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Plasmonics – High-Speed Photonics for Co-Integration with Electronics

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Abstract

Plasmonics is presented as a next-generation photonic technology for high-speed optical communications. It offers highest-speed modulators and detectors that are compact, cost- and energy-efficient, and compatible with CMOS electronics. We show how co-integration of plasmonics and electronics has enabled the fastest hybrid transmitter (222 GBd) or the world's first 120 GBd monolithic transmitter.

1. Introduction

Next-generation optical interconnects have to overcome the capacity gap between electronics and photonics. Current solutions are sufficient for links of tens or hundreds of Gb/s, but Tb/s will soon be required in datacentres [1, 2]. Hence, parallelisation and high line data rates are of particular need. A compact, fast, cost- and energy-efficient platform for electronic-photonic co-integration can achieve this goal [3].

Currently, a variety of photonic technologies for transmitters and receivers based on indium phosphide (InP) photonics [4-7], lithium niobate (LNB) photonics [8, 9], silicon (Si) photonics [10-12] or plasmonics [13-23] are being investigated, while no leading technology could yet establish itself. Possible reasons for this are limited device performance, technology costs, manufacturing maturity or challenges in co-integration with electronics. For example, Si photonics is already a mature technology with expected yearly revenues of 4 billion USD in 2025 [24]. Yet, its active components have large footprints, which renders scaling to higher speed a challenge – even though monolithic integration using specialised silicon-based CMOS photonics has been shown [25]. In contrast, plasmonics can easily reach highest speeds as the photonic technology with largest bandwidth [20] and ultra-low energy consumption [19]. Maturity and low costs in production can be achieved by combining plasmonics with well-developed photonics for passive components while co-integration with electronics has already been shown in hybrid [22] and monolithic [23] proof-of-concept transmitter demonstrations.

In this paper, an overview over the plasmonic technology for optical communication is given. The latest progress in plasmonic modulators and detectors is presented with a focus on the electronic-photonic integration, and the advantages of plasmonics for future optical interconnects are elaborated.

2. Plasmonics – High-Speed Photonics

Due to its unique advantages, plasmonic modulators and detectors might become the key active components in future high-speed optical communication systems for chip-to-chip, short-reach and long-reach scenarios [3].

Plasmonic Modulators

Plasmonics is a versatile high-speed platform offering solutions for phase, intensity and amplitude modulation in advanced Mach-Zehnder (MZ) [13, 22] and IQ [19] configurations. The modulators offer record 222 GBd symbol rate and 400 Gb/s data rate per lane and wavelength. Such high speeds are reached due to an electro-optical bandwidth exceeding 500 GHz [20] enabled by the compactness of plasmonic devices. Both the electrical and optical field are confined to the plasmonic slot filled with an organic [26] or ferroelectric [16] nonlinear electro-optic material. The strong overlap enables efficient modulation and operation at low voltages. This enables low-energy applications [19] at CMOS-compatible voltages [21]. Since plasmonic modulators are not bound to a photonic substrate [14] and can be parallelised on a ultra-compact footprint [18], they offer a flexible Terabit solution for (monolithic) integration with electronics [23].

Plasmonic Detectors

Plasmonic detectors are a high-speed and compact counterpart with substrate flexibility, which enables cost-efficient co-integration [27, 28]. Although the detector technology has not yet reached the maturity of plasmonic modulators, proof-of-concept experiments with germanium [15] and graphene [17] show promising results. An opto-electric bandwidth beyond 110 GHz, a responsivity of 0.5 A/W, and a symbol rate of 100 GBd have been shown on only a few µm^2 footprint.

3. Co-Integration with Electronics

Plasmonics is ideal for co-integration with electronics due its compact dimensions, high bandwidth, CMOS-compatible voltages and ease of parallelisation. Co-integration has been demonstrated in both hybrid and monolithic integration.

Hybrid integration is the state-of-the-art technology for co-integration due its flexibility in electronic and photonic design, fabrication and performance optimisation. Yet, it comes at the price of high manufacturing and testing costs, and interconnection of two chips at the most critical position of highest data rate. This causes degradation in signal quality and eventually limited bandwidth. Nevertheless, an InP electronic and plasmonic transmitter shows record symbol rates of 222 GBd with non-return-to-zero on-off keying [22].

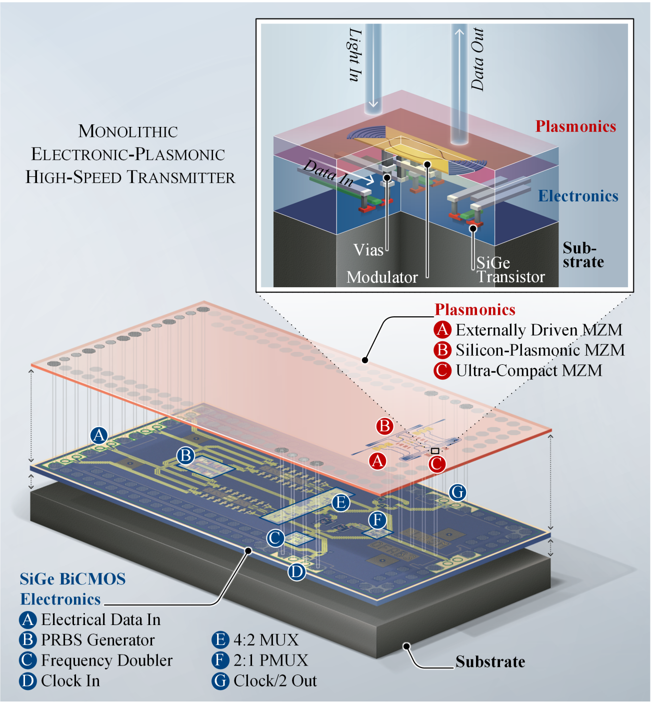

Fig. 1 Monolithic BiCMOS electronic-plasmonic transmitter [23].

Monolithic integration is considered the technology of the future as it combines electronics and photonics on a common substrate, which is expected to significantly reduce costs in manufacturing, assembly and testing. On top, the close proximity will achieve highest signal bandwidth and quality. A monolithic BiCMOS electronic-plasmonic high-speed transmitter has been demonstrated with symbol rates beyond 100 GBd [23]. The monolithic integration has been achieved through co-design of electronic, photonic and thermal performance. Fig. 1 depicts a blow-up of the transmitter chip with the electronic layers for 4:1 power multiplexing and the plasmonic layer for light intensity modulation stacked onto a common substrate. The zoom-in shows how the plasmonic MZ modulator is directly connected to the electronic driver through on-chip vias. Two modulator concepts have been developed – a 120 GBd silicon-plasmonic modulator with photonic circuitry and a 100 GBd ultra-compact plasmonic modulator with 29 × 6 μm^2 footprint. The monolithic approach is expected to reach unprecedented symbol rates beyond this first proof-of-concept demonstration as both BiCMOS electronics and plasmonics are not yet at their speed limitations.

4. Conclusions

Plasmonics offers a future-proof photonic platform for optical communications with high-speed solutions at the transmitter and the receiver. The compactness of plasmonics enables unique features such as high bandwidth, dense parallelisation and co-integration with electronics. Hybrid co-integration showed a record-performance of 222 GBd while the world's first 120 GBd monolithic integration demonstrates the technology's readiness to tackle the optical communication challenges of this decade.

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