International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 08 Issue: 01 | January - 2024 SJIF Rating: 8.176 ISSN: 2582-3930

A Review on Plasmonics : A New Era in the Field of Nanotechnology

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Abstract: Plasmonics has set up a new stage in the field of nanoscience and nanotechnology because of its exclusive features especially high speed data transmission with miniaturized dimensions. Plasmonics take the advantage of the exclusive optical characteristics of metallurgic ultra small structures to facilitate the guiding and controlling of light at the smaller confined areas. This extraordinary capacity provides an apparent probability of advancement for the designing of extremely unified photonic systems for processing of signals, visual imaging approaches for nanoresolution and sensors. The main purpose of this article is to revise the term plasmonics and present an outline for plasmonics with its major contributing areas.

INTRODUCTION

The necessity of forwarding huge amount of data over communication networks in small intervals of time has raised the demand for such a technology that can fulfill these requirements. The execution of photonic components with electronic appliances has encountered many difficulties because of the bulky size of photonic constituents and the low speed data transmission of electronics. A strong trend towards nanoscience and nanotechnology is encountered which is resulted from the benefits of smaller dimensions and assimilation of electronic circuits available in the computer industries. Plasmonics is considered to exhibit the reliable points of the two optical and electronic data transportation permitting the speedy transfer of messages over the nanowires. Sporadically plasmonics is also termed as "light on a wire", because it permits the transportation of information at optical frequencies ahead the surface of a small metallic conducting cable, inspite of the fact that the message transmits in the shape of electronic density distributions instead of transmitting in the form of photons. The field of plasmonics has emerged, with the target of producing a sub wavelength photonic framework for the guiding and confinement of electromagnetic energy in application areas such as photonics, optoelectronics, imaging and biological sensing. The choice of materials for SPP based waveguides and plasmonics has been centralized on the noble metals like gold (Au) and silver (Ag), due to the comfort of assembling nanostructures and the optical properties of these metals at near infrared regions and visible frequencies. The constantly increasing enthusiasm and wideness of research in the field of plasmonics has opened up the opportunities for the demonstration of complex active photonic functions based on the plasmonic devices.

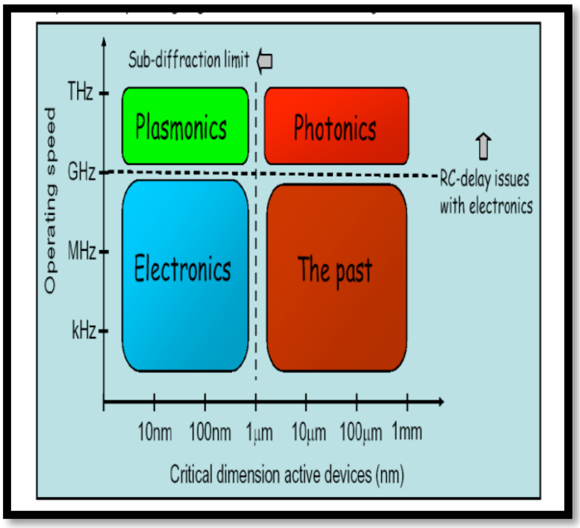

Figure 1. Executing regimes of different technologies

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Historical Background of Plasmonics

The exclusive optical features of metallic nanostructures were adopted by artisans to bring out lively colours in glass antique objects and in the church window glasses. The renowned example is the cup belonging to 4th century AD (now at the British Museum, London) known as the Lycurgus cup. The metallurgic nanoparticles were enclosed in the glass materials that produced distinct colours.

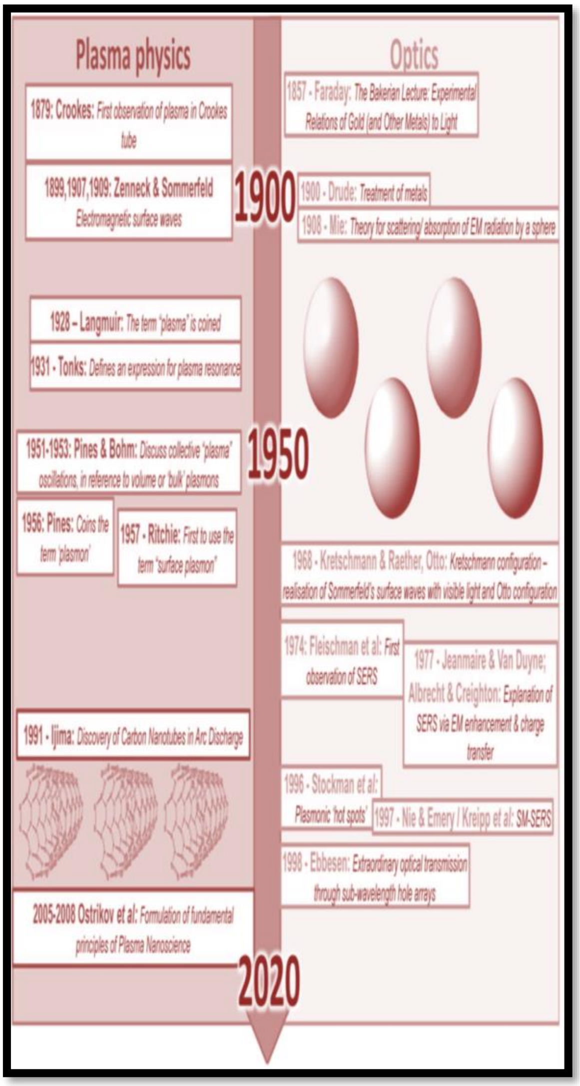

Figure 2. Historical timeline along with pertinent landmarks in the field of optics and plasma physics

The above figure shows the research increment and developments in the field of optics and its related fields during the past few years. "Rufus Ritchie" was the first person to coin the term "surface plasmon" in 1957. In 1857, Faraday performed the experiments in order to set up the relation of noble metals especially (gold and silver) with light. The base for the analysis of light scattering by metals was cleared up at the end of the first decade with influential works in conjunction with Drude's treatment of metals in 1900 and concepts for scattering and absorption of electromagnetic radiation by a sphere in 1908 popularly known as Mie's theory.

Figure 3. Lycurgus cup

The Lycurgus cup shown in the above figure appears red at the regions at which light is transferred through the glass and appears greenish at the areas where light is dispersed near the surface.

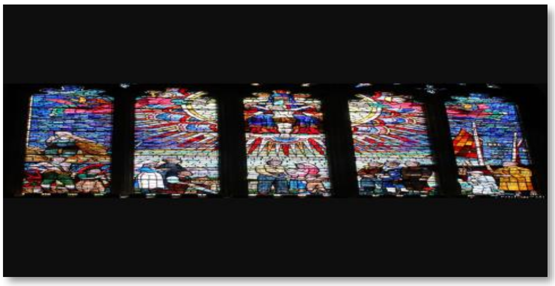

Figure 4. Church window glasses

Overview of Plasmonics

The science of plasmonics deals with the origination, manipulation and disclosure of surface plasmon polaritons (SPPs). Surface plasmon polariton (SPP) is defined as the quasi-particle that is generated due to coupling of light with the surface Plasmon (SP). Surface plasmons (SP) are defined as the fluctuating electron currents generated at the metal surfaces.

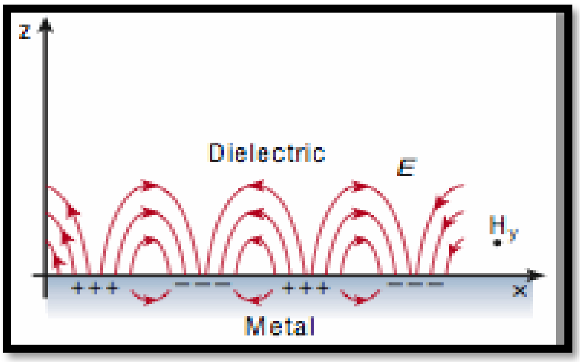

Figure 5. SPP propagating along the metal-dielectric interface

Figure 6. Noble metals used as plasmonic materials

Noble metals like gold and silver are used as the plasmonic materials because of their higher conductivity and ability to guide the light at the nanoscale regions.

Limitations of Surface Plasmon Polaritons

The heavy ohmic losses in metals leads to larger propagation losses which further reduces the propagation length of a surface wave travelling at the common boundary of conductor and insulator and the wave dissipates very shortly at the common boundary . In order to neglect these problems, hybrid wave guiding schemes have been proposed that offers tight light confinement with lower propagation loss and larger propagation length.

The imperfections of Surface plasmon polaritons (SPPs) are overcomed by designing and introducing an advanced kind of the plasmonic waveguide commonly known as " Hybrid Plasmonic Waveguide" (HPW) that has the potentiality of guiding light into smaller volumes with tight mode confinement, larger propagation length and lower losses. Hybrid plasmonic waveguide is designed by the combination of dielectric waveguide with the plasmonic waveguide. This waveguide is based upon the principle of mode coupling thereby enabling the tight light confinement with lower propagation losses.

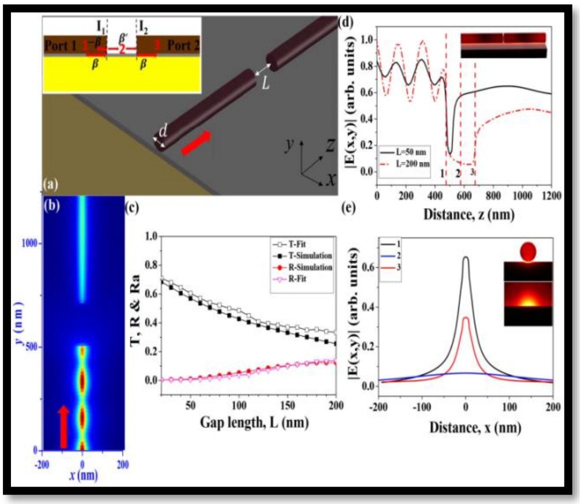

Figure 7. Schematic diagram of two nanowires based on hybrid plasmonic waveguide (HPW)

Major Application Areas of Plasmonics

Plasmonics possess a wide variety of applications in the present scenario. Some of these applications are summarized below:

(1) Plasmonic Solar Cell

A plasmonic solar cell is a kind of narrow coating solar cell that changes light into electricity with the cooperation of plasmons. The plasmonic solar cell uses the substrates that are reasonable as compared to silicon, such as glass, plastic or steel. One of the drawbacks of narrow coating solar cells is that they do not consume much light as absorbed by the thicker solar cells that are built up of materials with the identical absorption coefficient. Plasmonic solar cells enhance the absorption by scattering light with the help of metal nano-particles stimulated at their surface plasmon resonance. The approaching light at the plasmon resonance frequency causes the electronic oscillations at the surface of nanoparticles. The fluctuating electrons can then be occupied with the help of a conductive layer generating an electric current. The generated voltage is reliant on the band gap of the conduction film and the capability of the electrolyte in connection with the nanoparticles. An appreciable amount of research is still essential for allowing the technology to gain complete achievement and marketing of plasmonic enlarged solar cells. The designing of the plasmonic solar cell differs depending upon the approach being used to snare and scatter light across the surface and through the material.

Nanoparticle Cells: An ordinary design is to deposit metal nano-particles on the highest surface of the narrow layer solar cell.

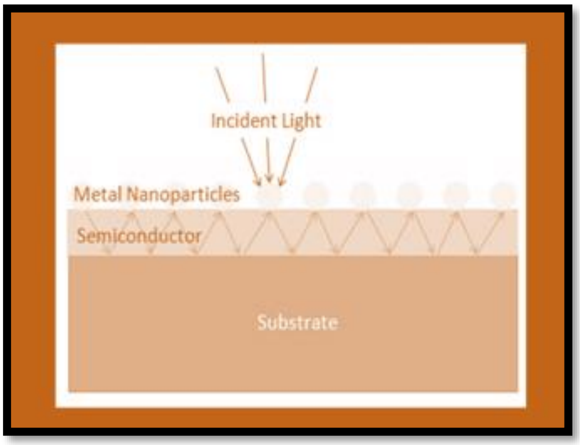

Figure 8. Schematic of the Plasmonic Solar Cell

When light strikes these metal nano-particles at their surface plasmon resonance, it is dispersed in various directions. This permits the light to travel along the solar cell and rebound in the middle of the substrate and the nano-particles allowing the solar cells to absorb more light.

Applications of Plasmonic Solar Cells

There is a greater amount of necessity for cost effective and more effective solar cells. The activities towards a greener world have aided to sparkle the research in the field of plasmonic solar cells. Presently, the solar cells can't surpass efficiencies of about 30% but with the advancements in the existing technologies, the prices can be further reduced.

Solar cells have an enormous capability to help in the rural electrification. According to a survey, almost two million villages nearby the equator regions have restricted approach towards electricity and fossil fuels. About 25% people in this world do not have access to electricity. Solar cells can also be used to generate power for light houses and even for warships gone out in the oceans.

(2) Plasmonic Waveguides

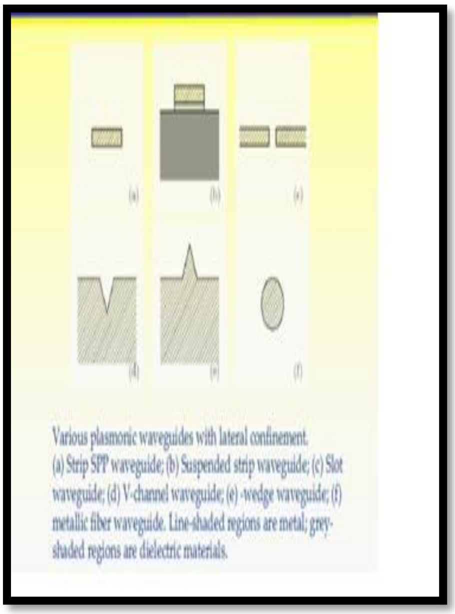

Figure 9. Different structures of SPP based waveguides

Various types of the plasmonic wave guiding structures can be designed by using the SPP.

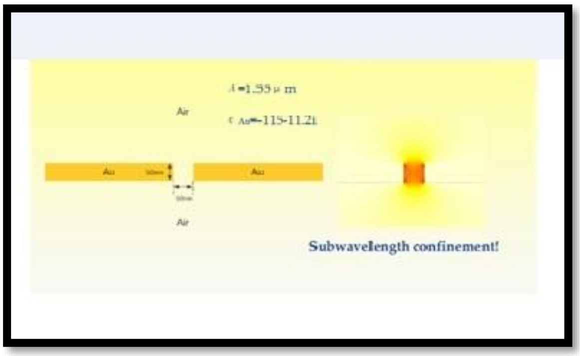

Figure 10. Plasmonic gap waveguide suffering from considerable amount of losses

(3) Plasmonic Biosensor

The field of plasmonic biosensors has been remained creative and carries on to produce nice outlook for future robust sensing platforms. The exclusive optical feature of plasmon resonant nanostructures allows analysis of nanoscale surroundings using easy optical characterization techniques. Biosensors based on propagating surface plasmon resonances (SPRs) in films are the most renowned plasmonic biosensors but there is a great capability in the upcoming technologies to exceed the reputation formed by film based SPR sensing. Propagating plasmonic sensors are those that depend upon the surface plasmons sustained by narrow metal films. The most commonly used metal film is gold as it generates SPRs that can be investigated by using visible wavelengths of light.

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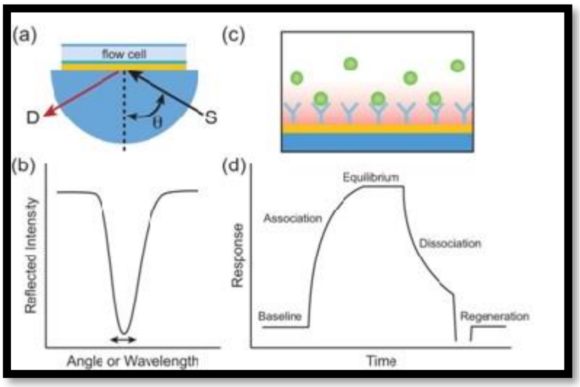

Figure 11. Excitation of surface plasmon resonance (SPR) in narrow gold film by using the Kretschmann configuration

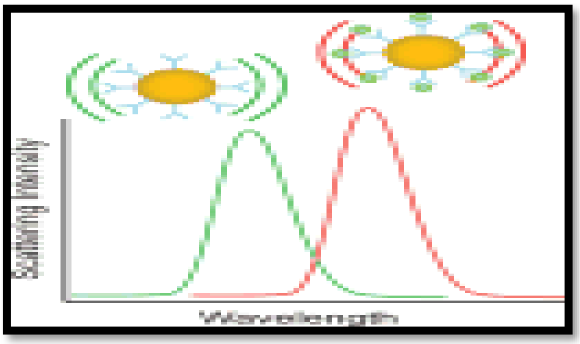

Figure 12. Generation of localized surface plasmon resonance (SPRs) from the plasmon resonant nanoparticles

The above figure depicts that a plasmon resonant nanoparticle functioning with the recipient molecules shows a red shift in the spectrum of scattering of its LSPR when it binds the target analyte

The relevant classification of plasmonic sensing is the utilization of localized surface plasmon resonances (LSPRs). LSPR based sensing is beneficial for analysis of the biological specimens because the detection schemes can be tuned to use wavelengths that do not coincide with the spectral properties of naturally appearing biological chromophores, such as hemoglobin in the blood samples for bettering the sensitivity in order to target the analytes.

(4) Plasmonic nanolaser

Nanolasers based on plasmonics are favorable for extremely small scale coherent sources of optical areas because they hold up extremely small sizes and show ultrafast dynamics. Plasmonic nano lasers are broadly used in the field of nano- optics and biology and have taken the experimentation applications to lower thresholds, higher rates of motion and smaller sizes. Coherent luminous sources with dimensions beneath that of the diffraction limit are propitious for unification of shortened photonic and electronic components as well as for augmenting the speed of optical communication.

Plasmonic nanolasers can support exceptional nanocavity architectonics leading to the magnification of electromagnetic (EM) fields which are especially confined at the extremely smaller scales and depicts speedy emissions. Nanolasers based on plasmonics also provide the facility to strengthen the weakened physical and chemical light-matter interrelation on the relatively smaller scales.

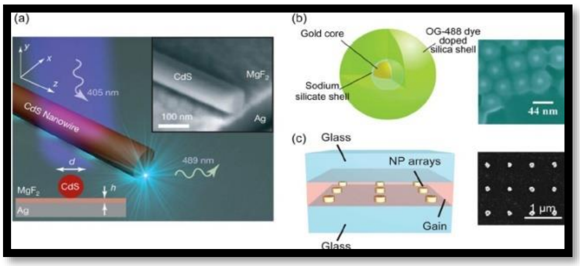

Figure 13. Schematic Design of Plasmonic nanolaser

The above figure (13) depicts the plasmonic nanolaser architecture where the semiconductor nanowire is inserted on a metallic film which is separated by an insulating medium. The metal

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(Au) crux is covered by the dye-doped silica shell and the gold nanoparticles are enclosed by dye molecules. Plasmonic nanolasers contains noble metallic ultra small structures that holds surface plasmon modes as the optical response and gain materials that have spectral radiation and spatial location imbricate with the surface plasmonic modes. This type of layout is influential because the gain can be compensated for inherent losses in the metallic ultra small cavities and the electromagnetic fields of the metallic nanostructures can improve both spontaneous and stimulated emission of the surrounding gain.

Latest Progress in Nanolasers based on plasmonics

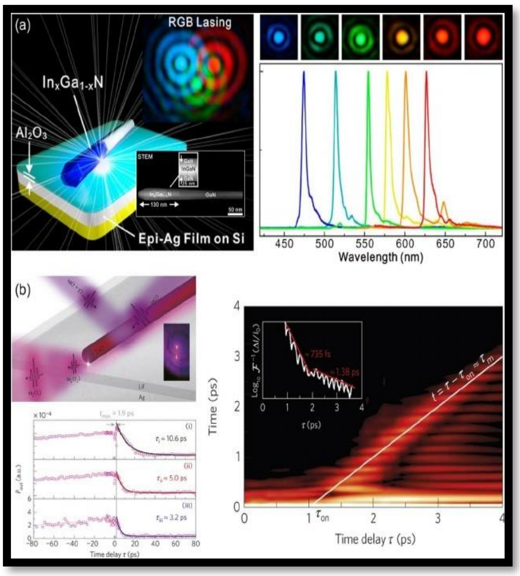

Figure 14. The figure depicts the recent progress in the field of plasmonics based nanolasers (a) Plasmonics based nanolaser with all colors (b) High speed plasmonic nanowire laser.

(5) Surface plasmon based fluorescence spectroscopy

Fluorescence spectroscopy based on the surface plasmons utilizes the highly enhanced EM field of the surface plasmonic mode for the excitation of surface bounded fluorophores. The capability to observe the interfacial refractive indices at the same time varies and the fluorescence signals provide a high platform for applications of surface plasmon fluorescence spectroscopy in surface immuno reaction detection.

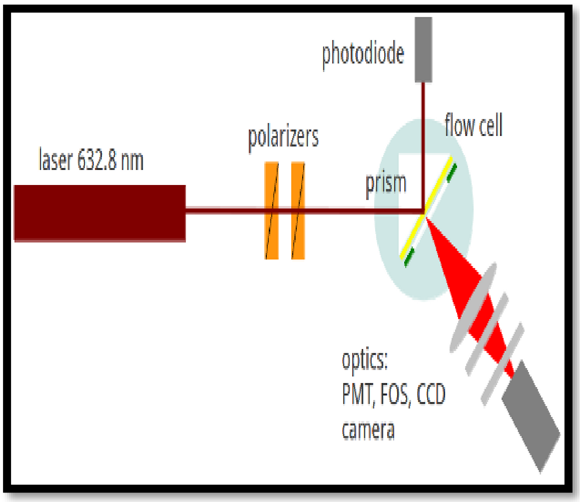

Fig. 15. Schematic design of surface plasmon based fluorescence spectroscopy

Recent advancement in Plasmonics

- In the past few years the field of plasmonics has shown its growth by leaps and bounds. Plasmonics has proven to be advantageous in the field of nanotechnology.
- Plasmonics has been applied in the biomedical area for the cancer therapy treatment, detection of brain tumours, HIV, anaemia.
- In the field of wireless technology, transmission lines are being made by using the technology of plasmonics for secured and distortion free communication.

- Biosensor based on surface plasmon resonance for alcohol detection, plasmonic based optoelectronic devices, plasmonic waveguide and nanoantennas.
- Removal of environmental pollutants by using plasmonic based nanomaterials
- All these achievements have been made possible by the advancement of the plasmonic technology.

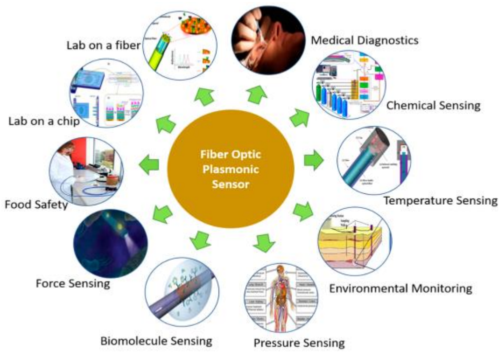

Fig.16. Fiber optic plasmonic sensor biological applications

Conclusion

Plasmonic nanostructures facilitate the confinement and controlling of light on the nanoscale by customizing the semiconductor optical properties. Plasmonics will drive us to a task of generating large speed communication systems, where we can transmit numerous streams of voice and enormous amount of data. Plasmonics is a tremendous blessing for nanotechnology. Moreover plasmonics is a bright field that has the capability to alter our society by enabling us to frame speedy, shorter and powerful devices. As long as people persists to observe the probabilities that plasmonics provide, the field of plasmonics will carry on to develop with latest inventions and findings right over the later corner.

References

[1] Wang, B. & Wang, G.P. Surface Plasmon polariton propagation in nanoscale metal gap waveguides. Opt.Lett.29, 1992-1994(2004).

[2] Maier, S.A & Atwater, H.A. plasmonics: Localization and guiding of electromagnetic energy in metal dielectric structures, J.Appl.Phys.98, 011101(2005)

[3] Barnes, W.L. Surface plasmon-polariton length scales: A route to sub-wavelength optics. J.Opt.A8, S87-S93 (2006)

[4] Volkov, V.S., Bozhevolnyi, S.I., Devaux, E.Laluet, J.Y & Ebbesen, T.W. Wavelength selective nanophotonic components utilizing channel plasmon polaritons. NanoLett.7, 880-884(2007)

[5] Pile, D.F.P., Gramotnev, D.K., Oulton, R.F. &Zhang, X. On long-range plasmonic modes in metallic gaps.Opt.Express 15, 13669-13674(2007)

[6] S.A. Maier, "Plasmon Waveguides", in plasmonics: Fundamentals and Applications (Springer, 2007), pp.107-129

[7] Rich RL, Myszka D, Curropin Biotechnical 2000; 11:54-61

[8] M.Z. Alam, J. Meier, J.S.Aitchison, and M.Mojahedi, "Super mode propagation in low index medium" ClEO – 2007 – JThD112, CLEO/QELS 2007

[9] Dmitri K.Gramotnev and Sergey I.Bozhevolnyi, Nature Photonics, Vol 4, February 2010

[10] L.Zhu, IEEE Photon.Tech.Lett.22 (8), 535-537(2010)

[11] Gwamuri, J; Giiney, D.O Pearce, J.M Tiwari, Boukherroub, John Wiley&Sons, Inc. pp.241-269(2010)

[12] Rashid Zia, Jon A.Schuller, Anu Chandran, and Mark L. Brongersma, Geballe Laboratory for Advanced Materials, Stanford, CA94305USA

[13] V.J Sorger, N.D.L-kimura, R.M .Ma, and X.Zhang, Nanophotonics 1(1), 17-22(2012)

[14] Muhammad Z.Alam, J.Stewart Aitchison, and Mo Mojahedi. Laser Photonics pev.8, No.3, 394-408(2014)

[15] Qing Zhao, Xiaoping Huang, En Lin, et al. Advances of plasmonic nanolasers opto-electronic engineering, 2016, 140-151