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Plasmonics - a Technology for Microscale High-Speed Integrated Optics

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Plasmonics is increasingly attracting the attention of the optical community [1-4]. The new field promises novel ultra-compact devices in combination with speed only limited by the RC constants of the attached driver circuits. This talk will review key aspects of plasmonics and will discuss opportunities and challenges of plasmonic communications.

Plasmonic communication is an emerging field that promises the generation, processing, transmission, sensing and detection of signals at optical frequencies along a surface of a tiny metal. The term "plasmonics" has been brought to the spotlight by H.A. Atwater and other pioneers in anticipation for an entirely new class of devices with ultra-compact dimensions operating up to highest bandwidths. Meanwhile more than 50'000 scientific articles pop up when searching the web for "plasmonics".

In the field of plasmonics it is not photons that carry the information but mostly surface plasmon-polaritons (SPPs). SPPs are electromagnetic waves coupled to charge density oscillations at the interface between a material of negative and a material of positive permittivity (e.g., a metal and an insulator, respectively). These electrons then oscillate at said optical frequency. In plasmonics the signal processing is performed on the SPP rather than the photons. After signal processing has been performed the SPPs are converted back to the optical domain.

While plasmonics is not a solution to all integrated optical applications, plasmonics has a strong case for devices

- Featuring active functionalities such as phase and amplitude modulation
- That require ultra-compact size
- That rely on ultra-fast speed and
- That should operate across a broad spectral operation

Challenges that plasmonics has to deal with are

- High losses and
- High resolution in fabrication

Plasmonics thus is a case for active devices with tight requirements on the footprint that need to operate at highest speed.

To keep losses low, plasmonic devices should be as compact as possible. I.e. if active photonic components are used they should feature the largest possible nonlinearity such that operations can be performed in micrometer rather than in millimetre long devices. Fortunately, plasmonics helps in achieving high nonlinearities. This is because plasmonic modes can be confined to dimensions way below diffraction limit and thereby increase nonlinear efficiencies. Another challenge are the lithographic resolutions needed to fabricate plasmonic structures. Feature sized below 20 nm are often needed. Currently, this is the domain of electron-beam lithography – a technology that scales poorly but that may soon be replaced by the next generation of scalable extreme UV lithography.

As an example we discuss the plasmonic Mach-Zehnder modulator depicted in Fig. 1, [5]. The modulator comprises of three sections. In a first section the photonic mode is converted into a plasmon and mapped onto two plasmonic modes that propagate to the left and to the right of metallic signal electrodes. In section 2, the electrodes not only guide the gap plasmons but also form the ground-signal-ground electrodes of a the modulator. Upon applying a voltage onto the signal electrode the refractive indices of the nonlinear electro-optic material in the gap changes. Finally, in the output of section 3 the plasmons are converted back into a photonic mode and - depending on the relative phase-relations - mapped back onto the subsequent silicon wire waveguide or radiated off due to destructive interference. The whole plasmonic waveguide is only 10 m in length and has been shown to operate up to 72 Gbit/s [5]. More recently we have introduce a plasmonic IQ-modulator [6] or demonstrated 100 Gbit/s operation [7]. Also multiple plasmonic modulators have been assembled to form an array on a very dense space for optical interconnect applications [8].

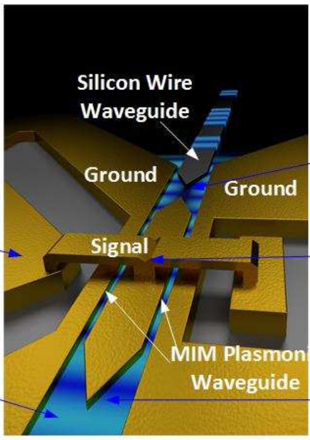

Fig. 1. Plasmonic Mach-Zehnder modulator. The plasmonic interferometer is formed by the metallic island and the metallic contact pads. An electrical signal can be applied to the island via a suspended bridge. [5].

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[1] H. A. Atwater, "The Promise of Plasmonics," *Scientific American,* vol. 296, p. 56.62, 2007.
[2] D. K. Gramotnev and S. I. Bozhevolnyi, "Plasmonics beyond the diffraction limit," *Nat Photon,* vol. 4, pp. 83-91, 2010
[3] M. L. Brongersma and V. M. Shalaev, "The Case for Plasmonics," *Science,* vol. 328, pp. 440-441, 2010.
[4] J. Leuthold, *et al.* ; Plasmonic Communications - LIGHT ON A WIRE. *Optics & Photonics News*. 28-35. May 2013
[5] C. Haffner, *et al.*, "All-plasmonic Mach–Zehnder modulator enabling optical high-speed communication at the microscale," *Nature Photonics,* vol. 9, pp. 525-528, Aug. 2015.
[6] C. Haffner, W. Heni, Y. Fedoryshyn, B. Baeuerle, A. Josten, Y. Salamin*, et al.*, "Ultra-compact plasmonic IQ-modulator," in *European Conference on Optical Communication (ECOC)*, 2015, pp. 1-3.
[7] W. Heni, *et al.*, "108 Gbit/s Plasmonic Mach-Zehnder Modulator with > 70-GHz Electrical Bandwidth," *Journal of Lightwave Technology,* vol. 34, pp. 393-400, 2016.
[8] C. Hoessbacher, *et al.*, "Optical Interconnect with Densely Integrated Plasmonic Modulator and Germanium Photodetector Arrays," in *Optical Fiber Communication Conference*, Anaheim, California, 2016, p. Th1F.6.