Plasmonic-Organic Hybrid Mach-Zehnder Modulators: Experimental Characterization of Intermodulation Distortions

M. Burla[1,*], C. Hoessbacher[1], W. Heni[1], C. Haffner[1], Y. Fedoryshyn[1], D.L. Elder[2], L.R. Dalton[2], J. Leuthold[1]
[(1)] Institute of Electromagnetic Fields, ETH Zurich, Gloriastrasse 35, Zurich 8092, Switzerland
[(2)] Department of Chemistry, University of Washington, Seattle, WA 98195-1700, United States

Plasmonic organic hybrid (POH) modulators demonstrated ultrafast operation (>170 GHz) [1], with ultra-compact footprints (100s μm^2) and ultra-low power consumption (25 fJ/bit) [2, 3]. Recently, they have also shown strong potential for analog applications, e.g. direct wireless-to-optical conversion of millimeter wave signals [4] and ultrafast optical antenna beamsteering [5]. In analog photonic applications, linearity is a crucial parameter as it directly affects the system spurious-free dynamic range (SFDR). The SFDR is a figure of merit that indicates the minimum and maximum power of the signals that can be handled by the system. It is defined as the ratio P_2/P_1 of input powers for which (P_1) the fundamental output signal power is equal to the noise power and (P_2) the n^{th}-order intermodulation distortion (IMD*n*) power is equal to the noise power [6]. IMD*n* are spurious frequency tones created due to the n^{th} order nonlinearities in the system. Here we report, for the first time, the experimental characterization of the distortions of POH Mach-Zehnder modulators and show their potential for analog applications.

The device under test is a POH Mach-Zehnder modulator (POH-MZM, Fig. 1a), as reported in [3], composed by a silicon strip-waveguide interferometer with one 12.5 µm–long POH phase modulator in each arm. Each phase modulator is realized with a 75 nm-wide slot waveguide (Fig. 1b) [3] filled with the organic electro-optic material DLD164 [7]. The phase modulators are driven in push-pull using a ground-signal-ground (GSG) RF probe configuration. We performed two-tone test experiments to characterize the second- and third-order intermodulation distortions (IMD2 and IMD3), which limit the SFDR in sub-octave and multi-octave conditions, respectively [6].

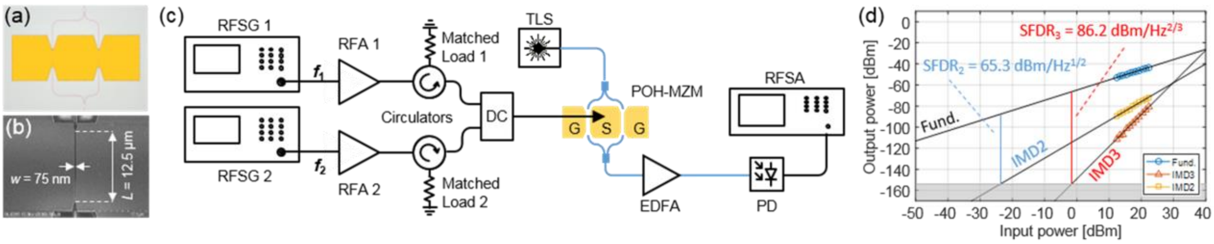

Figure 1. (a) Micrograph of a POH-MZM; (b) scanning electron microscope image of the plasmonic phase modulator slot waveguide in each interferometer arm. (c) Experimental setup for nonlinear distortions tests. (d) Intermodulation distortions for the POH-MZM.

The experimental setup is shown in Fig. 1c. Two tunable RF sources (RFSG) generate RF tones at 900.95 MHz and 901.15 MHz. Note that the test frequencies are only limited by the available passive RF equipment. The signals are amplified by two RF power amplifiers (RFA). Each amplifier output is connected to an isolator, realized by a circulator (0.7-1 GHz) where port 3 is connected to a matched load. Signals at the circulator outputs are combined using a 3 dB directional coupler (DC, 0.5-2 GHz). The signal at the coupler output drives the POH-MZM using a GSG probe. The optical carrier (+10 dBm) is provided by a tunable laser source (TLS). The light is carried on- and off-chip using silicon grating couplers. The optical output of the MZM is amplified using and EDFA and detected with a high-linearity, high power handling photodiode (PD, Finisar XPDV3120R, +13 dBm max. average input power). The RF spectrum at the PD output is measured using an RF spectrum analyzer (RFSA). The POH-MZM is operated in quadrature [6] with zero bias by adjusting the wavelength of the TLS to 1550 nm. The RF input power is swept from 12.4 dBm to 21.4 dBm. The corresponding powers of the fundamental (f_1, f_2), IMD2 (f_1+f_2) and IMD3 ($2f_1$-f_2 and $2f_2$-f_1) tones are measured with the RFSA and reported in Fig. 1d. With a noise floor of -152 dBm/Hz, an SFDR2 of 65.3 $dBm/Hz^{1/2}$ and an SFDR3 of 86.2 $dBm/Hz^{2/3}$ are obtained. The latter is used in broadband (>1 octave) applications, and it is comparable to the value of 89 $dBm/Hz^{2/3}$ obtained using a reference commercial GaAs modulator, and to the value of 90 $dBm/Hz^{2/3}$ achieved in [8] using linearized silicon modulators. The SFDR3 can be further increased by improving the received optical power, e.g. by reducing the optical propagation losses and the fiber-chip coupling losses, which have not been optimized. The presented results indicate that POH-MZM are promising candidates for ultra-compact and ultra-broadband modulators for analog and microwave photonic applications.

References

[1] C. Hoessbacher *et al.*, “Plasmonic Modulator with >170GHz bandwidth demonstrated at 100 GBd NRZ,” *Opt. Express* **25**, 1762, 2017.
[2] C. Haffner *et al.*, “All-plasmonic Mach–Zehnder modulator enabling optical high-speed communication at the microscale,” *Nat. Photonics* **9** (8), 2015.
[3] W. Heni *et al.*, “108 Gbit/s Plasmonic Mach-Zehnder Modulator with >70-GHz Electrical Bandwidth,” *J. Lightw. Technol.* **34** (2), 2016.
[4] Y. Salamin *et al.*, “Direct Conversion of Free Space Millimeter Waves to Optical Domain by Plasmonic Modulator Antenna,” *Nano Lett.* **15** (12), 2015.
[5] R. Bonjour *et al.*, “Plasmonic phased array feeder enabling ultra-fast beam steering at millimeter waves,” *Opt. Express* **24**, 25608, 2016.
[6] C. H. Cox, *Analog Optical Links: Theory and Practice.* Cambridge University Press, 2004.
[7] D. L. Elder *et al.*, "Matrix-assisted poling of monolithic bridge-disubstituted organic NLO chromophores," *Chem. Mater.* **26,** 872 (2014).
[8] C. Xiong *et al.*, "A linear push-pull silicon optical modulator," *OSA Technical Digest (online)*, 2016. p. FM3A.4.