Researchers clear the way for fast plasmonic chips

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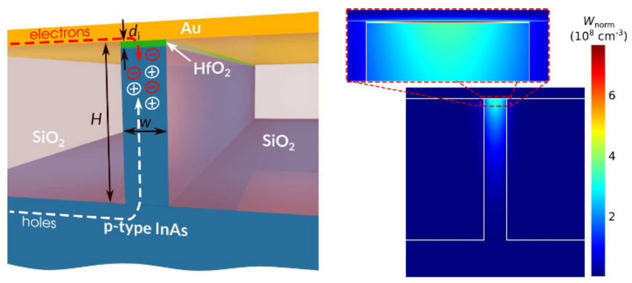


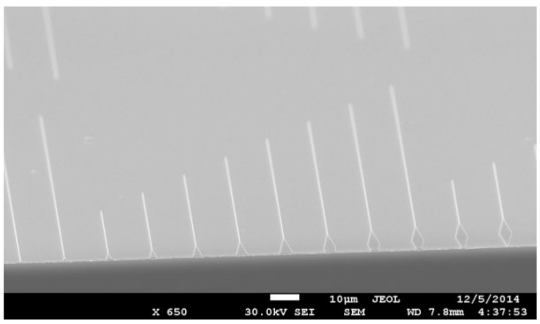
Schematic of the electrically pumped active hybrid plasmonic waveguide and energy density distribution of the surface plasmon field. Credit: Moscow Institute of Physics and Technology

Researchers from the Laboratory of Nanooptics and Plasmonics at the MIPT Center of Nanoscale Optoelectronics have developed a new method for optical communication on a chip, which will could decrease the size of optical and optoelectronic elements and greatly increase computer performance. According to an article published in *Optics Express*, they have proposed a way to completely eliminate energy loss of surface plasmons in optical devices.

"Surface plasmon polaritons have previously been proposed as information carriers for optical communication, but the problem is that the signal is rapidly attenuated propagating along plasmonic waveguides. Now, we have come very close to the complete solution of this problem. Our approach clears the way for the development of a new generation of high-performance optoelectronic chips," says Dmitry Fedyanin, the head of the research.

Modern electronics is based on the use of electrons as information carriers, but they have ceased to meet the contemporary requirements: Standard electrical copper wires and channels on chips cannot transfer information with speeds sufficient for modern microprocessors. This currently hinders microprocessor performance growth; hence, the implementation of new groundbreaking technologies is required to maintain Moore's law.

Transition from electrical to optical pulses can solve the problem. The high frequency of light waves (hundreds of terahertz) allows transferring and processing more data, and offers the possibility of increasing performance. Fiber optic technologies are widely used in communication networks, but the use of light in microprocessors and logical elements faces the problem of diffraction limit, since the size of waveguides and other optical elements cannot be significantly smaller than the light wavelength. These are micrometers for near-infrared radiation used in optical communications, which don't meet the requirements of contemporary electronics. Logical elements of standard contemporary processors are dozens of nanometers in size. "Optical electronics" can become competitive only if light is "compressed" to this scale.



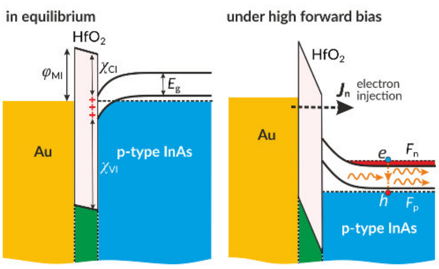
Nanoscale plasmonic waveguides under the scanning electron microscope. Credit: Moscow Institute of Physics and Technology

Overcoming the diffraction limit is possible by using surface plasmon polaritons, which are collective excitations that emerge due to interaction between photons and electron oscillations on the boundary between a metal and an insulator. They are also called quasi-particles, because they are quite similar to standard particles such as photons or electrons. Unlike three-dimensional light waves, surface polaritons "hold on" the boundary between two media. This offers the possibility of switching from conventional three-dimensional optics to two-dimensional optics.

"Roughly speaking, a photon occupies a certain volume in space, which is of the order of the light wavelength. We can 'compress' it, transforming it into a surface plasmon polariton. Using this approach, we can improve the integration density and reduce the size of optical elements. Unfortunately, this brilliant solution has its flip side. For the surface plasmon polariton to exist, a metal, or more specifically, an electron gas in the metal, is needed. This leads to excessively high Joule losses similar to those observed when current is passed through metal wires or resistors," says Dr. Fedyanin.

According to Dr. Fedyanin, the surface plasmon energy drops a billion times at distances of around one millimeter due to absorption in the metal, which makes the practical implementation of surface plasmons pointless.

"Our idea is to compensate the surface plasmon propagation losses by pumping extra energy to surface plasmon polaritons. It should be also noted that, if we want to integrate plasmonic waveguides on a chip, we can use only electrical pumping," explains the researcher.



Operating principle of the proposed electrical pumping scheme. Credit: Moscow Institute of Physics and Technology

Together with his colleagues Dmitry Svintsov and Aleksey Arsenin from the Laboratory of Nanooptics and Plasmonics, he has developed a new method of electric pumping of plasmonic waveguides based on the metal-insulator-semiconductor (MIS) structure and carried out its simulations. The results show that the passage of relatively weak pump currents through the nanoscale plasmonic waveguides can fully compensate the surface plasmon propagation losses. This means that it is possible to transmit a signal over long distances (in chip standards) with no losses. At the same time, the integration density of such active plasmonic waveguides is an order of magnitude higher than that of photonic waveguides.

"Working in optoelectronics, we always need to find a compromise between optical and electrical properties, whereas in plasmonics, it is almost impossible, since the choice of metals is limited to three or four materials. The main advantage of the proposed pumping scheme is that it doesn't depend on the properties of the metal-semiconductor contact. For each semiconductor, we can find an appropriate insulator, which achieves the same efficiency level as in double-heterostructure lasers. At the same time, we are able to maintain the typical plasmonic structure size at a level of 100 nanometers," says Fedyanin.

The researches note that their results are awaiting an experimental verification, but the key difficulty has been eliminated.

More information: Svintsov, D. A., Arsenin, A. V., & Fedyanin, D. Y. (2015). Full loss compensation in hybrid plasmonic waveguides under electrical pumping. *Optics Express*, 23(15), 19358. DOI: 10.1364/oe.23.019358

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