1. WHAT IS PLASMONICS?

Definition:
A technology that squeezes electromagnetic waves into minuscule structures may yield a new generation of super-fast computer chips and ultra-sensitive molecular detectors.

Mechanism:
Light beam striking a metal surface generates plasmons, electron density waves that can carry huge amounts of data. If focused on surface etched with circular groove the beam produces concentric waves organizing electrons into high & low density rings.

Surface plasmons can be excited on a flat nano-film, nanostrip or other shaped nanoparticles such as nanosphere, nanorod, nanocube and nanostar. When nanoparticles are used to excite surface plasmons by light, these are known as localised surface plasmons. 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 nanometres.

2.WHY A NEW TECHNOLOGY?

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.

Recently, however, scientists have been working on a new technique for transmitting optical signals through minuscule nanoscale structures. In the 1980s researchers experimentally confirmed that directing light waves at the interface between a metal and a dielectric (a nonconductive material such as air or glass) can, under the right circumstances, induce a resonant interaction between the waves and the mobile electrons at the surface of the metal. (In a conductive metal, the electrons are not strongly attached to individual atoms or molecules.) In other words, the oscillations of electrons at the surface match those of the electromagnetic field outside the metal. The result is the generation of surface plasmons--density waves of electrons that propagate along the interface like the ripples that spread across the surface of a pond after you throw a stone into the water.

3. FEATURES OF PLASMONICS:

Over the past decade investigators have found that by creatively designing the metal- dielectric interface they can generate surface plasmons with the same frequency as the outside electromagnetic waves but with a much shorter wavelength. This phenomenon could allow the plasmons to travel along nanoscale wires called interconnects, carrying information from one part of a microprocessor to another. 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.

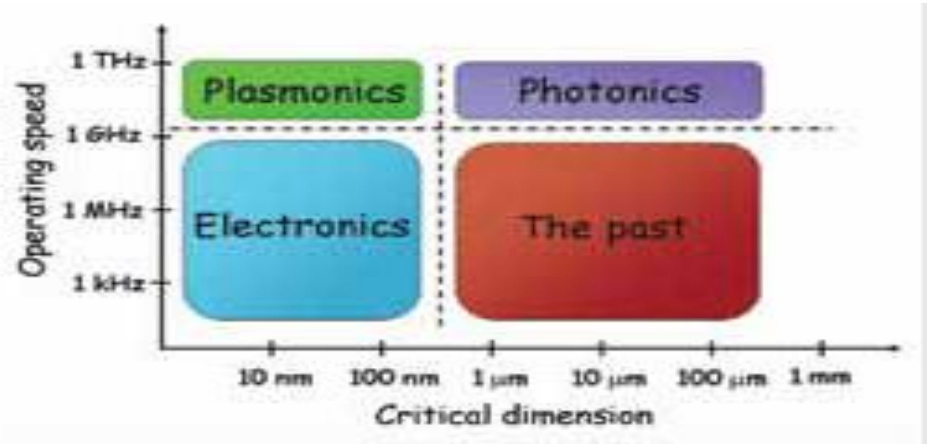


Fig. 4.1: Operating speed comparison of chip scale technologiess

The term "plasmonics" came into existence in 2000 from the word „plasmon‟, sensing that research in this area could lead to an entirely new class of devices. Ultimately it may be possible to employ plasmonic components in a wide variety of instruments, using them to improve the resolution of microscopes,

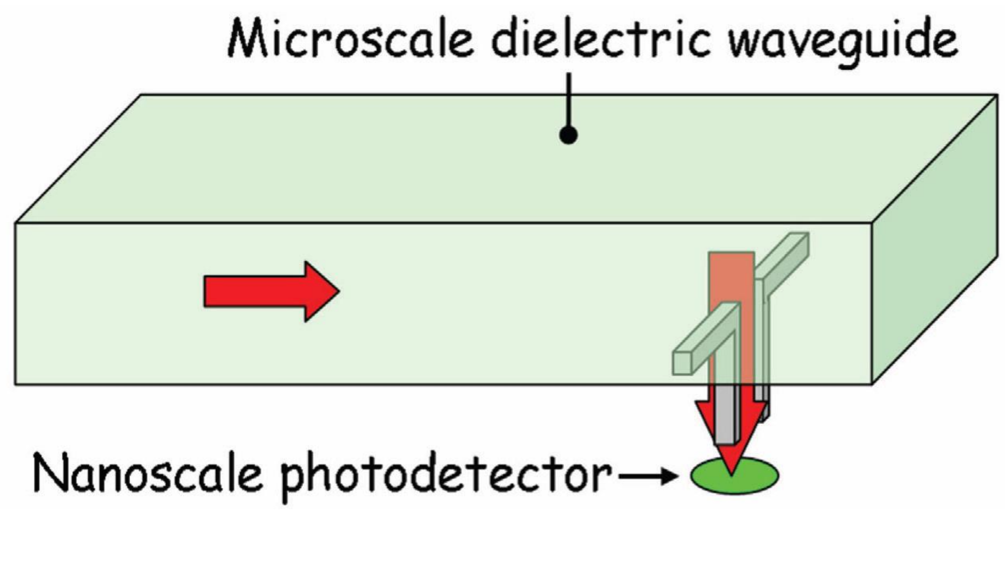
the efficiency of light-emitting diodes (LEDs) and the sensitivity of chemical and biological detectors. Scientists are also considering medical applications, designing tiny particles that could use plasmon resonance absorption to kill cancerous tissues, for example. And some researchers have even theorized that certain plasmonic materials could alter the electromagnetic field around an object to such an extent that it would become invisible. Although not all these potential applications may prove feasible, investigators are eagerly studying plasmonics because the new field promises to literally shine a light on the mysteries of the nano world.

For millennia, alchemists and glassmakers have unwittingly taken advantage of plasmonic effects when they created stained-glass windows and colorful goblets that incorporated small metallic particles in the glass. The most notable example is the Lycurgus cup, a Roman goblet dating from the fourth century A.D. and now held in the British Museum. Because of plasmonic excitation of electrons in the metallic particles suspended within the glass matrix, the cup absorbs and scatters blue and green light--the relatively short wavelengths of the visible spectrum. When viewed in reflected light, the plasmonic scattering gives the cupa greenish hue, but if a white light source is placed within the goblet, the glass appears red because it transmits only the longer wavelengths and absorbs the shorter ones.

The field of plasmonics received another boost with the discovery of novel "meta-materials"--materials in which electron oscillations can result in astounding optical properties. Two new classes of tools have also accelerated progress in plasmonics: recent increases in computational power have enabled investigators to accurately simulate the complex electromagnetic fields generated by plasmonic effects, and novel methods for constructing nanoscale structures have made it possible to build and test ultra small plasmonic devices and circuits.

At first glance, the use of metallic structures to transmit light signals seems impractical, because metals are known for high optical losses. The electrons oscillating in the electromagnetic field collide with the surrounding lattice of atoms, rapidly dissipating the field's energy. But the plasmon losses are lower at the interface between a thin metal film and a dielectric than inside the bulk of a metal because the field spreads into the nonconductive material, where there are no free electrons to oscillate and hence no energy-dissipating collisions. This property naturally confines plasmons to the metallic surface abutting the dielectric; in a sandwich with dielectric and metal layers, for example, the surface plasmons propagate only in the thin plane at the interface. Because these planar plasmonic structures act as waveguides, shepherding the electromagnetic waves along the metal-dielectric boundary, they could be useful in routing signals on a chip.

Although an optical signal suffers more loss in a metal than in a dielectric such as glass, a plasmon can travel in a thin-film metal waveguide for several centimeters before dying out. The propagation length can be maximized if the waveguide employs an asymmetric mode, which pushes a greater portion of the electromagnetic energy away from the guiding metal film and into the surrounding dielectric, thereby lowering loss. Because the electromagnetic fields at the top and bottom surfaces of the metal film interact with each other, the frequencies and wavelengths of the plasmons can be adjusted by changing the thickness of the film.



Fg. 4.2: Schematic of how a nanoscale antenna structure can serve as a bridge between microscale dielectric components and nanoscale electronic devices.

To generate plasmons that can propagate through nanoscale wires, researchers have explored more complex waveguide geometries that can shrink the wavelength of the signal by squeezing it into a narrow space.

Fortunately, the absorption losses can be minimized by turning the plasmonic waveguides inside out, putting the dielectric at the core and surrounding it with metal. In this device, called a plasmon slot waveguide, adjusting the thickness of the dielectric core changes the wavelength of the plasmons. It is shown that plasmon slot waveguides are capable of transmitting a signal as far as tens of microns.

Plasmonics can thus generate signals in the soft x-ray range of wavelengths (between 10 and 100 nanometers) by exciting materials with visible light. The wavelength can be reduced by more than a factor of 10 relative to its free-space value, and yet the frequency of the signal remains the same. (The fundamental relation between the two--frequency times wavelength equals the speed of light--is preserved because the electromagnetic waves slow as they travel along the metal-dielectric interface.) This striking ability to shrink the wavelength opens the path to nanoscale plasmonic structures that could replace purely electronic circuits containing wires and transistors.

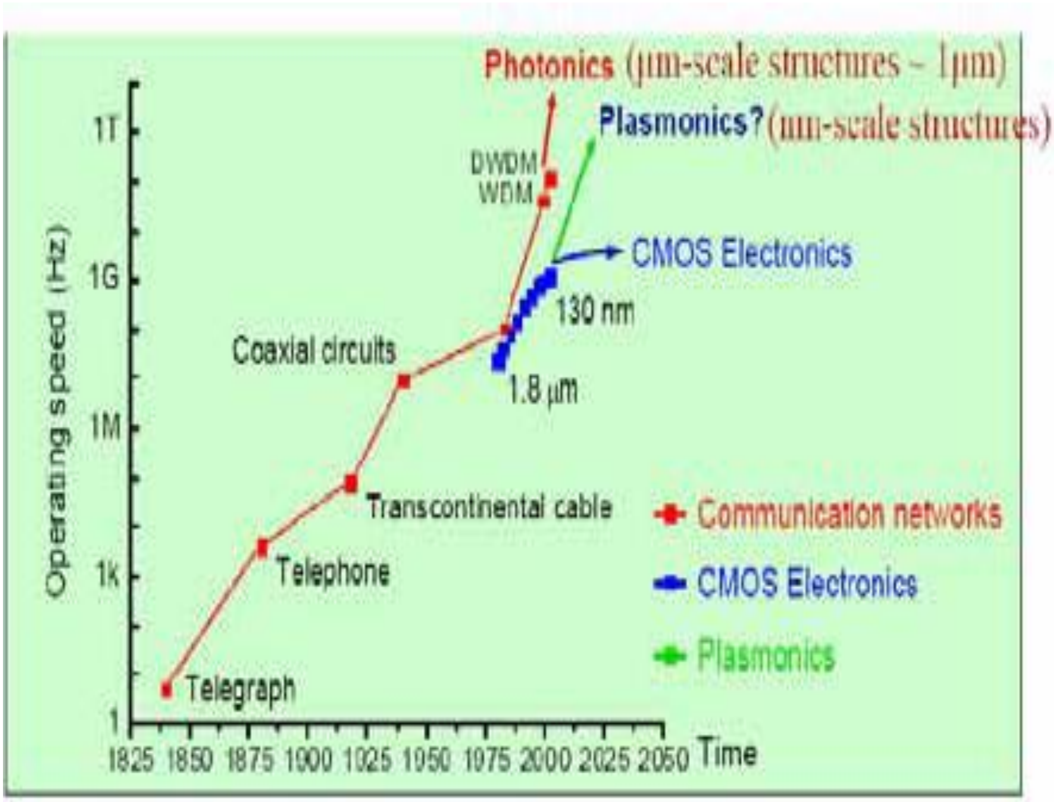


Fig. 4.3: Operating speed of data transporting and processing systems

Just as lithography is now used to imprint circuit patterns on silicon chips, a similar process could mass-produce minuscule plasmonic devices with arrays of narrow dielectric stripes and gaps. These arrays would guide the waves of positive and negative charge on the metal surface; the alternating charge densities would be very much akin to the alternating current traveling along an ordinary wire. But because the frequency of an optical signal is so much higher than that of an electrical one--more than 400,000 gigahertz versus 60 hertz--the plasmonic circuit would be able to carry much more data. Moreover, because electrical charge does not travel from one end of a plasmonic circuit to another--the electrons bunch together and spread apart rather than streaming in a single direction the device is not subject to resistance and capacitance effects that limit the data- carrying capacity of integrated circuits with electrical interconnects. Plasmonic circuits would be even faster & more useful if researchers could devise a "plasmonster" switch--a three-terminal plasmonic device with transistor like properties .

4. UNIQUE PROPERTIES OF SURFACE PLASMONS

Surface plasmons are those plasmons that are confined to surfaces and that interact strongly with light resulting in a polaritons. They occur at the interface of a vacuum or material with a positive dielectric constant with that of a negative dielectric constant (usually a metal or doped dielectric). They play a role in Surface Enhanced Raman Spectroscopy in explaining anomalies in diffraction from metal gratings, among other things. Surface Plasmon Resonance is used by biochemists to study the mechanisms and kinetics of ligands binding to receptors (i.e. a substrate binding to an enzyme).

Surface plasmon polaritons (SPP):

- electro-magnetic wave confined at the metal surface
- overcome diffraction limit:
- nano-optical components “light on a wire”
- Strongly enhanced local fields:
- resonant build-up, lightning-rod effect & non-linear optical effects, sensors
- To study propagation of spp a photon scanning tunneling microscope (PSTM) may be used

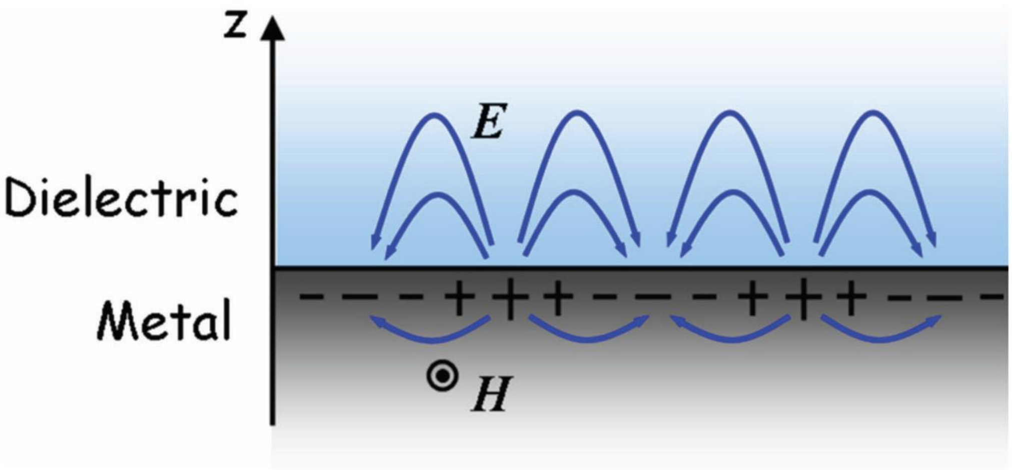


Fig. 5.1: An SPP propagating along a metal-dielectric interface.

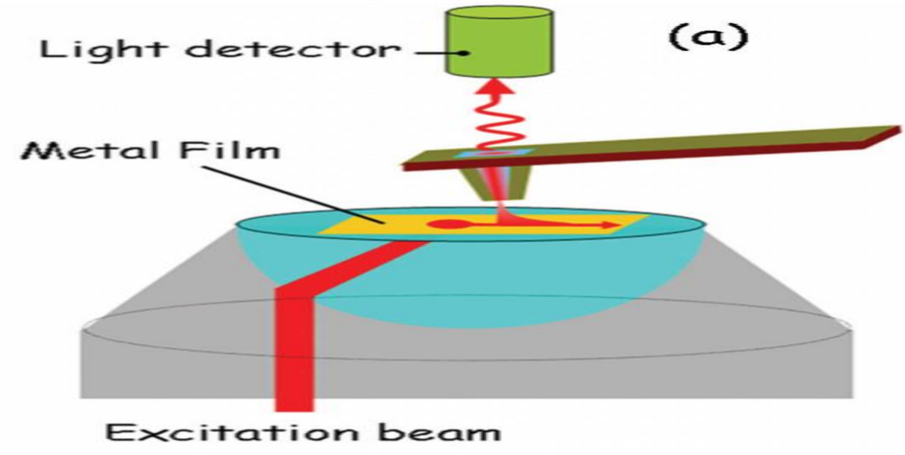


fig 5.2 Schematic of the operation of a PSTM that enables the study of SPP propagation along metal film surfaces

5. EXPERIMENTS AND SIMULATIONS IN PLASMONIC WAVEGUIDES

The valuable information about plasmonic structures provided by PSTM measurements allows us to evaluate the utility of plasmonics for interconnection. Plasmonic stripe waveguides provide a natural starting point for this discussion as such stripes very closely resemble conventional metal interconnects. Electron beam lithography has been used to generate 55 nm thick Au stripes on a SiO2 glass slide with stripe widths ranging from 5 μm to 50 nm. Au stripes are ideal for fundamental waveguide transport studies as they are easy to fabricate, do not oxidize, and exhibit a qualitatively similar plasmonic response to Cu and Al.

Fig. 3a shows an optical micrograph of a typical device consisting of a large Au area from which SPPs can be launched onto varying width metal stripes. A n scanning electron microscopy (SEM) image of a 250 nm wide stripe is shown as an inset. The red arrow shows how light is launched from a focused laser spot into a 1 µm wide stripe.

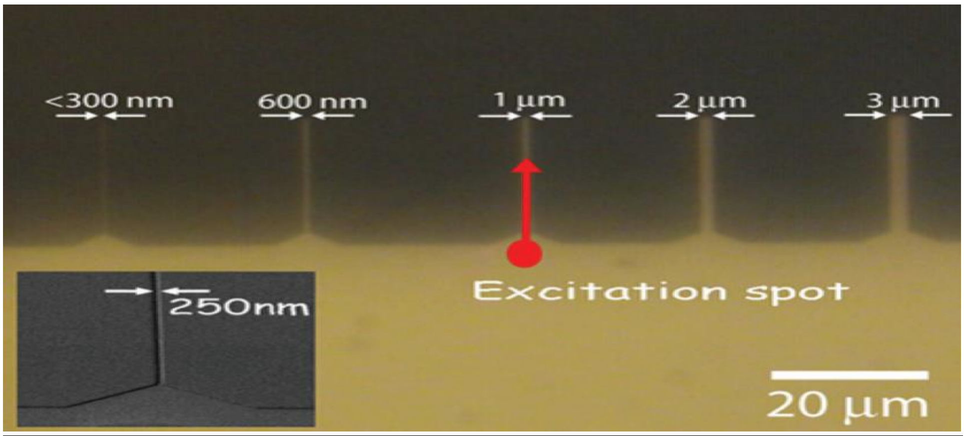


Fig 6.1 :Optical microscopy image of a SiO2 substrate with an array of Au stripes attached to a large launchpad generated by electron beam lithography

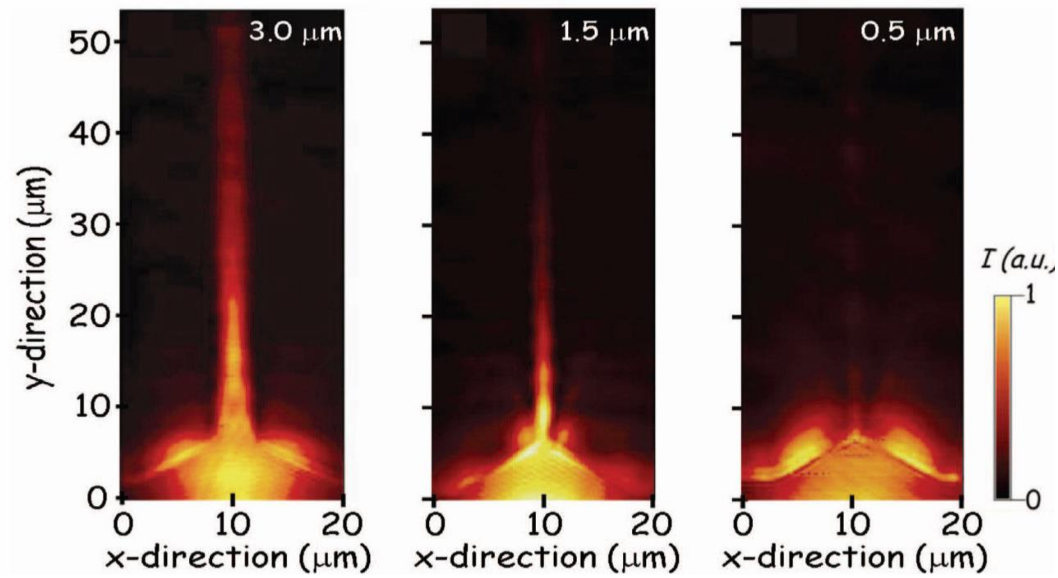


Fig 6.2: PSTM images of SPPs excited at λ = 780 nm and propagating along 3.0 µm, 1.5 µm, and 0.5 µm wide Au stripes, respectively.

Figure 3b, 3c, and 3d show PSTM images of SPPs excited at λ = 780 nm & propagating along 3.0 µm, 1.5 µm, and 0.5 µm wide Au stripes, respectively. The 3.0 µm wide stripe can be used to propagate signals over several tens of microns. Similar to previous far field measurements along Ag stripes, it is clear that the propagation distance of SPPs decreases with decreasing stripe width. A better understanding of this behavior can be obtained from full-field simulations and a recently developed, intuitive ray optics picture for plasmon waveguides. A selection of these simulation results is presented next, followed by a discussion of the potential uses for these relatively short propagation distance waveguides

6. APPLICATIONS

6.1. 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.

6.2. PLASMONSTER - A FASTER CHIP:

Slot waveguides could significantly boost the speed of computer chips by rapidly funneling large amounts of data to the circuits that perform logical operations. The Plasmonsters are composed of slot waveguides that measure 100nm across at their broadest points and only 20nm across at the intersection.

6.3. INVISIBILITY CLOAKS

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 air's, 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 meta-materials can reroute the electromagnetic waves traveling through it, diverting them around a spherical region within.

6.4. PLASMONIC NANOCELL THERAPY:

The potential uses of plasmonic devices go far beyond computing. Nanoshell that consists 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 infrared). This phenomenon has turned nanoshells into a promising tool for cancer treatment.

Halas, working with her Rice colleague Jennifer West, 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. The nanoshells can also be attached to antibodies to ensure that they target cancers. 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 photothermal 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 37 degrees Celsius to about 45 degrees C.

6.5 .PLASMONIC LED :

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 aluminum) could increase the intensity of the emitted light 14-fold.

Furthermore, plasmonic nano particles 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.

7. LIMITATIONS OF PRESENT MODE

Presently, electronics plays an important role in communication. In laboratories, though, photonics has started replacing electronics where a high data transfer rate is required. 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.

8. CONCLUSION

8. REFERENCE

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