



## Experimental and Theoretical Analysis for Plasmonic Graphene-Oxide as Energy Harvesting in IoT devices

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### Abstract

Energy harvesting within Internet of Things (IoT) devices pertains to the methodology of capturing and storing ambient energy to power diminutive, low-energy apparatuses. The phenomenon of surface plasmons, a collective of free electrons associated with graphene, constitutes a compelling subject in the domain of heterogeneous catalysis pertinent to energy harvesting. As a result, plasmonic catalysts based on graphene are amenable to extensive applications in energy harvesting and energy storage, underpinned by their exceptional characteristics, including a high charge carrier mobility of  $20 \text{ m}^2\text{V}^{-1}\text{s}^{-1}$  and a high theoretical surface area of  $2630 \text{ m}^2\text{g}^{-1}$ . This research presents both experimental and theoretical analyses employing the Finite-Difference Time-Domain (FDTD) method to investigate the potential of plasmonic-assisted nanocatalysis utilizing graphene oxide for energy harvesting and sustainable chemistry. Ultraviolet (UV) irradiation was employed as a methodical approach to progressively alter the chemical composition and structural characteristics of graphene oxide (GO) flakes, as substantiated by Atomic Force Microscopy (AFM) analysis. The ultrathin coatings and membranes derived from UV-irradiated GO flakes demonstrated the potential for tunable plasmonic energy harvesting. Moreover, the UV-treated superoleophobic GO membranes exhibited remarkable antifouling properties, rendering them highly suitable for advanced Internet of Things (IoT) applications.

**Keywords:** Energy Harvesting, Plasmonics, IoT, Graphene-Oxide, Energy Storage.

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## 1. Introduction

Currently great efforts are being devoted in exploring the plasmonic assisted catalysis as a sub-field in the field of nano-catalysis. Surface plasmons refer to electron oscillations on the noble metal nanoparticles. This phenomenon resulted from a large flow of electrons during light illumination. In addition, discovering different nanoparticles (NPs) have grown significantly. Two factors including their size and environment play an important role in reactivity of plasmonic NPs. It is understood by magnitude of electrons flow and

their lifetimes on the surface. Graphene, first 2D material with hexagonal arrangement, is a type of carbon material with extreme large surface area and  $sp^2$  bonded carbon atoms possess highest electron conductivity. Graphene proposed as an excellent candidate for energy production and storage applications including solar cells, fuel cells, batteries and supercapacitors owing to high tension, conductivity, large area, transparency, high charge carrier concentration and high electron mobility. In 2010 graphene, honeycomb structure, was discovered by A.Geim and K.Novoselov . graphene can be synthesized in different ways such

as: microchemical exfoliation, reduction of graphene oxide and chemical vapor deposition. Until now the most efficient method to produce high scale of graphene is graphene oxide GO. Currently the most prominent method to synthesis of GO is Hummers method. Besides in a great deal of studies modified Hummers method have been reported. It is noticeable that graphene is used in two common form graphene oxide and reduced graphene oxide with high conductivity [1-3].

The experimental and theoretical investigation of graphene-oxide energy harvesting capabilities report significant invention in innovations targeted at augmenting efficacy and sustainability in modern world technological landscape. Today's interconnected ecosystem is defined by a mounting composition of internet-linked devices and rising energy demand within the dynamic environment, increasing the urgency to innovate effective energy solutions. Research agenda on Plasmonic Graphene-Oxide necessitates a meticulous dissection of its distinct attributes as the key to effective energy harvesting. An exemplary comprehensive review of Plasmonic Graphene-Oxide properties found capabilities for augmenting energy harvesting exploitation, particularly in solar cells-based energy conversion or photodectors at near-infrared regions. Some groups underscores key prominent mechanisms like plasmonic excitation and light-matter interaction, which shape energy obtaining efficiency by enhancing energy obtaining spectrums and thus widening materials application in diverse fields [4-7]. The analysis of Plasmonic Graphene-Oxide driving energy harvesting activities in Internet of Things (IoT)-anchored environments reveals potential materials to offer applications and readiness to cope with evolving environmental diversity. Although, the configuration of the constitutive model, electro-deformation, and viscoelastic-optical properties deliver complexity towards solving theoretical models dynamics and developing parameters crucial to the actualization of energy conversion mechanisms. ASN et al. (2021) contribute to overcoming challenges delineating the role of surface plasmon polariton (SPP) waves in photonic nanostructures for IoTs as "planned and applied technology leveraging rising optical transmission spectrum for further applications in satellite communications and wireless systems." Although theorization of experimental phenomena elicits intrinsic advantages, it is challenging to contrast with environmental dynamics observed in the physical scale. Evaluation results delineate experimental capabilities of Graphene obtained from reduced

Graphene Oxide expanded by 500% the incident light energy while rectified the ideal nanoparticle as well. These findings show significant contrasts concerning growth videos of 20x, 40x, and 27x, respectively. Therefore, despite the theoretical claims, the emission functionalities of Graphene-Oxide towards metals assumes unexpected complications requiring experimental scrutiny and approximation to elicit truth concerning its role in energy harvesting applications [8-9].

In a nutshell, the need for energy constitutes a persistent challenge, and although increasingly a common environment in homes, industries, businesses, and organizations, it fundamentally impacts the ecosystems negatively due to expanded global warming potential. However, energy harvesting from renewable resources like solar is increasingly proposed as an ecological-friendly alternative to augment sustainable development. The evolution of integrated and efficient energy solutions concealed in the theory and future directions offered in Plasmonic Graphene-Oxide present potential for IoT applications. Recent research in the area showcases increasing attention toward traversing conservative energies harvesting efficiencies and theoretical limitations via innovative approaches to designing and obtaining an elaborate framework of theoretical and experimental investigations within the sector. Future research should concentrate on exploring nonlinear visco.elastic properties and thermoelectric qualities to enhance energy harvesting potential.

The rapid proliferation of Internet of Things (IoT) devices has significantly transformed modern technology, enabling smarter and more connected environments. These devices, ranging from smart home systems to industrial sensors, rely on constant power for functionality, necessitating innovative energy solutions to sustain their operation. However, traditional battery systems often prove inadequate due to size, recharging limitations, and environmental concerns. As a result, efficient energy harvesting techniques are essential for enhancing the longevity and sustainability of IoT applications. Advanced materials, such as plasmonic graphene-oxide composites, offer promising pathways for energy capture and conversion, effectively leveraging ambient energy sources like light and vibrations. By addressing the pressing need for reliable energy solutions in IoT devices, the integration of these novel materials can significantly bolster the efficiency and functionality of interconnected systems, facilitating broader adoption and innovative applications that redefine how we

interact with technology [11-12].

Plasmonic effects, characterized by the resonant oscillations of free electrons in metals when excited by incident light, play a pivotal role in enhancing the efficiency of energy harvesting technologies, particularly in the context of IoT devices [13]. These effects enable the concentration of electromagnetic energy at nanoscales, facilitating the harvesting of light energy that would otherwise be lost. In this regard, the incorporation of plasmonic materials, such as graphene-oxide composites, amplifies the interaction of light with the material, leading to increased absorption and subsequent energy conversion efficiency. The profound implications of this phenomenon extend to various applications, aiding in the development of sustainable energy solutions that are vital for the proliferation of IoT networks. By optimizing the plasmonic effects, researchers can address existing scalability and efficiency challenges, ultimately enhancing the performance and viability of energy-harvesting systems in an ever-demanding technological landscape [14-15].

In Fig 1. exhibited Different forms of graphene.

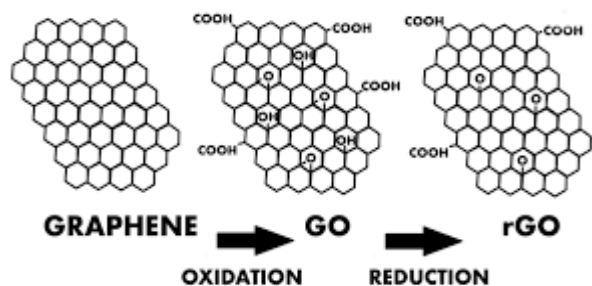


Fig. 1. Experimental Various Structures of graphene

In this study graphene oxide is synthesized successfully.

## 2. Experimental

### 2-1. Synthesis of Graphene Oxide

In 1985, Hummers demonstrated an alternative method for chemical exfoliation of graphite. As a typical process, 2g of graphite was added to a mixture of H<sub>2</sub>SO<sub>4</sub> and HNO<sub>3</sub> under ice bath and stirred for 30 min. following this, 6g of KMNO<sub>4</sub> was added slowly to the solution with constant stirring. Then 180 mL of deionized water was added to the mixture and following 25 mL of H<sub>2</sub>O<sub>2</sub> was all added drop by drop to the solution to remove the residual permanganate and manganese sulfate and oxygen. The color of the solution

changed from yellow to dark as illustrated in Fig. 2. Then black precipitation was washed several times to remove the dissolved mellitic acid salt with DI water and dried in an oven at 70 for 7h.

### 2-2. Characterization

AFM has emerged as the preferred instrument for the investigation of nanomaterials due to two primary factors: its high resolution and the availability of various modes that enable comprehensive characterization of nanomaterials, including their mechanical and electrical properties in addition to topographical analysis. Attaining exceptional resolution in the x, y, and z dimensions is vital for assessing phenomena at the atomic scale. AFM is among the few instruments capable of achieving the necessary resolution to analyze nanosheets that measure only a few angstroms in thickness. This capability is attributed to the resolution of commercial AFMs, which can reach lateral resolutions of less than a few nanometers and vertical resolutions exceeding 0.1 nm. Another significant advantage of AFM is its diverse range of measurement modes, which allow for the simultaneous evaluation of electrical and mechanical properties alongside topographical data. These modes can be utilized to investigate additional characteristics in depth or serve as a contrasting mechanism to assess the quality of synthesized graphene or the angular misalignment between stacked graphene layers. Consequently, AFM is an indispensable tool for the design of devices reliant on the stacking of two-dimensional materials. Furthermore, the AFM tip can be employed to manipulate samples at the nanoscale; for example, it can slice through graphene sheets. The resulting two halves of a single graphene sheet maintain the same crystal orientation, thereby enhancing control over angular misalignment during stacking. In addition to its imaging capabilities, another compelling reason for utilizing AFM is its compact design, which permits placement within a glovebox. This feature is essential when investigating graphene in conjunction with two-dimensional materials that are sensitive to oxygen or humidity Fig3. Shows atomic force microscopy (AFM) image of GO which confirm the thickness of the graphene layer is in nanoscale.

In addition, Uv-visible (UV) spectra in Fig. 4. Demonstrates a spectrum at 230 nm attributed to  $\pi$ - $\pi^*$  transition which confirmed the GO synthesis successfully.



Fig. 2. The preparation of graphene oxide from graphite powder

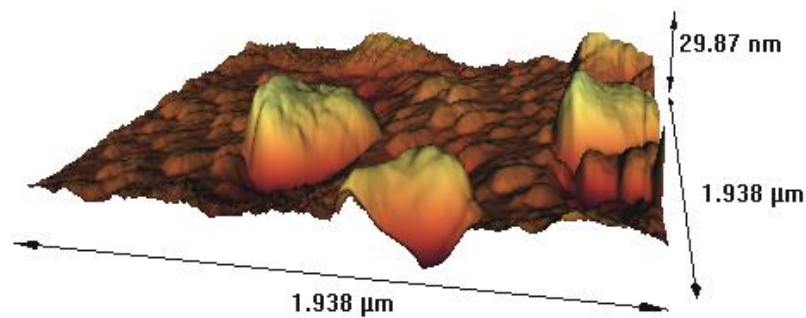


Fig. 3. Extracted results for AFM image of GO with considering its roughness

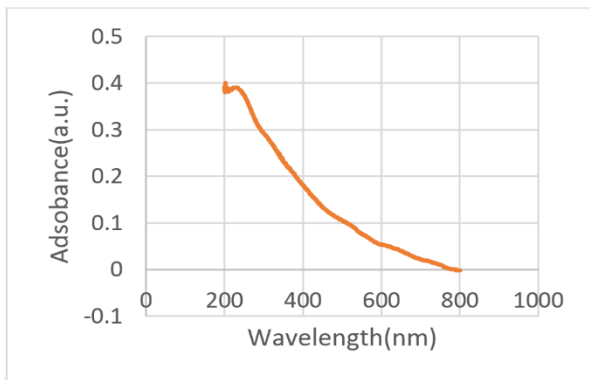


Fig. 4. UV spectrum of GO as wavelenth is changed from 0 to 1 μm

Furthermore electrical conductivity of GO was confirmed by a simple circute stem from high electron mobility of GO (Fig. 5).

In the following, Fig. 6. depicts X-ray power diffraction (XRD) pattern of GO. A chacrtristic peak near  $2\theta=12.6^\circ$  verfies graphitnes of GO nanolayer.

### 3. Theoretical Model

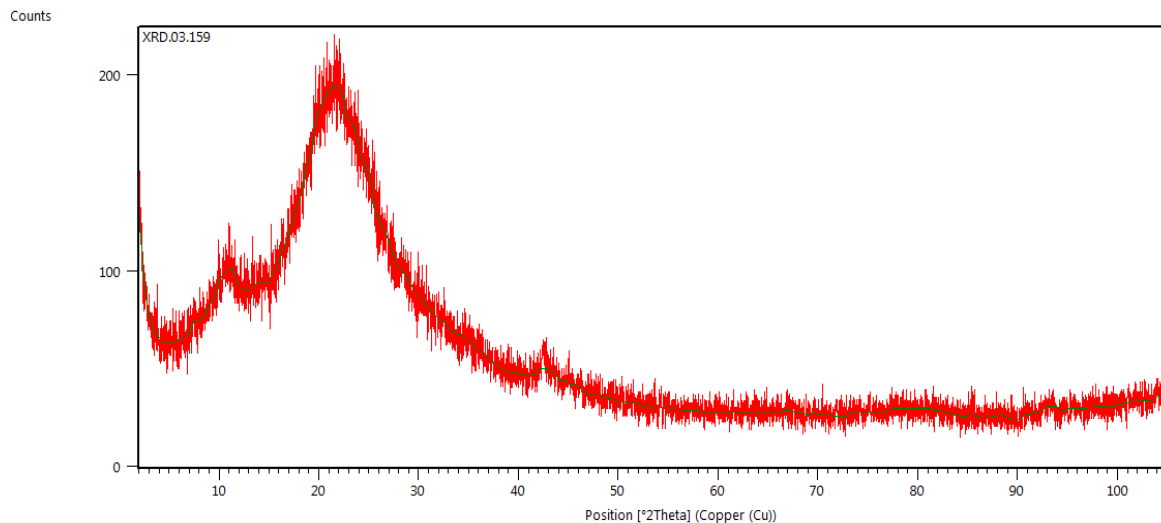
Finite-Difference Time-Domain (FDTD) is a numerical modeling technique used to solve Maxwell's equations for electromagnetic fields. It is particularly useful for simulating the behavior of electromagnetic waves in complex media and geometries. The FDTD method updates the electric and magnetic fields at each time step using finite difference approximations. The update equations are derived from Maxwell's equations and can be expressed as:

$$E_x^{n+1} = E_x^n - \frac{\Delta t}{\epsilon} \left( \frac{H_z^{n+\frac{1}{2}} - H_z^{n-\frac{1}{2}}}{\Delta y} - \frac{H_y^{n+\frac{1}{2}} - H_y^{n-\frac{1}{2}}}{\Delta z} \right) \quad (1)$$

$$H_x^{n+1} = H_x^{n-\frac{1}{2}} - \frac{\Delta t}{\mu} \left( \frac{E_z^n - E_z^{n-1}}{\Delta y} - \frac{E_y^n - E_y^{n-1}}{\Delta z} \right) \quad (2)$$



Fig. 5. Electrical conductivity of GO in a applied simple setup for energy harvesting



**Fig. 6. Extracted result XRD pattern of GO, which is an abbreviation for graphene oxide, has been meticulously analyzed and depicted in the context of its crystallographic characteristics and structural properties**

While the E and H refer to electric field profile and magnetic field profile, respectively.

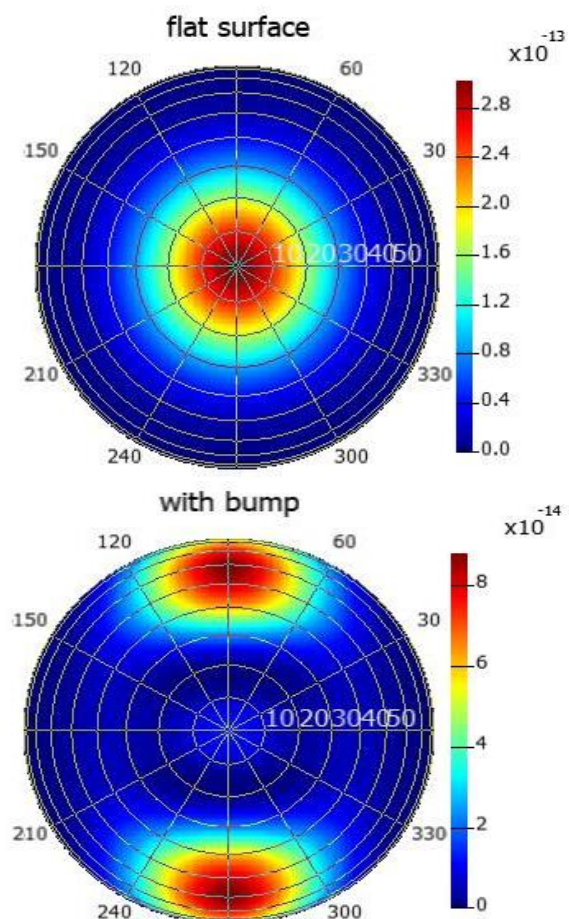
These update equations allow you to calculate the magnetic and electric field components at the next half time step based on the electric field components from the current time step. This staggered approach, similar to the electric field update, is essential for the accurate simulation of electromagnetic wave propagation in the FDTD method. The method is particularly useful in scenarios involving multiple scales, such as in complex materials or geometries.

In Fig. 6 the calculated flat surface of the structure is shown. As can be seen single mode and two mode is extracted and results are verified.

To examine the optical performance of the filter, the Finite-Difference Time-Domain (FDTD) method is employed. A single unit cell, as illustrated in Fig. 7, is analyzed under periodic boundary conditions (PBC) in the x and y directions, while perfectly matched layers (PML) are implemented on the top and bottom boundaries in the z direction. In this investigation, we utilized the commercial software Lumerical FDTD Solutions to explore the characteristics of the proposed structure. A two-dimensional simulation was conducted for a single unit of the grating within the xy-plane. The simulation area was defined by periodic boundaries in the x-direction and perfectly matched layer boundaries in the y-direction. The mesh sizes were configured to 0.1 nm along the x and y axes within the grating unit, with a gradual increase in size outside the cell unit.

Below are key aspects of the electric and magnetic field profiles in a typical wave propagation scenario, such as in free space. The

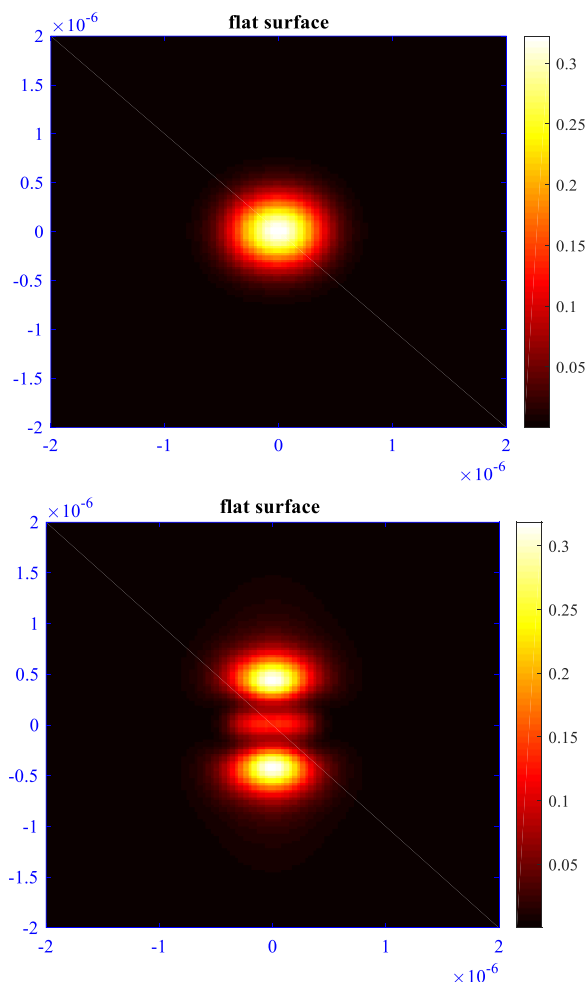
electric and magnetic field profiles are fundamental to understanding electromagnetic wave behavior.



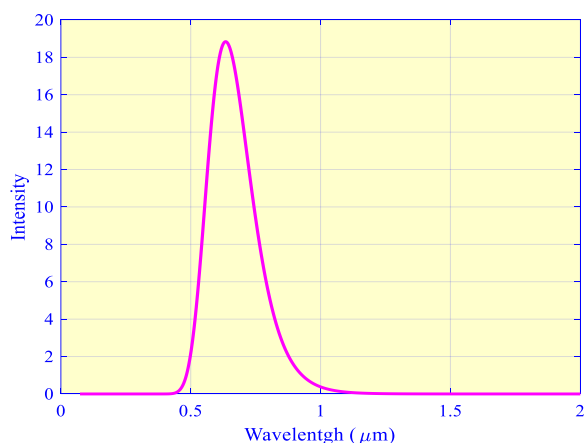
**Fig. 7. Flat surface with smith chart a) single-mode b) two-mode**

They oscillate in space and time, maintaining a specific relationship, and can be effectively

modeled and visualized using numerical methods like FDTD. In practical applications, these profiles are crucial for designing antennas, waveguides, and other electromagnetic devices. Fig. 8 flat surface for electric field profile is calculated for both modes.



**Fig. 8.** Result obtained from the finite-difference time-domain (FDTD) method reveals intricate details concerning the spatial distribution and characteristics of the electric field profile within the studied system. profile a) single-mode b) two-mode



**Fig. 9.** FDTD result for calculated intensity as wavelength changes from 0 to 2  $\mu\text{m}$

As you can see, in Fig. 8 the field monitor is shown for single-mode and two-mode.

Finally, the spectrum of structure as a function of wavelength is calculated and plotted in Fig. 9.

FDTD-calculated intensity versus wavelength when incident light polarized perpendicular two edges of the final structure. The arbitrary value of the intensity in the range of 500 nm to 1000 nm has maximum value. In this realm several invaluable works were proposed which can be verified by research groups [15-20].

#### 4. Conclusion

It is believed that in coming years more investigation will aim to research plasmonic nanocatalysis based novel nanomaterials and more attempts will be devoted to the cost effective, easy to use and better performance. Thanks to surprising properties of nanomaterials and integration with plasmonic technique, great achievements have been possible. Hence an excellent opportunities and unique way have been provided to optimize plasmonic nanocatalysis for different application including energy harvesting, selective and stable catalyst, green energy generation, energy storage and supercapacitor.

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## Biography

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Homa Faramani PhD student at Hamadan university of technology. Her research focuses on the synthesis and characterization of Graphene-based materials, with a particular emphasise on developing Graphene based materials for catalytic applications.

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Hamid Goudarziafshar Associated professor at Hamadan university of technology. Dr Hamid Goudarziafshar has published several articles in reputed journals and has contributed to advancements in novel Nanocatalyst. currently, they are working on developing, high-performance graphene-based materials for next generation catalyst.

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