Plasmonics-A New Device Technology

Rishabh Chickballapur Nagaraj[1] Sativada Monica[2] Dr. M. N. Thippeswamy[3]
[1, 2, 3]Department of Electronics & Communication Engineering
[1, 2, 3]Sri Venkateshwara College of Engineering, India

Abstract—Electronic circuits provide us with the ability to control the transport and storage of electrons. However, the performance of electronic circuits is now becoming rather limited when digital information needs to be sent from one point to another. Photonics offers an effective solution to this problem by implementing optical communication systems based on optical fibers and photonic circuits. Unfortunately, the micrometer-scale bulky components of photonics have limited the integration of these components into electronic chips, which are now measured in nanometers. Surface plasmon–based circuits, which merge electronics and photonics at the Nano scale, may offer a solution to this size-compatibility problem. Here we review the current status and future prospects of plasmonics in various applications including plasmonic chips, light generation, and nanolithography.

Key words: plasmonics, Surface Plasmon's, Invisibility Cloaks, Localized Surface Plasmons, Nano shells.

I. INTRODUCTION

Today's state-of-the-art microprocessors use ultrafast transistors with dimensions on the order of 50 nm. Although it is now routine to produce fast transistors, there is a major problem in carrying digital information to the other end of a microprocessor that may be a few centimeters away. Whereas copper wire interconnects carry digital information, interconnect scaling has been insufficient to provide the necessary connections required by an exponentially growing transistor count. Unlike transistors, for which performance improves with scaling, the delay of interconnects increases and becomes a substantial limitation to the speed of digital circuits .This limitation has become more evident over the past 1 to 2 years, as the annual increase rate of the clock speed of microprocessors slowed greatly.

Optical interconnects such as fiber optic cables can carry digital data with a capacity 91000 times that of electronic interconnects. Unfortunately, fiber optic cables are È1000 times larger compared with electronic components, and the two technologies are difficult to combine on the same circuit. External optical interconnects that can connect different parts of the electronic chips via air or fiber cables have also been proposed. However, the resulting bulky configuration has limited the implementation of this idea. The ideal solution would be to have a circuit with Nano scale features that can carry optical signals and electric currents. One such proposal is surface Plasmons, which are electromagnetic waves that propagate along the surface of a conductor. The interaction of light with matter in nanostructure metallic structures has led to a new branch of photonics called plasmonics. Plasmonic circuits offer the potential to carry optical signals and electric currents through the same thin metal circuitry, thereby creating the ability to combine the superior technical advantages of photonics and electronics on the same chip. Thus development of chip-scale electronics and photonics has led to remarkable data processing and transport capabilities that permeate almost every facet of our lives.

Plasmonics is an exciting new device technology that has recently emerged. 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.

II. WHAT IS PLASMONICS?

Definition: A technology that squeezes electromagnetic waves into minuscule structures may yield a new generation of superfast computer chips and ultrasensitive 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.

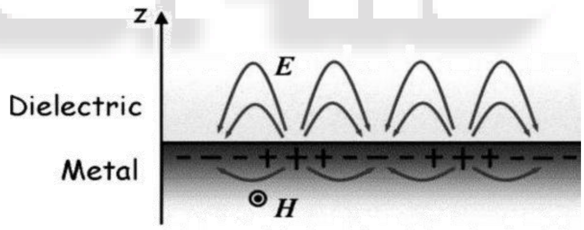

Fig. 1: Movement of Electrons

The ever-increasing demand for faster information transport and processing capabilities is undeniable. Our data-hungry society has driven enormous progress in the Si electronics industry and we have witnessed a continuous progression towards smaller, faster, and more efficient electronic devices over the last five decades. The scaling of these devices has also brought about a myriad of challenges. Currently, two of the most daunting problems preventing significant increases in processor speed are thermal and signal delay issues associated with electronic interconnection.

Optical interconnects, on the other hand, possess an almost unimaginably large data carrying capacity, and may offer interesting new solutions for circumventing these problems. Optical alternatives may be particularly attractive for future chips with more distributed architectures in which a multitude of fast electronic computing units (cores) need to be connected by high-speed links. Unfortunately, their implementation is hampered by the large size mismatch between electronic and dielectric photonic components. Dielectric photonic devices are limited in size by the fundamental laws of diffraction to about half a wavelength of light and tend to be at least one or two orders of magnitude larger than their Nano scale electronic counterparts. This obvious size mismatch between electronic and photonic components presents a major challenge for interfacing these technologies. Further progress will require the development of a radically new chip-scale device technology that can facilitate information transport between Nano scale devices at optical frequencies and bridge the gap between the world of Nano scale electronics and micro scale photonics.

III. COMPONENTS OF PLASMONICS

There are two main components of plasmonics:

1) Surface Plasmon (sp) Polaritons
2) Localised Surface Plasmons(LSP)

In Fig2 SPs are associated with surface charge oscillation having frequency almost equal to light. The energy required to receive and send a SP pulse can be less than that needed for the electric charging of metallic wire. 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 .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.

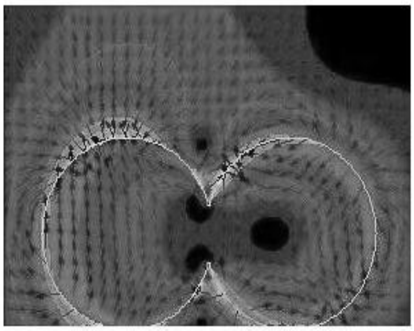

Fig. 2: Localized surface Plasmons

IV. FEATURES OF PLASMONICS

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 localized 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 Nano scale wires (called interconnects) carrying information from one part of a microprocessor to another with a high bit rate. Surface Plasmons can be excited on a flat nano-film, Nano strip or other shaped nanoparticles such as Nano sphere, Nano rod, and nanotube and Nano star. When nanoparticles are used to excite surface Plasmons by light, these are known as localized 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 nanometers. 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 Nano scale plasmonic structures that could replace purely electronic circuits containing wires and transistors. Plasmonic circuits would be even faster and more useful if researchers could devise a "plasmonster" switch--a three-terminal plasmonic device with transistor like properties.

V. PLASMONICS APLLICATIONS

A. 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 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.

B. 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 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, 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.

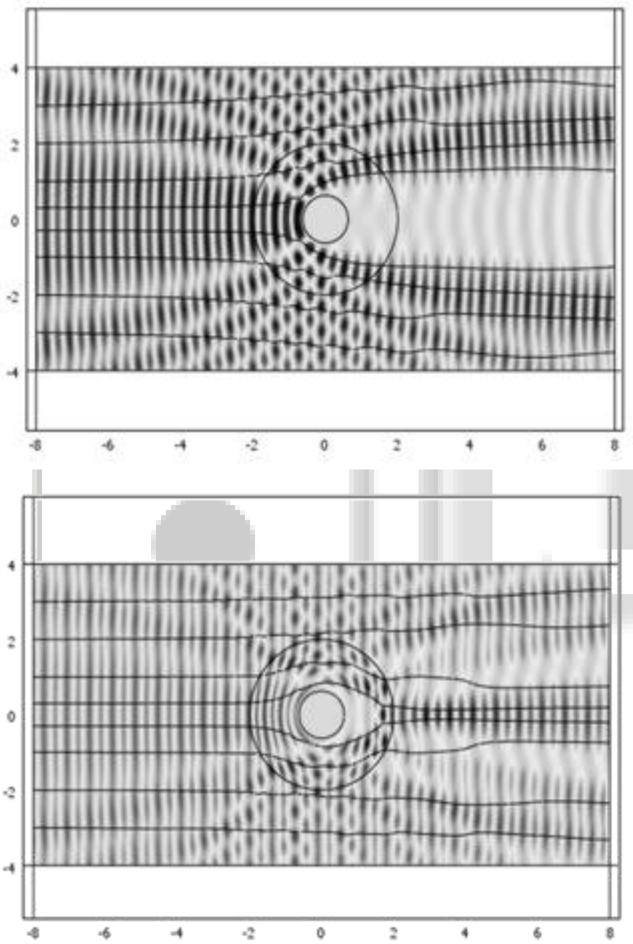

Fig. 3: Invisibility cloaks

Cloaking simulation in two dimensions:

1) The black disc blocks the light coming from the left and reflects it back, leaving a shadow towards the right (green/yellow).
2) The surrounding ring of cloaking material guides the light around the disc and thereby fills in the shadow.

C. 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.

D. Cure for Cancer:

The potential uses of plasmonic devices go far beyond computing**.** 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 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.

E. 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.

F. Biosensors:

1) Plasmonics has also been used in biosensors. When a particular protein or DNA molecule rests on the surface of a plasmon-carrying metallic material, it leaves its characteristic signature in the angle at which it reflects the energy. Currently the biggest application for Plasmons is in gold-coated glass biosensors, which detect when particular proteins or DNA are present - the bio-matter changes the angle at which light hitting the surface produces the most intense Plasmons.
2) Drawing blood is a daily reality for most people with diabetes. And while checking glucose levels probably isn't the worst part of the disease, it's such a pervasive nuisance that someone from nearly every scientific discipline has tried to invent a better way to

do it. They've pasted transdermal 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 detect 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.

G. Nano particles Inspire Solar Cells:

As demand grows for greener power generation and energy conservation, how can renewable technologies take on the might of goliaths of the fossil fuel industry?

In the case of thin-film solar cells, the weapon of choice comes in the diminutive form of metallic nanoparticles. Thanks to a combination of the resonant plasmonic properties of metallic nanoparticles with thin-film photovoltaic technology, a new generation of plasmonic solar cell has evolved with similar performance to silicon cells but at potentially a fraction of the cost.

Today, plasmonic solar cells are emerging as promising candidates amongst many solar energy technologies spurring continuing research to improve device performance. One leading research group in this area is based at the Centre for Sustainable Energy Systems at the Australian National University (ANU) who are working alongside other principal groups led by Harry Atwater and Albert Polman at Caltech, California, US and the FOM-Institute, AMOLF, the Netherlands, respectively. The group at ANU measured an enhanced photocurrent attributed to the increased trapping of light scattered into a thin-film silicon cell by silver metal nanoparticles excited at their surface plasmon resonance. Now, leading scientists in the field are looking to drive plasmonic solar cells out of the science of the small into the next big thing in the photovoltaic industry.

H. Plethora of Benefits:

Plasmon waves are of particular interest because these are at 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 microprocessors.

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.

VI. LIMITATIONS

The potential of plasmonics right now is mainly limited by the fact that Plasmons can typically travel only several millimeters before they peter out. 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.

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. FUTURE DIRECTIONS

As highlighted in the review, plasmonic components are rapidly evolving from discrete, passive structures towards integrated active devices. Such integrated active devices could revolutionize the bandwidth, speed, size, cost, power requirements of modern computational networks, enabling more efficient solutions to increasing complex 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. Plasmonic switches required for this are under development. Rotaxanes molecule is being used for this purpose. Change in shape of molecule is the principle of this molecular switch.

VIII. 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. The future challenge may be (a) developing high-gradient accelerators of charged particles (table-top colliders), and (b) designing novel nanostructures that will contribute to Nano scale optical imaging and spectroscopy of chemicals and biomolecules.

REFERENCES

[1] Articles from website http://www.sciencedaily.com
[2] Plasmonic technology and its applications by Dr. S. S. Verma, professor in Dept of Physics, SLIET, Longolwal, Punjab.
[3] Plasmonics, the next chip-scale technology – Rashid Zia, Anu Chandran and Geballe Laboratory for Advanced Materials, Stanford University, Stanford, California USA
[4] Fundamentals and applications of Plasmonics by Dr. Stephen Maier
[5] Plasmonics Promises Better Biosensors - IEEE Spectrum

