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Plasmons: A Minireview

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Abstract

Plasmons, quantum of plasma oscillations, are excited electrons in metals when subjected to sunlight or Vis-IR laser, which gives a wave-like collective oscillation of the surface density charges. Metal-insulator-metal -MIM devices can convert the infrared and visible light into electric current via surface plasmons. Some existent devices for such conversion are nominated and the principal problem to be solved is presented. Plexcitons and silver nanoparticles combined with graphene amazing properties are some of future ways to enhance the plasmonic possibilities.

Keywords: Surface plasmons; MIM; Plexcitons; Graphene

Mini Review

The conversion of light to electric power started in 1968, inspired by receiving antenna used for converting electromagnetic energy into direct current (DC) electricity (rectenna). The optical antennas can turn electromagnetic radiation in the visible domain, such as radio antennas turn it in sounds. In order to be applied in the solar cells, the broadband antennas can be used for direct conversion of solar energy to DC electric power. The photovoltaic (PV) solar cells are not the only devices which convert the light into electricity, some other devices can perform the same light-to-electricity conversion, for example solar-thermal collectors and rectennas. Several metallic nanostructures are known with optical effect in the visible/near-infrared wavelength domain, such as: whisker diodes or Schottky diodes. A lot of work was performed to extend this concept to visible frequencies (1000THz), leading to the obtaining of the metal-insulator-metal (MIM) diodes for rectification devices, the first patent being attributed to Marks [1].

Some of the most efficient photovoltaic cells use several semiconductors comprising expensive elements such as gallium and indium. For lowering fabrication costs the high-efficiency plasmonic layers can be conjunct with low-cost semiconductors meaning some metal oxides. In such way the plasmonic nanostructures are less expensive and present optical properties precisely tailored by changing their shape [2].

In a recent paper, authors reported a new device for infrared (IR) and visible light conversion to electric current with the aid of surface plasmons in a metal-insulator-metal (MIM) device [3]. Plasmons represent the common excitation of electrons in metals when subjected to sunlight or Vis-IR laser, which gives a harmonic oscillation of the surface charges identical to waves. The scattered light can be registered by spectrometers, which record light wavelengths [4].

The MIM device's design is close to the rectenna one. The difference consists in the wavelength of operating light, since rectennas operate with long-wavelength rays such as microwaves and radio, and the MIM device with an infrared to visible spectrum. When the MIM device is exposed to light, the photons are absorbed by the top and bottom metal layers. Each absorbed photon excites a metal's electron to higher energy state and it will be named "hot electron." Under half of these hot electrons can arrive at the metal-insulator interface and will be collected by the opposite metal layer. It must be noted that photon absorption in the two metallic layers produces opposite currents, so an external DC current cam be realised only if different absorptions are performed by the two metallic layers [3].

Wang and Melosh proposed the use of a prism to excite surface plasmons (SPs) on the surface of the two metallic layers. The SPs create higher concentration of hot electrons in one electrode by interaction with the focalised light. The SP efficiency is related to some features, namely the thickness of the layers, the type of metal, and the wavelength of the incident light. A metal-insulator-metal device was proposed to produce energy through plasmon absorption via surface plasmon excitation using the spatial confinement of electron excitation. Plasmons excited in the upper layer are absorbed and give high concentration of hot electrons which penetrate the insulating layer, producing electric current. The theoretical power conversion efficiency is almost 40 times greater than in the case of direct exposure on a broad spectrum of visible to IR domain [3].

The metallic optical antennas can collect part of the photon energy in a wavelength domain of hundreds of nanometers. Major technological problems lower yet the performance of optical devices in infrared and visible wavelength and one of the most important is that metals are not perfect conductors. The main problem is that the electrons present an increasing oscillation amplitude as well as an increasing phase lag when the frequency increases. If the phase lag is near 90^o the oscillation amplitude reaches a maximum and is only limited by the internal (ohmic and radiation) damping of the material. This amplitude is the surface plasmon resonance; for some metals (gold, silver, copper) in metal-insulator-metal (MIM) structures, the surface plasmon resonance is close to the visible domain. Plasmon resonances cannot appear in the case of perfect conductors because no phase lag exists between excitation and response for such materials. The presence of plasmon resonance is than characteristic for optical frequencies and lead to some response of antenna systems in this frequency domain, such as higher Ohmic losses than in the radiofrequency domain [1].

The plasmonic-based photovoltaics not so high efficiencies can be related to either essential physical limitations or not optimal designs. Plasmonic devices consisting of a plasmonic gold nanowire over a layer of titanium dioxide were obtained [2]. One setup contains gold directly on semiconductor, and one other implies one layer of titanium among the gold and the titanium dioxide. The first setup lead to a Schottky barrier which permitted only hot electrons to pass from the gold to the semiconductor and the second one all the electrons. This demonstrated that hot electrons were conducted by one plasmonic mechanism named field-intensity enhancement [2].

Some researchers demonstrated that graphene layers broadened the gold surface plasmon response – and diminished its lifetime – by transport of hot electrons [4]. Acting as an electron acceptor, the graphene speeds up the damping of the plasmons. The distinction between the quartz and graphene answer helps to calculate the electrons' change time [4].

The scientists from UC San Diego, MIT and Harvard University designed a new type of energy-moving particles, named "topological plexcitons," in order to enhance the exciton energy transfer (EET) that can higher the energy in solar cells and photonic devices. These particles are plasmons (surface electrons oscillations) united with excitons (excited electrons with their hole) and lead to enhanced energy flows in EET. The energy changes between matter and light can appear between light and metal (plasmon) and light and molecule (exciton). When the energy exchange is very fast, the individual plasmons and excitons lies together as hybrids named plexcitons [5].

The plexcitons increase the energy transfer length but its direction is uncontrolled, which diminished serious gains. One solution found was to design "topological plexcitons" on materials named "topological insulators" which are insulators internally, but surface conductors, so electrons will displace on the surface only. This way "plexcitonic" switches can be created for new types of solar cells to improve their efficiency [5].

The devices named tunnel-ling diode or MIM diode can provide zero-bias rectification, using two metals with different properties. This could lead to the obtaining of a passive rectenna system. These MIM diodes have not been used in the GHz-frequency domain because of the nano-fabrication problems [6]. Silver nanoparticles deposited on semiconductor substrate and covered with a-Si thin films showed increased optical absorption in NIR region. The investigations demonstrated that this increased optical absorption was related to the plasmon resonance at the silver nanoparticles, which was shifted to higher wavelength due to the high refractive index layers [7].

Only future will demonstrate the limitation of plasmons and plasmonic devices in perhaps not yet known domains of science and technology, but for now the field of applications is growing every year.

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