Current Research

Amitabh Ghoshal

I am currently doing research in the field of surface plasmon nanophotonics. In order for computer processers and other chips to work faster, the devices on the chips must get smaller. Reducing the size of the devices and the distances between them results in fundamental limitations of speed and heating. Optical devices have the potential to overcome these limitations because optical signals have very small heating losses. One of the possible solutions is using optical signals carried by surface plasmons. My research involves the design, fabrication, characterization, and analysis of plasmon based devices.

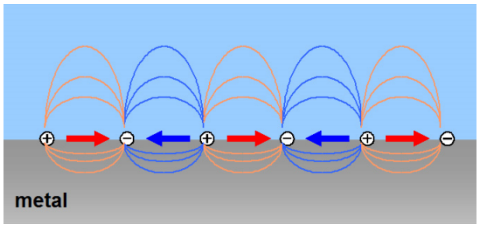

Figure 1. A schematic of what a surface plasmon travelling along a metal surface might look like.

The field of surface plasmon photonics thrives due to the optical properties of metals at the nanoscale (10 nanometers = 1/100,000th of a millimeter) that allow for the construction of optical devices with properties that differ from metal devices in the macro scale. Plasmons are collective oscillations of electrons. Metals have a large number of free-electrons in them, which is why metals conduct electricity well. Plasmons can propagate along the sea of electrons in a metal, near the surface, much like waves near the surface of an ocean. Figure 1 shows a schematic of what a surface plasmon wave might look like at an instant in time. The minus (–) signs represent areas where there is a large density of electrons, and the plus (+) signs represent areas where there is a lower density of electrons. Electrons are charged particles, and charged particles move in an electric field. Since light is a wave that is an oscillating electro-magnetic field, plasmons can be excited by light under specific conditions.

As a result of the optical properties of the metal, the wavelength of the surface plasmon is shorter than that of light of the same color (or frequency). This makes it difficult to excite surface plasmons with light, in the same way that it is difficult to walk quickly down steps that are not spaced to match your stride. However, it may be possible to excite surface plasmons efficiently using the unique properties of metal nanoparticles.

Along with extended metal surfaces, plasmons also exist on metal nanoparticles. Collective electron oscillations in a metal can be localized by limiting the shape of the material. For example, the electrons in a metal nanoparticle can oscillate collectively, much like water sloshing in a tumbler. Figure 2 shows a schematic of what such an oscillation might look like at an instant in time. As in Figure 1, minus signs (–) represent a high density of electrons, and the plus (+) signs a low density of electrons, and the arrow represents a collective movement of the electrons in the particle.

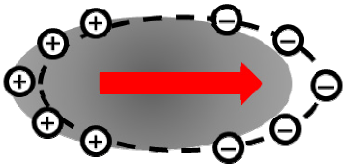

Figure 2. A schematic of what electron oscillations localized on a nanoparticle might look like at an instant in time.

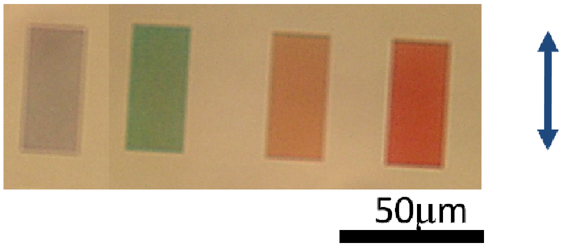

Figure 3. A microscope image of silver nanoparticle arrays. The black scale bar is 50 microns (1 micron = 1/1000th of a millimeter). The sample was fabricated using electron-beam lithography.

Nanoparticles (particles of size approximately 1/20,000th of a millimeter) can be made much smaller than the wavelength of light (the wavelength of visible light is approximately 1/2000th of a millimeter). Arrays of metal nanoparticles, with the nanoparticles spaced by the wavelength of the surface plasmon, can be used to excite surface plasmons on a metal surface. A microscope image of four nanoparticle arrays is shown in Figure 3; the individual nanoparticles cannot be seen. From left to right are dense arrays of silver nanoparticles of different shapes – the arrays have elongated particles that have sides in the ratio 1:1, 1:2, 1:3, and 1:4 from left to right, with the longer side along the vertical direction. The bright background is an underlying silver film on which surface plasmons can be excited. The direction of the oscillation of the electric field of the illumination light (polarization) is shown by the blue arrow on the right. As a result of the different particle shapes, the nanoparticles scatter light of different colors or wavelengths ranging from blue scattering by the left-most array to red scattering by the right-most array.

My research is focused on how to use such nanoparticle arrays to excite surface plasmons most efficiently. I am studying how the nanoparticle shape, volume, distance from the metal surface, and array spacing affect the efficiency of surface plasmon excitation. To understand the underlying physics of the nanostructures, I have designed and set up simulations of such nanoparticle arrays and found that the excitation efficiency of surface plasmons depends on the shape and volume of the nanoparticles. Reflectivity measurements (where the relative efficiency of reflection of different colors of light is measured) on similar nanoparticle arrays have revealed interactions between the particle shape and the array spacing, both of which must be optimized for efficient excitation of surface plasmons. I have had the opportunity to share these and other insights with the research community through journal publications and conferences presentations.

The results provide an understanding of the physical mechanisms underlying excitation of surface plasmons. Such understanding paves the way for designing highly efficient surface plasmon excitation structures resulting in minimization of energy lost, and consequently energy consumed. This is a first and crucial step towards the development of future plasmon based devices.