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Experimental Study on Structural, Morphological and Optical Properties of Nanocomposite Materials for Dielectric Applications

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A material that composed a components either nanoscale or nano-sized and have improved dielectric characteristics is called a nanocomposite material for dielectric applications. Dielectric materials can sustain an electric field with little energy loss since they are non-conductive. This study examined in detail the optical, morphological, and structural characteristics of materials made of tin dioxide/graphene oxide (SnO_2/GO), with an emphasis on the potential uses of these materials as dielectrics. The crystalline nature of the materials was revealed by using X-ray diffraction (XRD) to clarify the structural properties of the produced nanocomposites. This was done in a systematic manner. For the purpose of enhancing dielectric characteristics, morphological investigations using scanning electron microscopy (SEM) reveal a well-dispersed and linked structure. A significant defect density is discovered in the composite, and the energy dispersive X-ray spectroscopy (EDX) spectrum's exclusive Tin (Sn), carbon (C), and oxygen (O) content confirms the originality of the sample. The optical properties of the nanocomposites were studied using photoluminescence (PL) measurements, and ultraviolet-visible spectroscopy (UV-Vis) of the nanocomposite revealed a 3.7 eV energy of the band gap that is consistent with SnO. The tiny high fault density and grain size are in charge of the dielectric constant's observable increase. The synthesized SnO_2/GO nanocomposite shows promising properties use in dielectric applications.

Keywords: Nanocomposite, Tin Dioxide/Graphene Oxide (SnO_2/GO), Scanning Electron Microscopy (SEM), Morphology, Optical, Structural, Dielectric, X-ray diffraction (XRD).

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1. INTRODUCTION

Dielectrics have better power density and great rate capacity, which makes them popular materials for electric power systems, and contemporary gadgets use electrical energy storage. Due to its rapid charge/discharge velocity, extremely high density of power, and extended cycling life, the capacitor with dielectric properties is currently one of the greatest auspicious options when compared to other types of battery storage such as magnesium-based rechargeable ion batteries, zinc ion batteries and lithium. Even though batteries have greater capacity for both charging and discharging, their use is restricted in certain locations due to environmental contamination caused by the chemical elements of recharged ion batteries [1]. Materials with low dielectric loss and a high dielectric constant are used in parallel plate capacitors as the insulating substance. Many different materials have been considered for use in integrated capacitor applications. In the past, capacitors were made of ferroelectric materials with a high dielectric constant and persistent dipole moment. However, the high processing temperatures required for these materials above 600 °C have hindered their widespread applicability in high-charge storage applications. Polymeric materials are suitable substitutes because of their low processing needs. However, reduced dielectric constants limit the widespread use of polymer-based materials [2]. The use of nanoparticles within a dielectric matrix to improve certain qualities that are essential for electronic components is the process of

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creating nanocomposite materials for dielectric applications. Polymers such as epoxy or polyimide, ceramics like barium titanate or lead zirconate titanate (PZT), and metal oxides like titanium dioxide or zinc oxide are used matrix. These nanocomposites show enhanced mechanical robustness, thermal stability, and strong dielectric properties [3]. Effective energy storage technologies such as solar cells, batteries, and supercapacitors have shown their worth in real-world uses. In light of recent advancements in supercapacitors, batteries, and solar cells for energy storage, current situations using polymers or composites of polymers are discussed. In large-energy-density supercapacitors, where a significant amount of energy is collected at high discharge rates, the electrode of the capacitor is made possible by recent advancements in high mesoporous carbon produced by the pyrolysis of polymers [4-6]. In this study [7], we examine nanocomposite materials' optical, morphological, and structural characteristics for dielectric applications.

The rest of the paper's organization as follows: a literature review is presented in section 2, the methodology is described in section 3, the result and discussion in section 4, and section 5 describes the conclusion of the paper.

2. LITERATURE REVIEW

The article [8] emphasized the difficulties dielectric polymers provide for cable/wire insulation and capacitors. The main technological strategies for improving the dielectric strength of polymers and nanocomposites are also outlined, including film surface coating, filler-polymer interface technology, and the integration of nanoparticles into polymers. Interface innovations are receiving more attention, they include the inorganic coatings of polymer films, the core-shell systems' logical design, and the use of fillers that are thermally conductive and low-dimensional. Materials based on polymers are starting to show up as possible parts for high-energy storage systems. The research [2] described the creation of flexible, powerful composites using solution casting and modified carbon nanofibers (CNF) based on polyaniline (PANI) and poly vinyl alcohol (PVA). PANI/CNF/PVA composite film was used to create a metal-insulator-metal (MIM) capacitor with a large dielectric constant. The study [9] introduced a novel kind of one-dimensional photonic crystals that include layers of dielectric and nanocomposite components based on graphene. This layer of the nanocomposite is made of dielectric host material containing graphene nanoparticles. The characteristics of the photonic band gap in the visual and infrared ranges are examined using the transferred matrix approach, the Maxwell-Garnett equation, and the Kubo formula. The article [10] suggested using chitosan (CS) as a potent agent chelating and a great template for the manufacture of nanoparticles of metal oxide. Using various methods, Adding 10 %wt of MgO produced the CS-MgO nanocomposite film in comparison to CS. Several of the primary CS characteristic spikes were displaced in the FTIR as a result of their interactions with MgO, particularly with the NH_2andOHcollections. Additionally, SEM graphs demonstrated a distinct alteration in the morphological exterior of CS. Environmentally friendly materials are also a focus of current research [11], in addition to increasing energy density. Because polymer composites have so many uses, they are recognized as technically indispensable materials. Because of their exceptional dielectric characteristics, zinc oxide (ZnO) based polymer nanocomposites have been the subject of much investigation.

Using XRD, rGO and Al-doped ZnO's structural characteristics were confirmed. After Al was added to the ZnO lattice, a Wurtzite structure devoid of impurities phase was seen. The nanocomposite's morphological data, which shows the ZnO nanoparticles doped with Al to become distributed across the rGO sheet, was shown using a field emission scanning electron microscope (FESEM). They looked at the resulting composite's optic and dielectric characteristics [12]. The prepared samples' composition, surface appearance, and microstructure have been examined. The presence of rGO sheets and crystalline cubic MgO nanoparticles was verified by XRD analysis. The graphene sheets had the spherical MgO nanoparticles evenly distributed, as seen by an SEM. An examination using UV visible spectroscopic revealed a red shift in the absorbance curve that was depending on wavelengths [13]. The study [14] used an ex-situ casting technique to study synthetic nanocomposite (NCP) made of cadmium sulfide (CdS) nanoparticles (NPs) and Makrofol polycarbonate (PC). To create the NPs in the context of a stream of nitrogen gas, the procedure was a thermalized technique. The Rietveld refining of X-ray data revealed the cubic and hexagonal structures of the CdS. The work [15] Polyethylene oxide and polyvinyl pyrrolidone (PVP) mix matrix polymer nanocomposite (PNC) films integrated with nanoparticles of ZnO were synthesized and described as possible candidates to be used in the next microelectronic and optoelectronic devices. The structural characteristics of utilizing these PNCs were examined by XRD, FTIR spectroscopy, and SEM. Using polyvinyl alcohol (PVA), Cs, and titanium oxide (TiO_2), the research [16] attempted to produce PVA/Cs/TiO_2 flexible nanocomposite sheets for energy storage applications. An analysis was conducted between 100 Hz and 5 GHz to investigate the effect of TiO_2 on the PVA/Cs' electrical impedance, permittivity, energy economy and conductivity.

3. METHODS AND MATERIALS

In this section, we discuss about the nanocomposite material's measurements, sample, and preparation of the SnO_2 composite.

3.1 Material Synthesis

Tin dioxide nanoparticles and graphene oxide sheets are combined to create SnO_2/GO composites. When two or more components are combined, their unique qualities are frequently increased, which improves performance in a variety of applications, including sensors, batteries, and catalysis. Figure 1 depicts the Synthesis of the material.

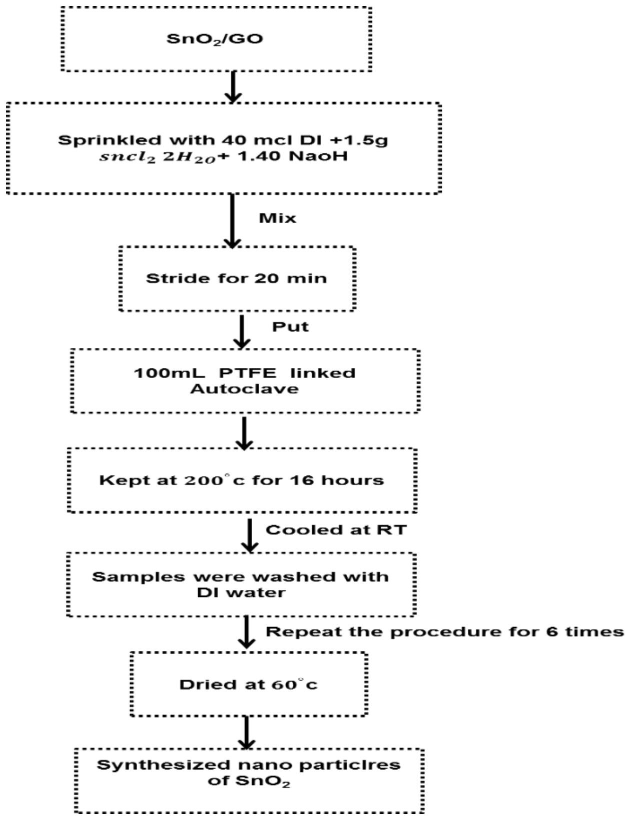

Fig. 1 – Synthesis of the material

3.2 Specifications

Using SEM and XRD, the structural features and surface morphology of the produced examples were assessed. The purity of the material was confirmed by the use of EDX, Raman spectroscopy, and FTIR methods for chemical structure and molecular bond examinations. Electrochemical impedance spectroscopy (EIS), cyclic voltammetry (CV), and Charge discharge (CD)methods were used to examine the electrochemical characteristics. Additionally, the SnO_2/GO nanocomposite's dielectric characteristics were examined.

4. RESULT AND DISCUSSION

In this section, we discuss the properties of nanocomposite materials in terms of structure, morphology, and optics for dielectric applications.

4.1 Structural Analysis

The XRD of the SnO_2/GO composite and pure SnO_2 nanoparticles is shown in Figure 2. Compared to SnO_2, the nanocomposite's peak intensities are lower, and its widths are wider. Because of the GO sheets, which eventually lessen the supply of SnO_2 precursors, the composite's expanded peaks clearly demonstrate the decreased SnO_2 size of the particles. XRD data confirms that the structure is stressed because of the reduction in SnO_2 size. In the SnO_2/GO nanocomposites, the cohabiting stages of SnO_2 and GO are visible in the XRD spectrum. The formula developed by Debye Scherer yields the respective estimated average crystallite sizes for SnO_2 and SnO_2/GO.

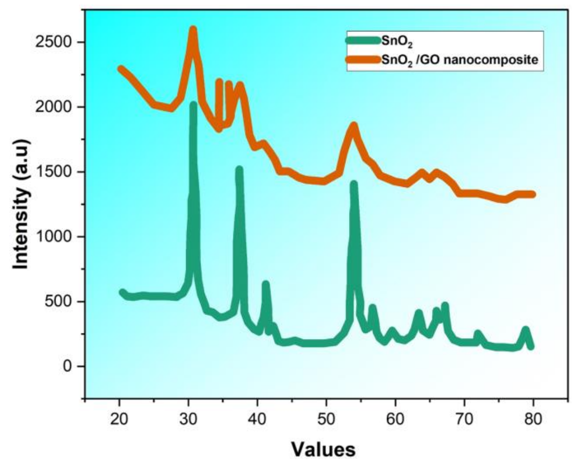

Fig. 2 – XRD pattern of the SnO_2/GO Nano composite and plain SnO_2

The nanocomposite SnO_2/GO's Raman spectra are exposed in Figure 3(a). A1g, D, and G bands, respectively. The D and G bands are claimed belong to GO, but the A1g band is associated with SnO_2. With improved crystallization, the strength of the A1g band rises. Small SnO_2nanoparticles are thought to be the cause of the A1g's breadth. When studying carbon-based materials, the bands D and G of GO may be changed to reflect the thickness of defects and the size of the grain of the carbon. Since graphite has an E2g mode, the peak located at 1587 cm^{-1} is recognized to the G band. Because of the 2D lattice's sp^2 hybridized carbon atoms, the E2g vibrational mode develops.Fourier-transform infrared spectroscopy (FTIR), as seen in Figure 3(b), was used to determine the function of groups and bonds of chemicals. The vibrational spectrum of pure SnO_2 shows two primary peaks: the anti-symmetric vibrates of Sn–O–Sn are responsible for one peak at 613 cm^{-1}, while the hydroxyl group is responsible for the second peak at 3451 cm^{-1}. The environment's humidity is the reason for the incorporation of the water molecule.

4.2 Morphology Analysis

Using a FE-SEM, a SEM study was conducted to examine the composite's surface morphology, as shown in Figure 4. The spherical SnO_2 incorporated nanoparticles between GO sheets and have edges that curve, as seen in Figures. 4(a). The SnO_2 nanoparticles' dispersion inside the GO sheets is well shown by the magnified position of (a).

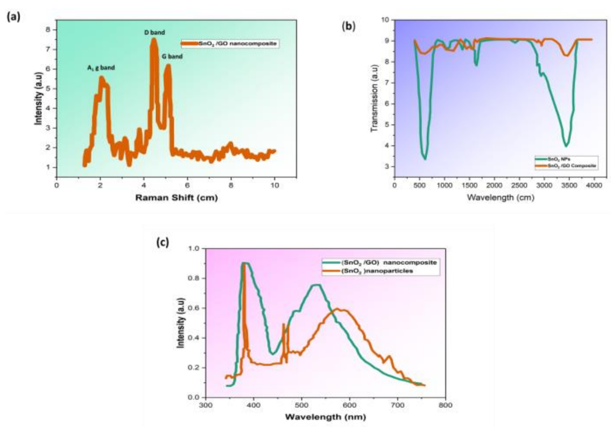

Fig. 3 – (a) Raman, (b)FTIR (c) PL

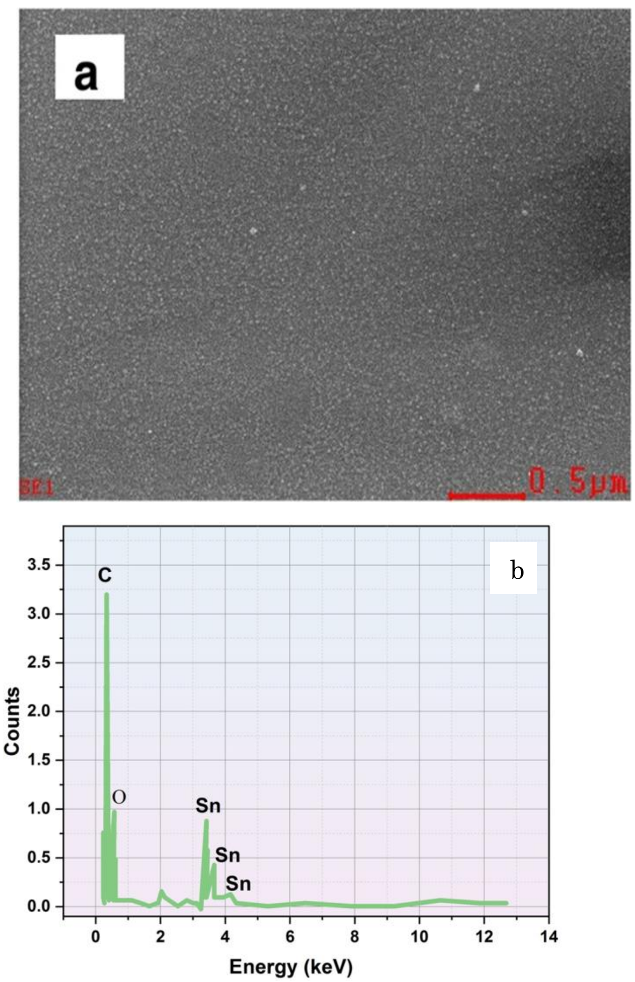

Fig. 4 – (a) Surface SEM image of SnO_2 and (b) EDX of SnO_2/GO nanocomposite

This improves the durability and surface area of GO sheets, which is beneficial for electrochemical purposes. The sample's EDX is shown in Figure 4(b), which provides information on the material's concentration and chemical makeup. Sn, C, and O are the elements that have been found. Figure 4(b) shows the percentages of weight and elemental atoms. According to the EDX data, the composite is made of GO and SnO_2.

4.3 Optical Properties of SnO_2/GO

Fig. 5 displays the UV-Vis spectrum of the Nano composition SnO_2/GO. According to the aforementioned spectra, the band gap energy is 3.84 eV. In comparison to pure SnO_2 nanoparticles, it confirms that the carrier concentration of the GO is higher. Therefore, by adding impurities, the band gap of SnO_2 may be adjusted. The movement of SnO_2/GO's optical band gap into the visible large frequency region demonstrates the material's viability for optoelectronic devices.

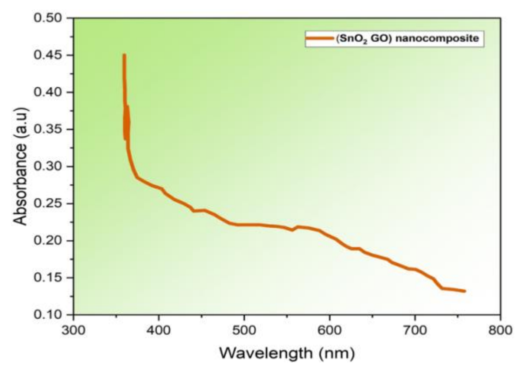

Fig. 5 – Spectra of UV-Vis Absorption of SnO_2/GO Nanocomposite

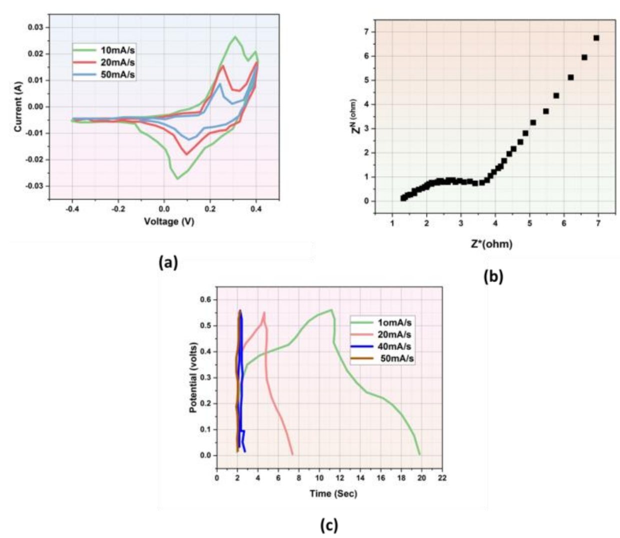

Fig. 6 – (a) Electrochemical assessment of SnO_2/GO nanocomposite, (b) Nyquist plot of SnO_2/GO, (c) Charge discharge curves for galvanostatic systems

Using the CV method, the material's capacity to store charge was investigated. The SnO_2/GO nanocomposite's cyclic voltammogram is shown in panel (a) of Figure 6. It is noted that the voltammogram is rectangular in form, has large peak currents and that the redox mechanism implicated is reversible. The patterned nano-sized SnO_2

surface on GO exhibits a pseudo capacitance, which contributes to the improvement of capacitance. In Table 1, the anodic and cathodic currents that correlate to the peak values of redox capacities are shown in the panel.

CONCLUSION

To conclude, the examination of SnO_2/GO nanocomposite materials' structural, morphological, and optical characteristics has yielded important information on their prospective use as dielectric materials.In accordance with the outcome, the creation of a SnO_2/GO nanocomposite with a rutile tetragonal structure was validated by XRD.A well-dispersed and linked structure was found by morphological characterization using SEM, which is crucial for maximizing dielectric characteristics. The findings of the UV-Vis spectroscopy showed that the presence of Go altered the optical bandgap, suggesting that the material may be susceptible to electromagnetic fields. Grain boundaries increased due to the huge number of grains in the composite, as shown by the dielectric characteristics. Increased concentration of flaws and a large number of grain boundaries led to an improvement in the dielectric characteristics. In the future, SnO_2's dielectric characteristics combined with GOs large surface area and conductivity, make a viable option for energy storage devices.

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Експериментальне дослідження структурних, морфологічних та оптичних властивостей нанокомпозитних матеріалів для застосування в діелектриках

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Матеріал, який складається з нанорозмірних компонентів та має покращені діелектричні характеристики, називається нанокомпозитним матеріалом для діелектричних застосувань. Діелектричні матеріали можуть підтримувати електричне поле з невеликими втратами енергії, оскільки вони не проводять. У дослідженні детально розглянуто оптичні, морфологічні та структурні характеристики матеріалів, виготовлених із діоксиду олова/оксиду графену (SnO_2/GO), з наголосом на потенційному використанні цих матеріалів як діелектриків. Кристалічна природа матеріалів була систематично досліджена за допомогою методу рентгенівської дифракції (XRD) для уточнення структурних властивостей отриманих нанокомпозитів. З метою покращення діелектричних характеристик морфологічні дослідження за допомогою скануючої електронної мікроскопії (SEM) виявляють добре дисперсну та пов'язану структуру. У композиті виявлено значну щільність дефектів, а ексклюзивний вміст олова (Sn), вуглецю (C) і кисню (O) в спектрі енергодисперсійної рентгенівської спектроскопії (EDX) підтверджує оригінальність зразка. Оптичні властивості нанокомпозитів досліджували за допомогою вимірювань фотолюмінесценції (PL), а ультрафіолетова спектроскопія (UV-Vis) нанокомпозиту виявила енергію забороненої зони 3,7 еВ, що відповідає SnO. Висока щільність невеликих дефектів і розмір зерна відповідають за помітне збільшення діелектричної проникності. Синтезований нанокомпозит SnO_2/GO демонструє перспективні властивості використання в діелектричних застосуваннях.

Ключові слова: Нанокомпозит, Діоксид олова/оксид графену (SnO_2/GO), Скануюча електронна мікроскопія (SEM), Морфологія, Оптика, Структура, Діелектрик, Рентгенівська дифракція (XRD).