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Thermal Crosstalk analysis of dual-drive push-pull Mach-Zehnder modulator and photodetectors for THz communication systems

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Higher peak data rates of 1 Tbps as envisioned for 6G and beyond require new carrier frequencies in the THz band of the electromagnetic spectrum [1]. Photonics and especially integrated photonic-electronic devices offer many unique advantages for generating such high carrier frequencies and processing the high bandwidth signals accompanied by such high data rates. Nonetheless, the thermal conductance of the chip material results in thermal crosstalk, which deteriorates the modulator performance for densely packed photonic circuit designs. An effective solution to combat this issue is air-filled deep trenches in the integrated modulator design. Here, we will demonstrate designs of a deep trench assisted dual-drive push-pull Mach-Zehnder modulator (MZM), which successfully alleviates the thermal crosstalk and improves the bandwidth and the bit error rate (BER) performance of the device. Also, we will briefly study the effect of thermal crosstalk on bandwidth, responsivity, and dark current on integrated photodiodes for THz band applications.

The thermal crosstalk analysis for a single MZM arm was illustrated in [2, 3]. We aim to extend the study for a p-i-n junction based dual-arm push-pull type MZM without introducing any trench and deep trench structures. In the p-i-n diode, the p++ and n++ wells, with typical doping concentrations of 5×10^{20} cm^{-3}, are used to apply the bias voltage (V_{bias}) externally. The p+ and n+ regions have a doping concentration of 2×10^{18} cm^{-3}. The dimensions of the doped heater and the deep trench are the same as used in [2]. Now, with a rise in temperature across the doped heater, there is a diffusion of a large amount of charge into the intrinsic (i) region of the modulator, as the diffusion coefficient of the holes and the electrons are directly proportional to the increase in temperature, and this degrades the modulator performance in terms of non-linearity and DC characteristics. A similar effect can be observed in integrated photodetectors, where an injection of minority carriers leads to a decrease in the small-signal bandwidth of the detector, which is paramount for THz applications. The air-filled deep trench assisted design limits the charge diffusion by providing thermal shielding and hence alleviates the thermal crosstalk to a large extent. We will illustrate the bandwidth and the bit error rate (BER) performance improvement for the deep trench scenarios in a dual-arm push-pull MZM. Furthermore, we simulate the impact of thermal crosstalk on optoelectronic bandwidth and responsivity of p-i-n type THz regime integrated photodiodes [4] with low dark current, fabricated by conventional CMOS technology on silicon substrates.

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