Energy consumption study of reverse-biased modulators in monolithic electronic-photonic technology

S. Hosseini[1]*, M. Cătuneanu[1], R. Henker[2], F. Ellinger[2], K. Jamshidi[1]
[1] Integrated Photonic Devices Lab, Technische Universität Dresden, 01069 Dresden, Germany
[2] Chair of Circuit Design and Network Theory, Technische Universität Dresden, Germany
* seyedreza.hosseini@tu-dresden.de

Electronic Photonic Integrated Circuits (EPIC) technology can be used to realize integrated photonic devices alongside with conventional electronic technology such as CMOS or BiCMOS. There is an alternative approach where photonic and electronic components are fabricated separately and then connected to each other using technologies such as wire bonding, flip-chip bump bonding or through silicon vias (TSV) [1]. The main challenge for the realization of high-speed devices is to realize energy-efficient devices [2, 3]. In this paper, the energy consumption of optical modulators as one of the main components of optical transceiver systems based on both pure photonic technology and EPIC technology are studied and compared. Modulator frequency response is simulated using 3D FDTD full wave commercial simulators (CST Studio). The characteristic impedance of modulator is later extracted using the scattering parameters. Furthermore, in order to avoid large computational processing time especially for longer lengths, a circuit model of modulator [3] is used and its results are compared with full wave simulations. Modulator transfer function and characteristic impedance predicted by circuit models are verified by those of full wave simulations as shown in Figs. 1a-1c. The energy consumption of optical modulator can be simply estimated as $E_c = \frac{1}{4}CV^2$ where C is modulator equivalent capacitance. C corresponds to dissipative capacitive elements of intrinsic and extrinsic parts and V is the voltage swing applied to modulator [3]. For pure photonic simulations, a 0.5 mm long traveling wave modulator (TWM) with GSG pads to apply bias voltage and RF signal as well as 50 Ω termination has been considered. Unlike pure photonic technology, the driver is monolithically integrated with modulator in EPIC technology. Thus the modulator needs no pads for external terminations and can also be connected to driver through metal routes in the first metal layers in order to avoid excess parasitic capacitances. Since the modulator parameters in the waveguide layer do not change for both technologies, the depletion capacitance and $V\pi$ are similar in both cases. Therefore, the difference of energy consumption between two technologies will be limited to the extrinsic capacitances. For example, full wave simulations result in the estimation of extrinsic capacitances of 61fF and 3fF for pure photonic and EPIC technologies for 0.5 mm length modulator, respectively. It represents about 95 %

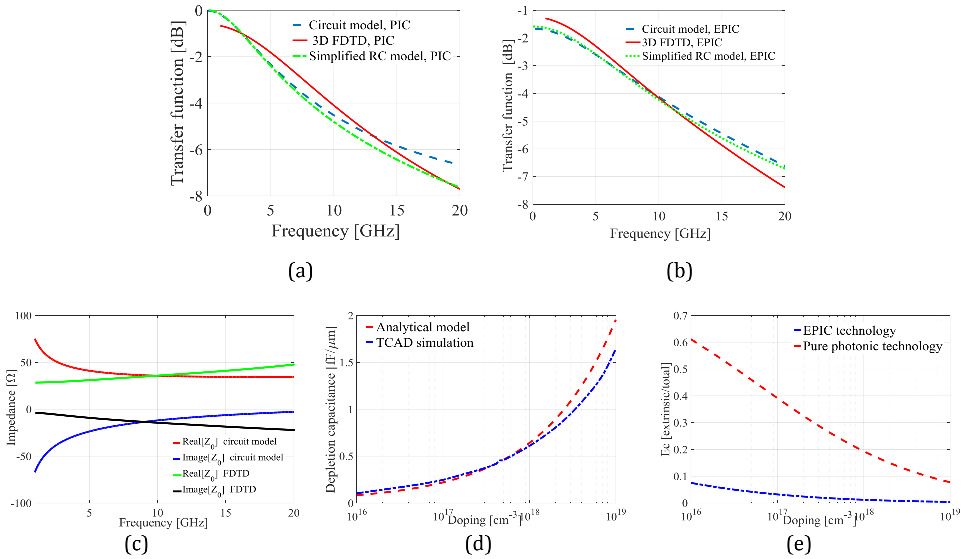

Fig. 1. Modulator transfer function simulations and comparison for a) pure photonic b) EPIC technologies. c) Modulator characteristic impedance. d) Intrinsic capacitance of modulator d) Extrinsic over total energy consumption of a standalone modulator.

enhancement of extrinsic energy consumption in EPIC rather than pure photonic. However, the main but constant energy term in both technologies is related to intrinsic capacitances. The intrinsic capacitance is obtained through our model which is validated by numerical simulations of electrical part (TCAD software) as illustrated in Fig. 1d. Total energy consumptions for both pure photonic and EPIC technology versus doping are obtained and shown in Fig 1e. As it can be seen, energy consumption difference is decreasing in high doping regions, which means common intrinsic energy consumption is a dominant term in both technologies. Extrinsic contribution of energy consumption will be higher if low doping levels are used. It means the EPIC technology would perform much better than pure photonic technology in terms of energy consumption if the low doping levels are used. Other important part of consumed energy in optical transmitters comes from driver's energy consumption. The driver's energy consumption mainly depends on, first the $V\pi$ and second the modulator length, i.e. how many segments the driver has to feed. By integrating the drivers with the modulators in EPIC technology less parasitics and also less energy consumption can be expected. It is shown that the energy consumption of a standalone modulator based on the EPIC technology (metals routed in bottom metal layer) is less than the similar modulator in pure photonic technology (metals routed in top metal layer) at fixed doping levels. It is shown that dominant term of modulators energy consumption in low and high doping levels corresponds to extrinsic and intrinsic consumed energy for both pure photonic and EPIC technologies, respectively.

This work is supported in part by the German Research Foundation (DFG) in the context of the collaborative research center, HAEC project.

References

[1] D. A. B. Miller, *Energy consumption in optical modulators for interconnects*, Opt. Express, no. 20, pp. A293-A308, 2012.

[2] S. Hosseini, K. Jamshidi, *Enhancement of bandwidth-energy consumption tradeoffs in reverse-biased modulators,* In Photonics Society Summer Topical Meeting Series *(SUM) IEEE,* pp. 94-95, 2016.