STUDY OF NANO OPTICS: PLASMONICS, PHOTONICS AND THE SIMULATION OF PHOTONICS USING DRUDE-LORENTZ MODELS

MS. JYOTI MALI[1],
[1]Research Scholar, Shri Jagdishprasad Jhabarmal Tibrewala University,
Jhunjhunu, Rajashtan, India

Abstract: This Paper summaries the different modeling and simulation of photonics and Plasmonics and Nanolasers. The paper includes modeling of photonics , using Durde-Lorentz models for gold and silver. Experimental data accordingly is used to interpolate the dielectric function and the index of refraction of bulk materials used in optics and photonics, on the tools available on nanohub.org These interpolations are possible only within a certain range of wavelengths taken from the initial experimental data sets. The research also includes the photonics crystal characteristics in an easy way by considering simple 2D photonic crystals which are composed of periodic dielectric structures in a two-dimensional world. These 2D are decomposed into two different categories: TE and TM. Maxwell's equations are thus eigenvalue equations solving for TE and TM modes.

Keywords: Nano Lasers, Plasmonics, Photonics, Nanohub, Nanotechnology.

I. INTRODUCTION

Nanostructures with metallic plasmonic in recent times have endorsed extensive research and involved into development of promising approaches for enhancing the performance of various opto-electronics devices. A variety of strategies of incorporating plasmonic metal nanostructures into different opto-electronics such as solar cell, light-emitting diode, multicolor photodectors, Nano LASER, etc are reviewed with its various research advancements , the benefits of using various plasmonic structures with its resulting enhancement mechanisms . Plasmonics covers the science and an application of noble metal structures which guide and easily manipulate visible light at a nanoscale length structures which are presently much smaller then the wavelength of light.

In order to keep up the trend according to Moore's law, the microelectronics industry requires miniaturization and large-scale integration to achieve advanced performances while continuing to reduce cost. However, as integrated circuits enter the nano-regime, quantum effects enter into the design picture. Meanwhile, photonic devices must also provide ultra-fast transmission rate as well as high information capacity. Among the various obstacles, the diffraction limitation is one of the most serious issues plaguing miniaturization of photonic systems. Only if the diffraction limitation is overcome and light sources on the sub wavelength scale are produced can the objective of fabricating tiny and ultra-fast photonic systems be fulfilled.

Hence, plasmonic are expected to be the key nanotechnology which will combine electronics and photonic components on the single chip. The properties of plasmonic which are sensitive to changes in the local dielectric environment are considered which are directly related to is size, spacing of the used metal nanostructure, shape, etc. There are various promising applications in chemical and biological sensing and imaging techniques, waveguides, superlenses, light harvesting, metamaterial, opto-electronics, and catalysis due to the intense local electromagnetic fields generated due to the excitation of surface Plasmon's. The integration of metal nanostructures into opto-electronics devices is believed to be the most promising approach to enhance the performance of device without increase in the size of it. To date, a surge of progress have been made towards plasmonic enhanced opto-electronic devices, such as solar cells, light-emitting diode, multicolor photodectors, Nano LASER, etc,.

Generally , Plasmonic system use two different types of surface plasmon resonances (SPR) inducing by the coupled electromagnetic radiation named as propagating Plasmon's and localized Surface Plasmon's. For the first type of Surface Plasmon polaritons (SPP), the plasmons propagate along the metal dielectric interface (in x- and y-directions), whereas the plasmon decay in z-direction evanescently. The localized surface plasmons resonances (LSPR) have higher intensities and spatial resolution as compared to the SPPs. In addition, LSPR offers a better tunability of the optical properties by altering the type of metal, size, shape, and the dielectric environment.

When light interacts with a particle which is much smaller than the wavelength, its conduction electrons can be displaced from their nuclei. Hence, opposite charges this act as a restoring force for the oscillating electrons will be build up on the particle's surface. Such oscillations are maximized when the frequency of light matches the inherent oscillating frequency of the nano particles. The position, Intensity, width of the LSPR band depends on the materials of the used nano particles, their size, shape, as well as on the characteristics of their local dielectric environment. In this regard, the design and fabrication of new plasmonic nanostructures would have deeply impact on the development of new approaches for plasmonic enhanced devices and on its efficiency.

Nanophotonic architectures have recently been proposed as a path to providing low latency, high bandwidth network-on-chips. These proposals have primarily been based on micro-ring resonator modulators which, while capable of operating at tremendous speed, are known to have both a high manufacturing induced variability and a high degree of temperature dependence. The most common solution to these two problems is to introduce small heaters to control the temperature of the ring directly, which can significantly reduce overall power efficiency. While plasmonic devices have several important advantages, a new hybrid photonic/plasmonic channel is proposed that can support WDM through the use of photonic micro-ring resonators as variation tolerant passive filters. Our aim is to exploit the best of both technologies: wave-guiding of photonics, and modulating using plasmonics. This channel provides moderate bandwidth with distance independent power consumption and a higher degree of temperature and process variation tolerance. We describe the state of plasmonics research, present architecturally useful models of many of the most important devices, explore new ways in which the limitations of the technology can most readily be minimized, and quantify the applicability of these novel hybrid schemes across a variety of interconnect strategies.

Of course, as with all technologies, there is a trade-off. The new hybrid photonic/plasmonic channel has a significantly higher insertion loss making it incompatible with scalable full crossbar designs. Furthermore, the new approach makes the trade-off between bandwidth (number of wavelengths on the channel) and temperature sensitivity explicit. This is an exciting time for the architecture community to engage the plasmonics community, as they are actively pushing the devices in many new directions, like using plasmonics to implement a photo-transistor that will eliminate the need for the TIA. Moreover, plasmonic nano-laser may lead to another way of direct modulation on-chip. Many papers have discussed new ways by which SPPs can be propagated over longer and longer distances.

Optical fibres provide the potential for increasingly high-speed and power-efficient communication. Surface plasmons, where light couples to propagating electron waves at the surface of a metal, can enable light to couple into waveguides with diameters that are significantly smaller than the infrared wavelength generally used in communications. Such systems have attracted considerable interest. In this issue, investigations into the manipulation of plasmon modes for waveguiding reveal new asymmetric modes that remain strongly confined over substantial propagation distances.

Metal–insulator–metal waveguides have demonstrated great potential as the basis of a number of plasmon-enabled photonic elements, such as sensors, routers, splitters and modulators. In this issue Lu et al at the Chinese Academy of Sciences report on a system that operates as a band-pass filter for multiple channels using a spectral feature, which they liken to electromagnetically induced transparency. The design overcomes the limitations of large size and geometrical complexity of other approaches to multiple band-pass filters.

Research into plasmonics has stimulated a host of novel developments in optoelectronic elements. This synopsis gives the introduction of the first all-optical limiter based on plasmons by researchers, as well as important advances in waveguiding and switching and device fabrication. It also include a novel technique for increasing the sensitivity of refractometers based on tilted fibre Bragg gratings, the application of localized surface plasmon resonances to enhance the performance of photodetectors , and plasmonic Schottky detectors that are currently receiving significantly interest.

In conclusion Opto-electronic device physics has been explored on a fundamental level towards enhancing light matter interactions. On this basis, novel nanophotonics building blocks have been realized and found to potentially out-perform traditional pure electronic or photonic devices. These findings are of importance towards fueling the global exponentially growing demand for data-bandwidth and novel functionalities such as sensing and bio-medical applications as well as ultrafast on-chip photonics. Especially with the raising energy consumption of information technology, nanoscale integrated hybrid circuits not only hold promise to deliver higher performance but also energy concise solutions due to enhanced physical effects.

II. OBJECTIVES

1. To Explore the fundamental interactions between light and matter towards devices application in the field of Opto-electronics and metal-optics, or plasmonics.
2. To demonstrate strong enhancements of such interactions using Simulation results evaluated.
3. To analyze a low loss deep-subwavelength waveguide which has been proposed .
4. To use the novel nanophotonics building blocks for deliver high performance .

Physics of Optoelectronic and This dissertation explores the fundamental interactions between light and matter towards devices applications in the field of Opto-electronics and metal-optics, or plasmonics. In its core, this dissertation attempts, and succeeds to demonstrate strong enhancements of such interactions. Here, surface plasmon polaritons, collective electronic oscillations at metal-dielectric interfaces, play a significant role, as they allow for nano-scale wavelengths with visible and near-infrared light. In particular the rate of spontaneous emission was shown to be significantly increased via increasing the local electromagnetic field density surrounding a photonic emitter. A nanoscale plasmonic cavity has been fabricated and shown to provide reasonable feedback while confining the optical mode beyond the diffraction limit of light.

In addition microcavities cavities were coated with metal demonstrating the highest cavity quality-factor for a plasmonic system to date. Furthermore, a low loss deep-subwavelength waveguide can been proposed and experimentally can be demonstrated. This novel waveguide uniquely combines ultra-small squeezed optical propagating fields with semiconductor technology, allowing for high waveguiding figure-of-merits; wave propagation versus mode confinement. Deploying near-field scanning optical microscopy, the tiny optical mode of such waveguides has been probed, revealing the first images of truly nanoscale optical waveguiding.

The challenge to demonstrate a sub-wavelength plasmon Nanolaser was successfully overcome by deploying the aforementioned hybrid plasmonic waveguide architecture.

Such Nanolasers were found to operate close to the thresholdless, ideal regime for lasers. The high optical loss of such plasmon Nanolasers was mitigated by utilizing the unique physical mechanism inside the plasmon Nanolaser cavity. In particular, this dissertation shows, that ultra-small optical modes are enhancing laser-mode selection leading to higher laser efficiencies and potentially reduced 2 laser thresholds.

Furthermore, this study of plasmon Nanolasers suggests a direct laser modulation bandwidth far exceeding that of any traditional laser and lastly discusses the integration of coherent nanoscale light source into ultra-compact integrated photonic on-chip solutions. Enhanced light-matter-interactions have further been explored towards combining photonic and logic, or computation.

Here, plasmonic-optically enhanced architectures were used to create optical non-linear effects with unprecedented efficiency and ultra-small device footprints. In particular, the electro-optical effect was deployed in a novel device interfacing silicon-on-insulator technology with hybrid plasmonics. For example results can be obtained by showing that one to two volt of electrical bias can switch an optical signal requiring only a few micrometer-long light-matter-interaction lengths. Furthermore, higher order non-linear effects, e.g. 3 rd order, have been predicted to boost such interactions even further paving the way towards efficient.

Scaling, coherence, and amplification of a subwave-length surface plasmon micropillar optical cavity have been studied using 3-D finite-difference time-domain calculations. Two experiments have also been conducted for the demonstration of the gain-assisted propagation of surface plasmon polaritons in a planar metal–semiconductor waveguide and the enhancement of the cavity-Q factor in a subwavelength surface plasmon micropillar cavity.

CHAPTER 4 . RESULT & DISCUSSIONS

Simulation of Photonics on Nanohub.org has been performed using experimental data and the simulation results are obtained using Drude-Lorentz models. Depending on the number of Lorentz kernels , the Drude-Lorentz model support different accuracy of the best-fit approximation. The imaginary part and sometimes, the real part of their dielectric functions can be very different depending on the source of published data. Therefore , in addition to the cubic spline interpolation of the raw experimental data , gold and silver can be interpolated using corresponding Drude-Lorentz best fit models. Simulations are performed in two categories one is metal category and the other is theoretical model. In the Metal Category the material used is Silver (Ag), range if 187-2066nm. The Interpolation method used is cubic spline Interpolation with quadric end points for 50 numbers of steps at minimum 200nm and maximum 500nm. In theoretical Model, the material used is Drude model for silver for the range 187-1937 nm for 50 numbers of steps . Parameters are obtained by fitting to the data from optical constants of the noble metals. A set of eigen frequencies exist for each wave vector k. The plot of frequencies v.s. wavefactors is so called band diagrams.

III. PLASMONICS AND PHOTONICS

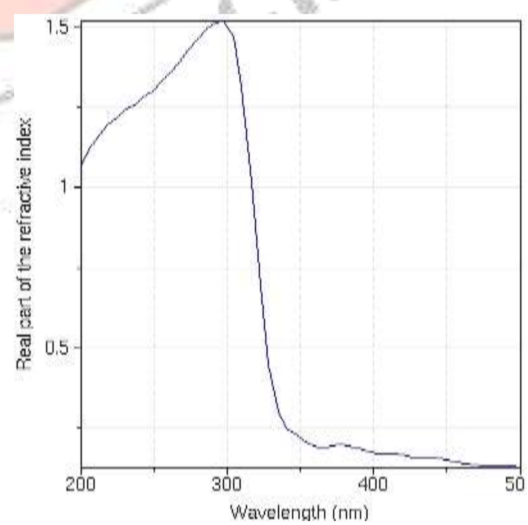

Figure 1

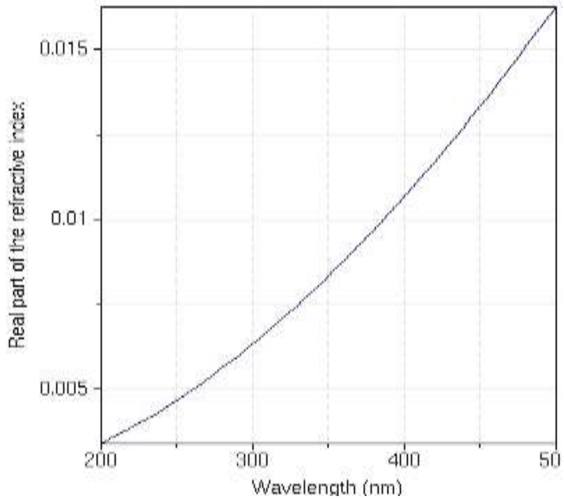

Figure 2

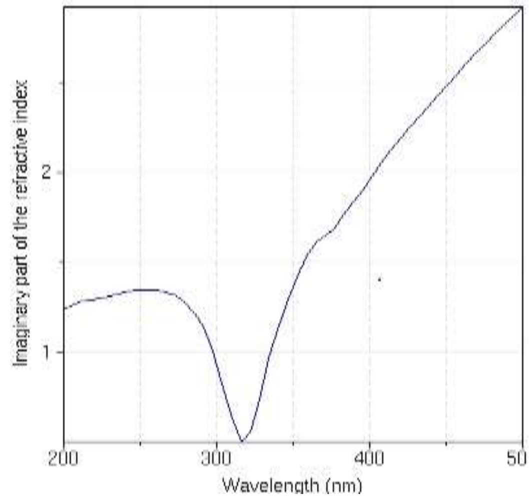

Figure 3

Plasmonic materials offer an opportunity to explore plasmonic effects such as subwavelength guiding, field enhancement, small volume sensing and other nonlinear effects due to its unique optical responses. Efforts have been made constantly to look for new promising plasmonic materials to meet the ever-increasing demand in plasmonics- related applications. So far, potential plasmonic materials include noble metals, highly-doped semiconductors, transparent conducting oxides, metal nitrides and 2D graphene . Here I only focus on two of them. One is conventional plasmonic materials, the noble metals such as Ag, Au, and Al. The other one is highly doped semiconductors which is a possible promising alternative aiming at different spectral region. It is known that noble metals behave like perfect electric conductors in the low frequency range such as hollow metal pipe waveguide used for a microwave region. At the high frequencies, such as visible region of spectrum, metal behavior changes qualitatively. The well known Drude model is widely used to fit the permittivity of noble metals in this range with an assumption that electrons are not bound.

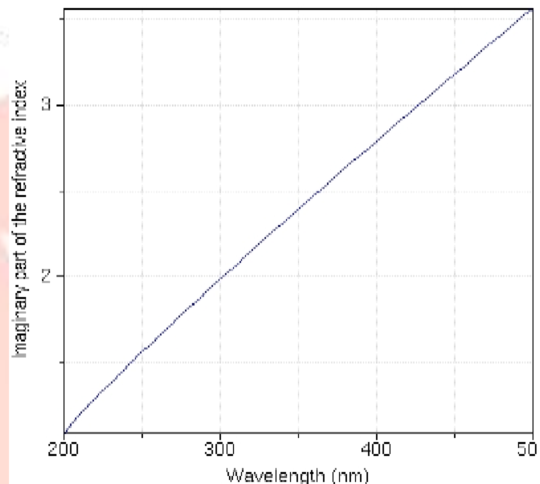

Figure 4

Typical value for gold are □□∞□=9.5, *p* □□=8.95eV, □□=0.069eV., the plots of real and imaginary parts of gold over the range from visible to near infrared using the above parameters and compare with experimental Johnson & Christy data. It shows a good agreement with experimental data. However, it should be noted that as wavelength decreases further below 600nm for gold, the imaginary part of permittivity deviates far from the experiment data due to occurrence of interband transitions. So the Drude model is valid only at a certain region. To model permittivity across the whole region, other factors such as interband transition and phonon absorption should be considered.

IV. SCOPE, LIMITATIONS & DELIMITATIONS

Innovative approaches to integrate the nanoscale coherent light sources with photonic components for on-chip applications are also important . In addition, other challenges exist in areas that have only begun to be addressed, such as far-field beam directionality and electrical pumping. Such challenges create opportunities for new materials, creative designs, and sophisticated nanofabrication techniques to push forward prospects of the nanoscale light sources. With such advances, the quest for even smaller and faster plasmonic nanolasers will lead to unprecedented ultra-compact devices with ultra-fast operation speeds. Intense, coherent light beams are expected to pave the progress in nano scale integrated photonic devices such as photonic chips. In addition, high-capacity EM data storage is possible with the aid of the high response speed and tiny light beam spot in plasmonic nano-laser systems. The extremely small, ultrafast, and coherent laser sources concentrate optical energy into sub wavelength regions and provide the necessary tools to probe interesting science on the single molecular scale and explore new applications such as ultra-high-resolution biomedical diagnostics.

Plasmonic nano lasers have no cutoff for device size but can have compromised performance because of losses from the metal. Recent advances in nano lasers focused on suppressing loss and amplifying Plasmon's with gain through new designs and materials. Intrinsic ohmic losses from the non-radiative dephasing of electrons via scattering with electrons, phonons, and impurities were mitigated by confining the EM fields to the dielectric layer. Scattering and radiation losses from roughened metal surfaces and cavity boundaries were reduced by using atomically flat metal films and arrays of plasmonic cavities. Typical gain materials to compensate losses in plasmonic nano lasers mostly rely on inorganic semiconductors and organic dye molecules.

Plasmonic nano lasers are expected to operate in the sub-ps regime but measuring the dynamics of plasmonic nano laser pulses is challenging for electrical detection techniques as well as time-resolved nonlinear spectroscopies. Plasmonic nano lasers have made considerable progress since their conception in 2003 and had many breakthroughs in 2014, especially regarding lasing wavelength tunability and determination of the modulation speeds . Creative applications of nano lasers were also reported, such as the use of such devices to detect explosives by monitoring the changes of the lasing emission. Moving forward, top-down nanofabrication techniques are needed to produce nano wire-on-film plasmonic nano lasers because the bottom-up semiconductor nano wire growth techniques and post-growth assembly on separately prepared dielectric and plasmonic layers are not amenable for large-scale production .

Nano-Photonics era will be to reduce the optical power level to the extreme, namely to the single photon level. From here, the bridge to quantum optics is a small one. The unique difference here. Other future directions include single molecular optical elements and finding bridges with or to the life-sciences. As mentioned before, plasmonics allows shrinking optical field (almost) to molecular level. Here sensors or detecting applications could find a strong partner in optics. Furthermore, with the current rising awareness of green-living, optically enhanced fields on a nanoscale are holding promise to allow for instance ultra-thin, yet high efficient photo-voltaic applications. Such novel solar cells could be very investment cost effective, due to low .processing and material costs of such tens of nanometer thin solar cells.

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