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Electrical Permittivity and Magnetic Permeability of $Fe_3O_4$and Ni_2O_3Nanomaterials

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Abstract

In this work, (Fe_3O_4 and Ni_2O_3) Nano-material thin films were deposited on ITO glass substrate, ten samples were prepared by sol-gel method with deferent concentrations (55.25, 78.7, 90.9 144.9 and 263.15) mg/cm^2 for each nano-material. The Nano crystal size of the deposited was found by the XRD technique. The UV-VIS spectrum was used to find refractive index and electric permittivity. The magnetic permeability was found by using the relation between refractive index and electric permittivity beside magnetic permeability. For Fe_3O_4 the electric permittivity and magnetic permeability were shown to increase when the concentration of Nano crystal decreases. However for Ni_2O_3 the electric permittivity and magnetic permeability increases upon increasing the molecular concentration.

Keywords: Electric permittivity, Magnetic Permeability, XRD technique, Crystal Nano Size.

Introduction

Nickel Oxide (NiO) is an important transition metal oxide with cubic lattice structure. Among the magnetic nanoparticles, fabrication of nickel nanoparticles (NPS) is often more difficult than that of the other particles. This is because they are easily oxidized. To achieve pure nickel nano-crystals, numerous methods have been conducted in organic environments in order to prevent formation of hydroxide or oxidation [1].Iron oxide nanoparticles (NPs) have attracted much consideration due to their unique properties, such as super paramagnetic, surface-to-volume ratio, greater surface area, and easy separation methodology. Various physical, chemical, and biological methods have been adopted to synthesize magnetic NPs with suitable surface chemistry [2]. The magnetic field strength and flux density are related to (Magnetic flux density in a material dependence on permeability and magnetic field strength) to each other. The proportionality constant is called the permeability, which is a property of the specific medium through which the H field passes and in which B is measured. The permeability has dimensions of Weber per ampere-meter (Wb/A m) or henries per meter (H/m) [3, 4]The permeability or relative permeability of a material is a measure of the degree to which the material can be magnetized, or the ease with which a B

field can be induced in the presence of an external H field. Another field quantity, M, called the magnetization of the solid, is defined (Magnetic flux density as a function of magnetic field strength and magnetization of a material) to be also related to the external magnetic field [5].In the presence of an H field, the magnetic moments within a material tend to become aligned with the field and to reinforce it by virtue of their magnetic fields [6].In most substances and over wide range of electric field strengths we find that the current density is proportional to the strength of electric field that causes it. The linear relation between current density J and field strength E is to the conductivity. The factor σ is called the conductivity of the material; its value depends on the material; it is very large for metallic conductors, extremely small for good insulator. It may depend too on the physical state of the material [7].

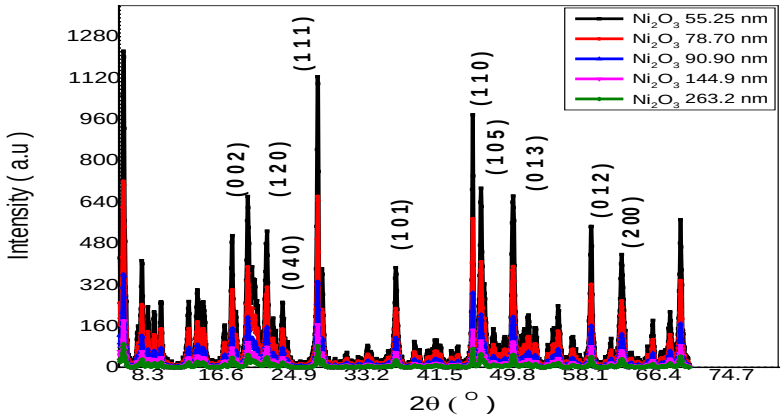
Electric Permittivity describes the amount of charge needed to generate one unit of electric flux in a particular medium. Accordingly, a charge will yield more electric flux in a medium with low permittivity than in a medium with high permittivity. Permittivity is the measure of a material's ability to store an electric field in the polarization of the medium. The SI unit for permittivity is farad per meter (F/m or $F \cdot m^{-1}$).The lowest possible permittivity is that of a vacuum. Vacuum permittivity, sometimes called the electric constant, is represented by ε_0 and has a value of approximately 8.85×10^{-12} F/m. The permittivity of a dielectric medium is often represented by the ratio of its absolute permittivity to the electric constant. This dimensionless quantity is called the medium's relative permittivity, sometimes also called "permittivity". Relative permittivity is also commonly referred to as the dielectric constant, a term which has been deprecated in physics and engineering as well as in chemistry [8].
Different attempts were made to account for the magnetic properties of Fe and Ni oxides. In the work done by Amyn S.Teja etal it was shown that the magnetic permeability of bulk Fe is smaller than that of Nano particles, where the permeability increases upon decreasing Nano size [9]. However the work done by Fardin Taghizadeh shows that the magnetic permeability of bulk Ni is greater than that of Nano Ni, which means that decreasing Ni Nano size decreases the magnetic permeability [10].

Material and Method

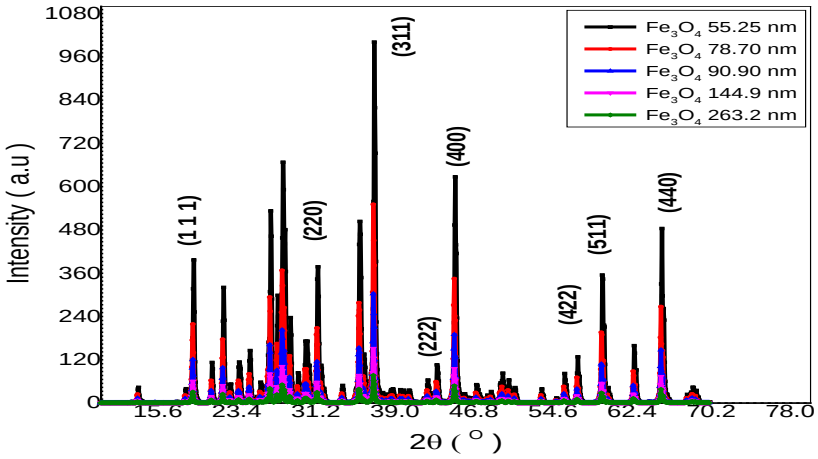
Samples Preparation

Nickel oxide thin films were prepared by spraying a 0.1 M solution of nickel nitrate of doubly distilled water onto the pre-heated amorphous glass substrates kept at (390˚C ± 10˚) C. Iron oxide thin films were prepared by spraying a 0.1 M solution of ferric nitrate of doubly distilled water onto the pre-heated amorphous glass substrates kept at (390˚C±10˚C). Film thickness was measured by using the weight difference method considering the density of the bulk nickel oxide. This film thickness is proportional to the concentration since we divide the mass by substrate area which gives concentration per unit area. As the density of thin films was certainly lower than the bulk density, the actual film thickness would be larger than the estimated values. The structural, optical characterization of the films deposited at optimized preoperative parameters was carried out.

Results



Fig(1): the XRD charts of the five Fe_3O_4 (Iron Oxide) sample



Fig(2): the XRD charts of the five Ni_2O_3 (Nickel Oxide) sample

Table (1) some crystallite lattice parameter (c- form , a,b,c, β,α, γ, density ,Xs(nm) and d – spacing) of all samples that meade by five Fe_3O_4 (Iron Oxide) sample

Sample nm	C-form	a	B	c	α	β	γ	Density ($g.cm^{-3}$)	Xs(nm)	d-spacing (A^o)
Fe_2O_3: 55.25	Cubic / F-Center	8.09	8.09	8.09	90	90	90	4.857	55.05	3.0297
Fe_2O_3: 78.7	Cubic / F-Center	8.39	8.39	8.39	90	90	90	5.102	56.06	2.21935
Fe_2O_3: 90.9	Cubic / F-Center	8.39	8.39	8.39	90	90	90	5.2071	56.10	2.22425
Fe_2O_3: 144.9	Cubic /Primitivty	8.35	8.35	8.35	90	90	90	5.2071	62.95	2.6007
Fe_2O_3: 263.2	Cubic / I-Center	9.4	9.4	9.4	90	90	90	5.808	64.25	3.59315

Table (2) some crystallite lattice parameter (c- form , a,b,c, β,α, γ, density ,Xs(nm) and d – spacing) of all samples that meade by five Ni_2O_3 (Nickel Oxide) sample

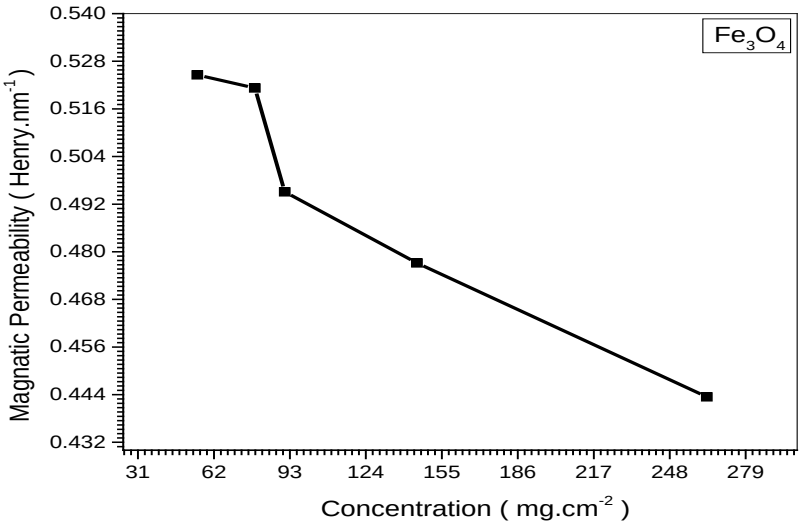
Sample nm	**C-form**	**a**	**b**	**c**	**α**	**β**	**γ**	**Density (g.cm^{-3})**	**Xs(nm)**	**d-spacing (A^o)**
Ni_2O_3: 55.25	Hexagonal/Primitivty	4.61	4.61	5.61	90	90	120	5.3175	53	2.74230
Ni_2O_3: 78.7	Hexagonal/Primitivty	4.61	4.61	5.61	90	90	120	5.3175	55.75	4.07930
Ni_2O_3: 90.9	Hexagonal/Primitivty	4.523	4.523	7.36	90	90	120	5.434	56.15	4.07975
Ni_2O_3: 144.9	Hexagonal/Primitivty	2.955	2.955	7.227	90	90	120	6.803	57.03	4.08000
Ni_2O_3: 263.2	Hexagonal/Primitivty	2.818	2.818	20.56	90	90	120	7.435	57.44	9.02055

Table (3) Electrical permittivity (ε) and magnetic permeability (μ) for all five Fe_3O_4 samples

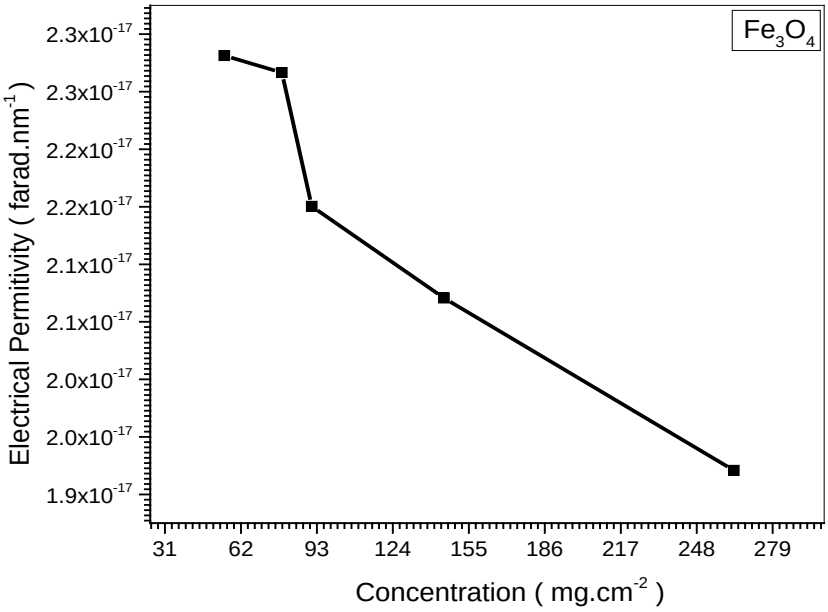
Concentration (mg/cm^2)	Electrical permittivity/ε (farad/nm)	Magnetic permeability/μ $\times 10^{-17}$ (hennery/nm)
263.15	0.44343	1.97079
144.9	0.47716	2.12073
90.9	0.49507	2.20031
78.7	0.52125	2.31665
55.25	0.52457	2.3314

Table (4) Electrical permittivity (ε) and magnetic permeability (μ) for all five Ni_2O_3 samples

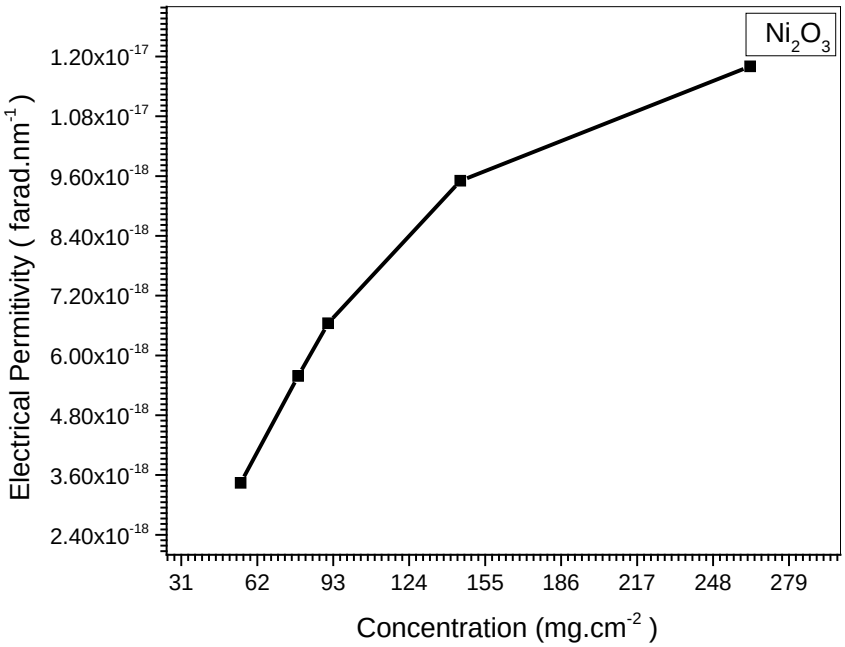
Concentration (mg/cm^2)	Electrical permittivity/ε (farad/nm)	Magnetic permeability/μ $\times 10^{-18}$ (hennery/nm)
263.15	0.26555	11.0822
144.9	0.21389	9.50604
90.9	0.14952	6.64518
78.7	0.12569	5.58615
55.25	0.07746	3.4426



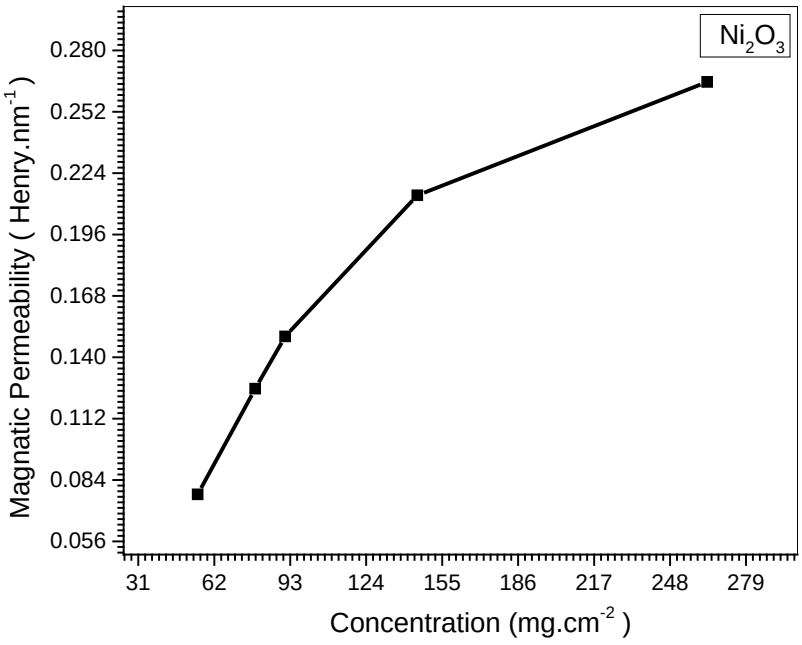
Fig(3): releationsheep between magnatic permeability and concentration of the five Fe_3O_4 (Iron Oxide) sample



Fig(4) :releationsheep between electrical permtivity and concentration of the five Fe_3O_4 (Iron Oxide) sample



Fig(5) :releationsheep between electrical permtivity and concentration of the five Ni_2O_3 (Nickel Oxide) sample



Fig(6) :releationsheep between magnetic permeability and concentration of the five Ni_2O_3 (Nickel Oxide) sample

Discussion

The XRD spectra for Fe_3O_4 and Ni_2O_3 in figures (1) and (2) are used to determine the Nano crystal size and density for Fe_3O_4 and Ni_2O_3 in tables (1) and (2) respectively. Table (3) beside figures (3) and (4) shows that the electric permittivity and magnetic permeability of Fe_3O_4 decreases as its concentration increase.But according to table (1) the increases too as the concentration increase but the number of Nano crystals n_s which is equal to

$$n_s = \frac{\text{Area}}{\text{crystal size}} = \frac{A}{x_s} \qquad (1)$$

Decreases, thus μ and ε decreases as the number of Nano crystals decreases.This means that each Nano crystal act as a single electric and magnetic dipole. Thus decrease of n_s decrease both μ and ε according to the relations

$$B = \mu H = \mu_0(H + n_s X_s H) = \mu_0(1 + n_s X_s)H \qquad (2)$$

$$D = \varepsilon E = \varepsilon_0 E + \varepsilon_0 n_s X_{es} E = \varepsilon_0(1 + n_s X_{es})E \qquad (3)$$

However the saturation is different for Ni_2O_3, where the increase of its concentration n increases its electric permittivity ε and magnetic permeability μ. This means that the Ni_2O_3 molecules themselves acts as electric and magnetic dipoles according to the relations

$$B = \mu H = \mu_0(H + n_s X_m H) = \mu_0(1 + n_s X_m)H \qquad (4)$$

$$D = \varepsilon E = \varepsilon_0 E + \varepsilon_0 n_s X_e E = \varepsilon_0(1 + n_s X_e)E \qquad (5)$$

For Ni_2O_3 table (2) shows that increase of N_i concentration increases its crystal size X_s. Thus increase of crystal size increases of the Ni magnetic permeability. Fortunately the results of magnetic permeability for Fe oxides obtained by Amyn S.Teja etal [9] agreas with our resluts, where they show that the permeability for bulk Fe less than the Nano particles and it increases as the Nano size decrease.it is very striking also to findthat our resluts for Ni oxide agreas also with the work done by Fardin Taghizadeh [10], where he shows that the magnetic permeability of the bulk Ni oxide is (55Oe) is higher than that of Nano particles (53.8Oe). This means that increase of Nano size increases magnetic permeability.

Conclusion

The electric permittivity and magnetic permeability of Fe_3O_4 are affected by the concentration of Nano crystals where they decrease upon increasing the concentration of Nano crystals. However for Ni_2O_3 the electric permittivity and magnetic permeability are affected by the concentration of the molecules, where they increase upon increasing molecular concentration.

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