S.P.R.

Surface Plasmon Resonance

Laser & Spectroscopy-II Project Report

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Academic Year 2024-2025

Acknowledgement

We take this opportunity to sincerely thank the faculty members who guided and supported us throughout this project. Their expertise, mentorship, and encouragement played a vital role in the successful completion of our work.

Dr Govind Dayal Singh — We are deeply indebted to Dr. Govind Dayal Singh for his exceptional mentorship, profound knowledge, and generous support throughout the course of our project. His insights helped us navigate challenges with clarity, and his enthusiasm for research greatly inspired us to aim higher with our work.

Prof. P. Senthil Kumar — We express our gratitude to Prof. P. Senthil Kumar for his thoughtful feedback, guidance, and valuable suggestions. His ability to break down complex problems and encourage critical thinking made a significant difference in our understanding and execution.

Dr. Subhajeet Paul — We sincerely thank Dr. Subhajeet Paul for fostering a supportive academic environment and always being approachable.

Dr. Debabrata Mishra — We sincerely thank Dr. Debabrata Mishra for providing essential support of gold film coating that was vital to our experimental setup

Mr. Satyendra Saxena — For providing hardware assistance to our experimental setup.

Mr. Kartikaye- For providing essential support in electronic components of the experimental setup.

We are extremely thankful to all of them for their invaluable contributions, which were instrumental in the successful realization of this project.

Contents

1 Introduction

Surface Plasmon Resonance (SPR) is a powerful technique for probing interactions at the interface between a metal and a dielectric. SPR occurs when polarized light hits a metal-dielectric interface at a specific angle, resulting in a resonance condition that excites collective oscillations of free electrons (plasmons) at the surface of the metal. These oscillations are highly sensitive to changes in the refractive index near the surface, making SPR ideal for biosensing and thin-film characterization.

SPR was first observed in the 1950s and gained momentum as a sensing technique in the 1990s due to its label-free and real-time detection capabilities.

1.1 Importance of SPR

Surface Plasmon Resonance (SPR) has emerged as a cornerstone technique in modern optics and sensing technologies due to its unique capabilities. The ability of SPR to detect changes at the nanoscale interface between a metal and a dielectric medium makes it invaluable in both fundamental research and practical applications.

1.1.1 Label-Free Detection

One of the most critical advantages of SPR is its **label-free** nature. Unlike fluorescence-based assays, SPR does not require the tagging or labeling of molecules. This:

- Preserves the native structure and function of biomolecules,
- Enables real-time monitoring of binding events,
- Reduces experimental complexity and cost.

1.1.2 Real-Time Monitoring

SPR can monitor molecular interactions in **real time**. This is especially important in:

- Kinetic studies (association/dissociation rates),
- Drug discovery (binding affinity and specificity),
- Surface chemistry (adsorption/desorption processes).

1.1.3 High Sensitivity to Refractive Index

The technique is extraordinarily sensitive to minute changes in the refractive index near the metal surface (on the order of $\sim$200 nm in penetration depth). This makes SPR ideal for detecting:

- Biomolecular binding,
- Chemical adsorption,
- Conformational changes,
- Thin film deposition.

1.1.4 Versatility Across Fields

SPR is a **multidisciplinary tool** used in:

Field	**Application**
Biosensing	Detection of DNA, proteins, antibodies, viruses
Environmental Monitoring	Detection of pollutants, toxins, or trace chemicals
Material Science	Characterization of thin films and nanostructures
Pharmacology	Drug-receptor binding and interaction studies
Surface Chemistry	Monitoring functionalization and grafting of surfaces

Table 1: Applications of SPR in various fields

1.1.5 Non-Destructive and Reusable

SPR is non-invasive and does not destroy the sample. This is particularly useful when:

- Studying expensive or rare biomolecules,
- Reusing the same chip for multiple cycles,
- Working with fragile biological systems.

1.1.6 Pathway to Advanced Plasmonics

SPR is a gateway to more advanced plasmonic phenomena and devices, such as:

- Localized Surface Plasmon Resonance (LSPR) in nanoparticles,
- Surface-Enhanced Raman Scattering (SERS),
- Plasmonic metamaterials and sensors,
- Integrated photonic–plasmonic chips.

1.2 Goal of Our Project

The goal of this project is to set up a basic Kretschmann configuration for surface plasmon resonance (SPR). In this setup, we use only a glass prism, a thin gold film, and air as the external medium. No analyte or sensing layer is included.

This simplified model serves as a foundation for understanding the SPR phenomenon and will help in future extensions involving actual sensing applications.

2 Fundamentals of SPR

2.1 Surface Plasmons

Surface plasmons are coherent delocalized electron oscillations [1] that exist at the interface between a metal and a dielectric. These oscillations can be excited under resonance conditions by incident light.

2.2 Excitation Mechanism

To excite SPR, the momentum of the incident photons must match that of the surface plasmons. This condition is generally achieved using:

- Prism coupling (Kretschmann or Otto configuration)
- Grating coupling
- Waveguide coupling

2.3 Kretschmann Configuration and Surface Plasmon Excitation

2.3.1 Overview

The Kretschmann configuration is the most commonly used setup for exciting surface plasmons in practical SPR experiments. It enables the coupling of incident light into surface plasmons at a metal-dielectric interface by overcoming the momentum mismatch between photons and plasmons.

This configuration is widely used in biosensing and optical characterization due to its relatively simple experimental implementation and high sensitivity to changes in refractive index near the metal surface.

2.3.2 Physical Setup

In the Kretschmann configuration:

- A thin metal film (typically gold or silver) is coated on the base of a high-refractive-index prism (like BK7 or SF10).
- p-polarized light is directed through the prism towards the metal layer at a variable angle of incidence.
- The metal film is thin enough to allow evanescent wave penetration and coupling to surface plasmons at the outer metal-dielectric interface (e.g., metal-analyte interface).

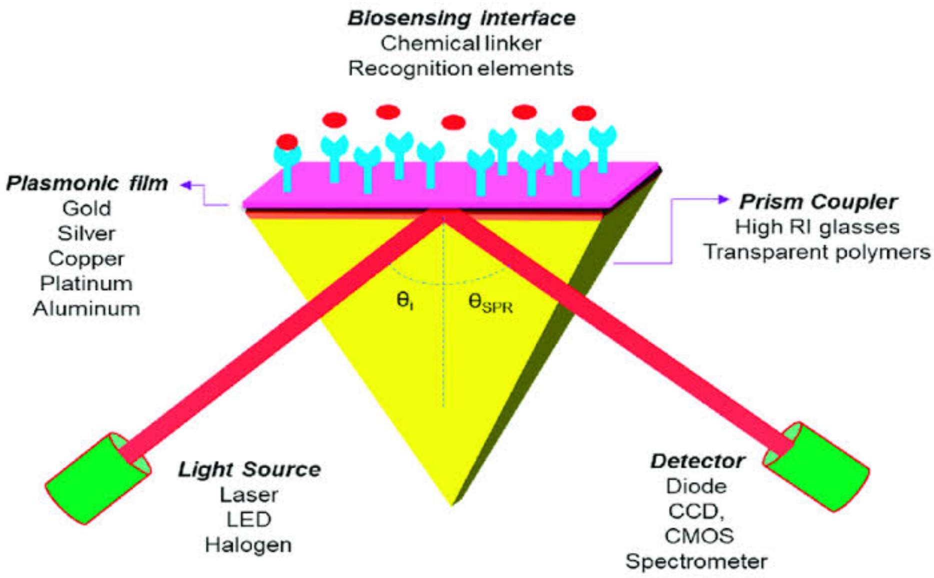

Figure 1: Primary Kretschmann configuration referred from [2]

2.3.3 Principle of Operation

The key to SPR in the Kretschmann configuration is total internal reflection and the resulting evanescent field. When light undergoes total internal reflection at the prism-metal interface, the evanescent field penetrates the metal and can excite surface plasmons if the following resonance condition is met:

$$k_x = k_{sp}$$

where,

$$k_x = \frac{2\pi}{\lambda} n_p \sin\theta \tag{1}$$

where:

- k_x is the in-plane component of the incident wave vector,
- k_{sp} is the wave vector of the surface plasmon,
- n_p is the refractive index of the prism,
- θ is the angle of incidence,
- λ is the wavelength of the incident light in vacuum.

This resonance condition causes a sharp dip in the reflected light intensity at a specific angle—the resonance angle—which shifts with changes in the refractive index of the adjacent medium.

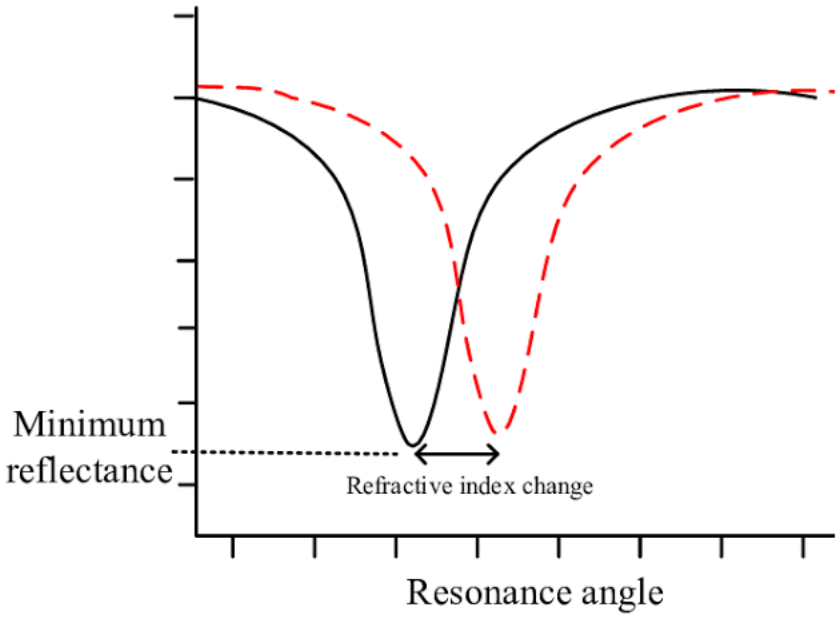

Figure 2: Dip in reflected light intensity at resonance angle

The wave vector [1] of surface plasmons at the metal–dielectric interface is given by:

$$k_{sp} = \frac{\omega}{c}\sqrt{\frac{\varepsilon_m \varepsilon_d}{\varepsilon_m + \varepsilon_d}} \tag{2}$$

where:

- ε_m is the complex dielectric constant of the metal,
- ε_d is the dielectric constant of the surrounding dielectric medium (typically the analyte or air),
- ω is the angular frequency of the incident light,
- c is the speed of light in vacuum.

For surface plasmon resonance to occur, this surface plasmon wave vector must match the in-plane component of the incident light wave vector, given by:

$$k_x = \frac{2\pi}{\lambda} n_p \sin\theta \tag{3}$$

Matching these two conditions:

$$\frac{2\pi}{\lambda} n_p \sin\theta = \frac{\omega}{c}\sqrt{\frac{\varepsilon_m \varepsilon_d}{\varepsilon_m + \varepsilon_d}} \tag{4}$$

This equation defines the **resonance condition** for SPR, which occurs at a specific angle θ where energy from the incident light is coupled into surface plasmon modes, resulting in a characteristic dip in the reflected light intensity.

3 Our Experimental Setup

Our experimental setup is inspired by the classical Kretschmann configuration used for exciting surface plasmons [3] at a metal-dielectric interface. In the standard model, a high-refractive-index prism is coated with a thin metallic film—typically gold—and an analyte or sensing layer is placed on the opposite side of the film. However, in our setup, we simplify the configuration by using only a glass prism, a thin gold film, and air as the external medium. This minimal arrangement allows us to study the fundamental behavior of surface plasmon resonance (SPR) in the absence of any analyte. The primary objective is to establish a baseline SPR system that can later be extended for sensing applications.

3.1 Working

The experimental setup itself is composed of several parts, as listed below:

- The setup is based on a wooden block with a extended wooden arm which can rotate up to 180 degrees. It is to be noted that setup is placed horizontaly instead of vertically as we see in common Kretschmann configurations.
- At the centre of rotating arm, a servomotor has been fixed on which a gold coated glass prism is mounted with the help of a circular base.

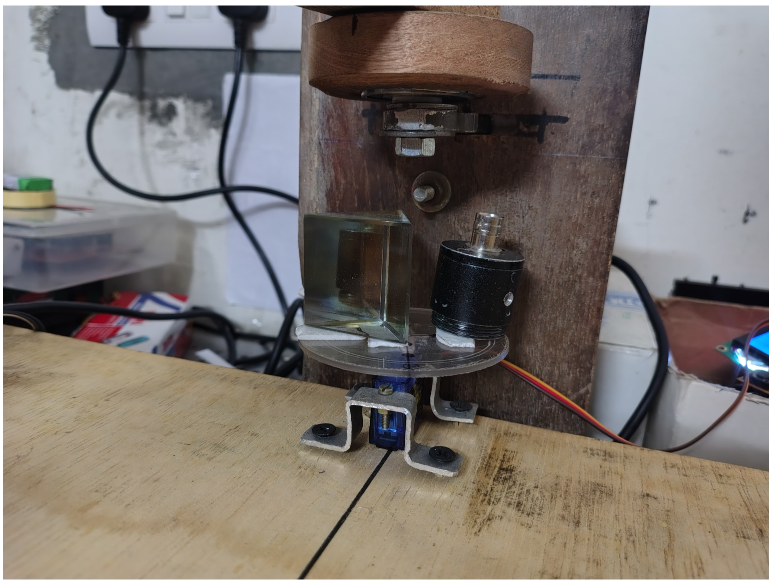

Figure 3: Gold coated prism mounted on servomotor at the centre of rotating arm

- The servomotor is rotated by a step of 2 degrees anticlockwise using Arduino microcontroller which also has a screen depicting the degrees it has been rotated.
- A red diode laser(650nm) is placed along the wooden table at its one end along the diameter of semicircle path traced by the arm.
- Prism is then rotated anticlockwise with steps of 2degrees from 0 to 90.
- Intensity of reflected beam from the gold film is measured using photodetector fixed at the rotating arm.

Picture of experimental setup is attached below for the reference:

Figure 4: Experimental Setup

4 Observation and Result

In this section, we present the observations and results obtained from our experimental setup based on the Kretschmann configuration. The setup, consisting of a glass prism (refractive index=1.5), a thin gold film (25nm), and air as the external medium, was designed to excite surface plasmons at the metal–air interface. By systematically varying the angle of incidence and monitoring the reflected light intensity, we identified the characteristic dip corresponding to the resonance condition. The results serve as a fundamental validation of the surface plasmon resonance phenomenon in the absence of any analyte, providing a reliable baseline for further studies involving sensing layers.

Plot of Reflective Intensity v/s Incidence Angle from the data points obtained in the experiment is plotted using gnuplot and is given below:

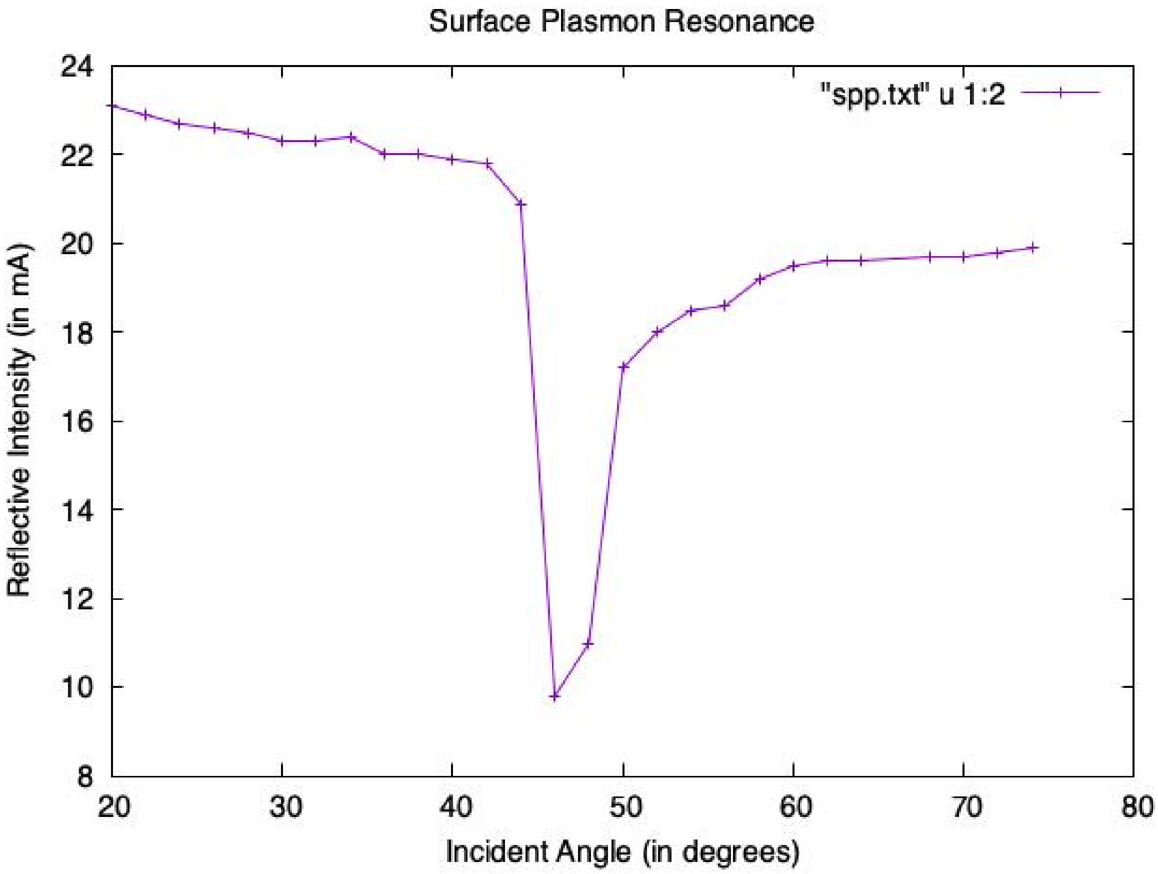

Figure 5: Dip in reflective intensity observed due to excitation of surface plasmons

The value of resonance angle for prism-gold film-air interface for this setup using 650nm diode laser is found to be nearly 46°

5 Discussion

The experimental setup successfully demonstrated the basic principles of surface plasmon resonance using a simplified Kretschmann configuration. The observed resonance dip in reflected intensity confirmed the excitation of surface plasmons at the gold–air interface, even in the absence of an analyte layer. While the results align well with theoretical expectations, there are several areas for refinement.

Future improvements could focus on enhancing the precision of angular measurements and minimizing noise in the detection system. Employing a more collimated and stabilized light source, as well as using higher-resolution detectors, could significantly improve data accuracy. Additionally, integrating automated rotation stages and real-time data acquisition software would streamline measurements and reduce human error. This foundational setup provides a robust platform that can be expanded to include sensing layers for real-time refractive index monitoring in biosensing and chemical detection applications.

References

[1] Lide Zhang Junxi Zhang and Wei Xu. "Surface plasmon polaritons: physics and applications". In: *Journal Of Physics D: Applied Physics* 45.11 (2012). DOI: https://dx.doi.org/10.1088/0022-3727/45/11/113001.

[2] Singh et al. "2D Nanomaterial-Based Surface Plasmon Resonance Sensors for Biosensing Applications". In: *Micromachines* 11 (Aug. 2020), p. 779. DOI: 10.3390/mi11080779.

[3] Hyuk Rok Gwon and Seong Hyuk Lee. "Spectral and angular responses of surface plasmon resonance based on the Kretschmann prism configuration". In: *Materials transactions* 51.6 (2010), pp. 1150–1155. DOI: https://doi.org/10.2320/matertrans.M2010003.

Appendix: Arduino Code for Angle Control Setup

```
#include <Servo.h>
#include <Wire.h>
#include <LiquidCrystal_I2C.h>

Servo myServo;
LiquidCrystal_I2C lcd(0x27, 16, 2);

const int resetButtonPin = 2;
const int increaseButtonPin = 11;
const int decreaseButtonPin = 4;
const int servoPin = 9;

int angle = 0;
bool lastResetState = HIGH;
bool lastIncState = HIGH;
bool lastDecState = HIGH;

void setup() {
  pinMode(resetButtonPin, INPUT_PULLUP);
  pinMode(increaseButtonPin, INPUT_PULLUP);
  pinMode(decreaseButtonPin, INPUT_PULLUP);
  myServo.attach(servoPin);
  myServo.write(angle);

  lcd.init();
  lcd.backlight();
  updateDisplay();
}

void loop() {
  bool resetState = digitalRead(resetButtonPin);
  bool incState = digitalRead(increaseButtonPin);
  bool decState = digitalRead(decreaseButtonPin);

  // Reset angle
  if (resetState == LOW && lastResetState == HIGH) {
    angle = 0;
    myServo.write(angle);
    updateDisplay();
    delay(200);
  }

  // Increase angle
  if (incState == LOW && lastIncState == HIGH) {
    if (angle < 90) angle += 1;
    myServo.write(angle);
    updateDisplay();
    delay(200);
  }
```

```

  // Decrease angle
  if (decState == LOW && lastDecState == HIGH) {
    if (angle > 0) angle -= 1;
    myServo.write(angle);
    updateDisplay();
    delay(200);
  }

  // Save current states for next loop
  lastResetState = resetState;
  lastIncState = incState;
  lastDecState = decState;
}

void updateDisplay() {
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Laser Project");
  lcd.setCursor(0, 1);
  lcd.print("Angle: ");
  lcd.print(angle);
  lcd.print(" deg");
}
```

Listing 1: Arduino code for controlling servo angle with buttons and LCD display