating Frequencies in the $Ni_{0.76-X}Mg_{0.04+X}Ca_{0.005}Co_{0.1}Cu_{0.075}Zn_{0.04}Fe_{1.96}O_{3.96}$ System

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Abstract: This work is an initial response to the demand for miniaturization of electronic circuits and the shift to higher operating frequencies. Development of high-density and low-magnetic-energy loss in the $Ni_{0.76-X}Mg_{0.04+X}Ca_{0.005}Co_{0.1}Cu_{0.075}Zn_{0.04}Fe_{1.96}O_{3.96}$ system, where x=0.01,0.02,0.03 and 0.04, was carried out. A conventional ceramic processing technique based on solid-state chemical reactions was employed. A hard option, that of using low-grade production oxide powders (≈99.1%) was taken. The microstructure was tailored using CuO as a sintering aid. The formulation employed the Co^{2+} to broaden the operating frequency in the MHz region, Mg^{2+} to increase the electrical resistivity and Ca^{2+} to neutralize the presence of SiO_2 , thus blocking the intergranular eddy currents hoppings. The air sintered (1140°C) material showed small-grain (≈2.3μm) microstructure.

Key Words: Low-Magnetic-Loss, Fine-grained Microstructure

Introduction

The general concern and direction of this study is guided by the push for miniaturization and the fact that many electronic devices are moving towards higher operating frequencies. In order to comply with this demands, ferrite materials with homogeneous and fine-grained microstructure, high density, narrow property tolerances, weak temperature dependencies of losses and reasonable cost of production are essentially required (Suresh and Patil, 1989). However, special attention should be drawn to the magnetic losses, which are the most important factors that govern the properties of any ferrite materials (Tebble and Craik, 1976). It is notable that applications at high frequencies frequently involve small-amplitude and weak signals. Hence the receiving antenna must not dissipate much of it's a.c signal. For low amplitude fields to which this work is confined, the loss can be parametrically represented by a relative loss factor:

$$\mathrm{Tan}\delta/\mu = \mathrm{Tan}\delta_h/\mu + \mathrm{Tan}\delta_e/\mu + \mathrm{Tan}\delta_i/\mu \qquad (1)$$

h, e,i and denote the hysteresis, eddy current and intrinsic loss respectively.

The complexity of the loss problem and the difficulty in reaching a full quantitative understanding of the loss mechanism(s) originate from the varied intrinsic/compositional and extrinsic/microstructure energy-dissipating effects.

Experimental Procedure: The density measurements were done using the Archimedes technique. The resistivity measurements were done after polishing the surface of the samples with Al_2O_3 (0.3μm)and coating them with silver paste. The magnetic measurements were carried out after each sample was wound with 5 turns of 0.3 mm diameter insulating copper wire. The wire ends were scraped by using a sand paper and were then coated with tin to ensure good contact during measurements. The sample was then connected to a Hewlett Packard 4284A Precision LCR meter. A series of inductance, Ls, and Q factor values were recorded from the lowest to resonance frequencies. The initial permeability values were calculated by introducing Ls to the equation below.

$$\mu_i = \frac{2\pi Lp}{N^2\mu_0 t \ln(D_o/D_i)} \qquad (2)$$

Where Ls is the parallel inductance, N is the number of turns, μ_0 is the permeability of free space (4π X 10^{-7} m/A), t the thickness, D_0 the outer diameter, and D_i is the inner diameter and t is the height of the samples.

Relative loss factor data were calculated by introducing equation 1 and Q value in the equation below

$$\text{Relative Loss Factor (RLF)} = \tan\delta/\mu_I \qquad (3)$$

Results and Discussion

The density and resistivity results and variation of RLF, initial permeability and Q-Factor as a function of frequency are shown in Table 1, Fig. 1, Fig. 2 and Fig. 3, respectively.

Table 1: Density and Resistivity Values of Samples N1M1, N1M2, N1M3 and N1M4 with Formula $Ni_{0.76-X}Mg_{0.04+X}Ca_{0.005}Co_{0.1}Cu_{0.075}Zn_{0.04}Fe_{1.96}O_{3.96}$ Measured at Room Temperature

Sample code	X	Density(g/cm^3)	Resistivity (Ω-m)
N1M1	0.01	5.224	86.42
N1M2	0.02	4.922	18.31
N1M3	0.02	4.859	18.56
N1M4	0.04	4.484	20.96

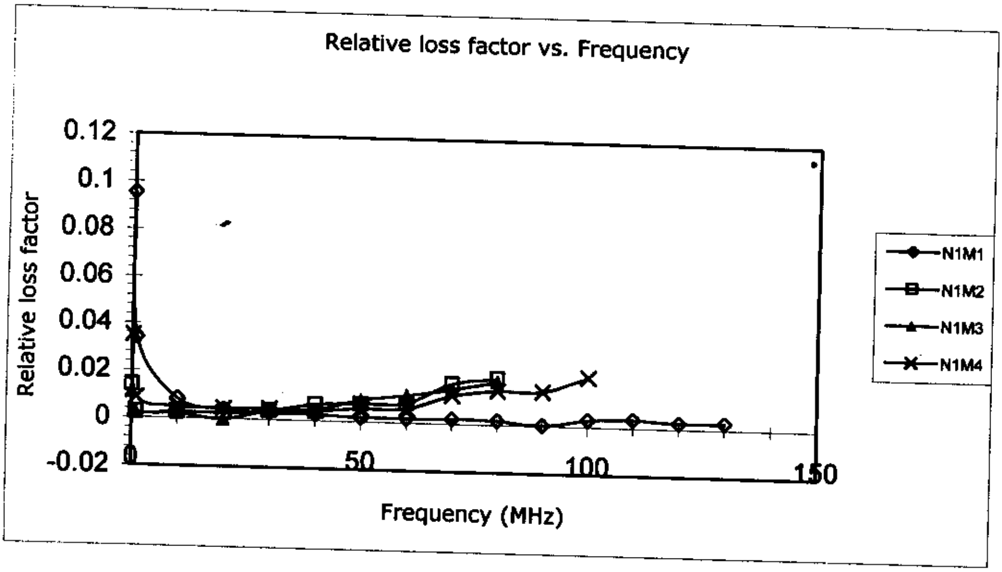

Fig.1: Relative Loss Factor vs. Frequency for Samples N1M1,N1M2, N1M3 and N1M4 Formula $Ni_{0.76-x}Mg_{0.04+x}Ca_{0.005}Co_{0.1}Cu_{0.075}Zn_{0.04}Fe_{1.96}O_{3.96}$ Measured at Room Temperature

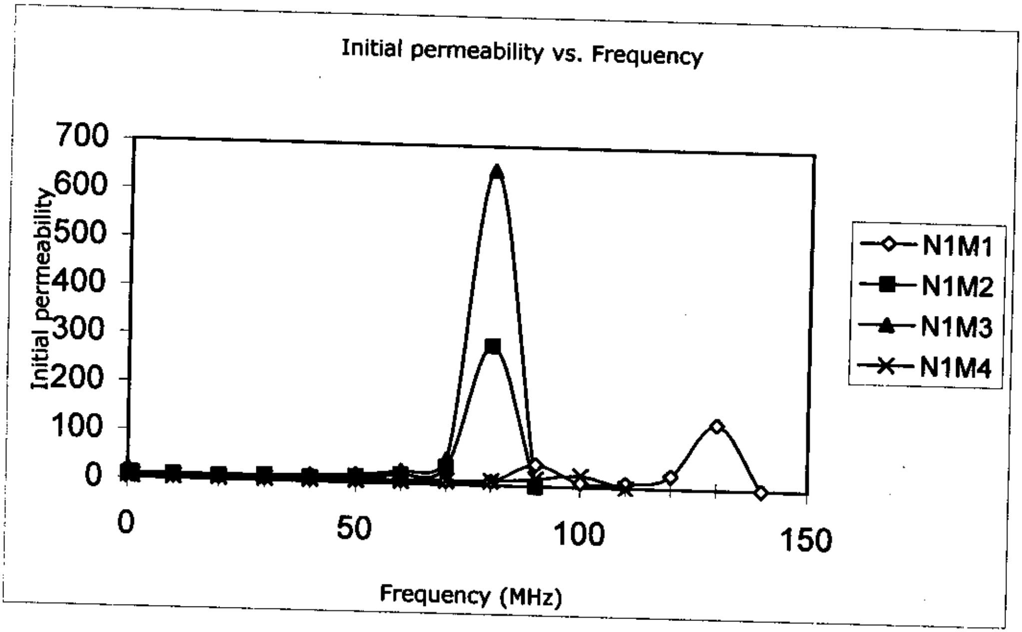

Fig. 2: Initial Permeability vs. Frequency for Samples N1M1,N1M2, N1M3 and N1M4 with formula $Ni_{0.76-x}Mg_{0.04+x}Ca_{0.005}Co_{0.1}Cu_{0.075}Zn_{0.04}Fe_{1.96}O_{3.96}$ Measured at Room Temperature

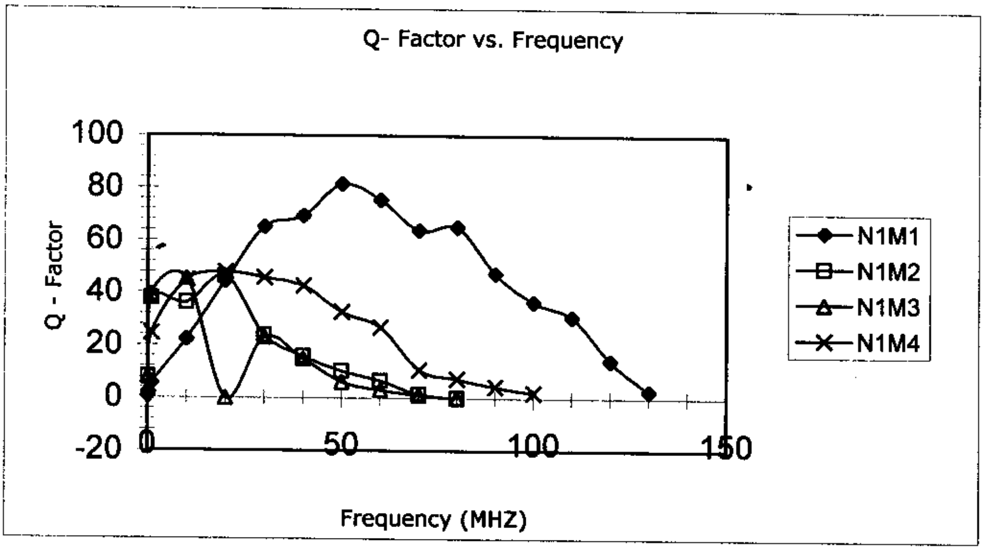

Fig. 3: Q-factor vs. Frequency for Samples N1M1,N1M2, N1M3 and N1M4 with Formula $Ni_{0.76-X}Mg_{0.04+x}Ca_{0.005}Co_{0.1}Cu_{0.075}Zn_{0.04}Fe_{1.96}O_{3.96}$ Measured at Room Temperature

It is obvious that the increase concentration of MgO led to an increased RLF. From Table 1 we observe a fall of resistivity with the increased MgO content. This is not expected, as $MgFe_2O_4$ was known to confer high resistivity for mixed ferrites. A probable explanation is that it was highly difficult to disperse the MgO powder particles which tend to agglomerate, during the mixing stage of the raw materials oxides. Thus, micro-regions of badly non-stoichiometric compositions would be created, giving rise, for instance to Fe^{2+} ions which could contribute to eddy current through $Fe^{2+} \leftrightarrow Fe^{3+}$ + e reaction. Thus, the more MgO added, the lower the resistivity and thus the lower the RLF values. There is a marked shift (to the left) of resonance frequency due to the increment of MgO (Fig. 2).

It is obvious that N1M1 exhibits the widest operating frequency (Figure 3) due to the wide range of Q-factor and the lowest RLF (Fig. 1). Observing Table 1 again, sample N1M1 gave the highest density. This is in accordance with the widest operating frequencies obtained. It is speculated that the movement of magnetic moments was somewhat pinned by the grain boundaries (Okomoto, 1984) and the presence of CoO (0.1 mole fraction) that shifted the resonance frequency to the right. In addition, the highest density for sample N1M1 indicates that it was a less porous material. It should also be noted that the presence of CaO was able to neutralize the SiO_2 exist in the low grade Fe_2O_3 powder and hence reducing the RLF.

Conclusion

Sample N1M1 with the highest density gave the lowest RLF in the widest frequency range.

Acknowledgement: The authors thank the Ministry of Science, Technology and the Environmental of Malaysia for the fund provided under IRPA grant no. 03-02-04-012 .

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