Surface Plasmon Resonance and Tamm Plasmon

Devansh Sharma
1811059

P443 Lab Report

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Abstract

The following experiment concerns itself with the study of Surface Plasmon Resonance and Tamm plasmon excitations in glass prism coated with thin gold layer and Distributed Bragg Reflector(DBR) respectively. Reflectivity spectrum is plotted for different incidence angles and Resonant wavelength is observed for each case. Surface plasmons are coherent delocalized electron oscillations that exist at the interface between any two materials where the real part of the dielectric function changes sign across the interface (metal-glass interface). Different light sources: white light source,He-Ne laser are used to observe SPR for s polarization and p polarization

1 Introduction

When gold layer is added to glass, free electrons in this metal layer can then act as a resonator. The energy for the resonance (energy transfer) comes from the evanescent wave produced by the totally internally reflected photons.

With the metal acting as a resonator, coupling/resonance can occur between the plasma oscillations of the free electrons in the metal and the bound electromagnetic field of the totally internally reflected photons. This coupling is the result of the momentum of the incoming light equaling the momentum of the plasma electromagnetic field, and is dependent upon certain conditions, including the wavelength of the incoming light, the illumination angle, and the refractive index of the prism, metal and aqueous layers.

2 Theory

2.1 Surface Plasmon Resonance

The surface plasmon wave is a surface wave confined at the interface between a dielectric and a metal. This experiment allows accurate determination of the angle of plasmon extinction and discussion of the principles of biosensors based on the SPR. A slight modification of the setup allows the investigation of the dependence of SPR on wavelength and illustrates the damping of SPR due to its coupling with the interband transitions of the gold thin film.

2.1.1 Plasmonics

SPR (surface plasmon resonance) is a physical process that is observed when polarized light hits a metal film under conditions of total internal reflection. At the interface between two transparent media with different refractive index (for example glass and air) the light coming from the side of the medium with the highest refractive index is partly reflected and partly refracted. Above a critical angle of incidence, no light is refracted through the interface and total reflection occurs. At the interface between the two media, a component of the electromagnetic field of the incident radiation, called evanescent wave, propagates up to a certain distance in the medium with a lower refractive index. The evanescent wave has intensity that fades quickly with an exponential trend.

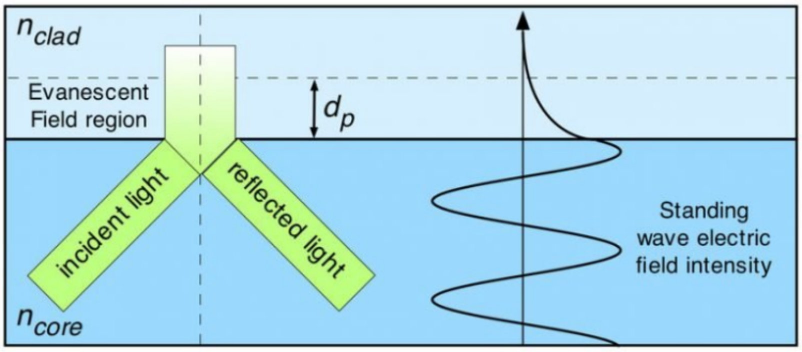
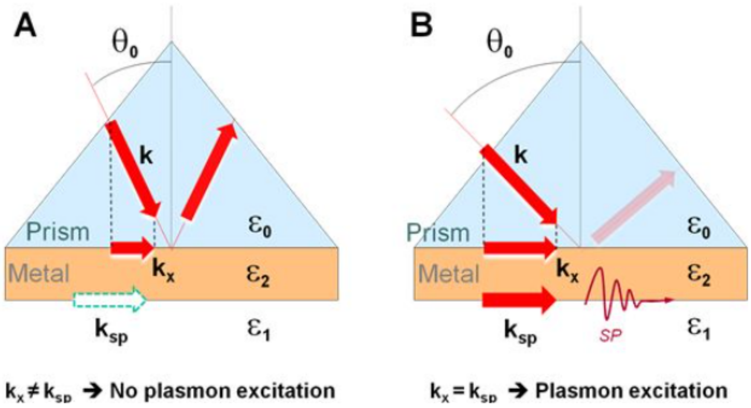


Figure 1: Progression of the evanescent wave

The electrons on the metal surface are mobile, they are defined as a liquid with a high electronic density (plasma) and create oscillations, which propagate in a parallel direction to the metal-dielectric interface. The propagating plasma waves are called superficial plasmons. When at a particular angle, the incident light wave vector mates with the moving electron vector (plasmons), resonance conditions occur. This coupling of the incident light with the surface plasmons leads to a loss of energy, since the energy of the photons is transmitted to the plasmons. Thus a minimum is observed in the intensity of the radiation reflected at the angle at which the resonance occurs.



To achieve the conditions that allow the occurrence of the phenomenon, a prism is often used on whose surface a thin metallic layer of gold is applied. The image below shows on the left (A) the case in which there is total reflection without resonance, on the right (B) instead the angle of incidence of the radiation conveys a moment that comes into resonance with that of the plasmonic wave, transferring energy to the plasmon and thus reducing the intensity of the reflected beam.
The dispersion equation of the SP wave is given by:

$$k_x^2 = \frac{\omega^2}{c^2}.\frac{\epsilon_1(\omega).\epsilon_2(\omega)}{\epsilon_1(\omega)+\epsilon_2(\omega)} \tag{1}$$

$$k_{1z}^2 = \frac{\omega^2}{c^2}.\frac{\epsilon_1(\omega)^2}{\epsilon_1(\omega)+\epsilon_2(\omega)} \tag{2}$$

$$k_{2z}^2 = \frac{\omega^2}{c^2}.\frac{\epsilon_2(\omega)^2}{\epsilon_1(\omega)+\epsilon_2(\omega)} \tag{3}$$

Here K_X is the wave vector of the incident wave, ϵ_1 is the dielectric function of medium 1 and ϵ_2 is for medium 2.
Let us consider an external wave propagating in air (medium 2, wavevector $\vec{k_2}$) g on the metallic surface with an incidence angle θ. The component of the wavevector parallel to the interface $k_{2x} = k_x$ obeys the dispersion relation:

$$\omega = \frac{k_x.c}{\sin\theta} \tag{4}$$

The wave is totally reflected and generates an evanescent wave on the other side of the interface. If θ_{int} is the incidence angle , the dispersion relation is written as:

$$\omega = \frac{k_x.c}{n.\sin\theta_{int}} \tag{5}$$

The excitation of the surface plasmon resonance (SPR) on a gold thin film is discussed within the Kretschmann configuration, where the coupling with the excitation light is achieved by means of a prism in total reflection.The condition for coupling the excitation wave with the SP wave is obtained by combining relations (1) and (5):

$$(n \sin \theta_{int})^2 = \frac{\omega^2}{c^2} \cdot \frac{\epsilon_1(\omega).\epsilon_2(\omega)}{\epsilon_1(\omega) + \epsilon_2(\omega)} \tag{6}$$

2.1.2 Experimental Setup

The experiment consists in having a beam emitted by both He-Ne laser (632.8 nm) and white light source hit on the prism prepared with the slide with the metal film and in measuring the intensity of the reflected beam. The measurement is made at different angles. For all these angles we are in the conditions of total reflection.

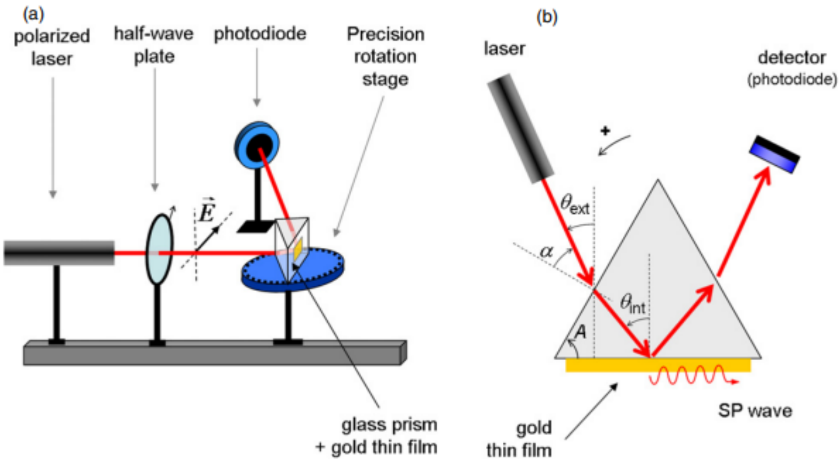


Figure 2: Experiment setup for plasmon excitation

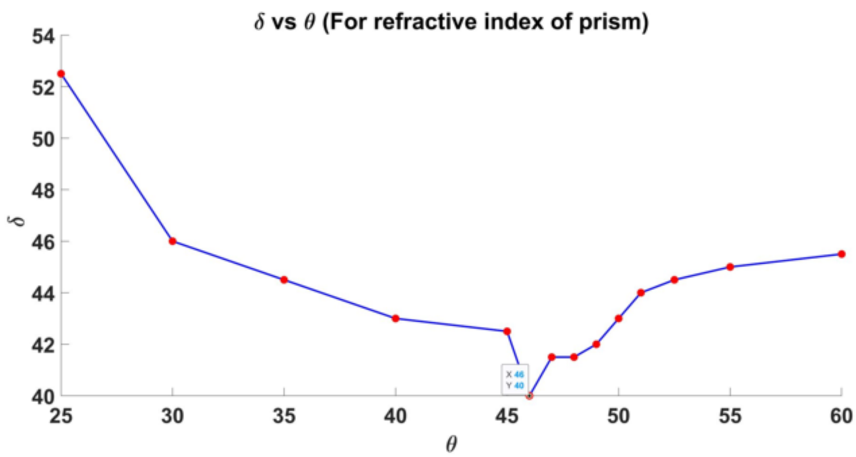
Value of θ_{int} is obtained by:

$$\theta_{int} = \arcsin \frac{\sin \theta_{ext} - A}{n} + A \tag{7}$$

3 Observations and Results

3.1 Calculation for Refractive index of Prism

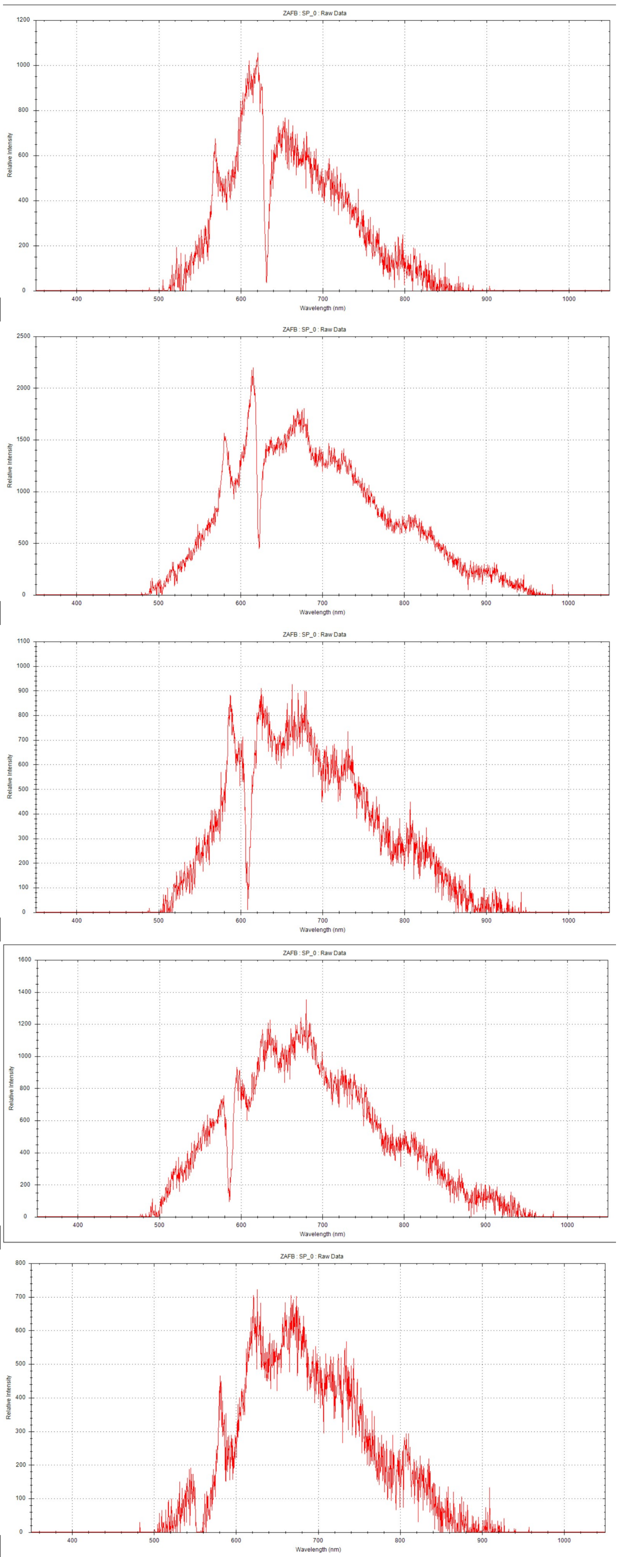
Refractive index of the glass prism is calculated by measuring angle of minimum deviation.



The refractive index for minimum deviation of 46° comes out as 1.5321

3.2 Surface Plasmon Resonance

3.2.1 p-polarized light



Experimental spectra for (a) 10°(b) 20°(c) 30°(d) 40°(e) 50°

3.2.2 s-polarized

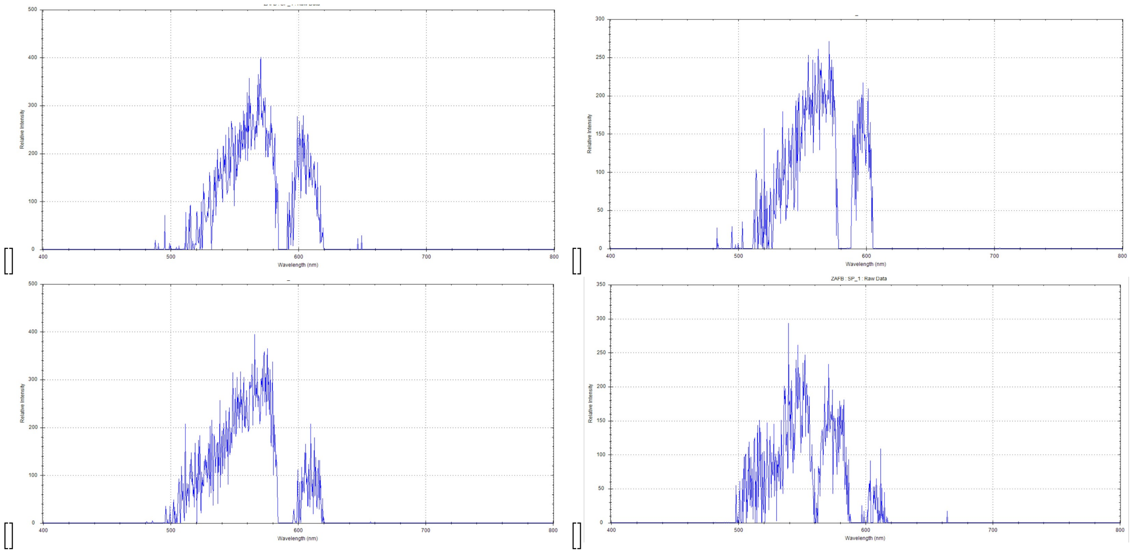
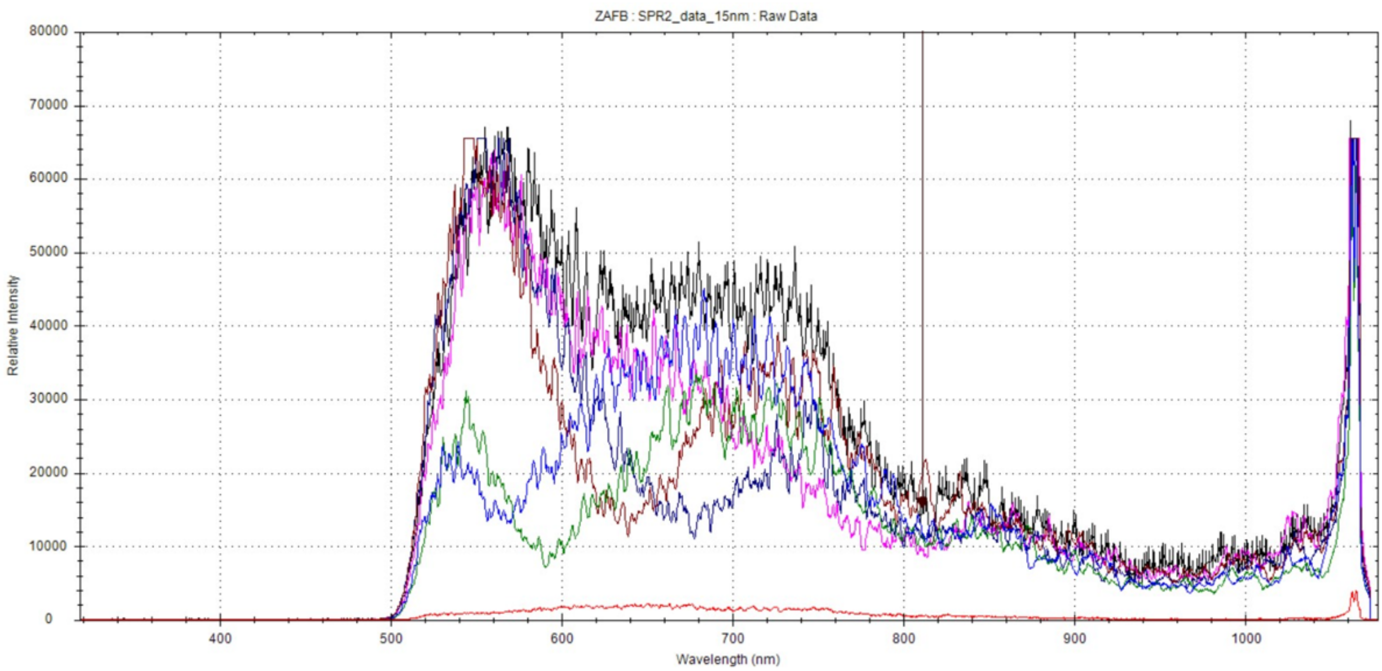


Figure 3: Experimental spectra for (a) 20°(b) 30°(c) 40°(d) 50°

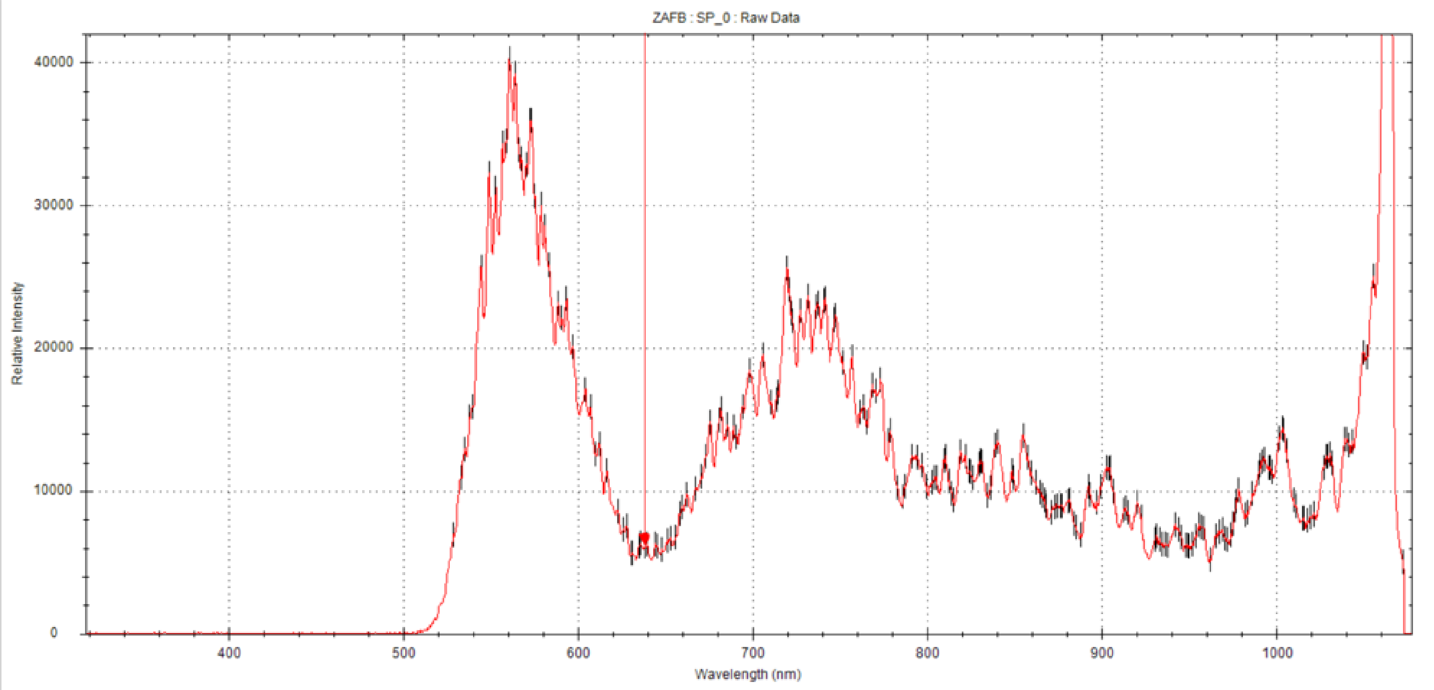
3.3 Tamm Plasmon

3.3.1 Using white light source



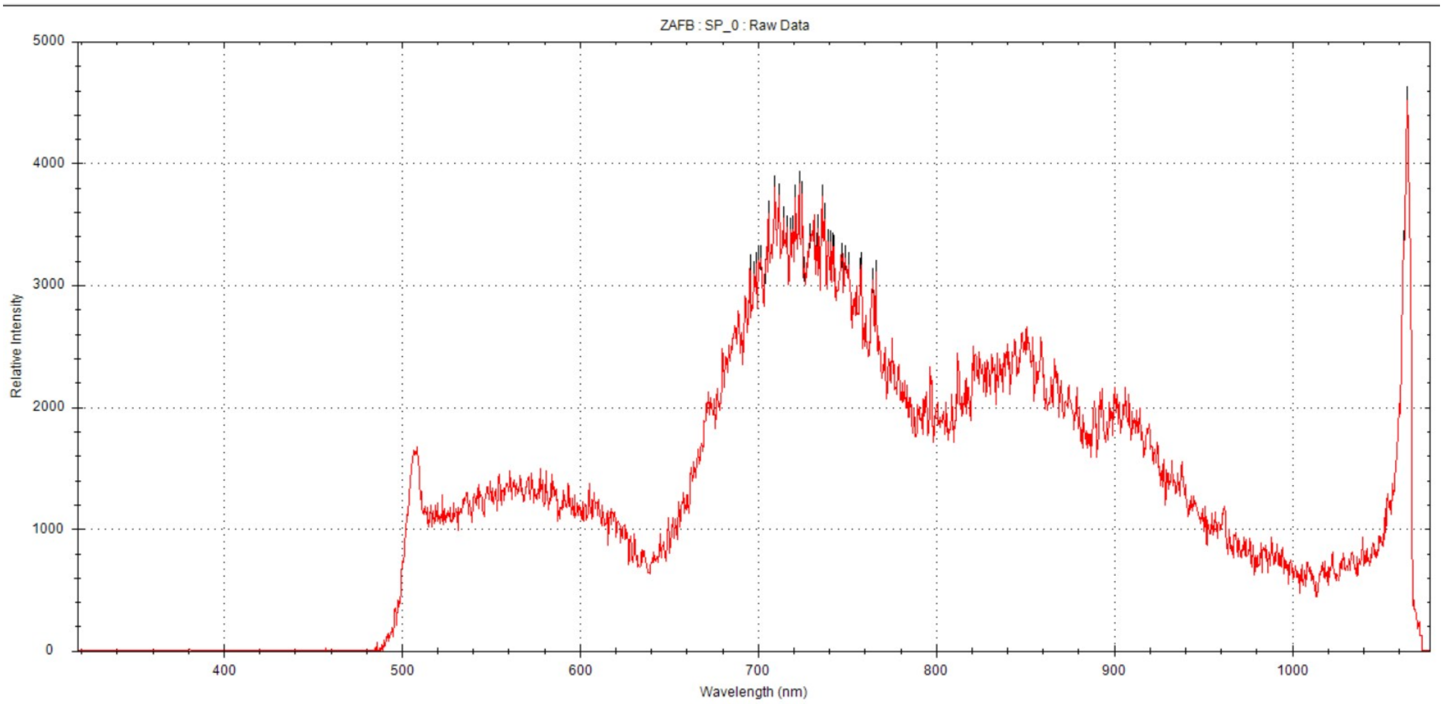
- Red: 60°
- Blue: 58°,566.96 nm
- Green: 58°,592.25 nm
- Dark red: 58°,639.24 nm
- Dark blue: 58°,679.09 nm
- Magenta: 58°,812.63 nm
- Black:50°

3.3.2 Using Super continuum Laser



Dip at 640 nm for $\theta_{int} = 42.8°$

3.3.3 Lab Demo Result



Dip at 637 nm for $\alpha = 26°$

4 Conclusion

Surface Plasmon Resonance and Tamm Plasmon is observed experimentally and verified with theoretical calculations for different light sources: white light source, He-Ne Laser and super continuum Laser.Refractive index of glass prism is calculated and n_{prism} came out to be 1.5321. Relative intensity is plotted with respect to wavelength for change in incidence angle.For prism, sharp dip is observed for $\theta_{int} = 42.8^{\circ}$ which is very close to theoretical value. Better results can be obtained if irregularities and scratches from the gold film can be fixed and also metal of suitable thickness is coated on the prism. Adding an additional water layer on the other side of the metal coating did not show SPR due to problem in modified setup.

5 References

- Hutter, Eliza, and Janos H. Fendler. "Exploitation of localized surface plasmon resonance." Advanced materials 16.19 (2004): 1685-1706.
- Homola, Jiří, Sinclair S. Yee, and Günter Gauglitz. "Surface plasmon resonance sensors." Sensors and actuators B: Chemical 54.1-2 (1999): 3-15.
- Pluchery, Olivier, Romain Vayron, and Kha-Man Van. "Laboratory experiments for exploring the surface plasmon resonance." European journal of physics 32.2 (2011): 585.
- Kaliteevski, M., et al. "Tamm plasmon-polaritons: Possible electromagnetic states at the interface of a metal and a dielectric Bragg mirror." Physical Review B 76.16 (2007): 165415.
- Sasin, M. E., et al. "Tamm plasmon polaritons: Slow and spatially compact light." Applied physics letters 92.25 (2008): 251112.