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Plasmonics Technology – A Review

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***Abstract*— Semiconductor devices, circuits and components are dependent upon miniaturization for transporting huge amounts of data at a high speed. However, the integration of modern electronic devices for information processing and sensing is rapidly approaching its fundamental speed and bandwidth limitations, which is an increasingly serious problems. One of the most promising solutions is believed to be in replacing electronic signals (as information carriers) by light. So a new emerging technology called 'plasmonics.' developed. Due to its frequency being approximately equal to that of light and ability to interface with similar-size electronic components, plasmonics can act as a bridge between photonics and electronics for communication. It exploits the unique optical properties of metallic nanostructures to enable routing and manipulation of light at the nano scale. A tremendous synergy can be attained by integrating plasmonic, electronic, and conventional dielectric photonic devices on the same chip and taking advantage of the strengths of each technology.**

***Index Terms*— Plasmonics, surface plasmon's, localized surface plasmons, electronics, photonics, nano shells, bio-sensor.**

I. INTRODUCTION

The term Plasmonics is derived from 'plasmons'. They are basically the quanta associated with longitudinal waves propagating in matter through the collective oscillation of large numbers of electrons. Plasma is a medium with equal combination of positive and negative charges, of which at least one from the charge type is mobile. With the increasing quest for transporting large amounts of data at a fast speed along with miniaturization both electronics and photonics are facing limitations. "Plasmon" is the quasi-particle resulting quantization of plasma oscillations just as photons and phonons are quantization of light and sound waves, respectively. Thus, plasmons are collective oscillations of the free electron gas density, often at optical frequencies. The energy required to receive and send a surface plasmon pulse can be less than for electric charging of a metallic wire. This could allow plasmons to travel along nano-scale wires (called interconnects) carrying information from one part of a microprocessor to another with a high bit rate. Plasmonic interconnects would be a great boon for chip designers, who have been able to develop ever smaller and faster transistors but have had a harder time building minute electronic circuits that can move data quickly across the chip. Surface plasmons can be excited on a flat nano-film, nano-strip or other shaped nano-particles such as nano-sphere, nano-rod, nano-cube and nano-star. When nano-particles are used to excite surface plasmons by light, these are known as localised surface plasmons.

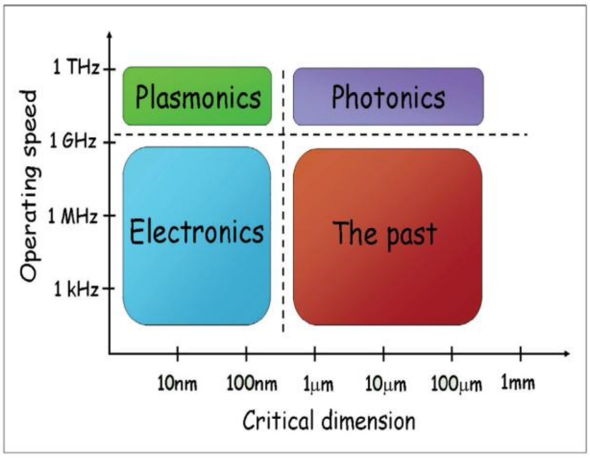

Fig. 1: Operating speeds and sizes of plasmonics and other devices

Silver and gold are of particular interest due to their high field enhancement and resonance wavelength lying in the visible spectral regime. The speed of these surface plasmons is almost equal to that of light with wavelength of the order of tens of nano-meters.

II. NEED OF A NEW TECHNOLOGY

Recently, electronics plays a very important role in communication. Inspite of that, photonics has started replacing electronics where a high data transfer rate is required. As we know, electronics is considered with the flow of charge (electrons). When the frequency of an electronic pulse increases, the electronic device becomes hot and wires become very loose. Hence according to the principle of "the higher the frequency, the higher the data transfer rate," a huge amount of data cannot be transferred from one place to another. On the other hand, when the size of an electronic wire reduces, its resistance (inversely proportional to the cross-sectional area of the wire) increases but the capacitance remains almost the same. This leads to time delay effects. In photonics, optical fibers (cylindrical dielectric/non-conducting waveguides) are used. These transmit light along their axis by the process of total internal reflection. The fiber consists of a core surrounded by a cladding layer, both of which are mad of dielectric materials. To confine the optical signal in the core, the refractive index of the core must be greater than of the cladding. The lateral confinement size of the optical cable is approximately half the wavelength of the light used. Hence the size of the optical cable is of the order of hundreds of nano-meters—larger than today's electronic devices.

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Optical fibers now span the globe, guiding light signals that convey voluminous streams of voice communications and vast amounts of data. This gargantuan capacity has led some researchers to prophesy that photonic devices--which channel and manipulate visible light and other electromagnetic waves--could someday replace electronic circuits in microprocessors and other computer chips. Unfortunately, the size and performance of photonic devices are constrained by the diffraction limit; because of interference between closely spaced light waves, the width of an optical fiber carrying them must be at least half the light's wavelength inside the material. For chip-based optical signals, which will most likely employ near-infrared wavelengths of about 1,500 nanometers (billionths of a meter), the minimum width is much larger than the smallest electronic devices currently in use; some transistors in silicon integrated circuits, for instance, have features smaller than 100 nanometers.

III. COMPONENTS OF PLASMONICS

There are two main components of plasmonics:
1) Surface Plasmon (sp) Polaritons
2) Localised Surface Plasmons(LSP)
SPs are associated with surface charge oscillation having frequency almost equal to light given in Fig. 2.

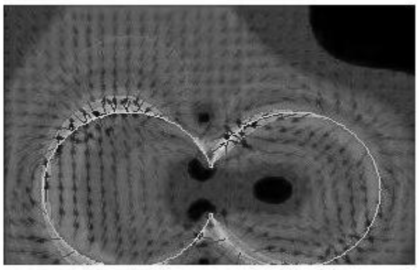

Fig. 2 : Localized surface Plasmons

The energy required to receive and send a SP pulse can be less than that needed for the electric charging of metallic wire. The article ends with a concise dialogue of promising applications of plasmonics in communication. It is hopeful that this will inspire the detailed study of plasmonics devices in the field of communication.
This could allow the Plasmons to travel along Nano scale wires (called interconnects) to carry information from one part of microprocessor to another with high bit rate. Plasmonics interconnects would be a great boom for chip designers which have been able to develop ever smaller and faster transistors that can move data quickly across the chip. Plasmon-based waveguides are not only a mode by which light can be guided on Nano scale, but also promise a path for chip scale device integration. Here, we provide a qualitative discussion on the factors that manage Plasmon excitation by different methods along with a brief description on some theoretical aspects of plasmonics.

IV. PLASMONICS APPLICATION

A. *Cure of Cancer*

The use of plasmonic devices go far beyond computing. However, scientists have developed structures known as nano-shells which consist of a thin layer of gold typically about 10 nanometers thick deposited around the entire surface of a silica particle about 100 nanometers across. When electromagnetic waves are exposed then it leads to the generation of electron oscillations in the gold shell; because of the coupling interaction between the fields on the shell's inner and outer surfaces, varying the size of the particle and the thickness of the gold layer changes the wavelength at which the particle resonantly absorbs energy. In this way, investigators can design the nano-shells to selectively absorb wavelengths as short as a few hundred nanometers (the blue end of the visible spectrum) or as long as nearly 10 microns.

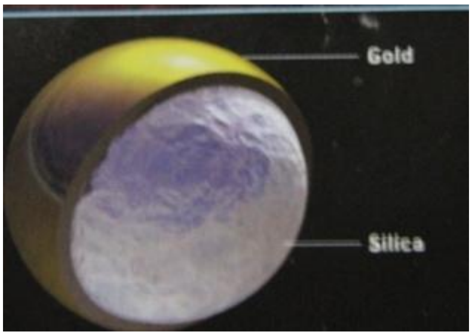

Fig 3 : Gold layer deposited around the surface of a silica particle

This phenomenon has turned nano-shells into a promising tool for cancer treatment. Scientists injected plasmonic nano-shells into the bloodstream of mice with cancerous tumors and found that the particles were nontoxic. What is more, the nano-shells tended to embed themselves in the rodents' cancerous tissues rather than the healthy ones because more blood was circulated to the fast-growing tumors. Fortunately, human and animal tissues are transparent to radiation at certain infrared wavelengths. The resonant absorption of energy in the embedded Nano-shells raised the temperature of the cancerous tissues from about 37 degrees Celsius to about 45 degrees C.

B. *Biosensors*

1) Plasmonics has one of its application as biosensors. When a particular DNA or protein molecule rests on the surface of a plasmon-carrying metallic material, it leaves its impact in the angle at which it reflects the energy. Presently the biggest application for Plasmons is in gold-coated glass biosensors, which detect when particular DNA or protein are present. Hence, the bio-matter changes the angle at which light hitting the surface produces the most intense Plasmons.

2) Oftenly diabetes patients have to draw blood as a daily routine in reality. It’s such an irritating deed that someone from nearly every scientific discipline has tried to invent a better way to do it as checking glucose levels probably considered as the worst part of the disease. They’ve pasted transversal patches to the skin and shone near-infrared light through the earlobes, but still nothing can beat the accuracy of a little drop of blood. A plasmonic interferometer that can examine very low concentrations of glucose in water and, with some reengineering, may also work with saliva. If things go as hoped, people with diabetes will one day measure glucose levels by spitting instead of sticking..

C. *Plethora of Benefits*

Plasmon waves are basically dependent upon the optical frequencies. The higher the frequency of the wave, the more the information we can transport. Optical frequencies are about 100,000 times greater than the frequency of today's electronic micro-processors. The key is using a material with a low refractive index, ideally negative, such that the incoming electromagnetic energy is reflected parallel to the surface of the material and transmitter along its length as far as possible. There exists no natural material with a negative refractive index, so nano-structured materials must be used to fabricate effective plasmonic devices. For this reason, plasmonics is frequently associated with nanotechnology.

Plasmonics explains how ultra-small metallic structures of different shapes capture and manipulate light and provides practical design tool for nano-scale optical components. The fact that light interacts with nanostructures overcomes the belief held for more than a century that light waves couldn't interact with anything smaller than their own wavelengths. When light of a specific frequency strikes a plasmon that oscillates at a compatible frequency, the energy from light is harvested by the plasmon, converted into electrical energy that propagates through the nanostructure and eventually converted back into light.

V. FUTURE DIRECTION

As explained in the review, plasmonic components are rapidly evolving from discrete, passive structures towards integrated active devices. Such integrated devices could transform the speed, cost, bandwidth, size, power requirements of modern computational networks, enabling more effective solutions to growing typical problems.

But, the primary goal of plasmonics is to develop new optical components and systems that are of the same size as today's smallest integrated circuits and that could ultimately be integrated with electronics on the same chip .The next step will be to integrate the components with an electronic chip to demonstrate plasmonic data generation, transport and detection. Plasmon waves on metals behave much like light waves in glass .That means we can use multiplexing. Plasmon sources, detectors, wires, splitters and power monsters can be developed. Applications mainly depend on controlling the losses and the cost of nanofabrication techniques. Finally, plasmonic Nano circuits combine a high bandwidth with a high-level compaction and make plasmonic components promising for all optical circuits. Plasmons can ferry data along computer chips.

VI. CHALLNGES REMAINING

In order to realize advanced active circuits , there is a need for active modulator and components operating at Ultra-high bandwidth and low power utilization. The potential of plasmonics right now is mainly limited by the fact that plasmons can typically travel only several millimeters before they peter out. So, the dream of making all-Plasmonic devices requires further research. Chips, meanwhile, are typically about a centimeter across, so plasmons can't yet go the whole distance. The distance that a plasmon can travel before dying out is a function of several aspects of the metal. But for optimal transfer through a wire of any metal, the surface of contact with surrounding materials must be as smooth as possible and the metal should not have any impurities.

For most wavelengths of visible light, aluminum allows plasmons to travel farther than other metals such as gold, silver and copper. It is somewhat ironic that aluminum is the best metal to use because the semiconductor industry recently dumped aluminum in favor of copper – the better electrical conductor – as it is wiring of choice. Of course, it may turn out that some kind of alloy will have even better plasmonic properties than either aluminum or copper. So, there are many challenges remaining.

Another classic semiconductor issue that the researchers will have to address is 'heat'. Chipmakers are constantly striving to ensure that their electronic chips don't run too hot. Plasmonics also will generate some heat, but the exact amount is not yet known. Even if plasmonics runs as hot as electronics, it will still have the advantage of higher data capacity in the same space.

VII. CONCLUSION

Plasmonics has the caliber to play an important and role in enhancing the processing speed of future integrated circuits. Plasmonics has developed an explosive growth over the last few years and our knowledge base in plasmonics is rapidly expanding. As a result, the role of plasmonic devices on a chip is also becoming more well-defined. In the past, devices were relatively slow and bulky. The semiconductor industry has performed an incredible job in scaling electronic devices to nano-scale dimensions. Unfortunately, interconnect delay time issues provide significant challenges toward the realization of purely electronic circuits operating above 10 GHz. In stark contrast, photonic devices possess a huge data-carrying capacity (bandwidth). Unfortunately, dielectric photonic components are limited in their size by the laws of diffraction, preventing the same scaling as in electronics. Finally, plasmonics offers precisely what electronics and photonics do not have i.e. the size of electronics and the speed of photonics. Plasmonic devices, therefore, might interface naturally with similar speed photonic devices and similar size electronic components. For these reasons, plasmonics may well serve as the missing link between the two device technologies that currently have a difficult time communicating. By increasing the synergy between these technologies, plasmonics may be able to unleash the full potential of nano-scale functionality and become the next wave of chip-scale technology.

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