Abstract—Samples of CoFe$_2$$_x$Cr$_x$O$_4$ where $x$ varies from 0.0 to 0.5 were prepared by co-precipitation route. These samples were sintered at 750°C for 2 hours. These particles were characterized by X-ray diffraction (XRD) at room temperature. The FCC spinel structure was confirmed by XRD patterns of the samples. The crystallite sizes of these particles were calculated from the most intense peak by Scherrer formula. The crystallite sizes lie in the range of 37-60 nm. The lattice parameter was found decreasing upon substitution of Cr. DC electrical resistivity was measured as a function of temperature. The room temperature thermoelectric power was measured for the prepared samples. The magnitude of Seebeck coefficient depends on the composition and resistivity of the samples.

Keywords—Ferrites, Crystallite size, Drift mobility, Seebeck coefficient, Thermopower

I. INTRODUCTION

Ferrites having low resistivity and low eddy current losses have been found to be the most versatile to be used for technological applications as in the case of stress sensors and recording media. Cobalt ferrite possesses an inverse spinel structure and the degree of inversion depends upon the heat treatment [1], [2]. The physical properties of the spinel ferrite developed due to distribution of cations among the tetrahedral A site and octahedral B sites. The dielectric properties and conductivity of the ferrites depend on preparation method, chemical composition and grain size, frequency and temperature [3], [4]. DC resistivity of ferrites as a function of temperature and drift mobility and activation energy was reported by different authors [5]-[7]. Several researchers reported the magnetic properties of spinel ferrites as well [8]-[12]. Ferrites are low mobility semiconductors. To know about the conduction mechanism in ferrites thermoelectric measurement is done. The thermo e.m.f. and its sign gives the conduction mechanism in ferrites thermoelectric -[12]. Ferrites are low mobility semiconductors. To know about the conduction mechanism in ferrites thermoelectric measurement is done. The thermo e.m.f. and its sign gives the conduction mechanism in ferrites thermoelectric measurement is done. The thermo e.m.f. and its sign gives the conduction mechanism in ferrites thermoelectric measurement is done.
Resistivity as a function of temperature and the results could be fitted by using the relation

\[ \rho = \rho_0 e^{\frac{\Delta E}{k_B T}} \]  

\( \rho \) is electrical resistivity at temperature T (K), \( k_B \) is Boltzmann constant and \( \Delta E \) is activation energy for electrical conduction process. The drift mobility \( \mu \) of the charge carrier in the synthesized sample is calculated by following equation

\[ \mu = \frac{1}{n e \rho} \]  

\( n \) is number of charge carriers, \( e \) the charge on electron and \( \rho \) is the resistivity at a given temperature.

Seebeck coefficient as a function of composition was measured and calculated as

\[ S = \frac{\Delta V}{\Delta T} \]  

Where \( S \) is Seebeck coefficient, \( \Delta V \) is emf developed across the sample and \( \Delta T \) is temperature.

III. RESULTS AND DISCUSSION

A. Structural and Morphological Properties

The XRD patterns in figure 1 show that the structure is cubic spinel structure with no additional phase (ICSD 01-076-2496).

![Fig. 1 XRD patterns for CoFe\(_2-x\)Cr\(_x\)O\(_4\) where \( x=0.0, 0.1, 0.2, 0.3, 0.4, 0.5\) (sintered)](image)

Table 1 shows the X-ray and measured density of the prepared samples. The decrease in ‘a’ was due to Cr concentration. Ionic radius of Cr\(^{3+}\) is 0.63 Å which was less than the ionic radius of Fe\(^{3+}\) which is 0.645 Å [18]. The size of octahedral B site was greater than tetrahedral A site. The addition of smaller ionic radii at B site results in decrease lattice constant.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>( x=0 )</th>
<th>( x=0.1 )</th>
<th>( x=0.2 )</th>
<th>( x=0.3 )</th>
<th>( x=0.4 )</th>
<th>( x=0.5 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho_\text{X}(\text{g/cm}^3) )</td>
<td>5.2</td>
<td>5.44</td>
<td>5.20</td>
<td>5.21</td>
<td>5.30</td>
<td>5.33</td>
</tr>
<tr>
<td>( \rho_\text{m}(\text{g/cm}^3) )</td>
<td>3.99</td>
<td>2.68</td>
<td>2.75</td>
<td>2.95</td>
<td>2.60</td>
<td>2.98</td>
</tr>
</tbody>
</table>

Table 1: X-RAY DENSITY ‘\( \rho_\text{X} \)’ AND MEASURED DENSITY ‘\( \rho_\text{m} \)’ OF SAMPLES \( \text{CoFe}_{2-x}\text{Cr}_x\text{O}_4 \) where \( X=0-0.5 \)

![Fig. 2 Variation of lattice constant ‘a’ with composition x](image)

B. DC Properties

The observed decrease in the value of dc-electrical resistivity with increase in temperature in figure 3 shows the similar trend as that of semiconductor materials. Plot of resistivity with \( 1/k_B T \) provides activation energy of the hopping \( E_a \).

![Fig. 3 Graph between resistivity (ln \( \rho \)) and temperature for \( \text{CoFe}_{2-x}\text{Cr}_x\text{O}_4 \) where \( x=0.0, 0.1, 0.2, 0.3, 0.4 \) and 0.5](image)

Exchange of electrons between Fe\(^{2+}\) and Fe\(^{3+}\) result in conduction mechanism in ferrites. So as a result there is local displacement of charges causing polarization. The magnitude of this exchange depends on Fe\(^{3+}\) and Fe\(^{2+}\) ion pairs on octahedral sites [18]. The decrease in activation energy is due to reduction of ion pairs. Figure 4 shows that drift mobility increases with increase in temperature.

![Fig. 4 Graph between drift mobility (\( \mu_d \)) and temperature for \( \text{CoFe}_{2-x}\text{Cr}_x\text{O}_4 \) where \( x=0.0, 0.1, 0.2, 0.3, 0.4 \) and 0.5](image)
This is due to enhanced mobility of the charge carriers due to thermal activation and it is not due to generation of charge carriers by increase of temperature. Also charge carrier concentration is reported to be constant throughout the temperature range [18].

C. Thermoelectric Properties

Thermoelectric effects give conversion of energy between heat and electricity directly. Thermoelectric power of Cr doped Co ferrite nanoparticles as a function of composition was measured at room temperature. The conduction mechanism in Cr doped Co ferrite is due to electrons because sign of Seebeck is negative for all the prepared samples. Seebeck coefficient as a function of Cr concentration for all the prepared samples is given in figure 5. All the samples were sintered at 750 °C.

The decrease in Seebeck coefficient ‘S’ is due to fact that if resistivity of the material increases, motion of charges becomes slow and as a result of which emf developed across the sample was low. Due to decrease in emf the Seebeck coefficient also decreases. The reported value of the Seebeck coefficient for the cobalt ferrite was in good agreement with our measured value. The difference in measured value was due to porosity of the samples, purity of the samples and surrounding temperature of the atmosphere. The Seebeck coefficients for the other compositions are an addition to the existing literature.

IV. CONCLUSIONS

Nanoparticles of Cr doped Co ferrite CoFe2−xCrxO4 where x=0 to 0.5 were prepared. These nanoparticles were prepared by co-precipitation method and were homogenous. The addition of Cr in Co ferrite creates changes in structure, electrical, and thermoelectric properties. The patterns of XRD show that the structures of all the samples were cubic spinel. The lattice constant ‘a’ decreased with the increase in the concentration of Cr. DC electrical properties of the samples were done by two probe method in a temperature range of 300K to 673K. The resistivity for all the prepared samples was decreased with increase in temperature. The decrease in resistivity with temperature was due to the fact that at elevated temperatures the hopping between Fe2+ and Fe3+ was increased as a result of which resistivity decreased. Sign of Seebeck coefficient show that charge carriers were electrons in our prepared samples. The decrease in Seebeck coefficient was due to increase in resistivity for that particular composition.

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REFERENCES