Optimum Science Journal

Journal homepage: https://optimumscience.org

Original Research Article

White Light Spectroscopy of Surface Plasmon Resonance Sensors

Fateme Gheibi[*], *Jafar M. Amjad*

Institute for Advanced Studies in Basic Sciences (IASBS), Zanjan, Iran.

ARTICLE INFO

Received 24 May 2024

Accepted 12 September 2024

Available Online 01 December 2024

Keywords:

White light spectroscopy

Surface plasmon resonance

Sensors

ABSTRACT

Optical methods such as ellipsometry, interferometry, spectroscopy, and surface plasmon resonance (SPR) have recently been used in developing optical sensors. SPR sensors have attracted attention due to their accuracy and sensitivity. Surface plasmons are waves created by the oscillation of free electrons that can be excited by light, between a metal and a dielectric medium. Sensors rely on the refractive index of the second medium to determine the resonance location. In this study, we used white light and total internal reflection through a cylindrical prism to focus on an SPR optical setup and Sensors with 50 nm coverage and 632 nm reference laser wavelength. This experiment evaluates the intensity and reflection index of surface plasmon resonance at different wavelengths to determine the electrical property ε of the surrounding medium and its application in assessing different materials.

To cite this article: Gheibi F. & Amjad, J.M. (2024). White light spectroscopy of surface plasmon resonance sensors. *Optimum Science Journal (OPS Journal*, *2*, 50-55. http://doi.org/10.5281/zenodo.13857404

1. Introduction

Surface Plasmon Resonance (SPR) is an optical phenomenon that occurs when collective electron oscillations are excited at the interface between a metal layer and a dielectric medium (Tang et al., 2010). This resonance happens under specific conditions, including p-polarized light, total internal reflection at the interface of a prism, and a coated sample with a thin metal layer (Wikipedia, n.d.). SPR has become a prominent chemical and biological sensing tool due to its real-time detection capabilities and high sensitivity (Brolo et al., 2004). The choice of light source plays a critical role in SPR sensor performance (Stahelin, 2013). White light sources have gained attention for their broad wavelength range, offering greater versatility compared to traditional monochromatic sources (Deprez, 2011). White light spectroscopy enables the exploration of surface plasmon excitation through a novel technique combining

[*]*Corresponding Author:* fatemegheibi.99@gmail.com

wavelength and angle scanning methods into a single scan method (Chen et al., 2002). This paper investigates the unique advantages of white light spectroscopy in SPR and its potential to advance biosensing technology. Several studies have demonstrated the benefits of white light spectroscopy in SPR applications. Nguyen et al. (2015) developed a surface plasmon resonance (SPR) system that leverages a high-resolution optical configuration for label-free sensor applications. Their research highlighted the system's enhanced sensitivity and spatial resolution in biosensing applications, effectively addressing the limitations typically associated with traditional SPR techniques. Similarly, Wang et al. (2019) discussed recent advancements in SPR imaging (SPRi) sensors, emphasizing improvements in spatial resolution and sensitivity for various biosensing applications. Also, these researchers reviewed recent advances in SPR sensing and emphasized the importance of light source selection in optimizing sensor performance. This research builds upon these previous studies by further exploring the unique advantages of white light spectroscopy in SPR and its potential impact on developing highly sensitive and selective biosensors. By combining wavelength and angle scanning methods into a single scan, we can harness the full potential of SPR and drive innovation in the field of chemical and biological sensing.

1.1. White Light Spectroscopy of SPR

White light spectroscopy is an essential analytical technique for studying light across a broad range of wavelengths (Wikipedia, n.d.). When electromagnetic radiation interacts with a material, it can be absorbed, transmitted, or reflected (Brolo et al., 2004). Spectroscopy quantifies these interactions, providing valuable insights into a sample's optical properties (Stahelin, 2013). The absorption and reflection of radiation by a material are influenced by its dielectric function $\tilde{\varepsilon} = \varepsilon_r + i\varepsilon_i$, where ε_r and ε_i represent the real and imaginary parts, respectively (Chen et al., 2002). These properties affect the material's conductivity, yielding crucial information about its optical behavior. In the context of SPR, white light spectroscopy allows for precise characterization and optimization of biosensor performance (Stahelin, 2013). By leveraging the unique benefits of this technique, we can potentially unlock new avenues for susceptible and selective biosensor development. In conclusion, this research contributes to the growing body of SPR literature by investigating the unique advantages of white light spectroscopy and its potential to advance biosensing technology. Building on previous studies, we aim to demonstrate the impact of white light spectroscopy on SPR performance and explore new opportunities for innovation in chemical and biological sensing.

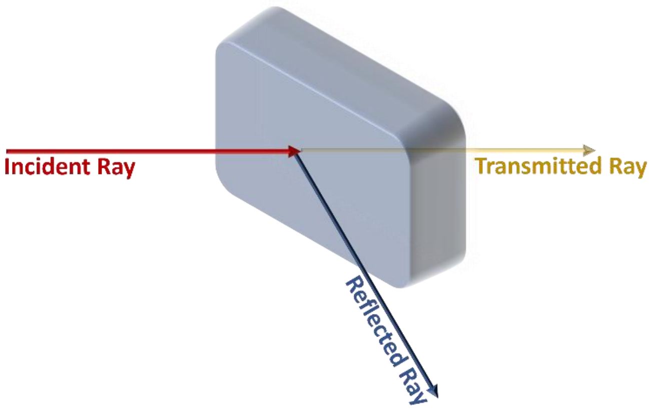

Figure 1. Transmission, reflection caused by incident light hitting matter

1.2. Theoretical Investigation

SPR can be investigated by either wavelength or angle scanning methods. Angle scanning involves altering the incident angle of light on the sensor surface, whereas wavelength scanning involves changing the wavelength of the light. Both techniques provide valuable insights into the sample's properties.

The goal of this project is to create an optical setup that combines angle scanning and wavelength scanning techniques. In this setup, each wavelength from the white light spectrum has its angle, indicating the mutual connection between wavelength and only its angle. By directing light at a 45° angle onto the prism, different wavelengths with different angles can be seen as a result of the reflection spectra, which show different SPR phenomena at specific angles for different wavelengths (Fig. 2(a)).

By rotating and radiating the prism at different wavelengths, extinction and resonance can be observed at certain angles. spectroscopic data show a spectrum that includes multiple SPRs. The minimum point indicates the wavelength, and resonance angle of the surface plasmon (Fig. 2(b)).

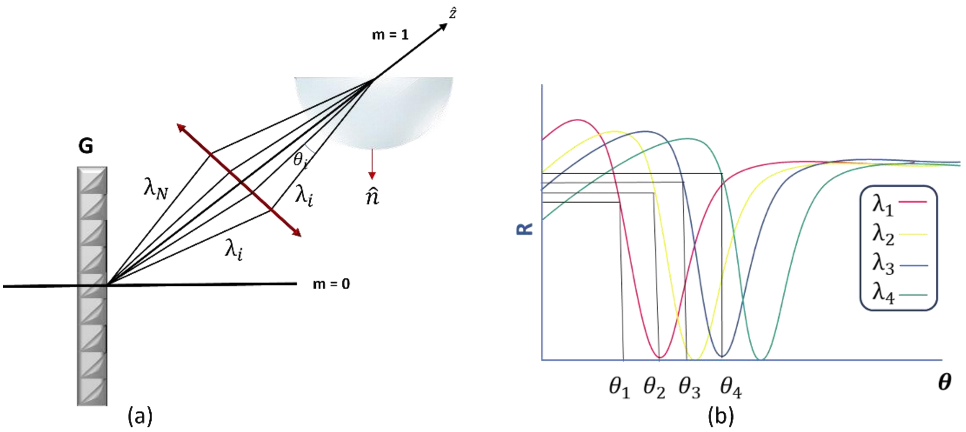

Figure 2. (a) The spectrum of white light that passes through G (the diffraction grating) and has different wavelengths hits the prism at different angles and is reflected. (b) SPR occurs at certain angles for different wavelengths. For wavelengths 1, 2, 3, and 4, the resonance angle is specified in height.

2. Methodology

The white light spectroscopy setup is shown in Figure 3. A broad white light source is transformed into a point light source using an aperture, then directed to a non-polarized beam splitter with a collimating lens. On the other hand, ND reduces the intensity of the laser light and enters the beam splitter. The beam splitter guides the light towards the optical axis. After passing through the lenses, lights go through the polarizer to be p-polarized. They are directed to the diffraction grating where it is separated into different wavelengths. In the following, we focus on the first order of the separated rays. The output lights are concentrated by a lens in the Kretschman structure, which includes a prism and an Ag-coated sensor. Due to the angle of incident light, which is greater than the critical angle, total internal reflection occurs. In the next step, the output lights become parallel after passing through the lens. Again, they became polarized and reached the CCD to record the SPR phenomenon. The data recorded with CCD has been analyzed by MATLAB to obtain desired information such as intensity profiles and refraction index.

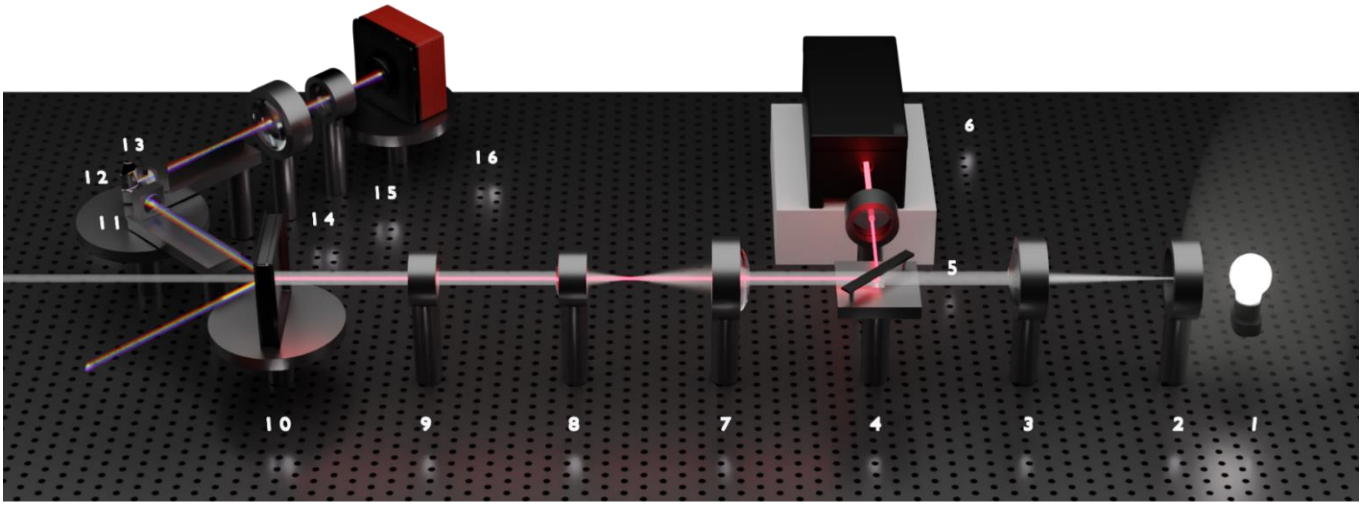

Figure 3. (1) Wide white light source to produce white light in the visible spectral width (2) Aperture to convert the wide light source to a point light source, (3) Collimator lens, (4) Beam splitter, (5) Nd for reducing intensity of laser light, (6) He-Ne laser, (7) lens, and (8) lens to magnify and extend the focal length, (9) Polarizer to have light with tm mode or p polarization, (10) Diffraction grating separates (disperses) light into its component wavelength., (11) lens to focus the light in the Kirschmann structure, (12) krechmann config. (prism & biosensor), (13) Collimator lens, (14) imaging lens, (15) p- polarizer and (16) CCD.

3. Results and Discussions

The laboratory setup detailed in the methodology section was calibrated through trial and error to achieve optimal performance. As mentioned earlier, two light sources were used: a helium-neon laser emitting at a wavelength of 632.8 nm and a broadband white light source. The purpose of this experiment was to compare the data obtained from both sources and achieve similar and close measurements, taking into account the wavelength-dependent nature of surface plasmon resonance (SPR).

To achieve this, the settings were adjusted and the SPR data from both light sources were repeatedly measured and compared until similar and close results were obtained. This approach allows to ensure the reliability and accuracy of the experimental setup by considering the unique SPR angle associated with each wavelength.

Further analysis of the SPR data revealed a close correlation between the helium-neon laser and broadband white light source. This finding indicates that the calibration process successfully maintained the experimental setup's accuracy and reliability, although further optimization is possible.

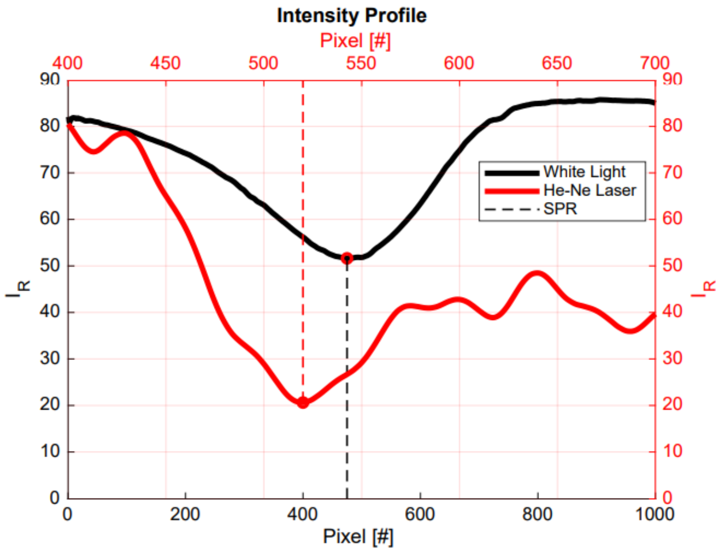

Figure 4. The black color plot shows white light surface plasmon resonance data with Ag-coated sensor. Red color plot shows He-Ne laser surface plasmon resonance data with Ag-coated sensor. Horizontal axis shows pixel position and vertical axis show intensity of reflection.

Figure 4 showcases SPR data from the two light sources on a single graph. The black diagram represents the white light source, while the red diagram corresponds to the helium-neon laser light source. The surface plasmon resonance region for both sources is highlighted with a dashed line. Note the different scales above and below the chart, causing the SPR regions to appear slightly distant; however, the peaks are located within a similar range.

After adjusting and calibrating settings for both sources, the red color of the white light spectrum closely matched the laser light (632.8 nm). This demonstrates the effectiveness of the methodology, which could be applied to other SPR-related experiments, emphasizing the importance of careful calibration and attention to each light source's specific characteristics.

In conclusion, the results and discussion presented here demonstrate the experimental approach's promising performance in obtaining consistent SPR data from both light sources. By refining and optimizing the calibration process, future research can benefit from more accurate and reliable results, highlighting the importance of considering the unique SPR angle associated with each wavelength.

4. Conclusions

In this study, we successfully demonstrated a novel optical technique that efficiently extracts material properties, such as refractive index and intensity information, using a single combined scan for different light sources. By comparing and analyzing the SPR data obtained from a helium-neon laser and a broadband white light source, we showcased the accuracy and reliability of our experimental setup.

To further enhance the data analysis process and facilitate the extraction of material properties, we plan to develop a custom MATLAB code as part of our future work. This code will aim to automate the analysis of the collected SPR data, reducing manual processing time and increasing the overall efficiency of the methodology. Additionally, it will enable rapid and accurate calculations of refractive indices and other parameters, demonstrating the practical applicability of our approach in various research and industrial settings.

As we refine our technique, our future work will focus on optimizing the calibration process to yield even more precise results. We will also explore the potential applications of this methodology in other SPR-related experiments, emphasizing its versatility and adaptability in the field. In conclusion, our findings lay the groundwork for further advancements in optical characterization techniques, ultimately contributing to a deeper understanding of material properties and their applications in diverse scientific domains.

Acknowledgment

This study was presented in the fourth ‘international conference on light and light-based technologies (ICLLT)’ in Gazi University in May 2024.

Declaration of Competing Interest and Ethics

The authors declare no conflict of interest. This research study complies with research publishing ethics. The scientific and legal responsibility for manuscripts published in OPS Journal belongs to the authors.

References

Brolo, A. G., Gordon, R., Leathem, B., & Kavanagh, K. L. (2004). Surface plasmon sensor based on the enhanced light transmission through arrays of nanoholes in gold films. *Langmuir*, *76*(12), 4813-4815. https://doi.org/10.1021/la0493621

Chen, S., Yu, Q., Li, L., Boozer, C. L., Homola, J., Yee, S. S., & Jiang, S. (2002). Detecting the adsorption of dye molecules in homogeneous poly(propylene imine) dendrimer monolayers by surface plasmon resonance sensor. *Journal of the American Chemical Society*, *124*(13), 3395-3401. https://doi.org/10.1021/ja0170201

Deprez, R. (2011). Prizes & awards: Best communication presentation or poster. August 28, 2024. Retrieved from https://www.deprezlab.fr/prizes-awards-best-communication-presentation-poster

Nguyen, H. H., Park, J., Kang, S., & Kim, M. (2015). Surface plasmon resonance: A versatile technique for biosensor applications. *Sensors*, *15*(5), 10481-10510. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4481982

Stahelin, R. V. (2013). Surface plasmon resonance: A useful technique for cell biologists to characterize biomolecular interactions. *Molecular Biology of the Cell*, *24*(7), 883-886. https://doi.org/10.1091/mbc.E12-10-0713

Tang, Y., Zeng, X., & Liang, J. (2010). Surface plasmon resonance: An introduction to a surface spectroscopy technique. *Journal of Chemical Education*, 87(7), 742-746. https://doi.org/10.1021/ed100186y

Wang, D., Loo, J. F. C., Chen, J., Yam, Y., Chen, S.-C., He, H., Kong, S. K., & Ho, H. P. (2019). Recent advances in surface plasmon resonance imaging sensors. *Sensors*, *19*(6), 1266. https://doi.org/10.3390/s19061266

Wikipedia. (n.d.). Surface plasmon resonance. August 28, 2024. Retrieved from https://en.wikipedia.org/wiki/Surface_plasmon_resonance