# Plasmonic Devices and Nanocircuits

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## Abstract

Plasmonics is an exploding new field of science which aims to mould the flow of light at the nanoscale using metals. Group IV photonics has seen tremendous recent progress in the development of high performance light sources, waveguides, modulators, and detectors. I will discuss new opportunities at the interface between these fields.

**Keywords :** Plasmonics, Si nanophotonics, Antennas, Detectors, Sources, Modulators

## 1. Introduction to plasmonics

The field of optics has a long and colorful history and by now the development of advanced optical structures has enabled tremendous control over the propagation and manipulation of light waves. This control is utilized in many important technological applications, including optical microscopy, solar cells, efficient solid state light sources that could replace conventional light bulbs and plays an important role in biotechnology, medicine, and the modern day telecommunications industry. Until recently, it was thought that the manipulation of light was limited by the fundamental laws of diffraction to relatively large, wavelength scale (about 1 µm) components. Plasmonics is an exploding new field of science and technology in which the flow of light can be molded at the nanoscale using metallic nanostructures. This newly found ability is rapidly impacting every facet of optics and photonics and is enabling a myriad of exciting new technologies.

At the origin of the unique behavior of metals are the easily accessible collective electron excitations, known as surface plasmons [1]. These excitations can be understood by realizing that a piece of metal can often be described as a box filled with a gas of negatively charged electrons. Similar to sound waves in a real gas, metals exhibit plasmon phenomena, i.e. density waves in the electron gas. When these electron density waves propagate along the surface of a metal they are strongly coupled to oscillating electromagnetic fields (i.e. light) and termed surface plasmon-polaritons (SPPs). Because of this coupling, SPPs are often treated as a special kind of light wave that can propagate along metal nanostructures. An SPP is pictorially illustrated in figure 1, with its oscillating charges (+ and **-**) and electric (*E*) and magnetic (*H*) light fields.

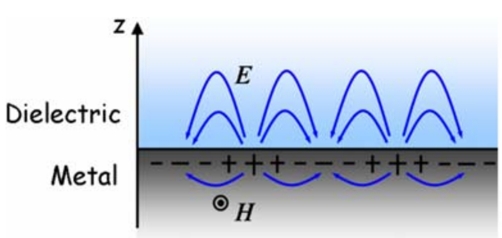


*Figure 1. Surface plasmon-polariton (SPP) propagating along the interface of a metal and a dielectric (e.g. glass or air). From an engineering standpoint a SPP can be viewed as a special type of light wave propagating along the metal surface. Their electromagnetic field intensity is highest at the surface and decays exponentially away from the interface.*

The notion that the optical mode diameter of SPPs can be significantly smaller than the wavelength of light, has generated significant excitement and sparked the dream that *one day we will be able to build optical tools and photonic devices that can fully exploit the nanoscale control afforded by metallic nanostructures and dramatically change the face of optics.*

## 2. Key opportunities for plasmonics

Recent developments in Plasmonics have demonstrated that many photonic devices and optical processes may be scaled to the nanoscale [2-4]. Using some recent examples from our group, I will show how many plasmonics applications make use of at least one of two unique properties of metals. One special property of metals is that they can perform simultaneous electronic and optical functions. It is well-established that metals are the materials of choice to carry electronic signals because of their high conductivity. More recently, it was found that they are also ideally suited for transport of optical signals based on their plasmonic properties. Based on this finding, a number of research groups set out to determine whether the metallic interconnects and waveguide structures on chips can be used to transport and actively manipulate electrical and optical signals simultaneously and thereby greatly enhance the performance of computers. It is important to realize that current silicon-based integrated circuit technology is already capable of making nanoscale metallic structures such as the copper and aluminum interconnects that route electronic signals between the transistors on a chip. This mature processing technology can thus also be used to our advantage to integrate future plasmonic devices with their semiconductor and dielectric photonic counterparts.

The second unique property of metals is that they can concentrate light and manipulate it at the nanoscale. This is impossible with dielectric (e.g. glass-based) optical components, which are limited in their size by the fundamental laws of diffraction. It turns out that even a simple spherical metallic particle can concentrate light to the nanoscale. A metal particle operates much like miniature version of a radio antenna that can effectively capture and concentrate radio waves. The time-varying electric field associated with light waves can exert a force on the gas of negatively charged electrons in a metallic nanostructure and drive them into a collective oscillation. At specific optical frequencies this oscillation is driven resonantly and can result in a very strong charge displacement and associated field enhancement around the particle. Currently, nanoscale optical antennas and resonators are engineered to produce large light intensity enhancements in nanoscale volumes [5,6]. Such high degrees of field concentration are currently finding applications in miniature, low-power modulators and ultra-fast detectors with enhanced light-matter interaction that rely on high field intensities and\or small mode volumes [7-9]. In reverse, antenna structures and plasmonic waveguides can also aid in enhancing the emission efficiency and directionality from deep subwalength, light-emitting nanostructures [10-13]. This notion enables new structures that allow for efficient charge injection by the same metals that perform a photon-extraction function. It is clear that Plasmonics is currently moving in many new directions and could provide enhancements in some performance parameters for group IV photonic devices. I will provide my personal assessment of the limitations and most exciting future opportunities for the field.

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