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# Electrical and Magnetic Properties of Chromium and Aluminum SubstitutedNi Ferrite

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## □ABSTRACT□

Ni $Al_xCr_x$ $Fe_{2-2x}$ $O_4$ ferrite system was prepared using a conventional double sintering ceramic technique.The powders of the oxides and carbonates (Iron, Nickel, Aluminum, and chromium)which form the sample were mixed in molar ratio(X = 0.1 … 0.8 in step 0.1).This research studies the influence $Al^{3+}$and$Cr^{3+}$ionssubstitutedFe$^{3+}$ ions in the octahedral sites of spinel ferrite structure.In this work,wenoticed that jump length decreases in octahedral sites with increasing X, while the magnetization of sample increases in the range $X \leq 0.6$ which corresponds tojump length $L \geq 2.928$ $A^0$

**Keywords :** Ni-ferrite , Jump length , resistivity , saturation magnetization.

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# الخصائص الكهربائية والمغناطيسية لفرايت النيكل المطعم بالكروم والألمنيوم

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## ملخّص

حضرنا الفرايت $Ni\ Al_xCr_x\ Fe_{2-2x}\ O_4$ بالطريقة السيراميكية التقليديةالثنائية التلبيد. وذلك بخلطمساحيق الأكاسيد والكربونات المكوّنة للعينة (أوكسيد الحديد + أوكسيد النيكل + كربونات الألمنيوم والكروم) بنسب موليةمحددة ($X = 0.1 \ldots 0.8$)بخطوة 0.1.ويهدف هذا البحث إلى دراسة تأثير استبدال شوارد $Fe^{3+}$بشوارد $Cr^{3+}$ و $Al^{3+}$في المواقع ثمانيةالأوجه في بنية سبينل فرايت.

ولاحظنا في هذا البحث أن طول القفز في المواقع الثمانية تناقص مع زيادة نسب الإضافة X، بينماتزداد شدة التمغنط للعينة المدروسة في المجال$X \leq 0.6$التي توافق طول قفزقدره$L \geq 2.928\ A^0$.

**الكلمات المفتاحية:** فرايت نيكل ، طول القفز ، المقاومة الكهربائية ، تمغنط الإشباع .

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## Introduction :

Ferrites have vast applications from microwave to radio frequency.

They exhibit relatively high resistivity at carrier frequency , sufficient low losses for microwave application and wide range of other electrical properties. $NiFe_2O_4$has aspinel structure [1] . The addition of trivalent ions like $Al^{3+}$ and $Cr^{3+}$ for $Fe^{3+}$

in $NiFe_2O_4$ influences the electrical and magnetic properties of the system [2-6].

A linear decrease in the lattice parameter with increasing Al, Cr content in the system Ni $Al_xCr_xFe_{2-2x}O_4$ has been noticed .

A gradual decrease of the magnetization was observed in this system

with increasing Al, Cr substitution. However, the rate of decrease of saturation magnetization is quite less during enhancing Cr substitution [8,9] . The electron conduction in ferrites was discussed on the basis of electronic exchange between $Fe^{2+}$ and $Fe^{3+}$ ions on the octahedral sites. The jump length of electrons in octahedral sites of Zn $Al_xFe_{2-x}O_4$ ferrite and conductivity was studied .

The decrease of jump length decreases the conductivity .

In the present work, we study the effect of jump length of electrons in

Ni $Al_xCr_x$ $Fe_{2-2x}$ $O_4$ ferrite on the conductivity and saturation magnetization

to be used in microwave application .

## The Importance and aims of this research:

The aim of this paper is to investigate the effect of Al and Cr additionson the electron jump length between $Fe^{3+}$ and $Fe^{2+}$ ions in the B- sitesof the Ni $Al_xCr_x$ $Fe_{2-2x}$ $O_4$ ferrite systems.It is also important to studytheelectronjump length influences on the electrical resistivity and saturationmagnetization of ferrite under study . In addition,this ferrite is nowusedin radio,television,microwave and satellite communication.

## Experimental :

Eight sample of Ni $Al_xCr_x$ $Fe_{2-2x}$ $O_4$ ferrite system X = 0.1 – 0.8 were prepared by usual ceramic methods [7] in steps of 0.1 .

The starting materials were $Fe_2O_3$, NiO , $Al_2(CO_3)_3$and $Cr_2$ $(CO_3)_3$, with purity 99.9%.

Theoxides were mixed in stoichiometric proportions to yield the desired compositions. The mixture was fired at 800 $^oC$ for 5 hours , then crushed and pressed into tablet of 2 cm diameter and 0.2cm thickness .The pressed tablet and toroids were sintered at 1100 $^oC$ for 5 hours in the furnace . The compositions were left to be cooled at room temperature . X- ray diffraction patterns confirmed the spinel cubic structure at room temperature using $\mathbf{CuK_\alpha}$radiation .

The jump length was estimated from the relations [11] in the A- sites and B - sites,respectivety :

$$L_A=\frac{\alpha\sqrt{3}}{2} \qquad (1)$$

$$L_B=\frac{\alpha\sqrt{2}}{4}$$

Where a is the lattice parameter estimated from X ray patterns . The resistivity was recorded from the reading of an electrometer ( keithley 610) at room temperature. The magnetization was measured using high fieldhysteresis loop technique at room temperature[12]

## Results and discussion:

**1.Effect of Al-Cr substitution on the jump length .**

The effect of Al,Cr substitutionin Ni $Al_xCr_x$ $Fe_{2-2x}$ $O_4$ ferrite on the jump length of electrons is illustrated in Fig (1) . The jump length decreases gradually with X . This can be explained by the following:

Neel [10] considered three kinds of exchange interaction between paired electrons of two ions lying : (i) both ions are at the A- sites (A-A-interaction),(ii) both ions are at B - sites (B-B interaction) and (iii) one Ion located at A- site and the other at B-site (A-B-interaction). AB interaction heavily predominates over AA and BB interactions . The AB interaction aligns all the magnetic spins at A-sites in one direction and those at B-site in the opposite direction . The net magnetic moment of the lattice is therefore the difference between the magnetic moments of B and A-sublattices, i.e.$M=M_B-M_A$ .

It is well known that $Cr^{3+}$ ions preferably occupy B - sites [7,8] ,as the number of $Fe^{3+}$ ions at B - sites continuously decreases. The $Fe^{3+}$ ions of B – sub-lattice decreaseand also the magnetization of B- sub lattice which leads to decrease the hopping rate of electrons at the B- sites . The decrease of the hopping rate is related to the jump length of electrons between $Fe^{2+}$ and $Fe^{3+}$ in the sub lattice . The behavior of our results is in agreement with previous work [13].

**2. Effect of jump length on the electrical resistivity .**

The resistivity dependence of the jump length of electrons at room temperature is shown in Fig (2) . The resistivity decreases slowly with increasingthe jump length.

This is attributed to the following :

When $Fe^{3+}$ ions at the B- sites are replaced by

paramagnetic $Cr^{3+}$ ions , B-sublattice magnetization decreases without affecting

A-sub-lattice magnetization which , in turn , weakens AB exchange interaction . As paramagnetic chromium ions weakly participate in exchange interaction .

This leads to a decrease in hopping rate of electrons at the B - sites which results in promotion of the electron hopping rate at the A - sites.

The increase of AA interaction makes the jump length of electron between $Fe^{3+}$ and $Fe^{2+}$ giving rise to electricalconductivity of the composition .

**3. Effect of jump length of the electrons on magnetization:**

The effect of jump length of electronon saturation magnetizationinNi $Al_xCr_x$ $Fe_{2-2x}$ $O_4$ ferrite at 4 koeis showed in Fig (3). It is obvious that the decrease of the jump length decreases the magnetization of the sample. This is attributed to the following :

Addition of $Cr^{3+}$ ion occupying B-sites [7-9] leads to the replacement of $Fe^{3+}$ ions . Because the $Cr^{3+}$ ion carries a reduced spin value of 3/2 as compared with 5/2 for the $Fe^{3+}$ ions, such a substitution in B - sites weakens the A-B interaction and decreases the magnetic exchange at the A - sites . Thus, the decrease in the saturation magnetization with the substitution of $Cr^{3+}$ decreases the jump length of electronsand thus lowers the B-sublattice magnetization and weakens A-B interaction.

**4. Dependence of the jump rate of electrons on Al, Cr contents .**

The diffusion coefficient of elections in the lattice of the present ferrites is estimated from the formula :

$$\mathbf{D = \frac{\sigma\, kT}{Ne^2}(2)}$$

Ddiffusion coefficient ,
σ electrical conductivity ,
T absolute temperature ,
e electroncharge ,
$N = 4 \times 10^{28}$ atoms / $m^3$ .
k Boltzman constant
The jump rate of electrons P ( jump frequency ) is estimated from relation [14] :

$$\mathbf{P = D / a^2} \quad \mathbf{(3)}$$

where a is the average lattice parameter which is deduced from X-ray patterns of eight samples.

Fig.( 4) describes the effect of Al, Cr contents in Ni $Al_xCr_x\ Fe_{2-2x}\ O_4$ ferrites on the jump rate of electrons . There is a decrease in the jump rate with enhancing Al, Cr contents . This is attributed to the replacement of $Fe^{3+}$by $Al^{3+}$, $Cr^{3+}$ ions which leads to decrease the concentration of $Fe^{3+}$ ions at the B sites . The hopping rate of elections depends upon the $Fe^{3+}$ ions concentration which results in a decrease of hopping rate of election between $Fe^{3+}$ and $Fe^{2+}$ions.

**Table (1) : contains the jump length, electrical resistivety and magnetization**

| contents (X) | L($A^o$) | Log ρ | $H_s$ (emu /g) |
|---|---|---|---|
| 0.1 | 2.936 | 5 | 29.4 |
| 0.2 | 2.934 | 5.2 | 25.7 |
| 0.3 | 2.932 | 5.5 | 20.6 |
| 0.4 | 2.930 | 6.2 | 16.4 |
| 0.5 | 2.928 | 6.4 | 8.8 |
| 0.6 | 2.926 | 6.5 | 7.3 |
| 0.7 | 2.924 | 6.7 | 8.3 |
| 0.8 | 2.922 | 6.8 | 8.3 |

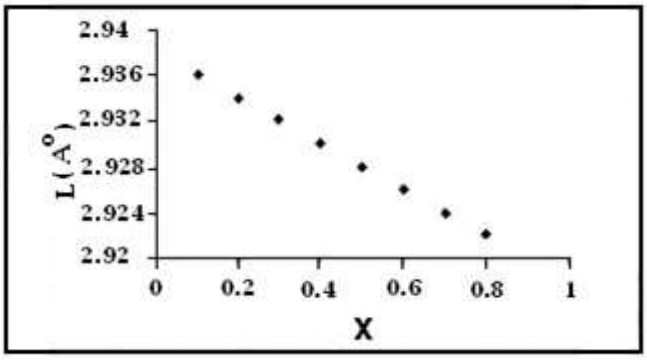


**Fig (1) :Effect of Al,Crcontents (X)on the jump length ofelectrons.**

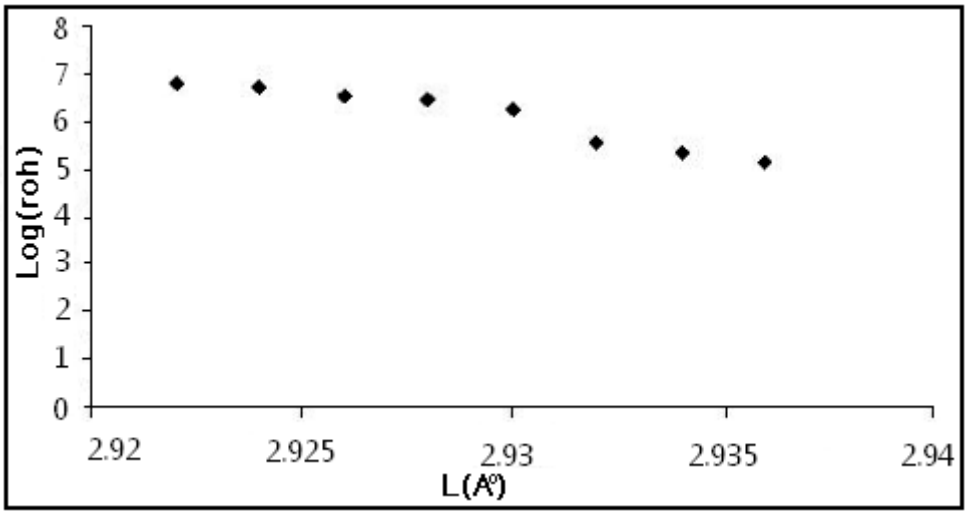


**Fig (2) : Effect of jump length of electrons on the electrical resistivity .**

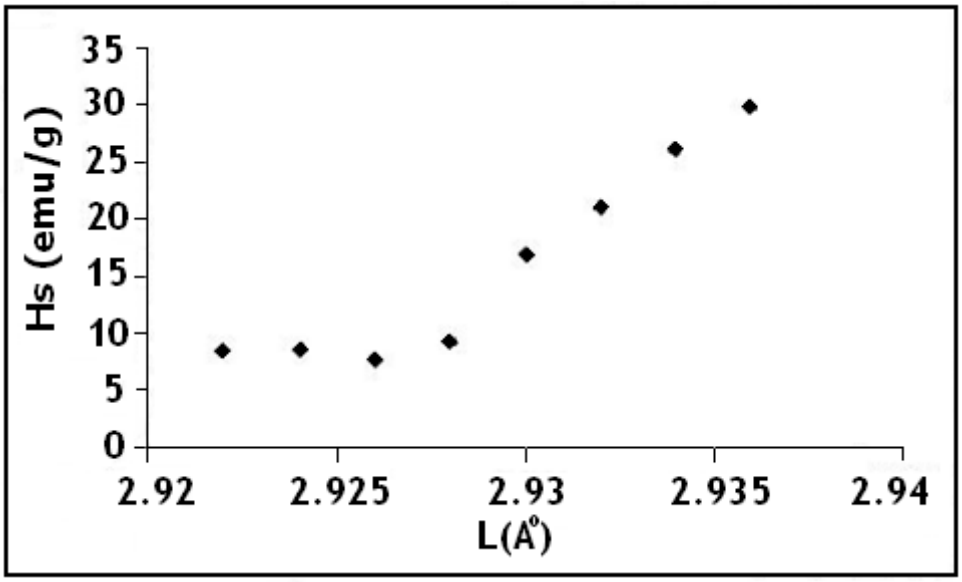


**Fig (3) : Dependence of magnetization onjump length .**

**Table(2):containsadditional rates of Cr , Al and jump rate of electrons .**

| Contents | P($Sec^{-1}$) |
|---|---|
| 0.1 | 10000 |
| 0.2 | 9000 |
| 0.3 | 6000 |
| 0.4 | 3500 |
| 0.5 | 1500 |
| 0.6 | 500 |
| 0.7 | 500 |
| 0.8 | 500 |

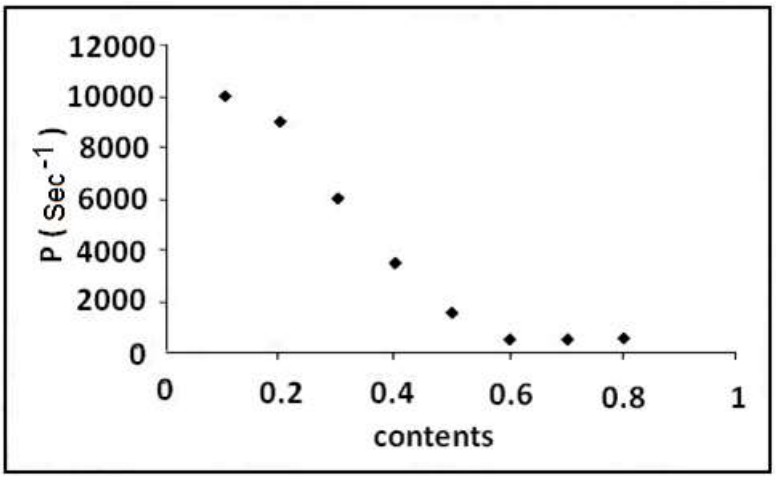


**Fig (4) : Effect of contents ( X ) on the jump rate of electrons ($Sec^{-1}$ )**

## Conclusion :

1. Increase of $Fe^{3+}$ concentrations as the B- sites increases the hoppingrate ofelectrons between ferric ions and ferrous ions .

2.The mechanism of conductivity is similar to the mechanism ofmagnetization .

3.The deceasing of magnetization is explained on the basis of exchangeinteraction and the effect of the anisotropy constant .

Both of these parameters suggest that canted spin occur in these systems.

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