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Eco-Friendly Synthesis and Characterization of Vanadium Oxide Nanoparticles and its Applications

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Abstract: ***Vanadium oxide (VO) nanoparticles were synthesized using a green method with Plumeria obtusa leaf extract as a natural reducing and stabilizing agent. This eco-friendly approach avoids harmful chemicals and supports sustainable synthesis. The prepared nanoparticles were characterized to confirm their structure and composition. Antibacterial studies showed moderate activity against common bacteria, indicating their potential as alternative antimicrobial agents. Anticorrosion performance was evaluated on mild steel in different media, where the nanoparticles showed better protection in alkaline conditions compared to acidic and neutral environments. The improved performance is due to the formation of a protective layer on the metal surface, which reduces corrosion. Overall, this study highlights a simple, low-cost, and environmentally safe method for synthesizing functional vanadium oxide nanoparticles with promising applications in biomedical and industrial fields.***

Keywords: Green synthesis, Vanadium oxide nanoparticles, Plumeria obtusa leaf, Antibacterial activity, Anticorrosion.

I. INTRODUCTION

Vanadium oxides represent a diverse group of inorganic compounds formed through the interaction of vanadium with oxygen, exhibiting multiple oxidation states ranging from +2 to +5. This variability in oxidation states imparts unique structural, electronic, and catalytic properties, making vanadium oxides highly versatile in scientific and industrial applications. Among them, vanadium(V) oxide (V_2O_5) is the most stable and widely studied, appearing as a yellow-orange crystalline solid with a direct band gap of 2.2–2.7 eV. Its semiconducting nature, high surface area, and layered orthorhombic structure enable applications in photocatalysis, smart windows, gas sensors, and energy storage devices such as lithium-ion batteries and supercapacitors [1],[6]. Furthermore, vanadium(V) oxide functions as a strong oxidizing agent and amphoteric oxide, allowing it to participate in diverse redox and catalytic reactions, including the industrial oxidation of sulfur dioxide to sulphur trioxide in sulfuric acid production. These properties highlight VO as a promising material in nanotechnology, green chemistry, and advanced energy systems. *Plumeria obtusa* L., a member of the family *Apocynaceae*, is a deciduous tropical plant cultivated widely for its ornamental and fragrant flowers. Beyond its aesthetic appeal, the plant has a long history of use in traditional medicine, where its leaves are employed to treat diabetes, wounds, skin diseases, and inflammatory conditions. Phytochemical investigations reveal that the leaves are rich in flavonoids, tannins, terpenoids, and triterpenoids, which contribute to antioxidant, antimicrobial, and wound-healing activities [7], [8]. Recent studies have explored the role of *P. obtusa* leaf extracts in green synthesis of nanoparticles, where phytochemicals act as reducing and stabilizing agents. These biosynthesized nanoparticles exhibit significant antibacterial properties, supporting their potential in biomedical and pharmaceutical applications. Traditional uses, such as decoctions for skin ailments and antidiabetic remedies, are now being scientifically validated, though further clinical studies are required to establish safety and efficacy [10], [11].

II. MATERIALS AND METHODS

A. Synthesis of the Vanadium Oxide (VO) nanoparticles

Healthy and mature leaves of *Plumeria obtusa* were collected, washed thoroughly with tap and distilled water, shade-dried at room temperature, and ground into fine powder. About 20 g of the powdered leaves was extracted in 400 mL of double distilled water by boiling for one hour. The aqueous extract was cooled, filtered, and stored for further use [21]. About 75 mL of the prepared aqueous plant extract was taken in a 100 mL conical flask, and about 2.5 g of LR vanadium pentoxide was gradually added to it.

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The mixture was stirred thoroughly to ensure uniform dispersion of the precursor in the plant extract. The reaction mixture was then subjected to ultrasonication at 35 °C for 4 – 5hours to enhance the interaction between phytochemicals and vanadium ions, facilitating nanoparticle formation. After completion of the reaction, the mixture was filtered using Whatman No. 1 filter paper to separate the solid product. The obtained residue was dried and subsequently calcinated in a muffle furnace at 500–550 °C for 4–5 hours to improve crystallinity and remove organic residues is shown fig.1**.** The synthesized nanoparticles was names as VO [12].

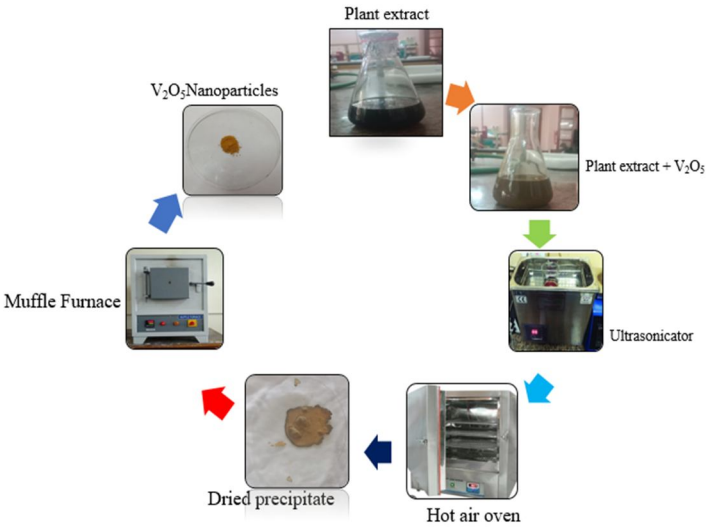


Fig. 1 Schematic representation for the synthesis of VO nanoparticles

B. Characterization Techniques

UV–Visible Spectroscopy Used to measure light absorption in the UV (200–400 nm) and visible (400–800 nm) regions. Diffuse reflectance spectra were recorded using a JASCO V-650 spectrophotometer over 200–900 nm with 2 nm resolution. Fourier Transform Infrared (FT-IR) Spectroscopy applied to identify functional groups in the synthesized nanoparticles. Samples were mixed with KBr, pressed into pellets, and analyzed using a Shimadzu IRTRACER-100 spectrophotometer. X-ray Powder Diffraction (XRD) employed to determine crystalline phases and structural properties. PXRD patterns were obtained using a Rigaku RINT 2500 V diffractometer with CuKα radiation (λ = 1.5406 Å). Field Emission Scanning Electron Microscopy (FE-SEM) conducted to examine surface morphology and microstructural features of the nanoparticles using a Supra 55 Zeiss instrument. Energy Dispersive X-ray Spectroscopy (EDAX/EDS) Utilized for elemental composition analysis. Performed with a Supra 55 Zeiss FESEM equipped with Oxford instruments X-Max EDX system. Thermogravimetric Analysis (TGA) **a**pplied to study thermal stability and weight changes with temperature. Measurements were carried out using a TG/DTA EXSTAR 6300 analyzer under controlled heating rates.

1) Antibacterial Activity

The test bacteria were cultured in peptone water and incubated at 35 °C for 3–4 hours. Mueller–Hinton agar plates were prepared, and 0.1 mL of the bacterial culture was spread evenly on the surface. After drying, sample-loaded discs (1000 µg/mL) were placed on the plates under sterile conditions. The plates were incubated at 37 °C for 18–24 hours, and the zone of inhibition was measured in millimeters to assess antibacterial activity.

2) Anticorrosion Activity

The anticorrosion activity of VO nanoparticles was studied by coating cleaned mild steel plates (5 cm × 2 cm) with a solution containing 0.1 mg of VO, then immersing them in acidic (HCl), basic (NH_4Cl), and neutral (seawater) solutions for 10 days, after which the plates were washed, dried, and examined for corrosion resistance.

III. RESULTS AND DISCUSSION

A. UV – Vis Analysis

The UV–Visible absorption spectrum shown fig. 2 of the green-synthesized VO nanoparticles shows absorption peaks at 265 nm and 276 nm in the ultraviolet region and a broad absorption band at 451 nm in the visible region.

The UV absorption peaks are due to π–π* electronic transitions and charge transfer transitions from oxygen (O^{2-}) to vanadium (V^{5+}) ions, confirming the formation of VO nanoparticles [11], [12]. The absorption band around 451 nm arises from d–d transitions and oxygen vacancy-related states in the VO lattice [13].

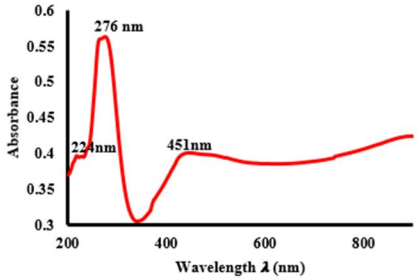


Fig.2 UV- Vis spectrum of VO nanoparticles

B. Fourier Transform Infrared Spectroscopy Analysis (FT- IR)

A strong and sharp peak at 1020 cm^{-1} is assigned to the characteristic V=O stretching vibration**,** confirming the formation of vanadium–oxygen bonds [14]. The absorption band at 818 cm^{-1} is attributed to V–O–V bridging vibrations**,** while the low-frequency band at 550 cm^{-1} corresponds to metal–oxygen lattice vibrations**,** which further confirms the successful formation of vanadium oxide–based material is shown fig. 3 [15].

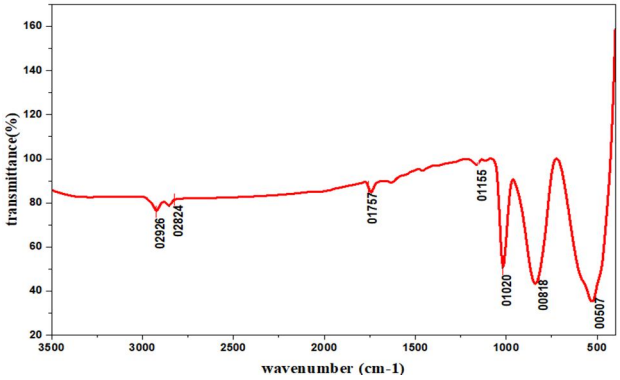


Fig. 3 FT-IR spectrum of VO nanoparticles

C. X-Ray Diffraction Analysis (XRD)

XRD analysis confirmed the crystalline nature of the synthesized VO nanoparticles is shown fig. 4. The diffraction peaks observed at 2θ values of 15°, 20°, 21°, 26°, 31°, 32°, 33°, 34°, 42°, 45°, 48°, 49°, 50°, 51°, 52°, and 60° matched well with the orthorhombic phase reported in JCPDS card No. 96-300-0426. The absence of extra peaks indicated high phase purity. The average crystallite size, calculated using the Debye–Scherrer equation, was found to be 2.37 nm, confirming nanoscale dimensions. The sharp and intense reflections suggested good crystallinity [16].

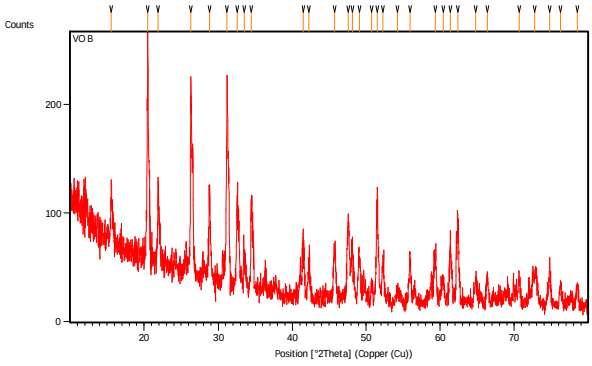


Fig. 4 XRD- Spectrum of VO nanoparticles

D. Field Emission Scanning Electron Microscopy Analysis (FESEM)

FESEM analysis revealed that the VO nanoparticles exhibit a rod-like morphology with elongated and aggregated structures. The particles are distributed in the nanometer range, forming a layered framework. Magnified images (fig. 5) showed nanorods with an average particle size of 348.35 nm, confirming their nanoscale dimensions and uniform crystalline nature. This morphology supports their potential in electrochemical and catalytic applications [17].

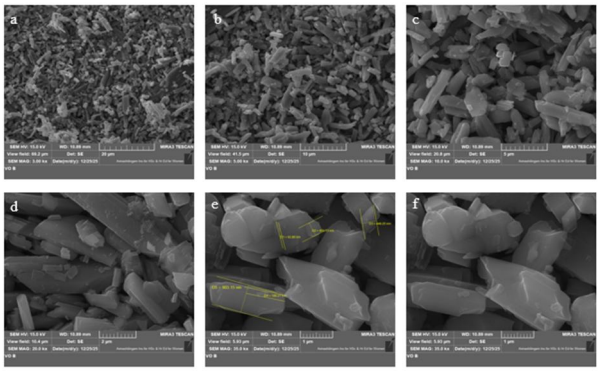
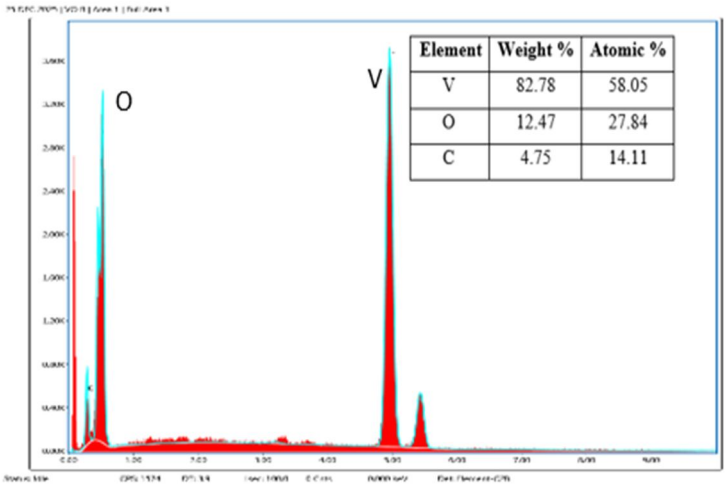


Fig. 5 FESEM images of VO nanoparticles in different magnification of a) 20 µm b) 10 µm c) 5 µm d) 2 µm e,f) 1 µm

E. Energy Dispersive X-ray Analysis (EDAX)

EDAX analysis confirmed the elemental composition of VO nanoparticles, showing fig. 6 vanadium and oxygen as the major constituents. The dominance of V and O peaks verified the oxide nature of the material and indicated successful formation of VO. Quantitative data revealed a higher weight and atomic percentage of vanadium compared to oxygen, consistent with the expected stoichiometry. These findings support the structural identification of VO nanoparticles and align with earlier reports on vanadium oxide nanomaterials, highlighting their suitability for energy storage and functional applications [1].



Element	Weight %	Atomic %
V	82.78	58.05
O	12.47	27.84
C	4.75	14.11

Fig. 6 EDAX- Spectrum of VO nanoparticles

F. Thermogravimetric Analysis (TGA)

TGA analysis demonstrated the thermal stability of VO nanoparticles across 0–1000 °C. The TG curve showed (fig. 7.a) a minor weight loss of 0.3% below 500 °C, attributed to evaporation of adsorbed moisture and volatile impurities. A second stage of weight loss, about 6.0%, occurred between 500 °C and 900 °C due to decomposition of residual organic compounds from the green synthesis process. Above 900 °C, the total weight loss reached only 7.3%, confirming that the nanoparticles remain stable at high temperatures. The low overall weight loss highlights the good thermal stability of the synthesized VO nanoparticles, making them suitable for advanced functional applications. TGA analysis confirmed that VO nanoparticles show as fig. 7.b about 30% total weight loss, mainly due to moisture and organic decomposition, and remain thermally stable at higher temperatures [18].

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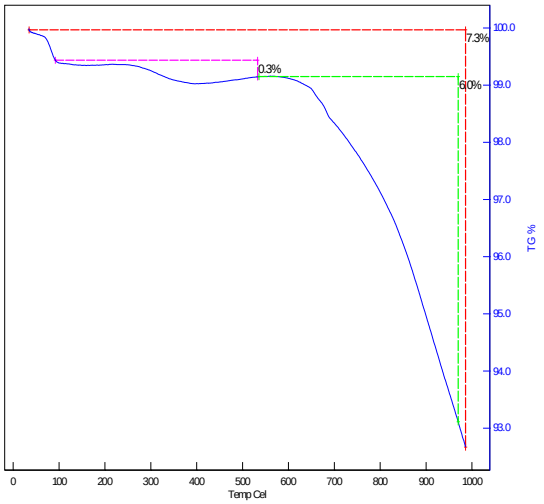


Fig. 7.a TGA curve of VO nanoparticles

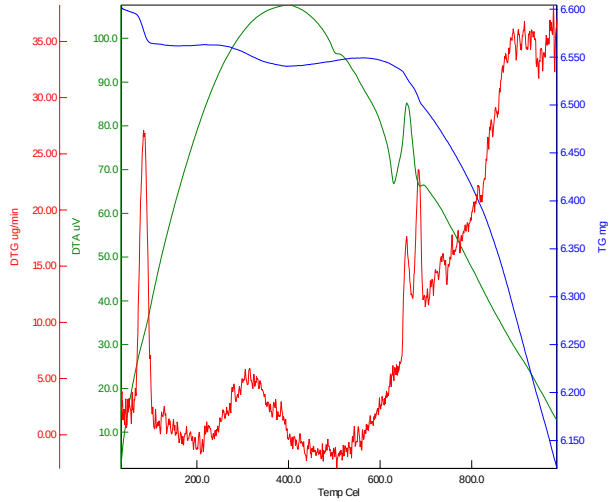


Fig. 7.b Companied TG, DTA, DGA – Curve of VO nanoparticles

G. Antibacterial Activity

The antibacterial activity of VO nanoparticles was confirmed by agar well diffusion tests against Gram-positive and Gram-negative bacteria. The inhibition zones ranged between 7–11 mm, showing moderate activity compared to ciprofloxacin (21–25 mm). VO displayed slightly stronger effects against *Escherichia coli*, *Staphylococcus aureus*, and *Bacillus subtilis*. Overall, VO nanoparticles demonstrated appreciable antibacterial potential, supporting their use in biomedical and antimicrobial applications [19].

Table 1: Antibacterial Activity for VO Nanoparticles

Bacteria	**Inhibition zone in mm**	
	Ab ciprofloxacin	**VO**
Escherichia coli	21	11
Staphylococcus aureus	25	9
Bacillus subtilis	24	10
Bacillus cereus	25	8
Kleibsiella pneumonia	22	9

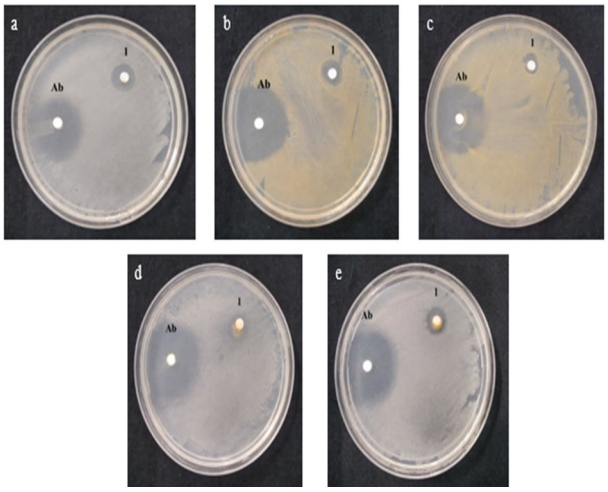


Fig. 8 Antibacterial activity of a) *E.coli*, b) *Staphylococcus aureus*, c) *Bacillus subtilis*, d) *Bacillus cereu*, d) *Kleibsiella pneumonia*

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H. Anticorrosion Activity

VO nanoparticles showed notable anticorrosion activity in acidic medium (28.45%), moderate effect in neutral medium (6.90%), and negligible protection in alkaline medium (-3.19%). This confirms their potential as effective anticorrosion agents, especially under acidic conditions is shows fig. 9 [20].

Table 2: Percentage of Anticorrosion Activity of VO Nanoparticles

Medium	Without nanoparticle	With Nanoparticle (%)	ΔW	Percentage of anticorrosion activity
Acid	0.32	0.21	0.11	28.45
Alkaline	0.40	0.42	0.02	-3.19
Neutral	1.30	1.19	0.05	6.90

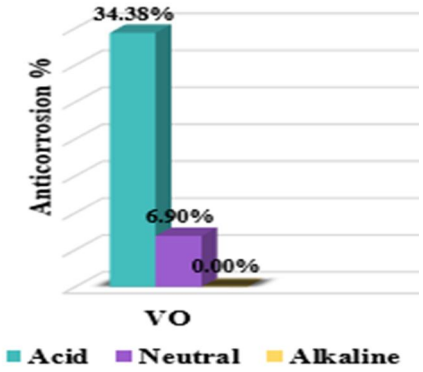


Fig. 9 Percentage of anticorrosion efficiency in different media

IV. CONCLUSIONS

The synthesized VO nanoparticles were successfully confirmed through UV–Vis, FTIR, XRD, FESEM, EDAX, and TGA analyses. The optical studies revealed strong absorption peaks linked to electronic transitions, while FTIR confirmed V–O bonding. XRD patterns showed an orthorhombic crystalline phase with nanoscale crystallite size, and FESEM images displayed rod-like morphology with uniform particle distribution. EDAX verified the elemental composition of vanadium and oxygen, supporting oxide formation. TGA demonstrated good thermal stability with minimal weight loss. Antibacterial studies showed moderate inhibition against Gram-positive and Gram-negative bacteria, with VO exhibiting slightly higher activity. Anticorrosion tests indicated strong efficiency in acidic medium, moderate in neutral, and negligible in alkaline conditions. Overall, VO nanoparticles possess high purity, nanoscale dimensions, thermal stability, and functional properties, making them promising for applications in catalysis, energy storage, biomedical, and protective coatings.

V. ACKNOWLEDGMENT

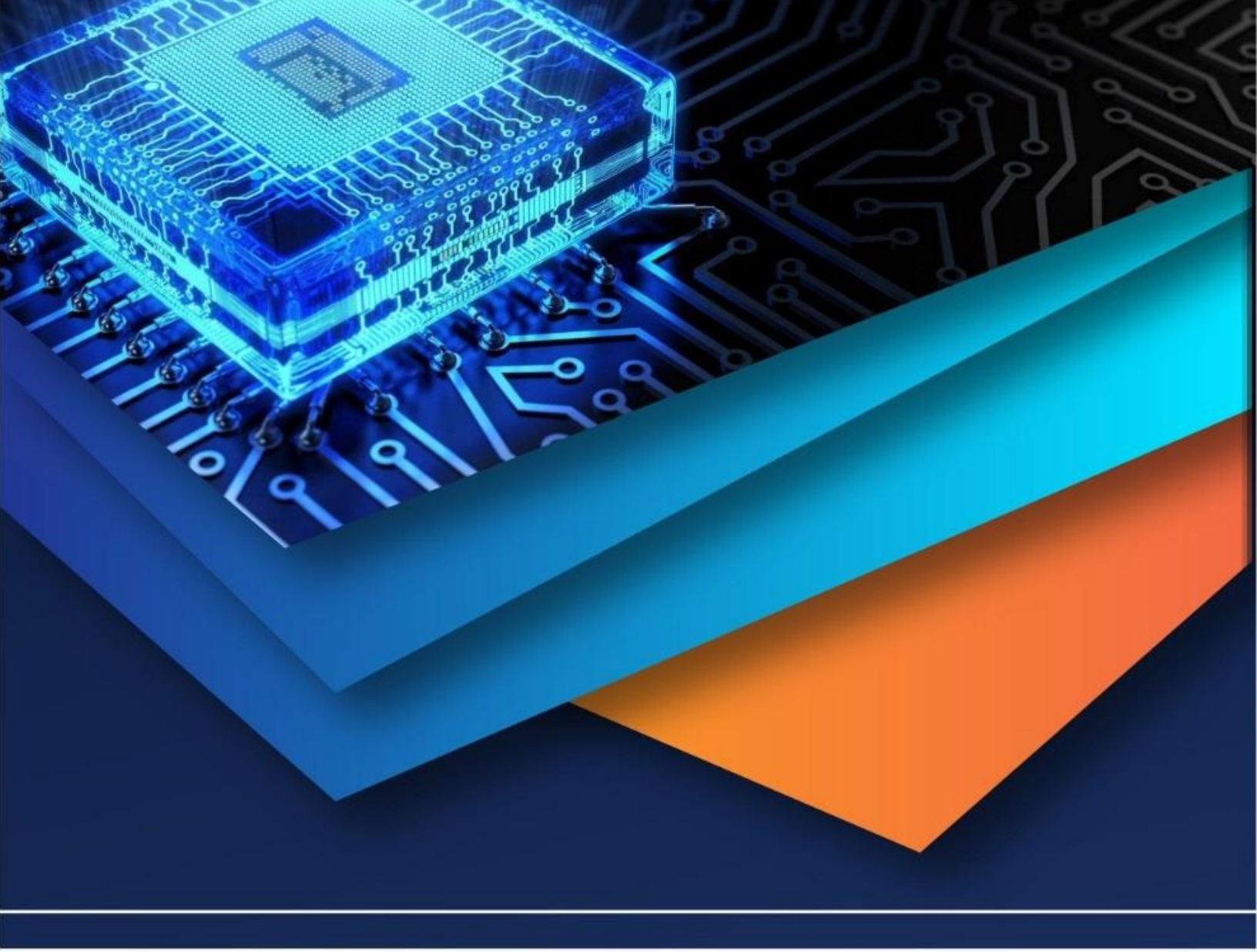
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