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A review on metasurface applications (Optical waveguides and Surface enhanced Raman) on optics-Surface plasmon view

Review Article

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Abstract
This paper deals with metasurface in different photonic applications. The main reason for our study is to show the great potential which metasurface has in applications within optical frequencies. A Significant part of this study focused on the history of metasurface and its different phenomenon specially the Surface Plasmon Polariton (SPP) phenomenon and its different applications. The basic theory of metasurface is introduced. The relation between metasurface and the SPP phenomenon is presented in this work. A comparison between different applications of the SPP phenomenon is investigated. A new approach and structures for metasurface in different applications such as Surface Enhanced Raman spectroscopy (SERS) and optical waveguides have been presented in this work. The connection between different applications and optics with the SPP phenomenon is presented. The physics of SPPs phenomenon and metasurface is represented briefly.

1. INTRODUCTION

Metasurface, which can cause an abrupt change in the phase of the incident wave above it, is a new kind of nanoscale optical components. They work as nano optical arrays which interact with the incident light to control its properties. Metasurface is classified into plasmonicmetasurface [1,2] and dielectric metasurface[3,4]. Dielectric metasurfaces are substrates made of high refractive index materials such as titanium dioxide and silicon as in[5,6]. This can produce variable guidance for the incident light properties. In comparison with Plasmonicmetasurface, they are based on metallic nanostructures electric or magnetic response due to light interaction. This response depend on their size and light orientation. This means that the plasmonicmetasurface depends on incident light polarization and frequency. The Plasmonic resonance represents electronic oscillations on the metallic layer inside the interface between metal and dielectric. The electronic oscillation can be a representation for Lorentz oscillation.

This oscillation can be called the SPP. This phenomenon can be noticed as a response for visible/near-infrared range light. For specific geometrical size, permittivity of metals which is positive differs from negative dielectric permittivity. At specific frequencies, both magnetic and electric dipole resonances are excited which helps in resonating electric and magnetic fields. This can enhance transmission and reflection responses of the surface according to our needs. Metasurface can be added in many applications in optics as holograms, communication devices ,biomedicals as SERS, computing , integrated circuits and etc.

In this article, A brief on the physics of nanoplasmonics with a discussion of its main phenomenon which is the SPPs will be introduced. Another approach is that an introduction for two different applications will be introduced with their physics. The first one is optical waveguidewhile the second one is The SERS using SPPs. A brief history about these applications will be introduced. Starting with the plasmonic metasurface history and grading from natural materials and metamaterials, then metasurface construction with its SPP physics is introduced in the following subsections.

1.1. Metasurface History

The light wave-particle duality by Compton in[7] proved that light has particle nature in which law of energy and momentum conservation can be applied. The famous De-Broglie equationof wavelength in[8] also defines that any particle motion is associated with wave having a wavelength relative to its particle's momentum. Studying the particle wavelength is very important to determine if there is reflection for the incident wave or it will path smoothly without any reflection or diffraction. The wavelength of the incident wave is very important as it can change the whole application or it can give us a new approach of studying or research according to the relation between the wavelength and the surface intermolecular distance (d). Fig.1 clarifies that we can see the electronic oscillations in the surface between metal and dielectric. Thisshows the absorption at the interface between metal and dielectric can be expressed as electronic oscillations. These oscillations has large value in the dielectric while they have small value inside the metal. So we can say that the incident wave some is reflected, refracted and some are absorbed at the surface interface (which is the SPP phenomenon).

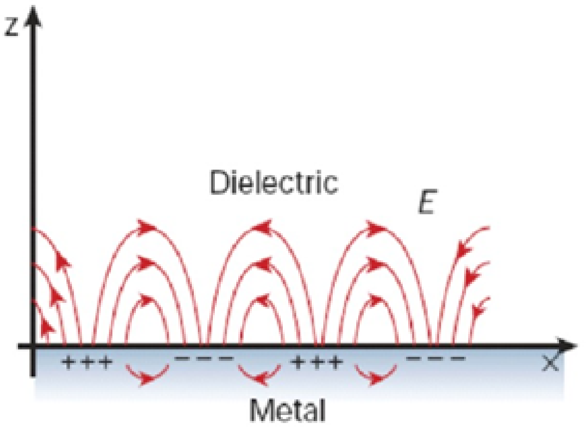


Fig. 1: SPPs between metal and dielectric interface

In 1902, Wood in[9] discovered strange oscillations known later as SPPs, where he found unexplained optical reflections in the metal dielectric gratings. In[10] Maxwell observed Brightcolors in metal-doped glasses. In 1903, Mie in[11] proposed light scattering of spherical particles. In 1956, Pines in[12] described the theory of energy losses experienced by fast electrons through metals where he described the deduced losses as oscillations of free electrons with name (Plasmons). In the same year, Fano in[13] introduced the term (Polariton). This term describes the coupled oscillation between electron and light inside the media of transmission.

After that, Ritchie in[14] put the first theoretical explanation of surface plasmons and electron energy losses. In[15] Plasmonic mode was found near the metal-dielectric interface where surface plasmon resonances excited on the grating giving anomalous behavior of metal spots.

Otto and Kretschmann in[16,17] introduced Optical excitation of surface plasmonson metal films. Kreibig and Zacharias in[18] used gold and silver as nanoparticles for SPPs for the first time. This gave huge progress in the metamaterial field of study. In[19], Cunningham and co-workers introduced term SPP for the first time. So after this historical background we can define Metamaterials as artificial materials which have negative permittivity and permeability which can be controlled by the incident ray frequencies at the interface between metals and dielectrics. When metals have negative refractive indices, it acts as dielectric. Due to law of energy conservation and generalized Snell's law; electrons act as oscillators at the interface between metals and dielectrics. The photonic interaction with materials are called polaritons, so these oscillations can be named by SPPs. The electronic oscillations have (1/10) penetration depth inside the dielectric. Plasmonic oscillations can be presented between metal and dielectrics as in Fig.1. The physics of this phenomena is discussed in[20] where different types of plasmonic resonance are introduced. The first one is bulk plasmons where longitudinal charge density waves with zero electric and magnetic fields are possible at surface or internally between the layers of material. This type is introduced also in[21,22]. The second one is the surface plasmons which contain electric and magnetic fields that breaks the well-known Snell's law and applies generalized Snell's law and fermat's principle. This type is the main type of this review and it is defined in[22,23,24]. Another important field of interest, is the size of our devices. This approach leads to minimize the designed structure to nanoscale and to many other obstacles. Heat generated inside these structures during fabrication is one of the most common obstacles. This means that the more reduction in our dimensions, the ease of their melting. In Fig.2 , an introduction for the progress of the dimensions of the devices by increasing frequency as in[25].

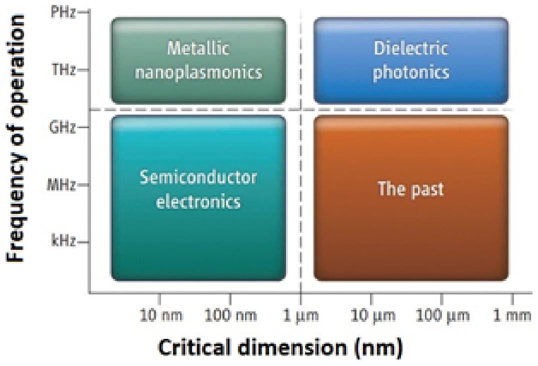


Fig. 2: Operating frequency versus the critical dimensions relation

In Fig. 2, The fabrication process was in microscale during Kilo and Giga hertz band also in the Tera and Pico bands which were bands of optical and microwave communication. So, we cansee that the fabrication process in past was much easier than the semiconductor electronics and the nanoplasmonic dimensions. Nanoplasmonic bands has two main considerations, The first one is the small nanoscale size in structures. The second one is the very high operating frequencies.

1.2. Difference between natural materials and metamaterials

There are many different point of views and definitions were introduced in many articles concerning material's molecular structure. The periodicity of the molecular arrangement in the natural materials tends to (λ/2) of the incident wave while metamaterials periodicity is less than the traditional surface tends to nanoscale. This means that metamaterials must be thinner than the traditional materials. This point of view was discussed briefly in[23]. Another point of comparison is the applied theory of both materials. Metamaterials apply Hygen's principle as in[26], where each element of wavefront acts as a secondary source. This leads to control thereflected wave fronts by the metaatoms material according to[27]. Magnetic and electric dipole moments of the atoms helps to control the reflected wave phase. Phase controlling is used in many applications such as holograms, mirrors and lens with small dimensions which can replace huge devices. This leads to great progress in this field of research.

The electronic oscillations are presented by Lorentz model which is reduced to drudemodel for negative permeability and permittivity as in[28,29]. Drude model is better in simulations than Lorentz model where Lorentz model defines the dispersion relation in the wave due to permeability while the drude model discuss the dispersion due to the oscillations of the electrons on the materials. Metamaterials have different interaction with the incident waves than the natural materials. Metamaterials can have change in their permittivity and permeability where it depends on the frequency of incident waves, this leads to negative values of refractive index. Frequency dependent negative refractive index materials allows to control different electromagnetic waves. Due to this unusual characteristic, metamaterials offer potential applications which cannot be designed by only natural materials. One of the numerous applications of the metamaterials is the phase compensation medium. Double negative indices (DNG) and positive indexed materials are combined together in such a way that the phase difference across the slab of this medium is zero. By combining double positive and double negative metamaterials, the phase difference can be controlled as in[30,31]. Many other applications can be introduced according to different responses in metamaterials as the magnetic dipole moment response in[32,33], the negative permeability as in[34,35] and also their mechanical response as in [36,37]. But the complexity of metamaterials responses could be a an obstacle specially in manufacture and cost.

1.3. Difference between natural metamaterial and metasurface

Due to complications of constructing metamaterials, a new approach to reduce the 3D structure with only a 2D structure. These structures have the important aspects of the metamaterials.

One of these aspects is the negative refractive index, which supports the SPP phenomenon discussed in first sections of this article. As a connection between generalized snell's law and SPP phenomenon, metasurfaces were constructed as an innovation and simplification for the nonlinear response of metamaterials. In this article, the main interest is studying negative refractive index principle on the metallic surface between the metal and dielectric interface.

The main phenomenon in the metamaterials is surface plasmons where electron oscillates in the layer between metal and dielectric. This phenomenon depends on the polarization of the incident waves and on the particles or molecules of the used material. Surfaces support the plasmonic phenomenon are called metasurface. The phenomenon found on metamaterials causes an attenuation in the electronic oscillation differs from photonic response of light wave. Different applications can be introduced as optical waveguides by SSPs phenomenon as in[38,39]. Superlens or optical lens can be made by the metasurface as in[40,41]. Holograms also can be made as in[42,43]. Many other applications will be introduced one of them is the SERS which will be discussed later in this work.

1.4. Metasurface and Surface Plasmon Polaritons

SPPs are photonic and electronic oscillations near the interface between metal- dielectric. This phenomenon was introduced in[44,45]. The control of SPP over near field is performed by metasurface. This was introduced in[46,47]. Bulky materials lead to many limitations of the plasmonic oscillations specially in high cost and fabrication complexity; to solve this problem we used metasurface as an expression of plasmonic oscillations. After many studies, metasurface can be named as SPP emitters. According to metasurface design dimensions and incident wavelengths , controlling polarization and phase can be achieved. Fig. 3 (a), shows discontinuous phase control due to helical SPP excitation and controlling polarization of incident circular polarization by changing the helical metastructure. In Fig. 3 (b), Rectangular and circular structures were designed to show differnt SPP response[48]. Multiplexing of SPP due to changing polarization and wavelength was presented in[49]. In Fig.3(c), two patterns of different plasmonic wavelengths show the plasmonic phenomenon due SPP. SPP control could be performed by perpendicular polarization states. This can be used in many applications as perpendicular plasmonic response by SPPs. This was used in Fig.3(d) in holographic metalens[50]. This can control coupling and propagation problems in SPPs and create different point sources to focus SPPs.

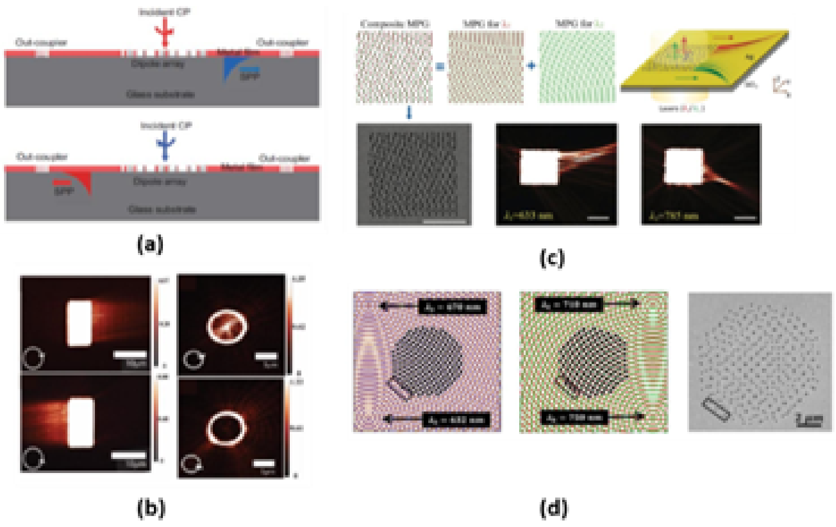


Fig. 3: SPPs polarization and phase control examples

1.5. Nonlinear response of metasurface

The metasurface can show linear and nonlinear responses of incident light phase control. The previous discussions showed the linear Response. In[51,52,53], nonlinear response of metasurfaces was studied. Nanoscale metasurfaces have great impact on nonlinear photonic applications. They provided new degree of freedoms in light interaction with matter. Different applications depend on this nonlinear response such as High resolution imaging with very high efficiency and phase control. By Pancharatnam-Berry Metasurface, controlling the higher order harmonic generations with dynamic plasmonicnanoantennas can be introduced. In[54], nonlinear polarization variation for continuous phase control can be introduced. Nanoantennas provide phase control due to rotational symmetries over local non-linearity. Due to circularly polarized incident light, different harmonic generations are produced. These harmonics are generated due to non linear spin rotations which couple with incident light. M-folded nanostructure allows different harmonics in order $n=lm\pm1$, where "+" and "-" corresponds to opposite directions of circular polarization in Fig.4(a). In[55], nonlinear coefficients of metasurfaces were controlled, this produced non linear shaping of phase and amplitude control. Second harmonic vortex beam generation in Fig.4(b). Harmonic generation vary by redesigning the nanoantennas of the metasurfaces. Fig. 4(c) shows experimental results of spin multiplexing for nonlinear holography as in[56].

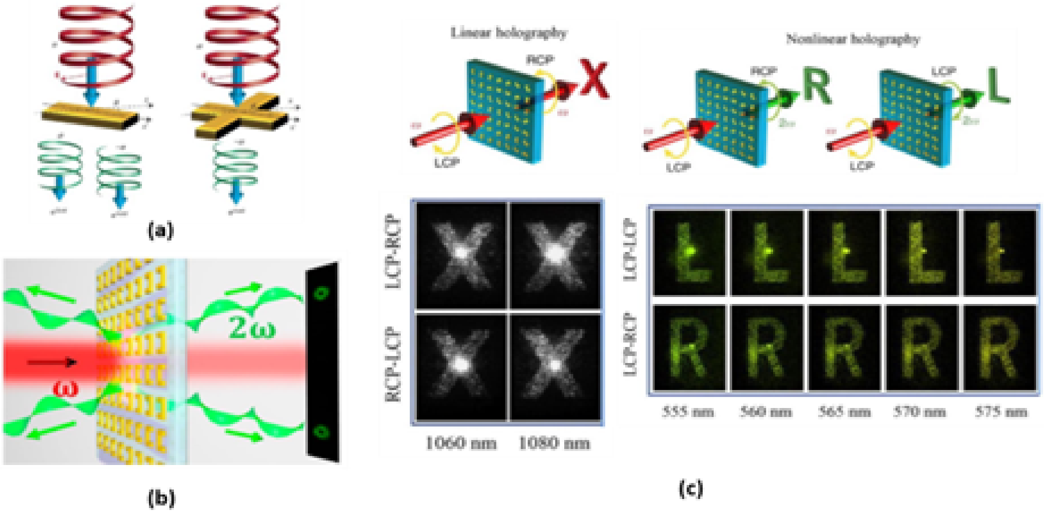


Fig. 4: Nonlinear polarization and phase control by SPPs

2. Theory of Surface plasmon polariton

SPP phenomenon are found in metasurface which is layer between metal and dielectric. Themetamaterials are materials which have different properties than the natural materials such as negative permittivity and permeability. This can be found in the surface between metal and dielectrics so we can call this layer as a metasurface. This was discussed in the previous sections. A Detailed discussion for the physics of the SPP phenomenon is introduced with proper equations and figures showing the unusual plasmonic oscillations.

The plasmonic oscillations show new approach for the reflection and refraction process which was discussed by the normal snell's law, where SPPs show absorption of the incident wave at the interface between metal and dielectric this leads for generalization of Snell's law which will be as shown (1) :

$$\sin(\theta_t)n_t - \sin(\theta_i)n_i = \frac{\lambda_o}{2\pi}\frac{d\Phi}{dx} \qquad (1)$$

Where n_t is the refractive index of the transmitting medium, n_i is the refractive index of the incidence medium, θ_t is the angle of the refracted ray, θ_i is the angle of incident ray, λ_o is the wavelength of the incident ray and $d\Phi/dx$ is the gradient change of the phase angle of the reflected wave. This equation shows that there is absorbed ray at the interface between metal and dielectric surface. This absorption is proposed as the plasmonic oscillation of electron. This approach can be shown in Fig. 3, where the incidence medium can be the dielectric (medium A). The transmittance medium is the metal (medium B), where the absorption or the surface plasmonic effect happens at the interface which is the X-axis in Fig. 3.

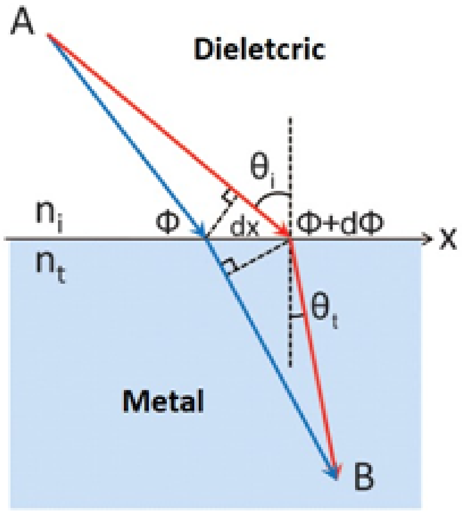


Fig. 5: Generalization of Snell's law

According to[20], wave continuity from the metal to dielectric will be assumed. This leads to many equations as (2), which shows the condition of wave continuity:

$$\frac{\varepsilon_1}{k_1} + \frac{\varepsilon_2}{k_2} = 0 \qquad (2)$$

Where ε_1 and ε_2 is the permittivity of metal and dielectric, while k_1 and k_2 are the wave vectors inside both metal and dielectric. For same wave vectors (3) will be introduced:

$$\varepsilon_1 + \varepsilon_2 = 0 \qquad (3)$$

Wave vector for SPP phenomenon will reduced by (4):

$$k_{\mathrm{spp}} = k\sqrt{\frac{\varepsilon_{\mathrm{d}}\varepsilon_{\mathrm{m}}}{\varepsilon_{\mathrm{d}} + \varepsilon_{\mathrm{m}}}} \qquad (4)$$

The penetration depth of the SPP inside the dielectric can be determined by (5):

$$\delta_{\mathrm{spp}} = \frac{1}{2k_{\mathrm{spp}i}} = \frac{\lambda}{2\pi}\left(\frac{\varepsilon_{\mathrm{mr}} + \varepsilon_{\mathrm{d}}}{\varepsilon_{\mathrm{mr}}\varepsilon_{\mathrm{d}}}\right)^{3/2}\frac{\varepsilon_{\mathrm{mr}}^2}{\varepsilon_{\mathrm{mi}}} \qquad (5)$$

Where ε_{mr} is the real metal permittivity and ε_d is the metal imaginary permittivity.

Optical response of any matter depends on its optical properties. Optical responses such as reflection, transmission, and dispersion varies from material to another. One of the most important optical properties is the refractive index of the matter. This property is the main response for SPP phenomenon on metasurface. Refractive index depends on atoms polarization of material or surface[57]. Electric permittivity ε and refractive index n are two main properties which affects phase velocity of molecules and control reflection, refraction and absorption. Refractive index can be expressed as complex function where n=n'+ik, where n' is the real value of refractive index which controls phase velocity. The imaginary part of refractive index is k. It affects wave attenuation inside the matter. Material absorption is controlled by permittivity complex function.

Different models are introduced to illustrate the atomic reaction of the materials and their oscillations due to interaction with incident light. Two different models described these interactions Drude and Drude-lorentz model as in[58,59]. These models described that electrons and nuclei of metallic atoms on the surface acts as harmonic oscillators due their interaction with electromagnetic waves. Energy bands of metals controls the complex optical properties. Incident photons interacts with metallic electrons leads to their excitation to higher levels and momentum. This makes electrons to be quasi-free electrons on the metallic layer[57]. Due to Drude model, the permittivity can be deduced as:

$$\varepsilon^{(D)}(\omega) = 1 - \frac{\omega_p^2}{\omega^2 + i\gamma\omega} \qquad (6)$$

where γ is the damping constant and ω_p is the plasma frequency of material, which defines the resonance oscillation frequency of the matter. The plasma frequency equation is determined by (7). Plasma Frequency differs from material to another, so different studies introduced the frequency of many materials such as gold (Au)[60], silver (Ag)[61] and aluminum (Al)[62]. This information is very important for SPP phenomenon which is an example for the electronic oscillations between metal and dielectric interfaces. according to past studies table(1.1) shows the plasma frequency for different materials

$$\omega_p = \sqrt{\frac{Ne^2}{m\varepsilon_0}} \qquad (7)$$

Where N is the electron density, e is the electron charge, m is the mass and ε_0 is the permittivity of free space.

	Ag	Au	Al
ω_p	$1.37\text{x}10^{16}$ Hz	$1.3\text{x}10^{16}$ Hz	$2.32\text{x}10^{16}$ Hz

Drude model could be applicable on many metals such as aluminum and gold. Due to[63], it cannot be applied accurately in many metals and it is valid for limited wavelength ranges. Lorentz description for different electronic response in many materials could fill the gaps in drude model especially for bound electronic components. As extension for drude model, Drude-lorentz model could express the metallic dielectric constants as approximation for different optical constants. The electric permittivity by drude-lorentz approximation can be expressed by:

$$\varepsilon^{(L)}(\omega) = \sum_{j=1}^{k} \frac{f_i\,\omega_p^2}{\left(\omega_j^2 - \omega^2\right) + i\omega\gamma_j} \qquad (8)$$

Silver dielectric function of electric permittivity in [64] was expressed by:

$$\varepsilon^{(D-L)} = 1 - \frac{f_0\omega_p^2}{\omega^2 + i\omega\gamma_0} + \sum_{j=1}^{k} \frac{f_i\,\omega_p^2}{\left(\omega_j^2 - \omega^2\right) + i\omega\gamma_j} \qquad (9)$$

In Fig. 6, a comparison between silver data of drude and lorentz models in limited range of wavelengths.

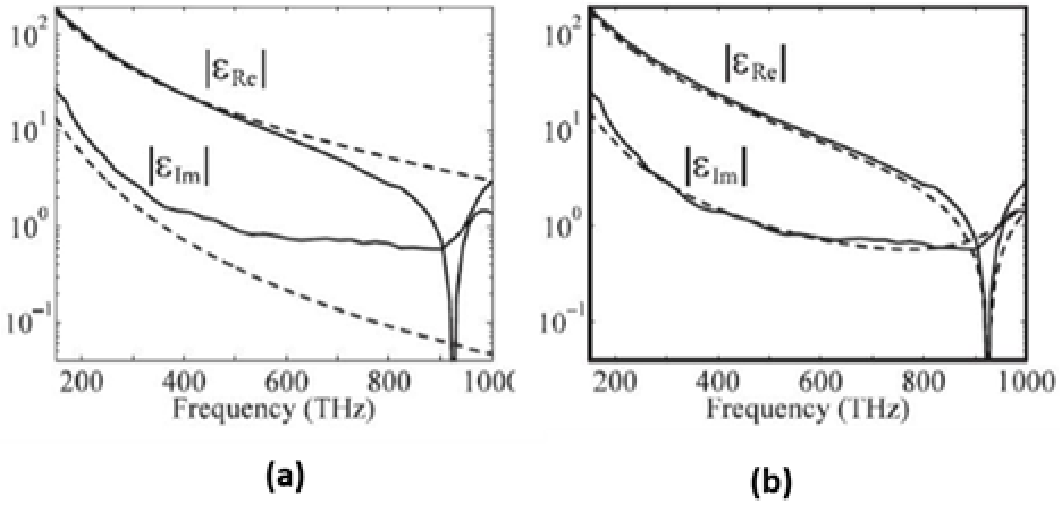


Fig. 6.: a) Drude model b) Lorentz model

3. Applications of metasurface depending on surface plasmonpolaritons phenomenon

Due to the great effect of metasurface in controlling wavefronts of incident waves. They have promising applications in many aspects. They can control amplitude and phase of reflected and absorbed incident waves by many methods and for many photonic applications. Fig.7 shows some different applications for metasurface.

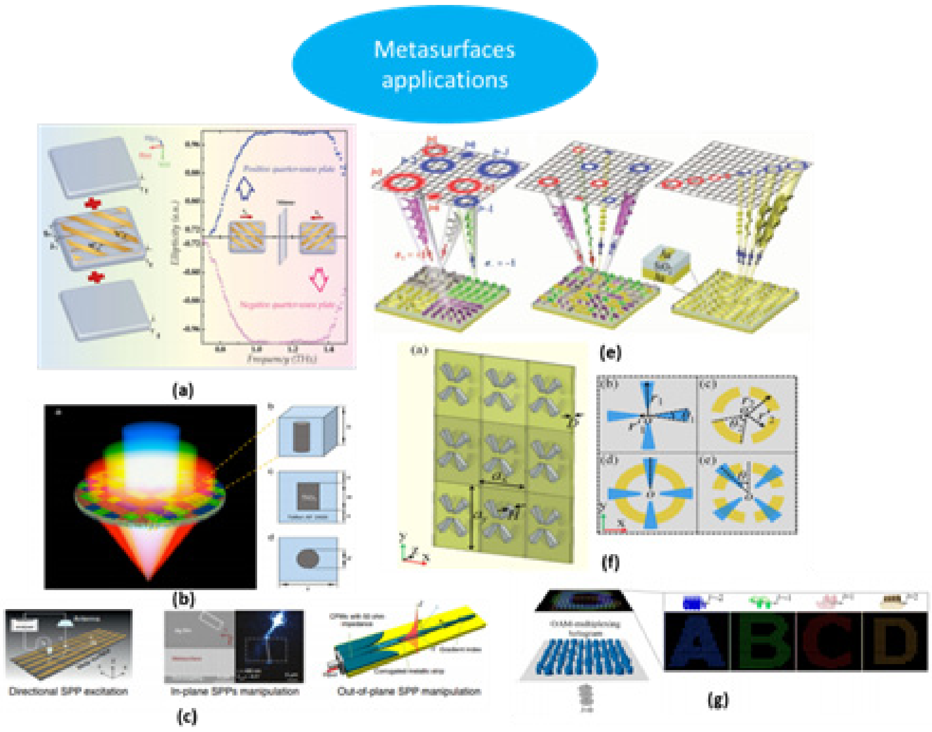


Fig. 7: Metasurface applications

Fig.7(a) presents a three-layers metasurface polarizer or wave plate in[65]. This wave plate can change polarization by angle 45 degrees.

One of the metasurface applications is the metalens. This lens can provide abrupt change in wavephase with in subwavelength scales. The abrupt change of incident wave phase was discussed by generalized Snell's law. Many metaplasmonic lens were studied before. Fig.7(b) shows metalens which collect all waves in a single point by (TiO2) surrounded by teflon substrate. This idea was discussed by Jun Yuan and his group in[66]. Light beam can be focused and twisted by optical vortices where it was discussed in[67] briefly with its physics and applications.

In[68], optical waveguides are introduced as in Fig.7(c). Another applications can be designed as optical vortices as Fig.7(e), (f) and in vortex beam generators[69] and[70]. Optical holograms as Fig.7 (g), planar lenses[71,72], axicons[73,74], beam splitters[75], polarization measurement devices[76], invisibility cloak[77], optical rotation[78] and spectrum splitters[79]. So many studies of metasurface can have many applications, some applications will be presented with its physics in this study.

3.1. Metasurface in polarization and phase control

Phase changes for incident light are produced on the metasurface layers over subwavelength scale. Different studies were performed for phase change. These structures are called nanoantennas.

Linear phase gradient distribution was introduced by capasso in[80], where each nanoantennaworks as unit cell to control phase from [0 to 2π] range. This control is derived as generalization of reflection and refraction laws by fermat's principle. Fig.8 (b) shows V-shaped nanoantennaswhich is designed for phase controlling of incident wave. Fig.8 (a) shows the response of electric field according to different incident wavelengths of light. V-gold antennas which generate interaction of linearly polarized light with V-shaped atoms support two plasmonic modes with different properties as in[81].

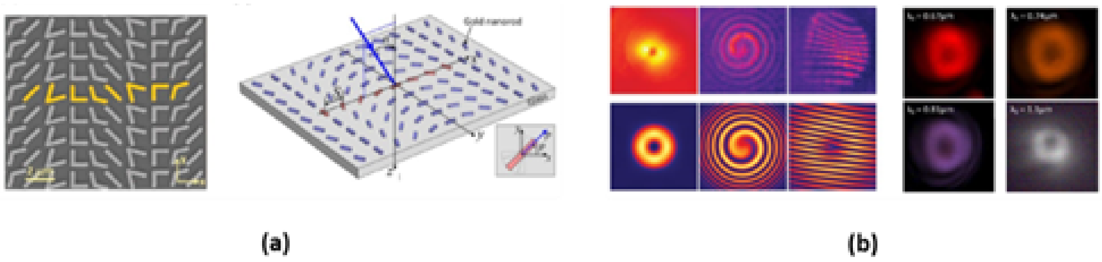


Fig. 8: a)V-shaped nanoantenna b) Different Plasmonic modes

In Fig.8(b), Hang *et al* introduced nano antenna works on Pancharatnam-Berry phase change[82,83]. Phase change generated by converting right hand circular polarization (RHCP) to left hand circular polarization (LHCP). It also shows experimentally based configuration of vortex beam. Metasurface has great importance due to broadband performance, easy in fabrication, ultrathin structure and many other characteristics. Polarization control by metasurfaces was presented in many studies as in[84]. In this study, different polarizers were introduced. Two different polarizers were presented. The first on is shown in Fig. 9(a), it shows quartz substrate in which gold is etched with its setup in spectrometer. This shape can control wave polarization according to its dimensions. In Fig.9(b), metasurface is introduced to the presented schematic of spectrometer. This structure has periodicity 500nm.

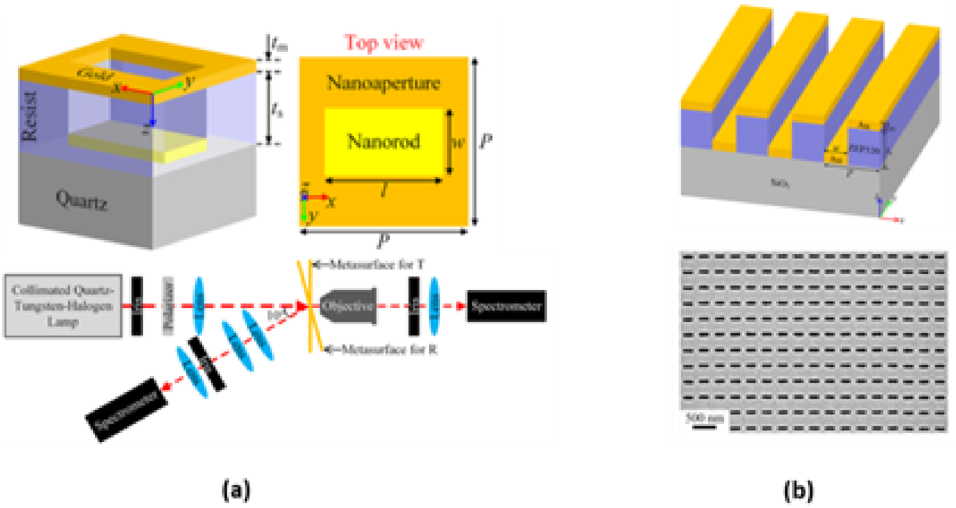


Fig. 9: a) Etched gold inside quartz substrate and spectrometer schematic b) another polarizer with periodic setup

3.2. Optical waveguides

Due to the electronic oscillations and their concentration in a definite boundary (hot spots), the Plasmonic effect can be used in many applications. One of these applications is the plasmonic optical waveguides as in[85], where nanosilver particles were used to determine the electromagnetic energy transfer. Another optical waveguide was introduced in[86] to show the ultra-smooth metals in plasmonic effect. In[87] the diffraction limit of the plasmonic effect was referred to detect the electromagnetic waves below this limit. The control of light propagation was controlled and confined in[88] (by metallic nanowires),[89,90]. The name of waveguides was changed as channels of electromagnetic waves added to resonators and interferometers which were discussed in[91,92] (V-shaped grooves) and[93]. The optical waveguides are in continuous progress. They can be used as a small unit of a big system. In[94], it was used as guides to continue the wave propagation inside a designed nanomultiplexer based on wave interference. Another approach was in logical circuits as in[39]. Dynamic switching for the plasmonic resonance can be controlled by many methods as Electricity or Graphene as in[38]. Various plasmonic structures having extreme confinement such as metallic nanoparticles[95] and wedges[96]. The plasmonic waveguide structures depend on its periodicity. This happens by applying periodic boundary conditions in different simulations. Periodic structures were repeated to control signal propagation and continue the wave guiding as in[97]. Nowadays, all optical waveguides work are added to larger systems of communications and optics. In (10), SPPs dependent optical waveguide length is calculated by:

$$L_p = \frac{1}{2\mathrm{Im}\,\{\beta\}} \tag{10}$$

Where L_p is the length of the SPP gap which gives the maximum electric field. This length is calculated in and Gap SPP. β is given by (11):

$$\beta = n_{eff} k_0 \tag{11}$$

Where k_0 is the incident wave number and can be calculated by (12):

$$k_0 = \frac{2\pi}{\lambda_0} \tag{12}$$

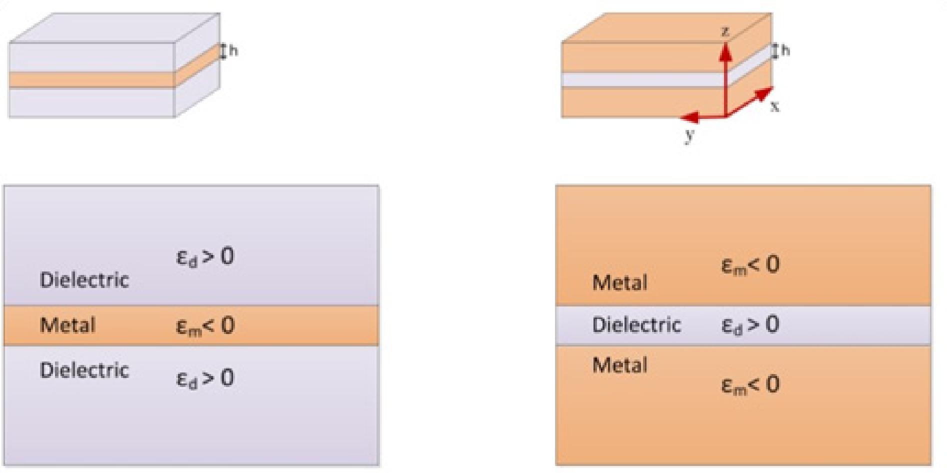
$$k_{G-SP} \approx k_0 \sqrt{\epsilon_d + 0.5\left(\frac{k^0_{G-SP}}{k_0}\right)^2 + \sqrt{\left(\frac{k^0_{G-SP}}{k_0}\right)^2 \left(\epsilon_d - \epsilon_m + 0.25\left(\frac{k^0_{G-SP}}{k_0}\right)^2\right)}} \tag{13}$$

Where k $^{0}_{(G\text{-}SP)}$ is calculated by (14):

$$k_{G-SP}^{0} = -\frac{2\epsilon_d}{h\epsilon_m} \qquad (14)$$

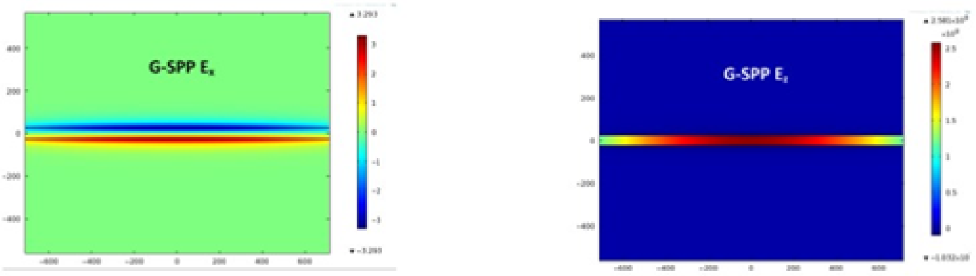
Optical waveguides can be an example for metal/dielectric interface, where we can have either a thin metal layer sandwiched between two layers of dielectrics or a thin dielectric layer surrounded by metals. These structures are shown in[97]. In Fig.10, part(a) shows metal sandwiched between two dielectrics and part(b) is the vice versa, the metallic height is labeled by dimension (h). These designs shows the Gap SPPs phenomena in the sandwiched layer.

According to the discussed equations, varying parameters in addition to Fig.4, the different electric field distributions were found as in fig.11.



(a) (b)

Fig. 10: a) Dielectric/metal/dielectric b) Metal/dielectric/metal



(a) (b)

Fig. 11: a) Ex b) Ez both at h=50nm

Where in fig.11 we can see maximum electric field inside the gap. Electric field in Z-direction (b) and less value in X-direction as in (a). The SPPs phenomena showed high electric field values inside the (Au) gaps so many other optical waveguides were published giving huge impact and effect in many applications. In[98], a plasmonic filter by teflon and silver interaction used as optical waveguides as in Fig.12.

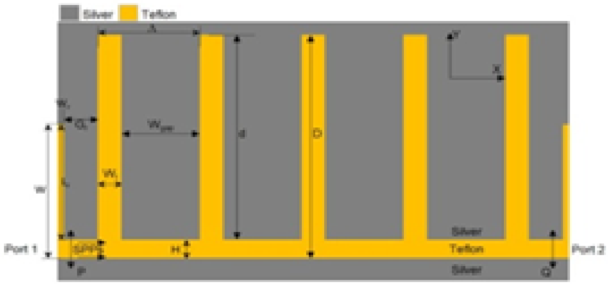


Fig. 12: Proposed Optical waveguide

The electric field distributions can be varied according to varying the proposed dimensions.

Many other forms of optical waveguides were published and measured. Some of these waveguides in different studies will be presented as shown in Fig.13.

In Fig.13(a), optical plasmonic waveguide is presented in[99]. It guides the optical wave and also change in effective refractive index by varying the waveguide dimensions. In Fig.13(b), another optical waveguide is presented in[100]. A low loss optical waveguide with metallic cap is presented and also the variation between effective refractive index with dimension change is presented. In Fig.13(c), another slot plasmonic waveguide in[101]. The refractive index variation with optical height at different widths is presented. The last presented optical waveguide is in Fig.13(d). This waveguide is layered by graphene layer which is used for optimization of optical resonance. This was presented in[102]. Many plasmonic waveguides depends on SPPs phenomenon and can be used in many applications.

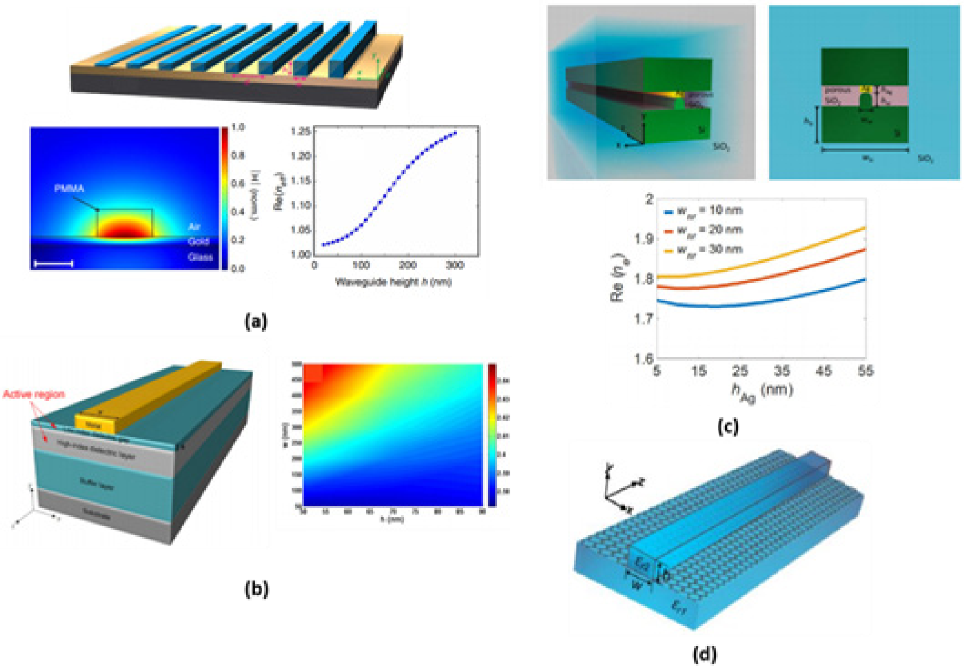


Fig. 13: Proposed Optical waveguide

3. Surface Enhanced Raman spectroscopy

Another application for the SPPs is the SERS. Raman spectroscopy is a method for molecular or atomic detection. Every atom have its own spectrum but some of these atoms are very small for the detection. Using plasmonic metamaterial to concentrate the electric field on the detected atom helps in enhancement the atomic fingerprint. Many SERS plasmonic studies were published with different experimental measurements and for different fingerprints. This point of view was recognized for the first time by Fleischmann and colleagues in 1974 by adding pyridine on silver Raman scattering measurements they thought that this enhancement due to surface area effect[103]. JeanMarie and Creighton in[104,105] identified the phenomenon also in 1977 with larger Enhancement factors. Philpot proposed the resonant Raman effect with plasmonic excitation in[106]. Localized surface plasmons in nanostructured metals was found by Mikovits who connected the SPPs to SERS. After 45 years a lot of researchers published on SERS and they discussed great details behind its theory where the design has huge change for substrates enhancement and they have discussed wide applications. SERS has become one of the most popular detecting techniques with large number of articles and papers published with large number of applications. In 2018 during 26th International conference on Raman Spectroscopy at Korea, a description to the nowadays state of the field and the path that we expect in the future was in this conference where the discussed active areas in this field with basic aspects for materials and applications and the development that is needed in this field in addition to the enhancing techniques were discussed. They discussed optimization methods and materials and their development concepts. This conference has a lot of sections in the field helping any researcher who was interested in this field of science to develop their thoughts and merge different branches with this field. This field has many applications and directions as in[107]. More explanation for Raman scattering that it is inelastic Scattering process between a photon and a molecule. SERS are very efficient method for increasing the Raman peaks intensities. The Raman detection can give very small peaks for different materials. Much work was made to enhance Raman sensing by increasing its signal strength and sensitivity. Three mechanisms can be used to enhance Raman scattering; first one is the Electromagnetic Enhancement which uses plasmonic resonance phenomenon (this method was used in this work). It leads to Enhancement factors (EFs) in the order of (10^{12}). The second one is the Chemical Enhancement in which we bind the Raman molecules to substrate, this leads to increase the Raman sensing. Chemical Enhancement leads to EFs in the order of (10^{2}). Finally the Geometrical Enhancement in which the geometry of the structure is modified to give the best shape for concentrating the plasmonic resonance. This modification can be performed by precising the scale of the plasmonic hotspots where the Plasmonic resonance can be formed and electric field can be concentrated. But in the geometrical enhancement method, there is complexity in fabrication process. Chemical enhancement method has major importance which is low cost compared with the electromagnetic enhancement while it has many drawbacks as it has low EF which tends to (10^{2}). While the electromagnetic enhancement method has larger EFs. Other drawback is that the chemical enhancement has nonhomogenous shapes or hotspots while the Electromagnetic is more homogenous so it is used widely with the surface plasmon resonance enhancement which enhance the molecules' finger prints. Molecules are organized as patterned metal layers such as gold (Au) and silver (Ag) nanoparticles (NPs). The discovery of SERS by surface plasmonic resonance was over 40 years ago. SERS with thin film dried nanograting needs less time in preparations and lasts for longer time with larger enhancement factors. Also it has a great advantage of mass production also the nanograting support better plasmonic resonance. Traditional SERS substrates were fabricated onto glass in[108], Ag in[109], paper in[110], Au in[111], silicon in[5]. Another type was through deposition of nanoparticles as in[112]. Au or Ag are used in plasmonic resonance with high efficiency and best optical properties in visible/near-infrared band as in[113]. Au, Ag and silicon has disadvantage of high cost to the chemical enhancement but better intensity in plasmonic resonance. They are better than glass in their efficiency where the glass shows overlapping between fluorescence and Raman shift but with lower cost. Copper and Aluminum foil are too flexible; this leads to nonhomogeneous metasurface layers as in[114,115]. Paper has lower intensity and stability problems but an advantage of low cost and reproducibility as in[116]. The recent progress in the SERS technology is adding Ag or Au with different substrate materials as glass in[116] which is used to enhance their Raman intensity but the most used grating is the Au nano gratings. SERS depends on SPPs phenomenon and the plasmonic wave number depend on (15):

$$K_{SSPS} = \frac{\omega}{c}\sqrt{(\varepsilon 1 * \varepsilon 2)/(\varepsilon 1 + \varepsilon 2)} \tag{15}$$

Where (K_{SSPs}) is the wave number of the SPP, ε1 and ε2 referred permittivity of metal and dielectric respectively.

The SPPs depend on the incident ray frequency, If the incident frequency is greater than the plasma frequency of the surface it leads to SPP. The plasma frequency can be determined by (16):

$$\omega_{SSPs} = \frac{\omega_p}{\sqrt{(1+\varepsilon d)}} \tag{16}$$

Where ω_p is the plasma frequency and εd is the dielectric permittivity. Different enhancement results for the Raman intensity, according to dimensions and shapes which depends on[112], (17):

$$EF = \frac{|E_{max}|^4}{|E|^4} \tag{17}$$

Where E the value of the incident electric field is, E_{max} is the value of the localized enhanced electric field due to surface plasmons resonance and EF is the enhancement Raman factor.

We can see different explanations for Raman enhancing techniques and physics in[117,118,119,120,121].

In Fig.14, two different SERS plasmonic layers are presented. Fig.14 (a) shows conical pyramid plasmonic layer were SERS samples are fixed above them. This structure is presented in[122], In Fig.14 (b) another plasmonic layer with EF tended to (10^{4}). This structure is presented in[123]. Some obstacles are found during sample fixing in SERS experimental measurements especially in sample fixing techniques. This problem was solved in[124], where sample fixing can happen by adding different adhesive materials between nanogold and different samples. Some bioreceptors can be added in biomedical samples. Another methods can be presented in different applications. SERS has huge impact in many applications especially in material detection, food pollution and many chemical applications.

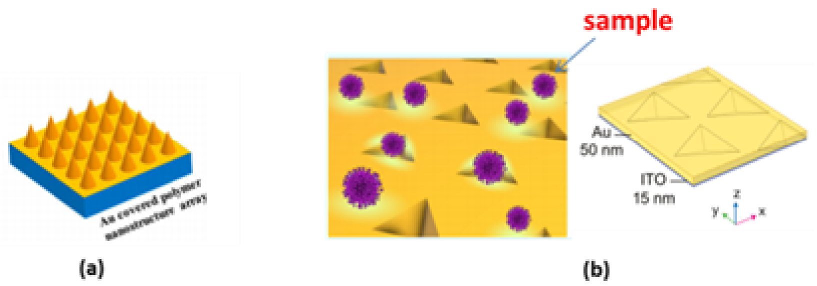


Fig. 14: Proposed Optical waveguide

In[112], an etched gold grating was simulated as rectangular and sinusoidal gratings. A comparison between sinusoidal and rectangular grating were performed. The sinusoidal grating gave the better EFs and the different figures for these gratings is be shown in fig.15 and fig.16.

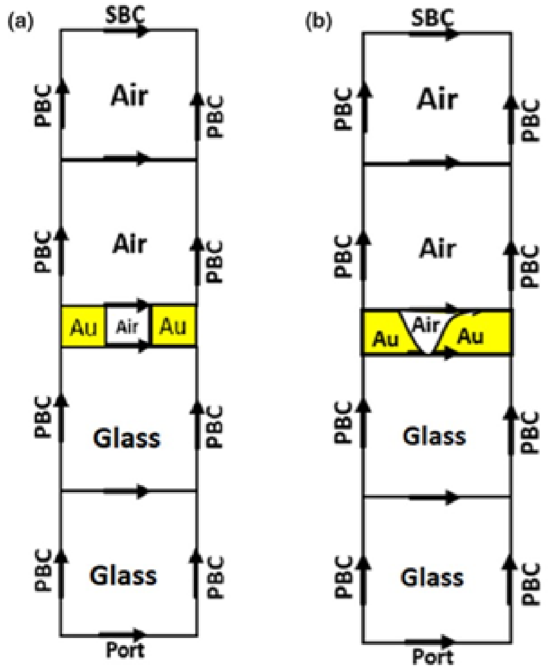


Fig. 15: a) Rectangular grating b) Sinusoidal grating

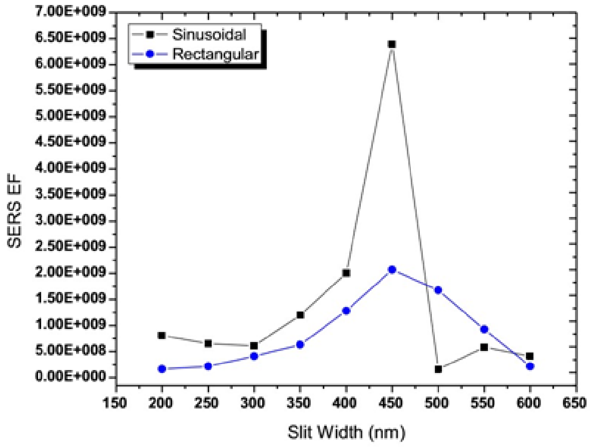


Fig. 16: Enhancement Factor comparison between rectangular and sinusoidal gratings

4. Conclusion

In this review, brief review on metasurface and SPPs phenomenon is presented. This review shows history of metasurface and SPPs phenomenon. It shows the connection between them with their physics and different applications are presented. Some applications are presented as SERS and optical waveguides with their theory and different shapes.

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