UTC Photodiodes on Silicon Nitride Enabling 100 Gbit/s Terahertz Links at 300 GHz

Dennis Maes[1,2,3,*], Sam Lemey[2], Gunther Roelkens[3], Mohammed Zaknoune[3], Vanessa Avramovic[3], Etienne Okada[3], Pascal Szriftgiser[4], Emilien Peytavit[3], Guillaume Ducournau[3] Bart Kuyken[1]

[1] Photonics Research Group, Department of Information Technology (INTEC), Ghent University — imec, Technologiepark-Zwijnaarde 126, 9052 Ghent, Belgium
[2] Internet Technology and Data Science Lab (IDLab), INTEC, Ghent University — imec, Technologiepark-Zwijnaarde 126, 9052 Ghent, Belgium
[3] Institute of Electronics, Microelectronics and Nanotechnology (IEMN), Universite de Lille, 59652 Villeneuve d'Ascq, France
[4] Laboratoire de Physique des Lasers Atomes et Molecules, Universite de Lille, 59652 Villeneuve d'Ascq, France
[*] dennis.maes@ugent.be

Abstract *By means of micro-transfer-printing, we bring high-speed UTC photodiodes to a SiN-platform. These waveguide-coupled photodiodes show a responsivity of 0.3 A/W and a bandwidth of 155 GHz. We further demonstrate that direct photomixing at 300 GHz is possible and enables data rates up to 128 Gbit/s ©2022 The Authors*

Introduction

Next-generation wireless networks will rely on smaller cells and larger bandwidths for increased capacity. Radio-over-fiber technology allows the implementation of such dense base station networks, by keeping the radio head hardware simple. Miniaturization of the base station hardware, leveraging silicon photonics technologies, keeps the size and cost down. For microwave photonic applications, Silicon Nitride (SiN) platforms offer very low-loss waveguides and some of the best integrated filters. However, by moving to higher carriers frequencies, in mmWave and terahertz bands, also the requirements on the photodiode bandwidth increase. Current SiN platforms lack such photodiodes and thus prevent microwave photonics applications at high frequencies.[1]. We demonstrate a communication link at 300 GHz enabled by a heterogeneously integrated uni-travelling-carrier (UTC) photodiode on SiN as optoelectronic transducer in the transmitter.

Photodiode fabrication

The UTC photodiodes are integrated on SiN waveguides by means of micro-transfer-printing. To this end, pickable coupons are made on the III–V source wafer, and after transfer-printing to the SiN target chip post-processed to include electrical contacts. A more detailed description of the fabrication can be found in our previous work[2].

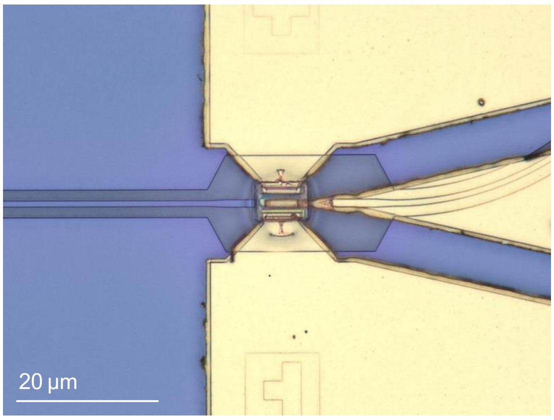

Fig. 1: The transfer-printed UTC photodiode on a SiN waveguide.

Terahertz link

To demonstrate the capabilities of the photodiode at terahertz frequencies, a data experiment around 300 GHz is set up. (Figure 2) Two C-band lasers are used, of which one signal is modulated using a Mach-Zehnder modulator (MZM). Both lines are combined and amplified to 13 dBm using an erbium doped fiber amplifier (EDFA) before coupling into the SiN photonic integrated circuit (PIC). The grating couplers introduce 9 dB loss, resulting in 4 dBm on-chip optical power. The mixed terahertz signal is then coupled out of the PIC by a 50 µm-pitched GSG-probe and fed to a WR-3 waveguide channel. Compared to most demonstrations, no electrical mixers at the transmit side are used, and the terahertz signal is directly mixed in the photodiode. At the receiver side the terahertz signal is down-converted using

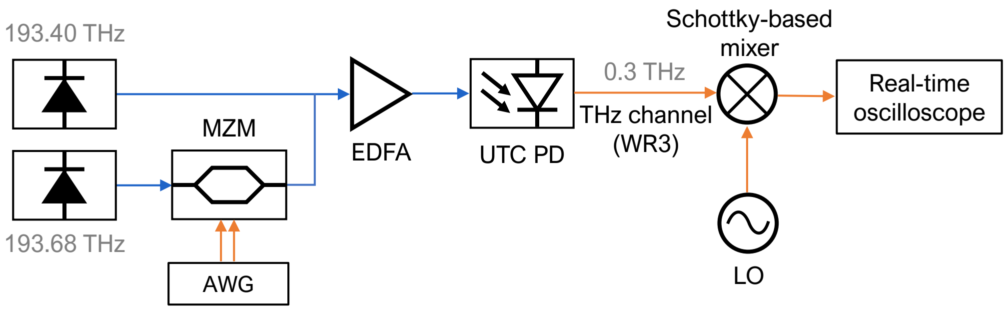

Fig. 2: In the experimental setup, two separate lasers are used for photomixing. One line is modulated using a MZM, before being combined and amplified by an EDFA. The light is coupled into the PIC using a vertical grating coupler and the the mixed terahertz signal is then transfered over a WR3 waveguide channel before down-mixing and sampling.

a Schottky-based diode mixer and sampled by a real-time oscilloscope before data processing.

Results

The frequency response of the waveguide-coupled photodiodes was measured using a set of power detectors. (Figure 3) For an active area of $2\times12\,\mu m^2$ the 3 dB bandwidth is 155 GHz at -1 V bias, which is eight times higher than the current state-of-the-art photodiodes heterogeneously integrated on SiN[1]. At zero bias, a bandwidth of 135 GHz is obtained, which is even higher than the best Silicon-on-Insulator (SOI) counterparts[3].

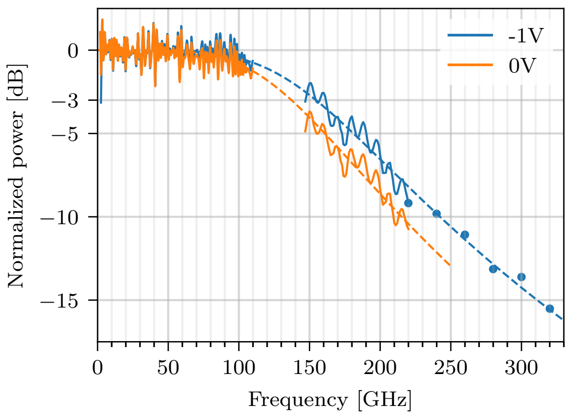

Fig. 3: The 3 dB bandwidth of the UTC photodiode is 155 GHz at -1 V bias, and 135 GHz at zero bias.

The remainder of the experiment was done for a photocurrent of 1 mA, well-below the saturation and break-down current. Given the responsivity of 0.3 A/W of these devices, corrected for grating-coupler losses (9 dB/coupler), this corresponds to an absolute level of RF-power above 1 µW at 300 GHz.

The performance of the THz-link was verified for mutiple constellation formats, including quadrature phase-shift keying (PSK) and 16-point quadrature amplitude modulation (QAM-16), at different symbol rates, ranging from 4 GBd to 32 GBd. This resulted in data rates up to 128 Gbit/s. Low error vector magnitudes (EVM) were obtained, with a clear inversely quadratic fit for increasing photocurrent (Figure 4).

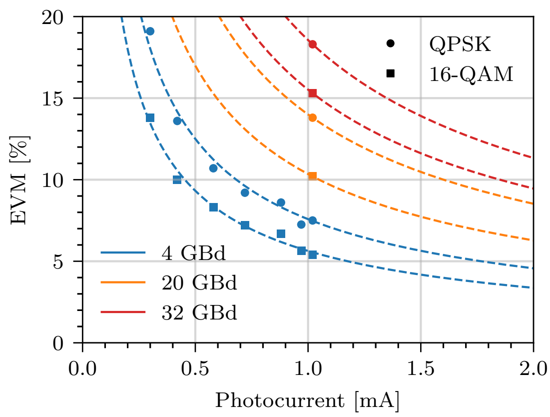

Fig. 4: The EVM in function of photocurrent.

Conclusion

Waveguide-coupled UTC photodiodes can be integrated on a SiN-platform by means of micro-transfer-printing. This heterogeneous approach delivers a high-performing photodetector with a responsivity of 0.3 A/W and high bandwidth of 155 GHz at -1 V bias and 135 GHz at zero bias. To the best of our knowledge, this is the fastest photodiode on SiN, and the fastest zero-bias photodiode cross platform. We have shown that data rates byond 100 Gbit/s are achievable using this device by direct photomixing at 300 GHz.

References

[1] F. Yu, K. Sun, Q. Yu, and A. Beling, "High-speed evanescently-coupled waveguide type-II MUTC photodiodes for zero-bias operation", *Journal of Lightwave Technology*, vol. 38, no. 24, pp. 6827–6832, 2020.

[2] D. Maes, G. Roelkens, M. Zaknoune, *et al.*, "Heterogeneous integration of uni-travelling-carrier photodiodes using micro-transfer-printing on a silicon-nitride platform", in *2021 Conference on Lasers and Electro-Optics Europe & European Quantum Electronics Conference (CLEO/Europe-EQEC)*, IEEE, 2021, pp. 1–1.

[3] S. Lischke, A. Peczek, J. Morgan, *et al.*, "Ultra-fast germanium photodiode with 3-dB bandwidth of 265 GHz", *Nature Photonics*, vol. 15, no. 12, pp. 925–931, 2021.