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Surface Plasmon Enhanced Optical Amplifier in Gold Nanostructure by Standing Wave Generation within the Communication Window

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Abstract: The surface plasmon resonance enhanced standing wave generation in a Kretschmann geometry comprising a 3 µm long, 1 µm thick ZnSe layer (n = 2.457) and a 29 nm thin Au layer (n = 0.38+10.75i) is observed, designed and simulated here. The proposed configuration amplifies two times the intensity of the incident wave through standing wave generation at 1550 nm and 25 ºC temperature. The observed intensity of the standing wave for p-polarized light near the metal surface is varied from 0 to 47.8 (a.u) by increasing distance from 0 to 1000 nm in the vertical direction and from 0 to 3000 nm in the horizontal direction in the optical component facet. Here the proposed source of fundamental is an external cavity tunable laser operating in TM_{00} mode at a center wavelength of 1550 nm which is pulse modulated at a repetition frequency of 1 KHz and amplified by an erbium-doped fiber amplifier having 5 mW incident powers with 4 mm^2 beam cross-sectional area. Within the communication window this idea expedites the way of measuring the phase change in terms of varying intensity which further explores the new avenues for position tuning with the standing wave.
Key words: Counter propagating waves, Standing wave, Surface Plasmon.

Introduction

It is well known that Michael Faraday along with James Clerk Maxwell proved the wave properties of light i.e. “Light is an electromagnetic wave” where the mathematical derivation was explored by J. C. Maxwell and the experimental verification was established by M. Faraday in 18th century[1,2] against which number of experiments were performed among them one of the most important experiments was related to counter propagating waves. Here counter propagating waves are basically two waves propagating in opposite direction to each other. If the two opposite travelling waves with same frequencies and wavelength interfere over a certain points then owing to constructive interference they produce the standing waves. Due to the property of maintaining constant position they are also known as stationary waves whereas the first observation of the stationary wave was reported by the German physicist O. Wiene in the year 1890[3]. When a quasi monochromatic light is shown upon normally on a mirror, a band of parallel black and white pattern of light was developed on the photographic plate owing to the formation of nodes and antinodes of the standing light waves[4,5,6].

For generating standing wave[7,8,9] the concept of surface plasmon may be utilized. Surface plasmon stands for the coherent electrons oscillation at the interface between any two materials, like metal-dielectric interface such as metal sheet in air whereas this charge oscillation creates electromagnetic fields both outside and inside the metal[10]. The collective oscillation of electrons stimulated by incident light is termed as surface plasmon resonance (SPR) at which the frequency of incident photon couples with the frequency of surface electrons oscillating against the restoring force of the positive nuclei. The idea of generating standing waves through two counter-propagating surface plasmon waves expedites the way of increased resolution and sensitivity in case of surface plasmon resonance based sensors.

Proposed scheme

For amplifying the intensity of the standing wave with the help of surface plasmon within the communication window (1550 nm) the proposed configuration is shown in Fig. 1 which comprises a ZnSe prism (n = 2.457) and 29 nm thin gold (Au) layer (n = 0.38+10.75i)[11] which is coated on the optical component's facet.

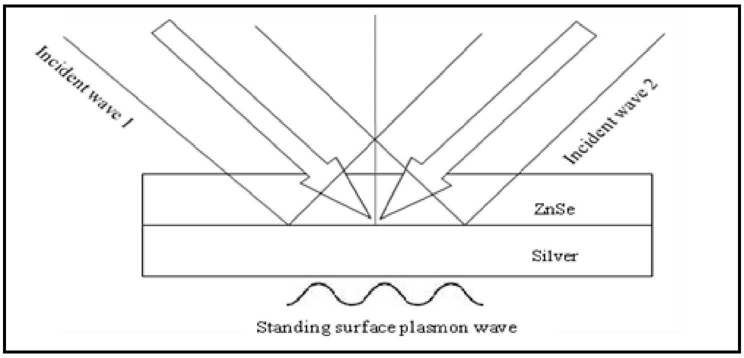

Fig. 1: Surface plasmon enhanced standing wave generation in ZnSe prism.

From the reflectance vs incident angle graph, as show in Fig. 2 the resonant angle for three layer configuration is 24.48 º. When p-polarized counter propagating plane waves are shown upon the prism against this resonant angle then it constructively interfere with each other to produce a standing wave.

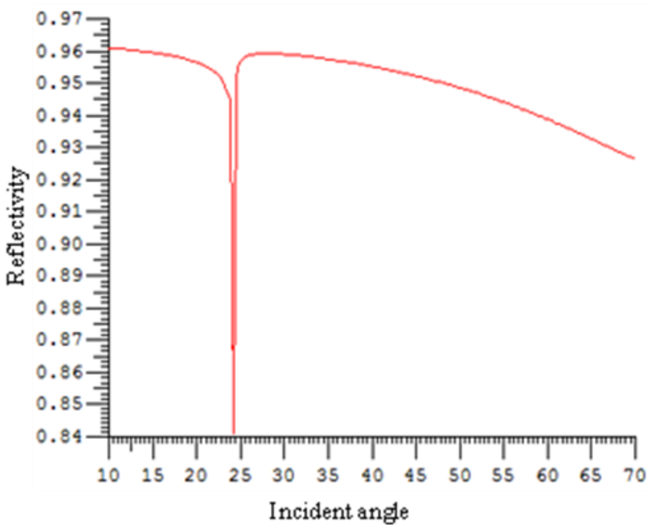

Fig. 2: Reflectivity vs incident angle (Degree)

The electric fields of a p-polarized incident light for surface plasmon resonance is expressed as [12,13,14].

$$E_{p,i} = \begin{bmatrix} -\cos\theta_i \\ 0 \\ \sin\theta_i \end{bmatrix} \exp(ik_i x \sin\theta_i + ik_i z \cos\theta_i) \qquad (1)$$

where k_i stands for the wave number and θ_i stands for the angle of incidence. The transmitted field at the interference is depicted by -

$$\mathrm{E}_{p,t} = \frac{t_p}{\eta}\begin{bmatrix} -i\sqrt{\sin^2\theta_i - \eta^2} \\ 0 \\ \sin\theta_i \end{bmatrix} \exp(ik_i x \sin\theta_i)\exp(-k_i z\sqrt{\sin^2\theta_i - \eta^2}) \qquad (2)$$

where t_p denotes the three layer Fresnel transmission coefficient for p-polarized light and $\eta = n_t/n_i$. Here n_t and n_i stands for the refractive index of Au layer and ZnSe respectively. Thus the field at the interference when the two counter propagating p-polarized lights are incident at the same angle is depicted by –

$$E^{sw}_{p,t} = \begin{bmatrix} \begin{bmatrix} -i\sqrt{\sin^2\theta_i - \eta^2} \\ 0 \\ \sin\theta_i \end{bmatrix} \exp(ik_i x\sin\theta_i) \\ + \begin{bmatrix} i\sqrt{\sin^2\theta_i - \eta^2} \\ 0 \\ \sin\theta_i \end{bmatrix} \exp(-ik_i x\sin\theta_i) \end{bmatrix} \times \exp(-k_i z\sqrt{\sin^2\theta_i - \eta^2}) \qquad (3)$$

Hence the intensity of the resulting standing wave is expressed as -

$$I^{sw}_{s,t} = 2\left|\frac{t_p}{\eta}\right|^2 (2\sin^2\theta_i - \eta^2)(1 + \frac{\eta^2}{2\sin^2\theta_i - \eta^2}\cos(2k_i x\sin\theta_i)) \times \exp(-k_i z\sqrt{\sin^2\theta_i - \eta^2}) \qquad (4)$$

Result and discussion

Using Equation (4), we have obtained the intensity of the standing wave for p-polarized light near the metal surface which is shown in Fig. 3. From the Fig.3 it may be observed that by increasing distance from 0 to 1000 nm in the z direction and from 0 to 3000 nm in the x direction the intensity of the standing wave is varying from 0 to 47.8 (a.u).

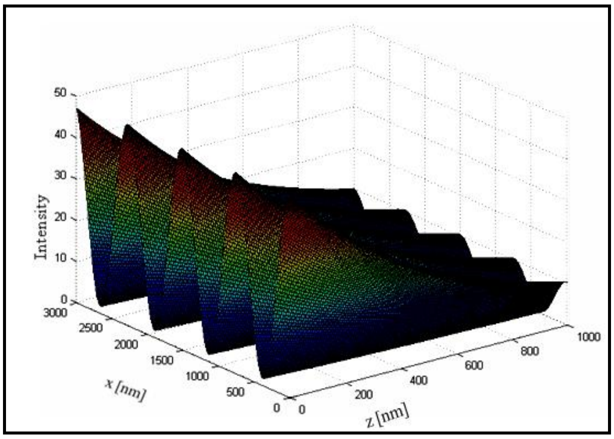

Fig. 3: Variation of intensity of standing wave with respect to x (perpendicular to incident point) and z (along the incident point) axis.

The simulated data also indicates that sinusoidal standing wave pattern is formed near the metal surface which decays exponentially away from the surface and shown in Fig. 4.

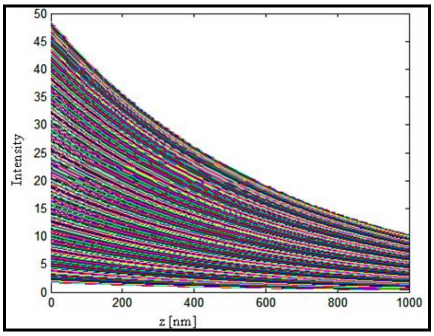

Fig.4: Exponentially decay of the intensity of sinusoidal standing wave.

With the proposed arrangement the intensity of the standing wave is increased within the communication window. The proposed configuration may be useful for measuring the phase change in terms of change of intensity and for position tuning with the standing wave.

Conclusion

Surface plasmon resonance is a well-known phenomenon depicting the coherent electrons origination from the collective electronic oscillations at the interface between any two materials like metal-dielectric interface. At the resonance condition i.e. when the frequency of the incident photon couples with the frequency of the surface electrons, collective oscillation of electrons take place which is termed as surface plasmon resonance. Standing waves will be produce when two surface plasmon waves are incident from the opposite direction to each other. Through this paper we are exploring the amplification of the intensity of the standing wave with the help of surface plasmon resonance within the communication window, for which a Kretschmann configuration consisting of a 3 µm long, 1 µm thick ZnSe layer coated with 29 nm gold layer has been used. The observed intensity of the standing wave is varies from 0 to 47.8 (a.u) by increasing distance from 0 to 1000 nm in the vertical direction and from 0 to 3000 nm in the horizontal direction in the optical component facet. This idea expedites the way of measuring the phase change in terms of change of intensity which further explores the new avenues for position tuning with the standing wave.

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