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Magneto-Optical Properties of $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ Nano Ferrite for Application of Soft Magnetic Material

Babasaheb E. Phunde[1], Madhav M. Kandre[2], Limbraj S. Ravangave[3]
[1,3]*Physics Research Centre Shri Sant Gadge Maharaj College, Loha Dist. Nanded (Maharashtra) 431708 India*
[2]*Department of Chemistry, Shri Sant Gadge Maharaj College Loha Dist. Nanded (Mahashtra) India*

Abstract: ***$Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ spinel ferrite powder is successfully synthesized using sol-gel auto combustion technique. The structural, optical and magnetic properties investigated by using X-ray Diffractometer, FTIR Spectrometer, Scanning Electron Microscope and Vibrating Sample Magnetometer (VSM). XRD analysis confirmed that formation of Nano crystalline cubic spinel structure of the sample. The crystallite size of synthesized nanoparticles is about 29.45nm. The IR study support the confirmation spinel structure of $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ sample. Band gap energy E_g obtained using UV-Visible absorption data is about 2.4238 eV. The magnetic properties have been studied from VSM data shows that $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ spinel ferrite is a soft magnetic material.***

Keywords: Ni-Cu-Zn ferrites, UV, VSM, NiFe2O4, Soft magnetic Material.

I. INTRODUCTION

Soft magnetic materials are early magnetized and demagnetized having low intrinsic coercivity and low remaance. Nickel Cupper Zinc ferrite (NiCuZn Fe2O4) in an examples of soft magnetic materials, are used in transformer core[1], in magnetic memory[2], in antenna rods[3], in biomedical field[4], catalysis, and solar cells[5,6]. The structural units of mixed ferrites consists of divalent metal oxides and trivalent ferric oxides.

It is represented by chemical formula A [B_2] O_4 where A is a divalent cations like Mn, Zn. Cu, Ni, Cd etc and B is trivalent cation Fe^{3+} and it is exhibited cubic spinel structure in which divalent metal ion A occupies at tetrahedral site and trivalent ferric ion B at tetrahedral as well as at octahedral sites respectively.

The divalent metal ion can be replaced by other divalent metal ions and Fe^{3+} can also be replaced by other trivalent cations like Al, Cr, and rare earth ions such as Gd, La etc. to improve the various extensive properties such as optical band gap, electrical resistivity and magnetic properties[7-10].

There are limited work reported in the literature on magneto-optical properties of Gd^{3+} doped NiCuZn fe_2O_4 nano spinel ferrite. Hence in the present report attempt have been made on synthesis and and investigation of magneto-optical properties of Gd^{3+} doped NiCuZn fe_2O_4 spinel ferrite.In preparation of spinel ferrites various techniques have been used such as Co-precipitation[11], Hydrothermal[12], Spray drying[13], Sol-gel method[14] etc. Among these techniques Sol-gel auto combustion method involve easy steps, very economic and less time consuming[14-16].

Hence in present work Sol-gel auto combustion technique have been employed in synthesis of $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ nano spinel ferrite. The structural, optical and magnetic properties of synthesized $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ investigated by using X-ray Diffractometer, FTIR Spectrometer, Scanning Electron Microscope and Vibrating Sample Magnetometer (VSM) and results are reported.

II. MATERIAL AND METHODS

In the present work, $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ nano spinel ferrite particles were synthesized by using sol-gel auto combustion technique. The chemicals used are analytical grade (AR) nickel nitrate (Ni $(NO_3)_2.6H_2O$), cupper nitrate (Cu $(NO_3)_2.6H_2O$), gadolinium nitrate (Gd $(NO_3)_3.9H_2O$), ferric nitrate (Fe $(NO_3)_3.9H_2O$), Zinc nitrate $Zn(NO_3)_2.6H_2O$ and citric acid ($C_6H_8O_7$) in proper proportion. The citric acid is used as fuel. The metal nitrates to fuel (citric acid) ratio was taken as 1:3. Ammonia solution was added to maintain the pH 7. Temperature required for the synthesis of nanoparticles is around 110 ˚C. The as-synthesized powder is sintered at 800 ˚C for 4 hour.

III. RESULTS AND DISCUSSION

A. *Structural Investigations*

XRD patterns of $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ nano ferrite powder is shown in figure 1. The XRD pattern exhibit significant peaks at (111), (220), (311), (222), (400), (422), (511) (440) and at (533) reflections. The peaks in the XRD pattern are assigned to cubic spinel structure of the sample. Similar cubic spinel structure for $Ni_{0.4}Zn0.2Mn_{0.4}Fe_2O_4$ was reported in the literature [17]. The average grain size was calculated using well known Scherer's[18] formula (1),

$D = \frac{0.94\lambda}{\beta \cos\theta}$ ---------- (1),

Here λ is the wavelength of the x-ray and β is the full width at half maximum intensity in radians. The values of lattice constant 'a' (Å) for cubic sample[18] is determined by using the relation,

$a = d_{hkl}(h^2 + k^2 + l^2)$--------(2) where (hkl) are the lattice constants. The unit cell volume (V) was calculated by using the following equation;

$V = a^3$ --------(3), where, V is the unit cell volume a is the lattice constant. The X-ray density[18] (d_X) was calculated by using the following relation,

$d_x = \frac{Z \times M}{V \times N_A}$ gm/cm^3 ----------(4), where, Z s the number of molecules per formula unit (Z = 8 for spinel system), M is molecular mass of the sample, V= a^3 is the unit cell volume and NA is the Avogadro's number. *The obtained XRD data and* estimated crystallite size, lattice constant 'a', unit cell volume 'V'and X ray density were displayed in table 1. Particle size confirm that synthesized ferrite powder in nano stricture. The values of lattice constants, unite cell volume and X-ray density are comparatively similar to reported in literature for soft magnetic material[13-17].

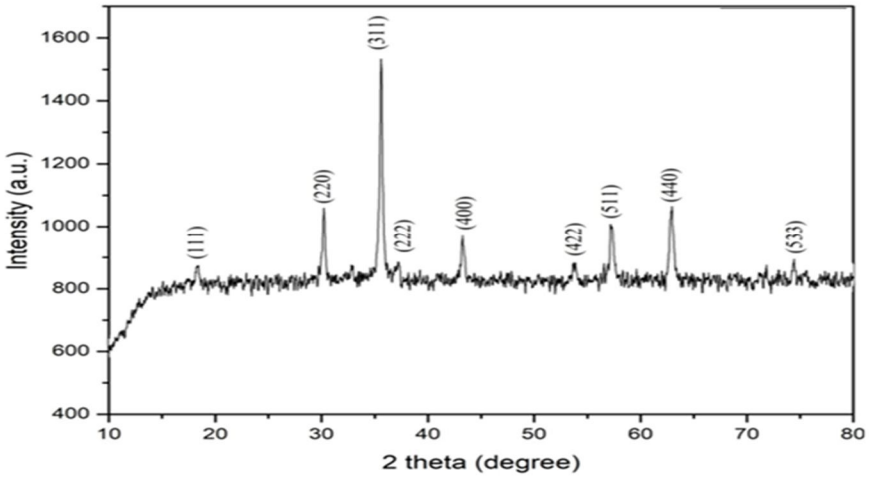

Figure 1. XRD of $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ nano ferrite powder

Table 1. Structural Parameters of $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ nano ferrite powder

(hkl)	2 θ (degree)	d(Å)	FWHM	Lattice Constant 'a'	Particle size D(nm)	Unit Cell Volume	Density (dx) (gm/cm^3)
(111)	18.435	4.8089	0.4433	8.3752	29.33	583.562	5.6255
(220)	30.283	2.9490	0.3512				
(311)	35.653	2.5161	0.2835				
(400)	43.351	2.0855	0.3759				
(422)	53.749	1.7040	0.7501				
(511)	57.317	1.6061	0.3373				
(440)	62.898	1.4764	0.4134				
(533)	74.405	1.274	0.8229				

B. Infrared (FTIR) Spectroscopy Investigations

IR spectrum of sample $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ scanned in the renge 400 to 4000 cm^{-1} was presented in figure 2. IR spectra represents absorption bonds arround 471.35 cm^{-1} and at 572.34 cm^{-1} show the characteristic bands of frequencies v_2 and v_1 related to intrinsic lattice vibrations of octahedral and tetrahedral coordination compounds of spinel ferrite structure [20] The absorption peaks due to C–O and C-O_3 ion vibration are depicted in FTIR spectrum at arround 11500 to 2357.33 cm^{-1} [21,22]. The FTIR spectrum reveals a peak at 1000 cm^{-1} that is reported in literature due to the incomplete decomposition of the products. Two prominent peaks appeared around 795-800 cm^{-1} are attributed to (Gd-O) strtcheing vibrations [23]

C. URFACE morphology OF $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ SPINEL FERRI

Figure 3 shows the SEM images of the $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ spinel. The SEM scan illustrate that micrograph composed of largely agglomerated nanoparticles of the sample. The large clusters of $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ ferrites formed by assembling of small spherical grains of nearly consistent in size. The dipole-dipole interactions among the uncapped nanoparticles results in agglomeration of nano sized particles

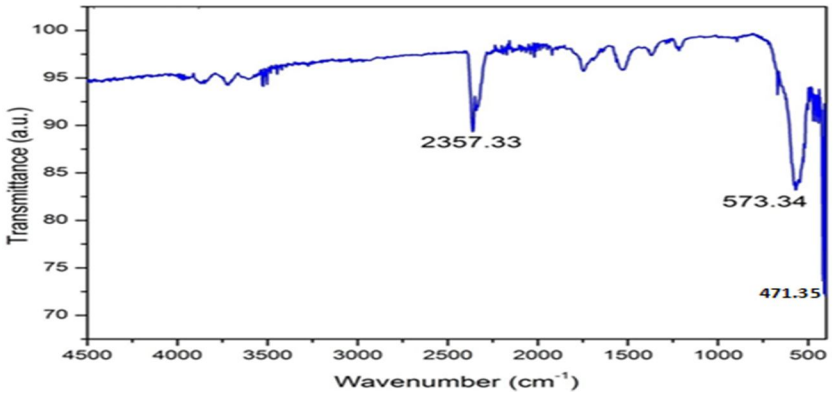

Figure 2 FTIR Spectra of $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ Spinel Ferrite

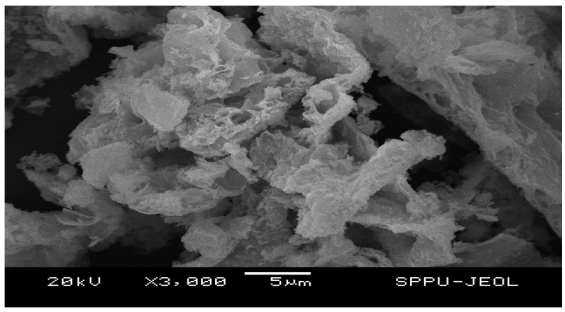

Figure 3. SEM Scan of $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ Ferrite

D. EDAX ANYLYSIS OF $Ni_{0.4}Cu_{0.3}Zn_{0.3}Fe_2O_4$ and $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ FERRITE

The EDX spectra of $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ is shown in Figure 5. EDX analysis confirm the presence of Ni^{2+}, Cu^{2+}, Zn^{2+}, Gd^{3+}, Fe^{3+} and O^{2-}elements with some traces of CO_2 capped on it due to atmospheric interaction of sample. The expected stoichiometry was maintained and illustrated in Table 2.

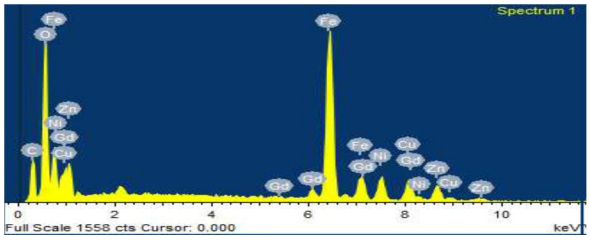

Figure 4. EDX Spectra of prepared Ferrite

Table 2. Elemental weight % and Atomic% of $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ Spinel Ferrite

Elements	C K	O K	Fe K	Ni K	CuK	Zn K	Gd L	Total
Weight %	10.22	46.93	22.18	7.47	5.38	5.00	2.81	100
Atomic %	15.10	57.16	18.12	5.56	1.73	1.56	0.77	100

E. EFFECT of Cu^{2+} and Gd^{3+} Doping on Absorption and Optical Band Gap

UV-Visible absorption spectra of $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1875}O_4$ nano spinel ferrite is shown in figure 5. The spectra show absorption is maximum in the 200 to 600 nm range and the tailed down[24]. The optical band gap energy (E_g) is estimated by using Tauc relation[17] as given by ;

$\alpha h\nu = B(h\nu - E_g)^n$ ------(5) , where, α is the linear absorption coefficient of the material, B is the proportionality constant, h is Planck's constant (6.6260×10^{-34}J.s), ν is the photon frequency. The Tauc plots for $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ is presented in figure 6.

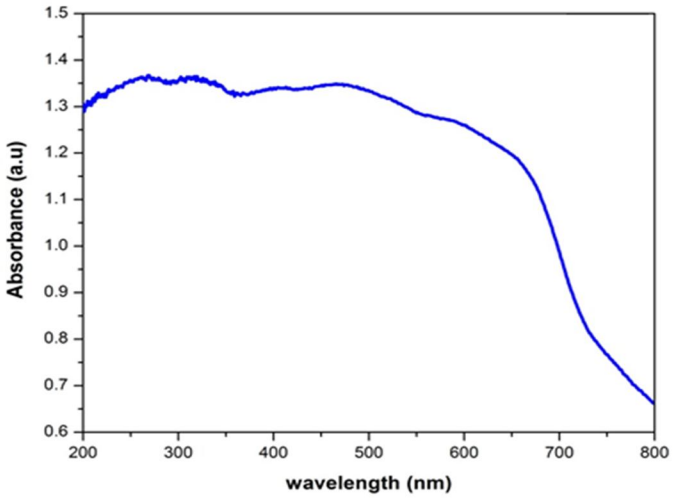

Figure 5. Absorption Spectra of prepared Ferrite

The optical band gap estimated by using Tauc plot is about 2.375 eV. The similar band gap is reported in literature for lanthanum doped Ni-Zn nano ferrite[9, 25].

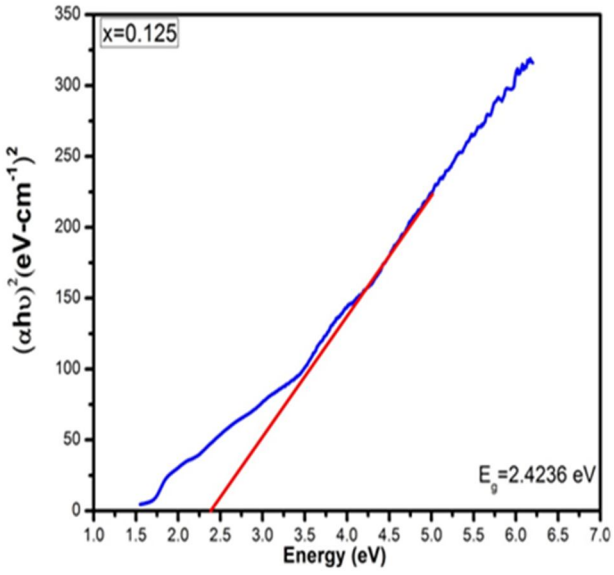

Figure 6. Tauc plot of Spinel Ferrite

F. Magnetic Properties Prepared Spinel Ferrites

Figure. 7 shows the M-H plots of the sample. $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.87\ 5}O_4$ exhibit narrow magnetic hysteresis loops which indicate the ferromagnetic behavior of the sample. These type of ferrites were useful in making magnetic cores for high frequency inductors, [26-27]. The saturation magnetization, remnant magnetization, coercivity and remanence ratio are measured from M-H loops and values are given in Table 3. The hysteresis curves decide that the magnetic material is either soft or hard. Presently prepared $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.87\ 5}O_4$ spinel ferrite exhibit significantly narrow hysteresis loops, low magnetic remanence low coercivity and high saturation magnetization[9, 19]. These finding are comparatively similar as reported in the previous literature for soft ferrite material[19,28-30]. Therefore such Nano ferrite was recommended for cores and coils of low inductance. The improvement in the magnetic properties due to cation distribution caused by doping various transition and rare earth elements[29-30].

IV. CONCLUSION

In Conclusion, $Ni_{0.5}Cu_{03}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ mixed spinel ferrite is prepared via a sol-gel combustion method. XRD pattern revealed that formation of a cubic spinel ferrite structure. IR study concluded that prepared ferrite has cubic spinel ferrite structure. The study of magnetic properties concluded that $Ni_{0.5}Cu_{03}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ Nano ferrite is a soft magnetic material and can be used in cores, coils of low inductance, and in memory storage devices.

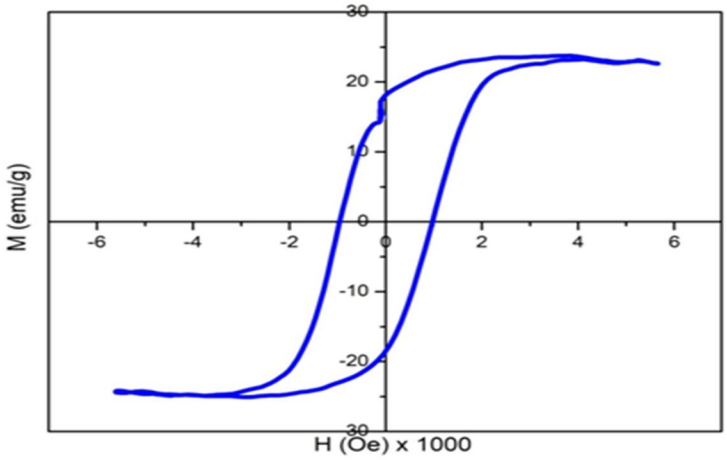

Figure 7. M-H plot of $Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$ Spinel Ferrite

Table 3: Saturation magnetization (Ms), Remanence magnetization (Mr), Coercivity (H_C), Remanence ratio (Mr/Ms), magnetic anisotropy constant (K1) and Bohr magnetron moment (n_B)

Sample	M_s (emu/g)	M_r (emu/g)	H_C (Oe)	M_r/M_s	Anisotropy constant (K_1)	n_B
$Ni_{0.4}Cu_{0.3}Zn_{0.3}Gd_{0.125}Fe_{1.875}O_4$	24.9044	19.8206	30.556	0.7958	807.67	1.1461

V. ACKNOWLEDGMENT

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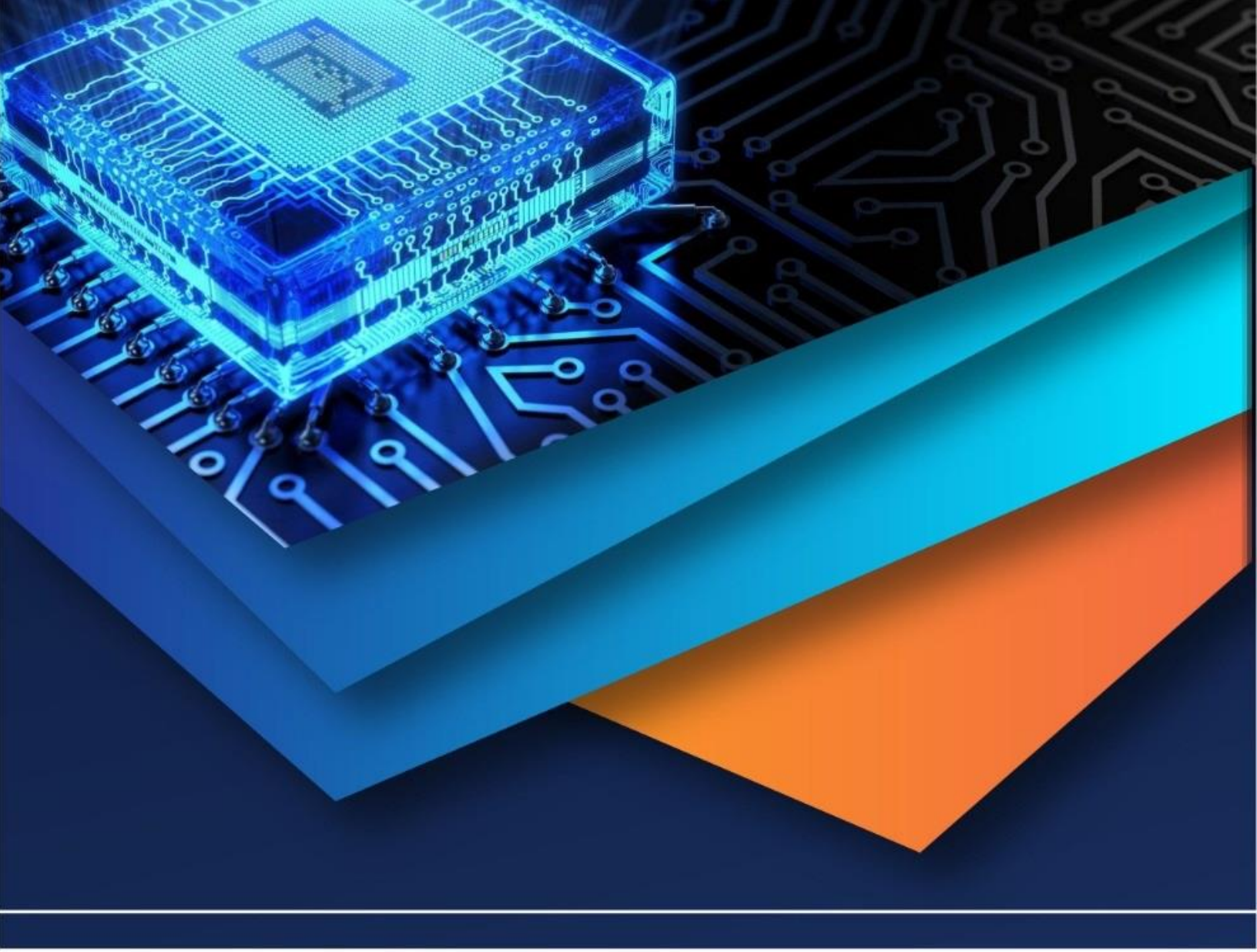

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