Nano Scale Disruptive Silicon-Plasmonic Platform for Chip-to-Chip Interconnection

Initial testing and characterization of plasmonic modulators

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Executive Summary

This document shall incorporate (all) rules procedures concerning the technical and administrative management of the project and is therefore to be updated on a regular basis. Please look at www.navolchi.eu regularly for the latest version.

Change Records

Version	Date	Changes	Author
0.1 (draft)	2013-11-18	Start	Argishti Melikyan
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Introduction

The plasmonic phase modulator with a device length of 34 μm and a metallic slot size of 200 nm is fabricated on silicon on insulator (SOI) platform, where the silicon nanowire waveguides are used as access waveguides [1]. The fabrication procedure is described in Milestone 11, "Fabrication of plasmonic modulator on a SOI platform" and Deliverable 3.4, "Report on fabrication of modulators". Light is coupled into the silicon nanowire using standard diffraction grating couplers. Photonic mode guided through the silicon nanowire subsequently excites the gap surface plasmon polariton mode in the modulator section. We use metallic tapers as photonic-plasmonic mode converters [2]. In the end of the modulator section the plasmonic mode is back converted in photonic mode. Light is coupled out from the chip using second grating coupler.

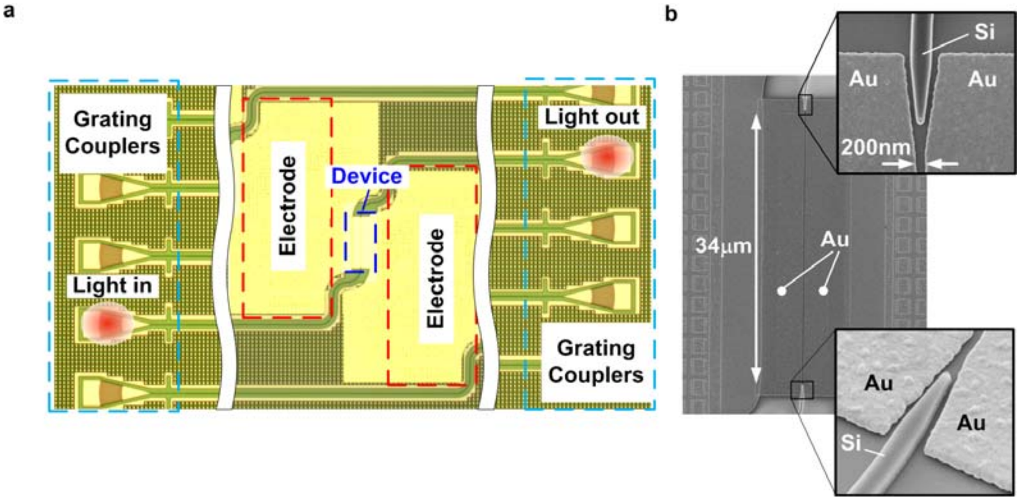

Figure 1 Fabricated plasmonic phase modulator on silicon on insulator platform. (a) Optical microscope image of the device. Silicon nanowire waveguides are used as access waveguides for the plasmonic modulator. Light is launched in and out from the chip using grating couplers. (b) Scanning electron microscope image of the modulator with a length of 34 μm and a slot size of 200 nm. Metallic tapers are used for photonic to plasmonic mode conversion.

Characterization of the fabricated phase modulators is performed at the KIT laboratory and the overview of the results is presented below.

Passive optical characterizations

We used the experimental setup given in Fig. 2(a) for passive optical characterization. Light with from a tuneable laser source (TLS) is coupled into the device using a single mode fibers and a diffraction grating coupler. The transmitted optical power at the output of the device is measured with optical spectrum analyser (OSA). We measured the optical loss of the modulator section by taking an equal-length of SOI strip waveguide as a reference. The fabricated modulators show broadband optical transmission, Fig. 2(b). The average total loss is 12 dB (black solid line), close to the theoretically expected value (blue dashed horizontal line).

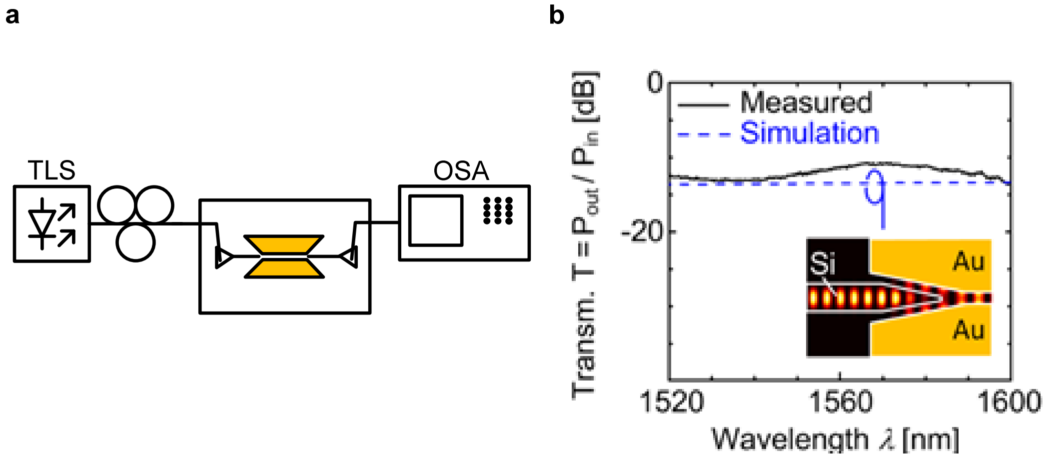

Figure 2 The experimental setup used for passive optical characterization and the transmission spectrum of the plasmonic phase modulators. (a) The experimental setup used for measuring the optical losses of the device. Light from the tuneable laser source (TLS) is launched into the chip and the transmission spectrum is measured at the output using optical spectrum analyser (OSA). (b) The transmission spectrum of the 34 μm long device with a slot size of 200 nm, black solid line. The theoretically expected transmission spectrum is given in the blue dashed line.

Electro-optic characterizations

We characterized the electro-optic frequency response of the devices using the measurement setup illustrated in Fig. 3(a). The device is electrically contacted with a GSG RF Probe. The RF frequency response of the device is studied by driving the modulator with a sinusoidal signal having a frequency in the range $f_m = (1\ldots45)$ GHz and an amplitude of $U = 0.8$ V. The optical carrier with frequency $f_c = \omega_c / (2\pi)$ is phase modulated with a frequency f_m and a phase

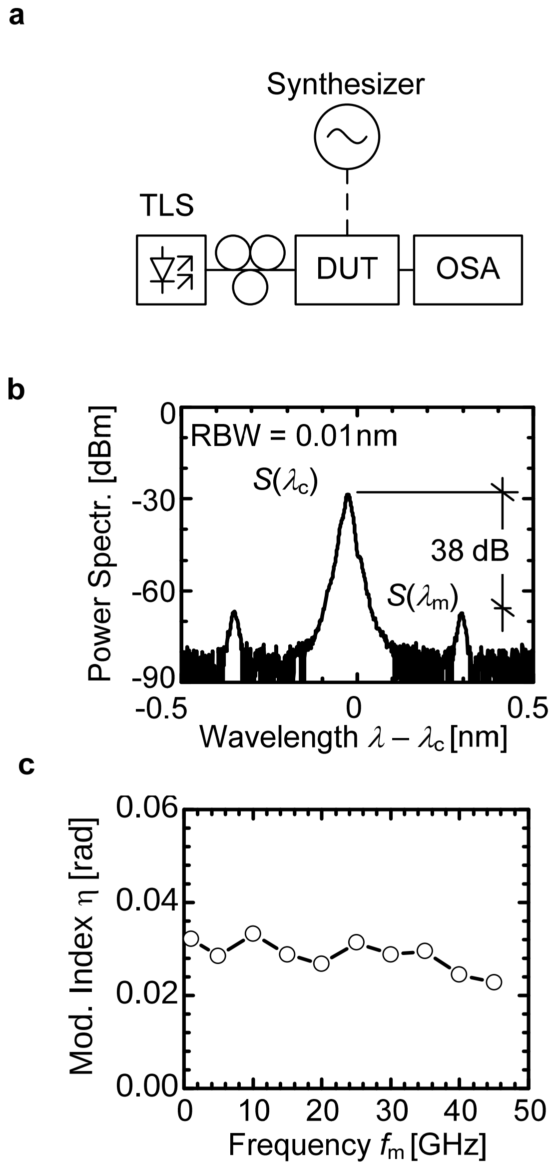

Figure 3 Measured performance of the plasmonic phase modulators. (a) Experimental setup used for measuring the phase modulation index η for various RF and carrier frequencies. Infrared light from the tuneable lasers source (TLS) is sent to the device under test (DUT). The modulator is driven by a sinusoidal electrical signal with an amplitude of $U = 0.8$ V, and the optical spectrum is measured at the output of the chip with an optical spectrum analyser (OSA). (b) Spectrum of 40 GHz RF signal. The power ratio of carrier (frequency f_c) and first side band $S(f_c)/S(f_m)$ (RF modulation frequency f_m) is used for estimating the phase modulation index. (c) Modulation index η versus RF frequency f_m for modulator with a length of 34 μm. The frequency response is flat up to a modulation frequency of at least 45 GHz.

modulation index $\eta \sim U_m$, resulting in an optical signal $\cos(\omega_c t + \eta \sin \omega_m t)$. The carrier has a relative amplitude in proportion to the zeroth-order Bessel function $J_0(\eta)$, and the first sideband has an amplitude in proportion to the first-order Bessel function $J_1(\eta)$. From the ratio of the respective line heights in the power spectrum, $J_0^2(\eta)/J_1^2(\eta)$, one therefore can extract the modulation index η. Fig. 3(b) displays the optical spectrum at the modulator output when driven with a 40 GHz sinusoidal signal U_m with an amplitude of $U = 0.8$ V. We measure the phase modulation index η for each frequency. The driving voltage amplitude is kept constant during the RF frequency sweep by calibrating the electrical power absorbed in a matched load, before the RF probe was connected. The measured phase shift is shown in Fig. 3(c) as a function of the RF modulation frequency up to 45 GHz for modulator with a length of 34 μm. The flat frequency response of the device indicates its potential for high speed modulation. The measured modulation index varies by 7.5 % within this 80 nm wavelength range. An achieved nonlinearity of $r_{33} = 13$ pm/V.

Data modulation experiments

To test the usability of the fabricated modulators in the real systems, we performed data modulation experiments with a data rate of 28Gbit/s. Light with a wavelength of 1550.92 nm is first amplified with an erbium doped fiber amplifier (EDFA). After passing through an optical band pass filter and a polarization controller, light is launched into the chip. The phase of the surface plasmon polariton is then modulated with a PRBS data pattern at the voltage swing of U_{pp} = 7.5V. Resulting BPSK signal at the output of the device is detected using optical modulation analyser (OMA). The measured constellation diagram with its corresponding error vector magnitude (EVM) and bit error rate (BER) is given in the Fig. 4.

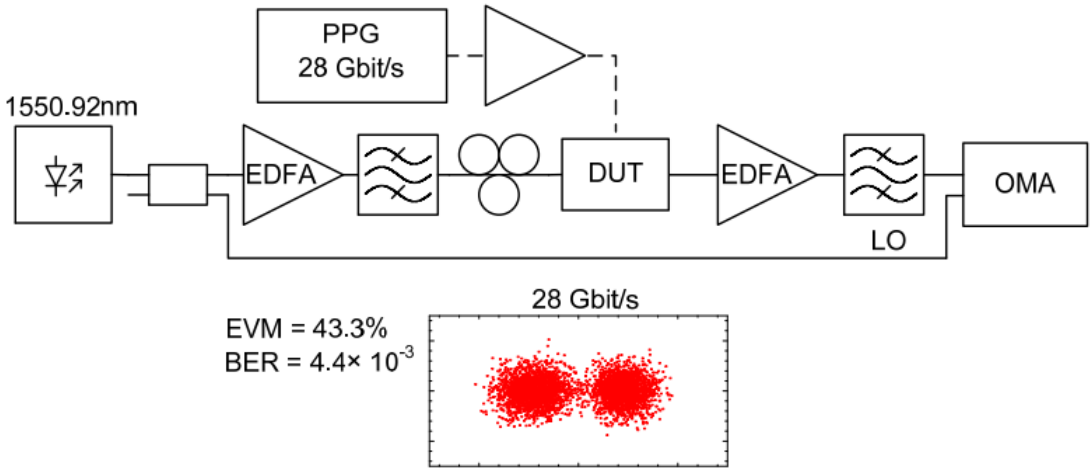

Figure 4 The experimental setup used for modulating the phase of the SPP with a date rate of 28Gibt/s with its corresponding constellation diagram. Resulting phase modulated signal is detected with an optical modulation analyser (OMA). The error vector magnitude and the bit error rate are given in the left side of the constellation diagram.

[1] Melikyan, A., et al., Surface plasmon polariton high-speed modulator, Conf. on Lasers and Electro-Optics (CLEO'13), San Jose (CA), USA, CTh5D.2 June 9–14, 2013. PDP

[2] Pile, D. F. P. and Gramotnev, D. K. Adiabatic and nonadiabatic nanofocusing of plasmons by tapered gap plasmon waveguides. Appl. Phys. Lett. 89, 041111 (2006)