DEPARTMENT OF
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*Synopsis Of*

# SENSITIVITY ENHANCEMENT OF GRAPHENE OXIDE GOLD NANOCOMPOSITES BASED SERS SENSOR FOR DETECTION OF MICRONUTRIENTS

*A Thesis*

*To be submitted by*

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**ROLL NO: BM22D0001**

*For the award of the degree*

*Of*

**DOCTOR OF PHILOSOPHY**

# 1 Abstract

Optical biosensors serve as a pivotal tool for clinical diagnosis as they offer fast, sensitive, and accurate detection of various analytes, facilitating early disease diagnosis, and point of care testing. Among various optical biosensing techniques such as Surface Plasmon Resonance (SPR), Localized Surface Plasmon Resonance (LSPR), Reflectometric Interference, Bioluminescence, Ellipsometry, and Evanescent Wave Fluorescence, Surface-Enhanced Raman Spectroscopy (SERS) stands out for its inherent ability to provide distinct molecular fingerprints, enabling single-molecule detection and offering exceptional chemical specificity and sensitivity. In the human body, micronutrients and metabolites play a significant role in regulating metabolism and sustaining tissue function, and are essential for maintaining good health over time. Although they are required in small quantities, their impact on overall health is critical, and their deficiencies lead to severe, life-threatening diseases like cancer, cardiovascular disease, and cognitive impairment. In this thesis work, the detection of micronutrients was performed by SERS substrate made of graphene oxide gold nanocomposites(GOAu). Firstly, GOAu was synthesized by a one-pot green synthesis approach. Following the synthesis, the SERS substrates were fabricated by the drop-casting technique. The fabricated nanocomposites were used to quantify micronutrients and metabolites. Initially, the SERS substrate was utilised for the detection of zinc complex in nutritional supplements. SERS substrate enhances the inherent weak Raman characteristic peaks of zinc complex by utilizing the synergistic effect of graphene oxide gold nanocomposites (GOAu) and observed $\sim$21-fold enhancement as compared to individual graphene oxide and gold nanoparticle with the inherent characteristic peaks at 265, 690, 952, and 1452 $cm^{-1}$. The proposed SERS substrate achieved a detection limit of 1 nM with an enhancement factor of $2.1 \times 10^7$. Following this, a point-of-care immunosubstrate-based sensor was developed utilizing surface enhanced Raman spectroscopy (SERS). Vitamin D3 was detected by subjecting an anti-vitamin D3 coated GOAu SERS substrate, and the characteristic Raman peaks at 1223,1253, and 1527 $cm^{-1}$ were observed. In addition, a $\sim$5-fold increase in peak intensity with an enhancement factor of $4.9 \times 10^6$ was achieved due to the synergistic Raman signal enhancement. Further, a SERS sensor was developed by immobilizing a capture DNA sequence onto a GOAu substrate. When the target DNA is introduced, it binds to the complementary capture DNA on the substrate.This binding event, which is influenced by the presence of Vitamin D3 at varying concentrations, leads to the detection of the target DNA. The characteristic Raman peaks of the target DNA sequences were observed at 467, 783, 1295, and 1617 $cm^{-1}$, with a $\sim$2-fold enhancement in Raman signal intensity. Eventually, the automated detection of creatinine using Raman spectral peaks obtained from a graphene oxide gold nanocomposite (GOAu) coated SERS substrate was developed. The GOAu substrate enhances the weak Raman signal, allowing for the identification of inherent peaks of creatinine at 604, 678, 836, and 904 $cm^{-1}$. In addition, deep learning feedforward neural network model, utilizing ReLU activation, was employed to enable the detection of ultra-low creatinine concentrations with an LoD of 1 pM, where characteristic Raman peaks are not clearly distinct due to low signal-to-noise, and achieved a detection accuracy of 98%. Hereby, this thesis presents valuable insights on the significant role of graphene oxide-gold nanocomposites based SERS substrates for the detection of mi-

cronutrients and further explores the integration of deep learning neural network model for the ultra low detection of metabolites.

# 2 Objectives

To address the identified research gaps, the following objectives were formulated.

1. To investigate the dual enhancement of graphene oxide and gold nanocomposites and to analyze bio assay reaction kinetics of micronutrient levels using finite element analysis in COMSOL Multiphysics 5.5.

2. To synthesize and fabricate graphene oxide gold nanocomposite based SERS substrate by optimizing the graphene layer thickness and geometry of gold nanoparticle for achieving the enhanced Raman signal and also to study its interaction onto various substrate materials.

3. To detect various micronutrients and metabolite levels using the fabricated SERS substrate.

4. To validate the fabricated SERS substrate for real time sample analysis.

# 3 Existing Gaps Which Were Bridged

In recent years, graphene oxide gold nanocomposites were used as powerful substrate for their ability to deliver synergistic signal enhancement and stability compared to traditional metallic nanostructures or single-component substrates (Parambath *et al.* (2024))(Vianna *et al.* (2016)). These substrates are especially employed for various applications . But the exploration of this substrate in the quantification of micronutrients and metabolites are highly challenging and also necessary for trace level concentration detection. For achieving this, the optimization of the shape and size of the nanoparticle and thickness of the graphene layer are significant.

In this context, the fundamental challenge in SERS is creating a robust, uniform, and highly enhancing substrate. To address these challenges, graphene oxide (GO), when combined with gold nanoparticles (AuNPs), significantly overcome the limitations of traditional, pure metallic SERS substrates.Traditional SERS substrates, often based on colloidal AuNPs or patterned metal films, suffer from low Reproducibility and less uniformity as the 'hot spots' are randomly distributed, leading to high signal variability between measurements. In order to overcome this, GO is used as it acts like a scaffold that promotes a uniform distribution and controlled aggregation of the AuNPs, leading to a higher density of reproducible, inter-nanoparticle hot spots across the substrate. This results in an increased average SERS enhancement factor.

Another challenge is limited sensitivity at trace Levels as the pure metal substrates often lack the chemical enhancement mechanism necessary for non-adsorbing or weakly-adsorbing molecules, limiting the ultimate detection limit. This is overcome by the graphene oxide component that introduces a chemical enhancement (CE) mechanism alongside the electromagnetic enhancement (EM) from the AuNPs. GO can interact through $\pi - \pi$ the electrostatic forces with the target analytes (i.e., Creatinine, Vitamin

D), bringing them into the optimal 'hot spot' proximity, thereby achieving ultrasensitive detection (down to femtomolar or picomolar levels).

Additionally, matrix interference and non-Specific adsorption is a major challenge. Measuring Vitamin D in complex matrices (like serum or even supplements) faces interference from lipids, proteins, and other compounds.Large surface area of the graphene oxide and the resulting $\pi - \pi$ stacking can offer a high-affinity binding site for the planar steroid ring structure of Vitamin D. This selective chemical pre-concentration on the GO surface, combined with the extreme SERS enhancement from the proximal AuNPs, allows for ultrasensitive and selective quantification that is competitive with or superior to traditional methods like ELISA or HPLC.

Thus, this research directly bridges the gap by addressing the challenges and developing graphene oxide-gold nanocomposites based SERS sensor for the detection of the micronutrients and metabolites. The proposed work is a novel contribution because it provides a highly sensitive and stable platform specifically engineered for micronutrient detection. By achieving an enhancement factor of $10^6$ -$10^8$, this research offers a practical method to detect these low-concentration analytes. A key technical contribution is the focus on improving the reproducibility, stability, and repeatability of the substrate, which are critical challenges in making SERS a reliable quantitative analytical technique. The synthesis and characterization of this novel nanocomposite, along with the optimization of its performance, lay the foundation for future SERS-based nutritional diagnostics.

# 4 Most Important contributions

## 4.1 Numerical analysis of designing SERS based biosensor

Graphene is a powerful two-dimensional (2D) material, with its distinguishing structure and outstanding properties, finds its potential as substrate for Raman signal enhancement (Ling *et al.* (2010)). Studies reveal that integrating graphene and noble metal plasmonic nanostructures has been a promising method for inflating light–matter interaction within visible wavelengths.In this work, the enhancement of electric field strength due to the synergistic effect of graphene oxide gold nanocomposites is studied by simulating nanocomposites coated various substrates in COMSOL using the wave optics module. Herein, the thickness of graphene layer, geometry of gold nanoparticles, materials used for substrate are varied and optimized for achieving enhanced electric field strength. Following optimization, the nanocomposite is deposited onto a microchannel and its performance is validated in COMSOL Multiphysics for the detection of vitamin D.

Initially, substrate is simulated applying perfectly matched layer and scattering boundary conditions. Subsequently, the electric field strength is calculated by introducing gold nanoparticles of different diameters 10,30, 60 and 100 nm with an interparticle distance of 5,10,20,50 and 100 nm. In addition, the quantum tunneling effect due to graphene is eliminated by the optimized monolayer graphene of thickness 5nm.Herein, it was observed that graphene gold nanocomposites with diameter 60 nm, interparticle distance of 5 nm and graphene gold nanocomposites with monolayer graphene of thickness 5 nm onto the substrate yields a significant enhancement giving $\sim 1.3$ times more electric field strength due to the nanocomposites when compared to gold nanoparticles without graphene. The enhancement of scattered light intensity in the interface of gold nanoparticles coated with graphene is $\sim$ 2.8 times greater than the substrate without graphene (Fig. 1). Studies shows that gold nanoparticles placed in close proximity offers dual enhancement and this can be observed from the obtained results.

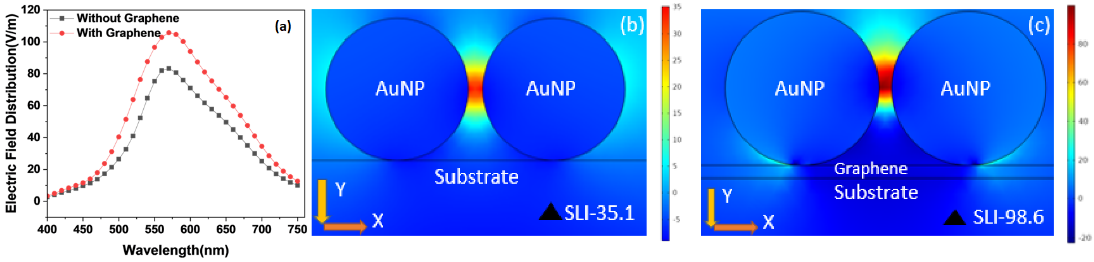


Figure 1: (a) Electric field enhancement for with and without graphene onto gold coated silica substrate, Scattered Light Intensity (SLI) of gold nanoparticle of diameter 60 nm, interparticle distance of 5 nm using COMSOL, (b) without graphene, (c) with graphene.

With the optimized parameters, the nanocomposite is deposited onto a microchannel and its performance is validated in COMSOL Multiphysics for the detection of vitamin D.The kinetics of affinity reaction between the bio receptors immobilized onto the substrate and analyte in blood is studied. In which, the sample is transported through the microchannel of dimensions (200 $\mu$m $\times$ 150 $\mu$m) towards the sensing surface, where the vitamin D bioreceptors are immobilized. The detection limit of vitamin D using the proposed microchannel . The analyte of varying concentration is introduced and the surface reaction is monitored.graphene gold nanocomposite is coated above the PMMA microchannel substrate. It could be observed that substrate coated with graphene gold nanocomposite has $\sim$1.9 times higher binding surface reaction as compared to bare PMMA substrate and is shown in Fig. 2a.The surface reaction difference between 1 fM and 1 pM is higher in comparison with the $3\sigma$ standard deviation limits. Thus, the proposed microchannel achieved a detection limit of 1 pM for detecting vitamin D in blood Fig. 2b.

This study presents a comprehensive theoretical analysis focused on optimizing the size and shape of gold nanoparticles and the thickness of the graphene layer within a nanocomposite.This optimized nanocomposite is expected to play a significant role in the detection of micronutrient deficiency. This application could be highly valuable for evaluating the health of women and children globally, meeting a critical need.Furthermore, the insights from this theoretical work are being used to guide the experimental development of a point-of-care (POC) biosensor.This work is discussed in chapter 3 of the thesis.

## 4.2 Detection of Zinc complex in nutritional supplements

Micronutrients play a significant key role in the prevention of diseases (Shergill-Bonner (2017)), and particularly zinc is essential, as it is involved in inevitable activities like enzymatic reactions, wound healing , enzyme catalysis in human metabolism , and serves as an excellent biomarker for early diagnosis of various cancers. In this work, Graphene

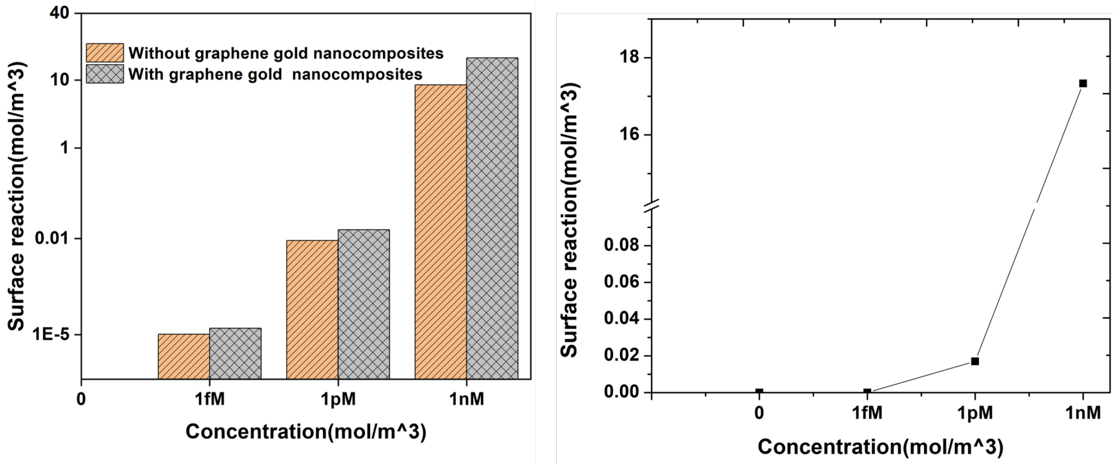


Figure 2: (a) Sensitivity enhancement due to graphene gold nanocomposite coated microchannel for various concentrations of analyte, (b) Dose response plot showing the limit of detection achieved using graphene gold nanocompoiste coated PMMA microchannel

oxide gold nanocomposites (GOAu) were synthesized as reported in (Meenakshi *et al.* (2021)) using green tea extract as a reducing agent with 50 ml of graphene oxide (GO) solution (sonicated for 90 min to exfoliate into individual graphene layers) and 50 ml of tetra chloroauric ($HAuCl_4$) solution. The obtained nanocomposite solution was kept at room temperature, cooled, centrifuged at 7000 rpm for 20 min and stored at 4 °C and characterized.An aqueous solution of GOAu nanocomposites (50 µL) was deposited onto different substrates like PDMS, glass slides, silicon wafer and aluminum foil using drop casting technique. This fabricated SERS substrate is utilized for the detection of zinc complex in nutritional supplements.

GOAu nanocomposites was characterized using UV visible absorbance spectroscopy which exhibited a prominent absorbance peak at 538 nm corresponding to the localized surface Plasmon resonance (LSPR) of gold nanoparticles and 270 nm corresponding to the reduction of GO.Further, the Raman spectrum of the GOAu nanocomposites was investigated which showed characteristic D-band (1350 cm$^{-1}$) and G-band (1597 cm$^{-1}$) peaks, attributing to the vibrational modes of defective carbon atoms and sp$^2$ hybridized carbon atoms, respectively.

In order to experimentally verify the application of the proposed GOAu nanocomposite coated substrate for the detection of zinc acetate, varying concentration of zinc acetate ranging from mM to nM are drop casted onto the GOAu coated SERS substrate. The limit of detection studies is carried out by considering various concentrations of zinc acetate (mM, $\mu$M and nM) and the measurements are repeated for three times ($n = 7$). The Raman spectral measurements are carried out and the inherent spectral peaks of zinc acetate are observed . Further, the limit of detection is calculated from the dose response plot and the error bar is calculated using the $(3.3 \cdot \sigma/S)$, where $\sigma$ corresponds to the standard deviation and $S$ corresponds to the slope. Thus, from the Fig.2a-b, the intensity for the different concentrations of the zinc acetate at $952$ cm$^{-1}$ is analyzed and the proposed sensor achieved a detection limit of 1 nM for detecting the presence of zinc acetate.Furthermore, Raman spectral measurements are challenging to achieve repeatable data, the proposed substrates are tested for acquiring repeatable results. This is examined by repeating the Raman spectrum of 1 mM zinc acetate 7 times and is shown in Fig. 2c. From the figure, the relative standard deviation (RSD) is calculated and found to be 13, which confirms the suitability of the proposed substrate for Raman measurements Fig.2d.

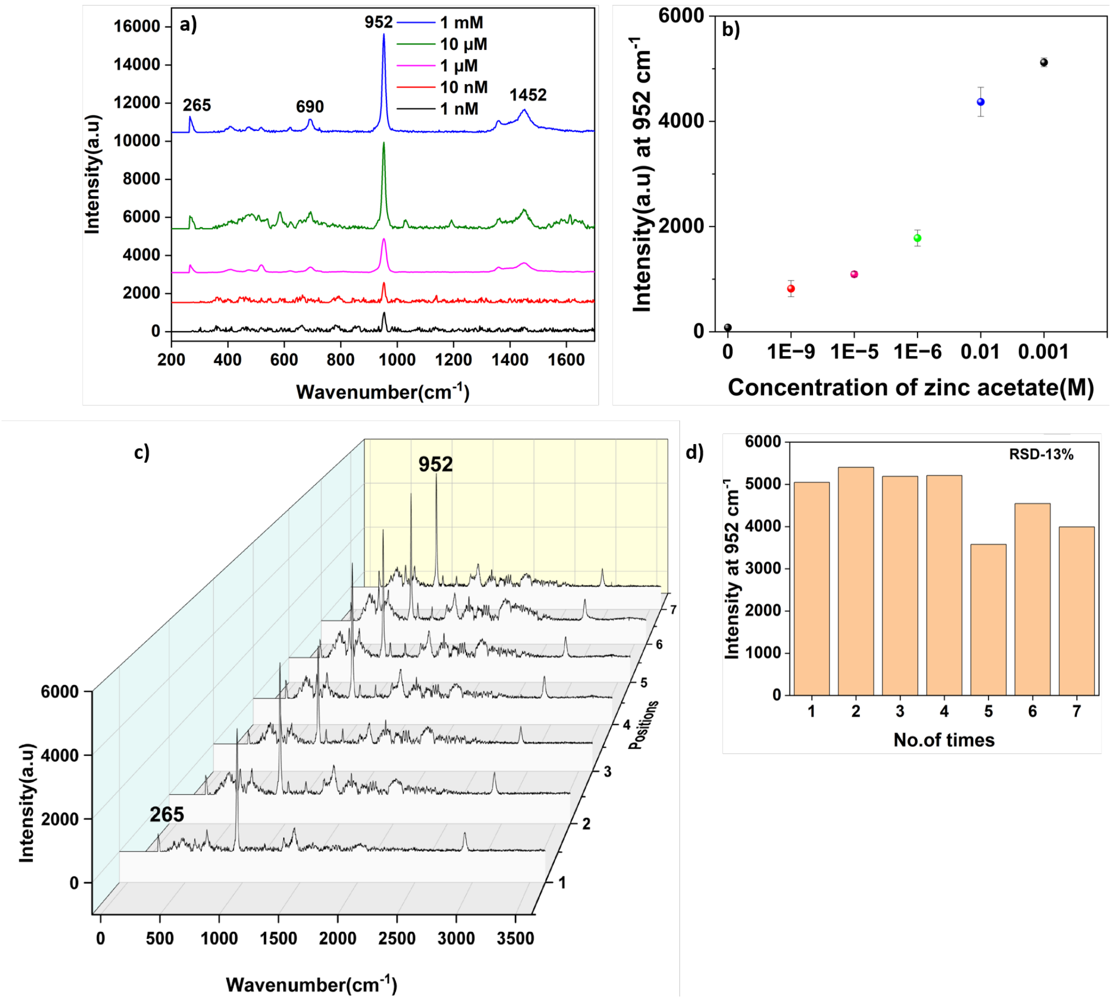


Figure 3: (a) Measurement of Raman spectral peaks for varying concentrations of zinc acetate, (b) Sensitivity plot for different concentrations of zinc acetate obtained from 3 different trials, (c) Raman spectrum of Zinc acetate repeated for 7 times, (d) Raman signal intensity of 1 mM zinc acetate at 952 $cm^{-1}$

The graphene oxide gold nanocomposites coated silicon substrates for the detection of zinc acetate based on surface enhanced Raman spectroscopy utilizing the synergistic Raman signal enhancement are investigated in this study. The proposed GOAu substrate achieved $\sim$21-fold synergistic enhancement in Raman signal intensity as compared to the individual graphene oxide and gold nanoparticle, and is useful for the sensitive and selective detection of zinc acetate in nutritional supplements. This is discussed in chapter 4 of the thesis.

## 4.3 SERS based immunosensor and aptasensor for detection of vitamin D

Vitamin D is an essential micronutrient in regulating calcium-phosphorus homeostasis, maintaining bone growth in human beings. 25-hydroxyvitamin D3 is the biomarker for detecting the concentration of vitamin D present in serum.The clinically significant vitamin D level of the human body is 20-40 nM (Shah *et al.* (2018)). Hereby, maintaining the level of vitamin D is crucial for the sustenance of better health. Inadequate and poor oral intake, limited sun exposure, aging, and renal insufficiency are the factors that contribute to the decreased level of vitamin D.

In this work, vitamin D3 is detected by coating onto SERS substrate. For the detection of vitamin D3, 10 µl of 2-mercaptoethanol was deposited on the SERS substrate. After 24 hours, glutaraldehyde was deposited onto the substrate. Anti-vitamin D3 of concentration 10 nM was prepared in PBS and used for coating onto SERS substrate. 10 µl of anti-vitamin D3 solution is drop casted onto the substrate and allowed to dry for 3 hours at 4°C. Vitamin D3 of stock concentration 1 mM was prepared in PBS and diluted to varying concentrations, including 1mM,1µM, and 1nM. Onto the antibody-coated substrates, 10 µl of vitamin D3 solution of each concentration was drop cast onto the SERS substrate. After 10 minutes, Raman measurements were recorded by WP-785-R-ERIL-C equipped with a laser of excitation wavelength of 785 nm with 100 mW laser power. The exposure time for obtaining the SERS spectra was 2.5s.

When vitamin D3 is added, due to the interaction with the antibody, Raman spectral peaks were detected at 1223, 1253, and 1527 $cm^{-1}$ which is in line with C-H bending vibration, OH-bending vibration, and the C=C stretch line in molecular structure of vitamin D3 which is in correlation with the reported work(Balcers *et al.* (2022)).

The effect of functionalizing with 2-mercaptoethanol, glutaraldehyde, and antibody coated onto the substrate was investigated. Furthermore, the ratio of Functioanlised GOAu and bare vitamin D3 yield five-fold enhancement due to the binding reaction of anti-vitamin D3 and vitamin D3 and also yields better signal enhancement than the functionalized Au and GO substrate Fig.4.

Additionally,an aptasensor was developed for the detection of vitamin D3. The Raman spectra of GOAu-capture probe(CP)-VitD3-Target probe(TP) exhibited distinct biomolecular fingerprints of the target sequence with key peaks at 467 $cm^{-1}$ (polysaccharide), 783 $cm^{-1}$ (cytosine), 1295 $cm^{-1}$ (amide III), and 1621 $cm^{-1}$(adenine and guanine), reflecting precise molecular identification. Immobilization of the target sequence onto GOAu nanocomposites enhanced Raman scattering significantly due to the combined effects of gold nanoparticle electromagnetic enhancement and charge transfer mechanism of graphene oxide, resulting in a two-fold Raman signal enhancement (5). A notable design feature is the direct immobilization of the probe DNA onto GOAu via strong amide bonds (R-C(=O)NH-R), eliminating the need for Raman tags and complex probe modifications, thus preserving the single-stranded availability of the capture probe for hybridization and enhancing detection robustness. This immobilization on SERS-active GO-AuNPs enabled sensitive detection of varying concentrations of vitamin D3. The comprehensive analysis of vitamin D detection, specifically utilizing immunosensor and aptasensor techniques, is presented in Chapter 5 of thesis.

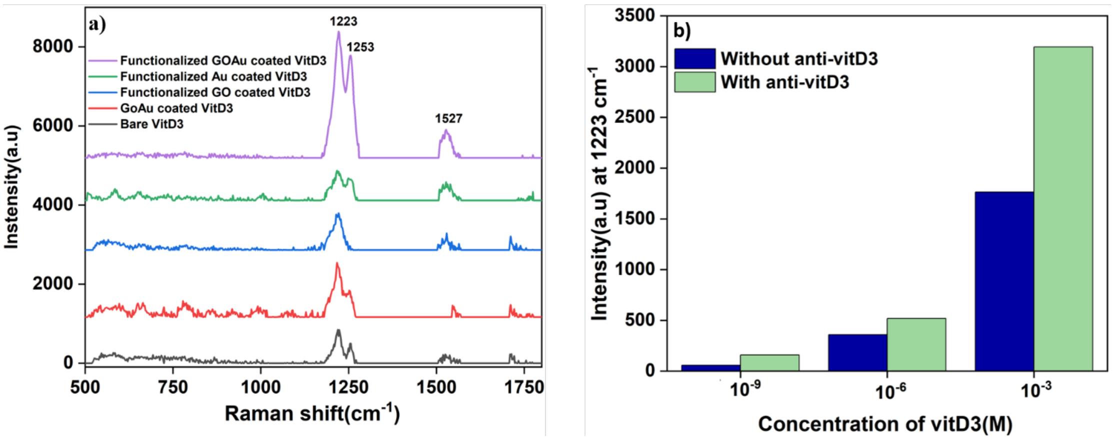


Figure 4: Synergistic Raman signal enhancement of vitamin D3 of 1 mM concentrations of (a) Bare, GOAu, Functionalized Au, Functionalized GO and Functionalized GOAu coated substrate, (b) GOAu coated and anti-vitaminD3 coated SERS substrate

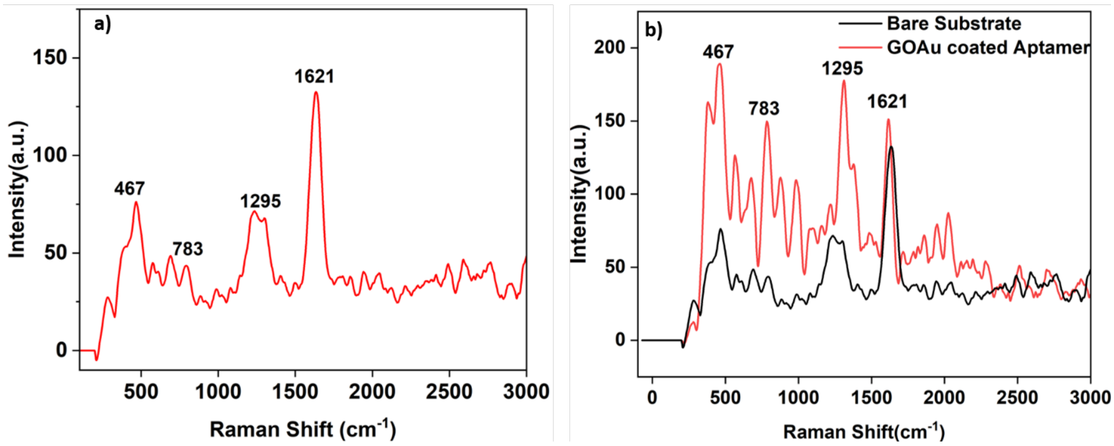


Figure 5: (a) Raman Spectrum of Target sequence for the detection of vitamin D3 (b) Synergistic enhancement of GOAu

## 4.4 Ultrasensitive detection of Creatinine using deep learning SERS sensor

The global incidence of chronic kidney disease (CKD) is more prevalent, affecting billions of people and causing many life-threatening diseases. Creatinine, a byproduct of muscle metabolism, is a crucial biomarker for assessing CKD and kidney function for diagnosing diseases such as diabetes, kidney stones, Addison's disease, and liver dysfunction (Ito *et al.* (2024)). Normal creatinine blood levels range from 44 to 97 µM for men and 53 to 106 µM for women (Gupta *et al.* (2024)).In this work, a GOAu-coated SERS sensor for the selective and sensitive detection of creatinine was developed, exploiting the inherent Raman bands of creatinine at 604, 678, 836, and 904 $cm^{-1}$. The substrate was optimized to yield enhanced Raman signals for creatinine detection.It was observed that the Raman signal for creatinine onto silicon wafer yields ∼22-fold enhancement than the PDMS substrate and ∼56-fold more than that of the parafilm substrate Fig. **??**.Thus, silicon wafer is used as the substrate for further detection of creatinine. The dual enhancement of SERS substrate is investigated and it could be observed that the GOAu nanocomposites coated SERS substrate yields $\sim$7-fold enhancement than the bare creatinine due to the synergistic enhancement of the GO and AuNPs. Thus, the inherent Raman spectral peaks were observed at 604 cm$^{-1}$ assigned to C-H bending vibration, 673 cm$^{-1}$assigned to N-H bending and C- $NH_2$ stretching, 836 cm$^{-1}$ due to C-O stretching, and 901 cm$^{-1}$ due to C-C stretching Fig. **??** which is in consistent with the previous literature (Zhang *et al.* (2022)).

The preprocessed Raman spectral data acquired from GOAu coated SERS substrates were fed to the proposed deep learning feed forward neural network model which consists of 21,000 training datasets and 3124 test datasets (including various concentrations ranging from pM to mM of creatinine and non-creatinine spectra). For, quantitative detection, the different concentrations of creatinine are labelled into five classes. These preprocessed datasets include all the extracted features such as peak intensity, ratio, peak width, and baseline corrected values. The size of the input layer is 1 x 2048 which includes the intensity values across 2048 specific wavenumbers. The deep learning model utilizes the entire preprocessed spectrum as input to allow the network to automatically learn relevant features, rather than relying only on literature reported [9] four distinct Raman peak numbers. The construction and configuration of this deep learning model was demonstrated using TensorFlow and Keras.

Hyperparameter tuning was performed for developed neural network model in optimizing the number of neurons in the hidden layer, batch size, and epochs, resulting in optimized parameters for accurate classification. By first identifying whether the sample contains creatinine, it provides the ability to separate and analyze the other constituents present in the urine, such as urea and uric acid. The first layer is the input layer that feeds to the hidden layer, consisting of 512 neurons and 256 neurons (obtained after optimization), and utilizes the ReLU activation function. The Adam optimizer is chosen to enhance convergence rates during training due to its adaptive learning rate capabilities. This deep learning model utilized training and testing parameters with the epoch of 500 and batch size is set to 10, with a learning rate of 0.001, balancing between convergence speed and stability.

The confusion matrix for classifying the creatinine and non-creatinine data is shown in Fig. 6a and the confusion matrix for classifying different concentration of creatinine ranging from pM to mM is shown in Fig. 6b and the accuracy for each concentration of creatinine is shown in Fig. 6c.The comprehensive analysis of ultra-sensitive creatinine detection, specifically achieved through a deep learning neural network model, is included in Chapter 6 of the thesis.

# 5 Conclusions

This research focuses on the design and development of a high-performance graphene oxide gold nanocomposite based SERS sensor. The primary objective is to achieve a superior enhancement factor, targeting a range of $10^6$ to $10^8$, while ensuring that the sensor demonstrates high reproducibility, stability, and repeatability. The thesis proposes a novel approach that begins with a theoretical investigation using COMSOL Multiphysics. This simulation work was crucial for optimizing key substrate parameters,

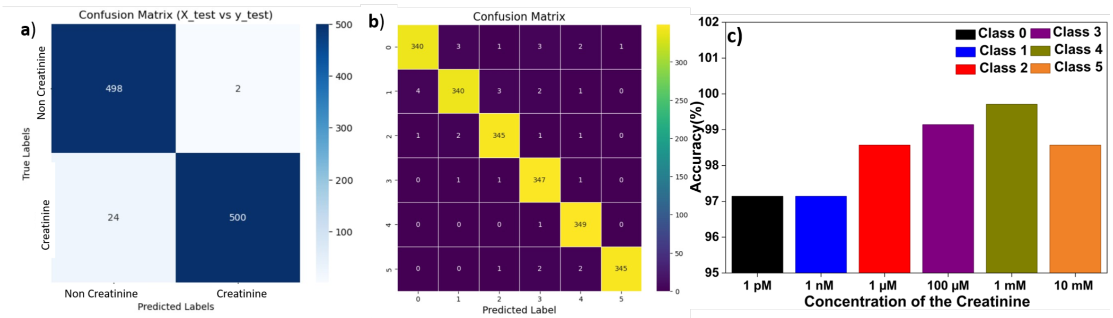

Figure 6: Confusion matrix for (a) Classification of creatinine and non-creatinine, (b) Quantitative detection of creatinine, (c) Accuracy for different concentrations of creatinine

including the size of the gold nanoparticles, the thickness of the graphene oxide sheet, and the interparticle distance between the gold nanoparticles. Following the theoretical optimization, the GOAu nanocomposite was fabricated using a one-pot green synthesis approach. The synthesized material was extensively characterized using analytical techniques, including UV-Visible absorbance spectroscopy, Raman spectroscopy, Scanning Electron Microscopy (SEM), particle size analyzer, and zeta potential measurements. The developed sensor was then successfully applied for the detection and quantification of several analytes, including zinc complex, Vitamin D3, aptamers and creatinine. This work addresses fundamental challenges in SERS based sensing, particularly concerning the reproducibility and long-term stability of the substrate for detecting vitamins and metabolites. The thesis concludes by summarizing these key contributions and suggesting directions for future research.

# 6 Organization of the Thesis

The outline of the thesis is as follows:

(a) Chapter 1: Introduction

(b) Chapter 2: Literature Review

(c) Chapter 3: Numerical analysis of designing SERS based biosensor

(d) Chapter 4: Detection of Zinc complex in nutritional supplement

(e) Chapter 5: SERS based immunosensor and aptasensor for detection of vitamin D

(f) Chapter 6: Ultrasensitive detection of Creatinine using deep learning integrated SERS sensor

(g) Chapter 7: Conclusions and Future Scope

# 7 List of Publications

**I. REFEREED JOURNALS**

1. **Vennila Preethi S**, Annasamy. G*, Graphene oxide gold nanocomposites based SERS sensor for detection of Zinc complex in nutritional supplements, **Optical Materials, 163**, 117024 (2025). **(Impact factor: 3.8)**
2. **Preethi, S. V**, Annasamy, G*, Graphene oxide gold nanocomposites coated SERS based immunosensor for detection of vitamin D, **Diamond and Related Materials**, 112572 (2025). **(Impact factor: 5.1)**
3. **Vennila Preethi S** ,Annasamy. G*, Ultrasensitive detection of Creatinine using deep learning integrated Graphene Oxide Gold Nanocomposites SERS sensor, IEEE Sensors Letters Accepted,(2025).

**II. UNDER REVIEW/COMMUNICATED**

3. **Vennila Preethi S** ,Annasamy. G*, Role of SERS substrate on detection of micronutrients and metabolites- the current state and future trends,(Under Preparation)(2025).

**III. CONFERENCE PUBLICATION**

5. **Vennila Preethi S**, Annasamy, G*, Theoretical insights of dual SERS enhance ment of graphene oxide-gold nanocomposites for biosensing application, **In Women in Optics and Photonics in India 2022**, (Vol. 12638, pp. 5-7), (pp. 1-5).SPIE
6. **Vennila Preethi S**, Annasamy, G*, Finite element modelling of Graphene Oxide-Gold Nanocom posite Coated Microchannels for Vitamin D Biosensor development, **In 2023 16th International Conference on Sensing Technology**, (pp. 1-5).IEEE
7. **Vennila Preethi S**, Annasamy, G*, Graphene oxide-gold nanocomposites coated SERS-based biosensor for detection of zinc ions in blood, **Proc. SPIE 13108**,Women in Optics and Photonics in India 2023, 131080L. SPIE.

**IV. PRESENTATIONS IN CONFERENCES BASED ON THE THESIS**

8. **Vennila Preethi S** and Gowri Annasamy*, Hybrid Graphene Oxide Gold Nanocomposites based SERS Sensor for Detection of Creatinine, International Conference on Emerging Advanced Nano materials 2024, University of Newcastle, Australia(ICEAN 2024).

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