“Plasmonics - A Vision of future”

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ABSTRACT

Currently communication systems are based on either electronics or photonics. However, with the increasing quest for transporting large amounts of data at a fast speed along with miniaturisation, both electronics and photonics are facing limitations. Due to their mismatched capacities and sizes, it is very difficult to cobble them to get a high bitrate with miniaturisation. So researchers are pioneering a new technology called ‘plasmonics’ which can act as a bridge between photonics and electronics as its frequency being approximately equal to that of light and its ability to interface with similar size electronic components for communication.

Keywords:Electronics, photonics, plasmonics, optical frequencies, photons, components, plasmons

I. INTRODUCTION: WHAT IS PLASMONICS?

The term ‘plasmonics’ is derived from plasmons- quanta associated with collective excitation of free electrons in metals. Plasmonics is a technology that squeezes electromagnetic waves into minusculestructures may yield a new generation of superfast computer chips and ultra sensitive detectors. Plasmons are density waves of electrons created when light hits the surface of metal under precise circumstances. These density waves are created at optical frequencies , being very small and rapid waves they can theoretically encode a lot of information, more than what’s possible for conventional electronics. Surface plasmons are associated with surface charge oscillations. Their frequency is almost equal to that of light; optical frequencies are about 10^5 times greater than the frequency of today’s electronic microprocessors. So light can be used to excite them on the surface of a material in a localised regime. 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 nanoscale wires(called interconnects) carrying information from one part of a microprocessor to another with a high bitrate.

II. LIMITATIONS OF PRESENT MODES

Presently electronics and optics play a major role in communication systems. Electronics deals 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 by the principle of “the higher the frequency, the higher the data transfer rate,” a huge amount of data cannot be transferred. 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 fibres (cylindrical dielectric/non-conducting waveguides) are used. These transmit light along their axis by the process of total internal reflection. The fibre consists of a core surrounded by a cladding layer, both of which are made 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 nanometres—larger than today's electronic devices. Optical fibres 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 fibre 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. Recently,however, scientists have been working on a new technique for transmitting opticalsignals through minuscule nanoscale structures.

III. COMMUNICATION WITH PLASMONICS

Plasmonic structures can exert huge control over electromagnetic waves at the nanoscale. As a result, energy carried by plasmons allows for light localisation in ultra-small volumes— far beyond the diffraction limit of light. To generate surface plasmons, it is necessary to excite the metal-dielectric interface in which the dielectric constant of the metal is a function of frequency and negative. At the nanoscale, the electromagnetic (EM) field of the EM wave displays the electron cloud due to its well coupling, which is not possible in the case of bulk matter. Hence plasmonics is frequently associated with nanotechnology. Investigators have found that by creatively designing the metal dielectric interface, they can generate surface plasmons with the same frequency as the electromagnetic wave but with much smaller wavelength. This phenomenon could allow plasmons to travel along nanoscale wires called 'interconnects' in order to carry information from one part of the microprocessor to another. Plasmonic waveguides are attracting much attention owing to their ability to operate in various parts of the spectrum—ranging from visible to far-infrared region. Metallic nanowires can provide lateral confinement of the mode below the diffraction limit. Nanowires have larger attenuation than planer films but light transport over a distance of several microns has been demonstrated. A chain of differently-shaped nanoparticles (such as spheres and rods) can be used to transport EM waves from one nanoparticle to another via the near-field electrodynamic interaction between them. If the second particle is situated in the near field of the other and so on along the chain, EM energy can be propagated within the lateral size confinement less than the diffraction limit. In a chain of closely spaced nanostructures, the propagation distance depends upon the shape and nature of materials, separation between them as dielectric medium and other mediums also.

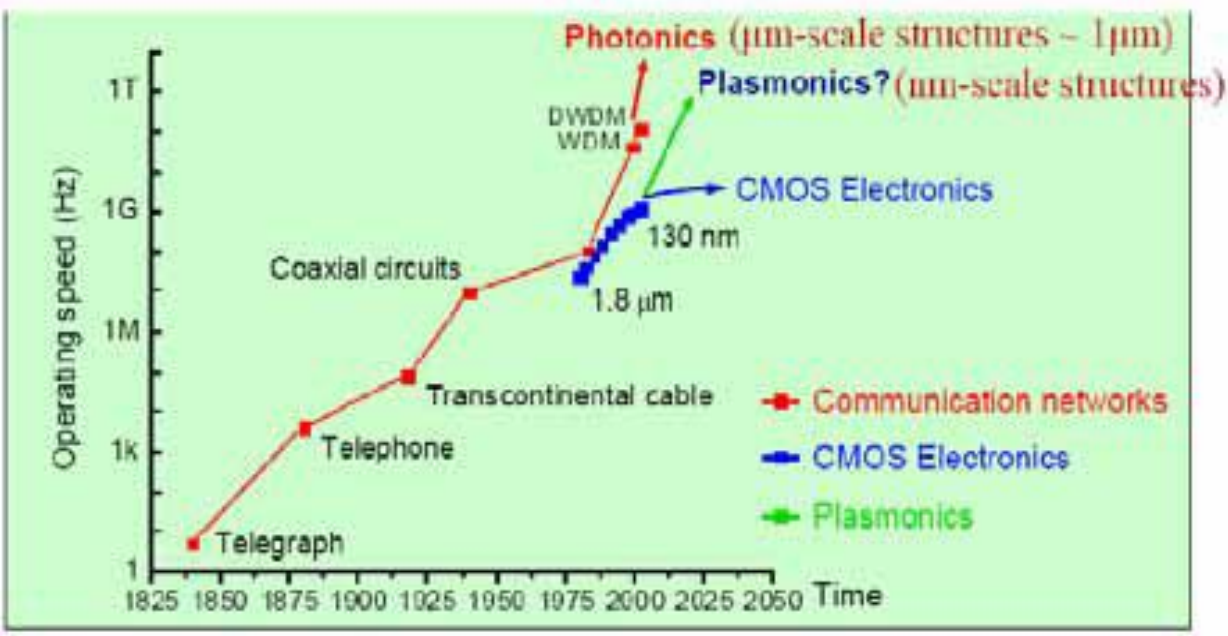


Fig.1 : Operating speed of data transporting and processing systems

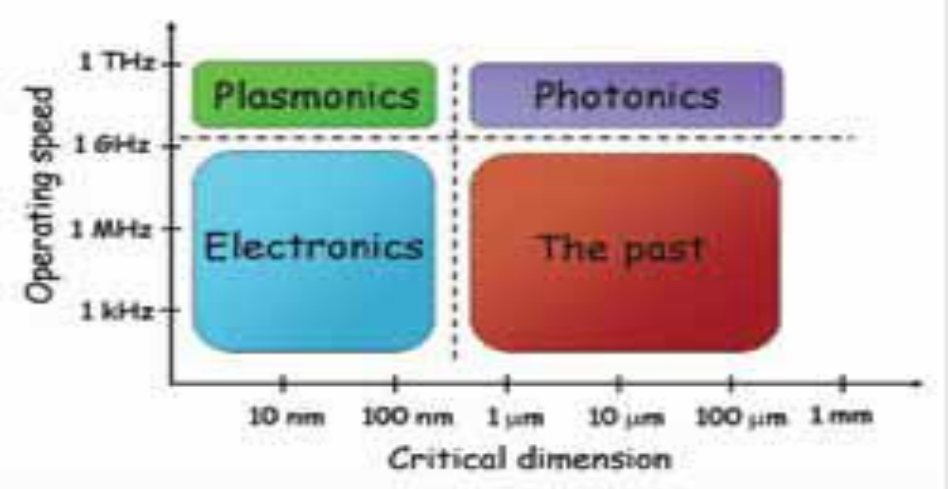


Fig.2 : Operating regimes-applicable size and speed scale-for plasmonic and other devices.

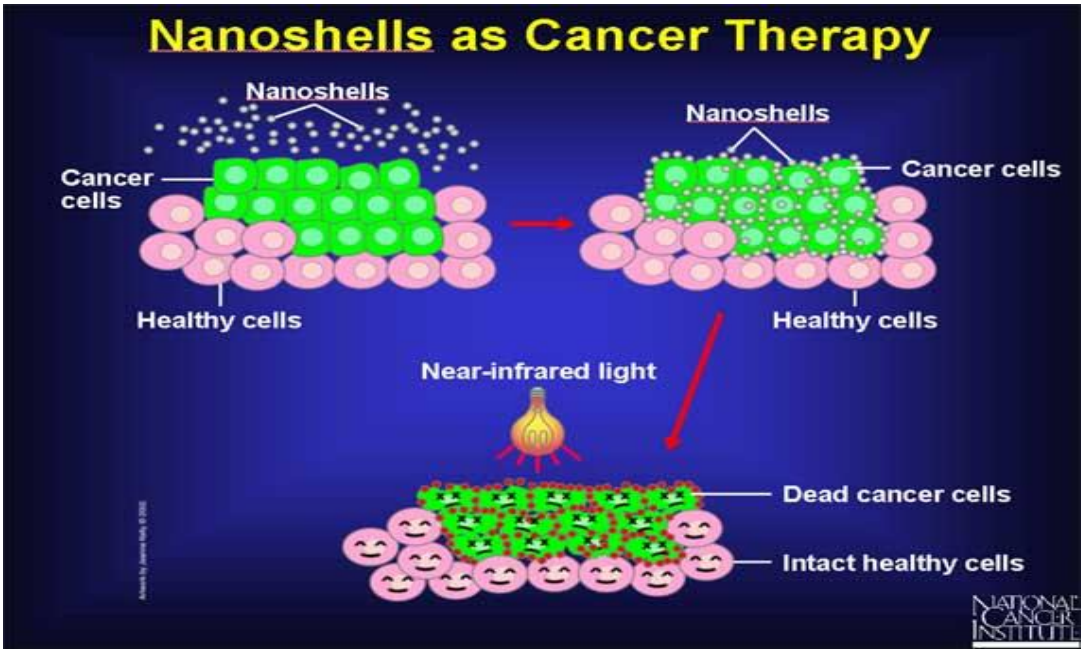
IV. APPLICATONS

Plasmonsters: A faster chip

Plasmon waves behave on metals much like light waves behave in glass, meaning that plasmonic engineers can employ all the same ingenious tricks—such as multiplexing, or sending multiple waves—that photonic engineers use to cram more data down a cable. Meanwhile, because plasmonic components can be crafted from the same materials chipmakers use today, Scientist are hopeful that they can make all the devices needed to route light around a processor or other kind of chip. While an all-plasmonic chip might be feasible someday, Plasmonic wires will act as high-traffic freeways on chips with otherwise conventional electronics. Local arrays of electronic transistors would carry out the switching necessary for computation, but when a lot of data needs an express lane to travel from one section of a chip to another, electronic bits could be converted to plasmon waves, sent along a plasmonic wire and converted back to electronic bits at their destination. The development of chip-scale electronics and photonics has led to remarkable data processing and transport capabilities that permeate almost every facet of our lives.

Nanoshells: A cure for cancer

The potential uses of plasmonic devices go far beyond computing, however. Scientists have developed structures called nanoshells that 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. Exposure to electromagnetic waves generates 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 nanoshells 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 (the near infra□red). This phenomenon has turned nanoshells into a promising tool for cancer treatment . Scientists injected plasmonic nanoshells into the bloodstream of mice with cancerous tumors and found that the particles were nontoxic. What is more, the nanoshells 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. When the researchers directed near-infrared laser light through the mice's skin and at the tumors, the resonant absorption of energy in the embedded nanoshells raised the temperature of the cancerous tissues from about 37 degrees Celsius to about 45 degrees C. The photo thermal heating killed the cancer cells while leaving the surrounding healthy tissue unharmed. In the mice treated with nanoshells, all signs of cancer disappeared within 10 days; in the control groups, the tumors continued to grow rapidly. Houston-based Nanospectra Biosciences is currently seeking permission from the Food and Drug Administration to conduct clinical trials of nanoshell therapy in patients with head and neck cancer.



Invisibility cloak:

The most fascinating potential application of plasmonics would be the invention of an invisibility cloak. A material's refractive index is the ratio of the speed of light in a vacuum to the speed of light in the material. Exciting a plasmonic structure with radiation that is close to the structure's resonant frequency can make its refractive index equal to airs, meaning that it would neither bend nor reflect light. The structure would absorb light, but if it were laminated with a material that produces optical gain--amplifying the transmitted signal just as the resonator in a SPASER would—the increase in intensity would offset the absorption losses. The structure would become invisible, at least to radiation in a selected range of frequencies. A true invisibility cloak, however, must be able to hide anything within the structure and work for all frequencies of visible light. It is showed that a shell of metamaterials can reroute the electromagnetic waves traveling through it, diverting them around a spherical region within. SPASER - PLASMONIC ANALOG OF LASER. The acronym SPASER stands for Surface Plasmon Amplification of Stimulated Emission of Radiation. It can be fabricated using semiconductor quantum dots and metal particles. Radiative energy from the quantum dots would be transformed into plasmons, which would then be amplified in a plasmonic resonator. Because the plasmons generated by a SPASER would be much more tightly localized than a conventional laser beam, the device could operate at very low power and selectively excite very small objects. As a result, SPASERs could make spectroscopy more sensitive and pave the way for hazardous-materials detectors that could identify minute amounts of chemicals or viruses.

Plasmonic LED and Quantum dots:

Plasmonic materials may also revolutionize the lighting industry by making LEDs bright enough to compete with incandescent bulbs. Beginning in the 1980s, researchers recognized that the plasmonic enhancement of the electric field at the metal-dielectric boundary could increase the emission rate of luminescent dyes placed near the metal's surface. More recently, it has become evident that this type of field enhancement can also dramatically raise the emission rates of Quantum dots and quantum wells--tiny semiconductor structures that absorb and emit light—thus increasing the efficiency and brightness of solid-state LEDs. It is demonstrated that coating the surface of a gallium nitride LED with dense arrays of plasmonic nanoparticles (made of silver, gold or aluminium) could increase the intensity of the emitted light 14-fold. Furthermore, plasmonic nanoparticles may enable researchers to develop LEDs made of silicon. Such devices, which would be much cheaper than conventional LEDs composed of gallium nitride or gallium arsenide, are currently held back by their low rates of light emission. It is found that coupling silver or gold plasmonic nanostructures to silicon quantum-dot arrays could boost their light emission by about 10 times. Moreover, it is possible to tune the frequency of the enhanced emissions by adjusting the dimensions of the nanoparticle. Careful tuning of the plasmonic resonance frequency and precise control of the separation between the metallic particles and the semiconductor materials may enable us to increase radiative rates more than 100-fold, allowing silicon LEDs to shine just as brightly as traditional devices.

V. FUTURE DIRECTIONS

In the field of plasmonics, studying the way light interacts with metallic nanostructures will make it easier to design new optical material devices. Plasmon sources, detectors and wires as well as splitters and even plasmonsters can be developed. Applications mainly depend on controlling the losses and the cost of nanofabrication techniques. Enhanced and directed emission of semiconductor luminescence (quantum dots) may well find commercial application in plasmon-assisted lighting in the near future. Finally, plasmonic nano-circuits combine a high bandwidth with a high level of compaction and make plasmonic components promising for all-optical circuits. Plasmonic wires will act as high-bandwidth freeways across the busiest areas of the chip. Plasmons can ferry data along computer chips. Plasmonic switches required for this are under development. Rotaxanes molecule is being used for the purpose. Change in the shape of the molecule is the principle of this molecular switch.

VI. CHALLENGES REMAINING

Despite many advances in the field of plasmonics, several important open questions and problems remain. For example, how can plasmons be efficiently excited with nanoscale resolution? Surface plasmon polaritons are usually excited using far-field optical techniques, which have a higher resolution than plasmonic phenomena under investigation. “What are the fundamental processes that determine the losses of surface plasmon polaritons?” is another important question. the dream of making all-plasmonic devices requires further research. In order to realise advanced active circuits, there is a need for active modulator and switching components operating at ultra-high bandwidth and low power utilisation. Finally, the use of a particle beam rather than a light beam to excite surface plasmon polaritons raises questions and novel opportunities regarding the selectivity with which surface plasmon modes with different symmetry can be excited.

VII. CONCLUSION

The ideas of Plasmonics illustrate the rich array of optical properties that inspire researchers in this field. By studying the elaborate interplay between electromagnetic waves and free electrons, investigators have identified new possibilities for transmitting data in our integrated circuits, illuminating our homes and fighting cancer. Further exploration of these intriguing plasmonic phenomena may yield even more exciting discoveries and inventions interactions between electromagnetic waves and matter. That includes laser-plasma and laser-solid interactions, nano-photonics, and plasmonics.

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