High-Speed Photodetectors

(Invited talk)

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ABSTRACT

This talk will review advances in photodetectors for high-speed applications with focus on analog systems. Recent results from flip-chip bonded modified uni-traveling carrier photodiodes and high-power photodiode arrays on silicon will be discussed.

Keywords: photodiode, photodetector

INTRODUCTION

High-speed photodiodes continue to be critical components in a wide range of photonic systems. In analog photonics applications including radio-over-fiber, radio frequency (RF) signal generation, and antenna remoting, photodiodes (PDs) with high power handling capability and high linearity are required to maintain high RF gain and large spurious-free dynamic range [1]. To this end our team at University of Virginia has developed discrete, surface-illuminated InGaAs/InP modified uni-traveling carrier (MUTC) photodiodes that achieved -2.6 dBm RF output power at 160 GHz [2]. For integrated microwave systems on silicon, we developed arrays of Ge/Si photodiodes that provide 10 dBm RF output power at 12 GHz.

1. HIGH-SPEED MODIFIED UNI-TRAVELING CARRIER PHOTODIODES

Similar to a uni-traveling carrier (UTC) PD [3], the MUTC PD includes an un-depleted narrow-bandgap absorber and a wide-bandgap electron drift layer. In addition, and to facilitate electron transport at the heterojunction interface, an un-doped absorber with an appropriate thickness is inserted between the un-depleted absorber and the drift layer. The fact that the photocurrent is mostly based on electron transport provides higher speed since electrons typically have higher velocities than holes, especially at low electric fields. The drift layer is lightly n-type doped for charge compensation. The charge from the ionized donors pre-distorts the electric field and can counteract the space charge screening effect at a high current and thus avoids saturation [4]. A critical factor that limits the RF output power of a PD is Joule heating in the high-electric field region. We have shown that improvements in RF output power can be achieved by flip-chip bonding the PD onto an AlN or diamond substrate that has high thermal conductivity [5].

Previously, we have demonstrated back-illuminated charge-compensated MUTC PDs with 9.6 dBm RF output power at 100 GHz [6]. To enhance the 3 dB-bandwidth, these devices were designed with a high-impedance coplanar waveguide (CPW) between the PD and the RF probe pad that provided inductive peaking at 100 GHz. To increase the RF output power at higher frequencies (beyond the 3 dB bandwidth), we recently flip-chip bonded similar MUTC PDs to a low-inductance transmission line on a AlN submount. The PD's pads were attached to a CPW with a 130-µm signal-to-ground gap using thermo-compression Au-Au bonding (Fig.1 inset). A short tapered transmission line connected the stub to a 50 Ω probe pad with a 54-µm signal-to-ground gap. This optimized CPW design reduced the frequency response roll-off beyond 100 GHz and extended the usable frequency range up to 160 GHz. Figure 1 shows the measured RF output power. A 9-µm diameter PD reached a maximum RF output power of −2.6 dBm at 160 GHz and −3 V, and a saturation current of 40 mA. The dark current was 0.4 nA and the responsivity was 0.2 A/W at 1550 nm [2].

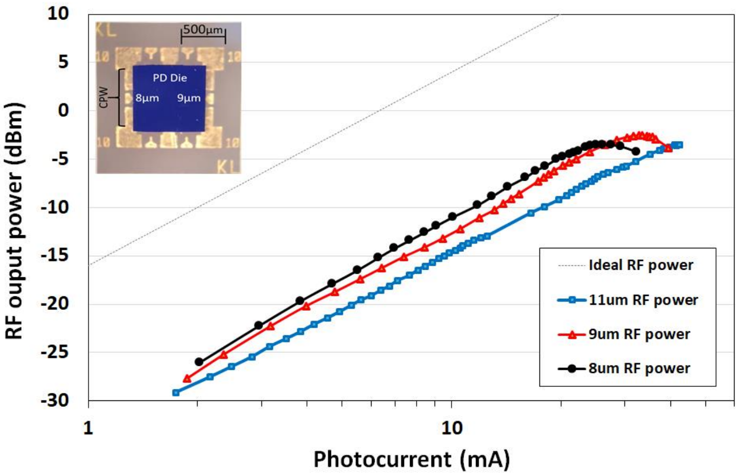

Figure 1. Radio frequency (RF) output power at 160 GHz of modified uni-traveling carrier photodiodes with 11 µm, 9 µm, and 8 µm diameters. The inset shows a PD die on the submount after flip-chip bonding.

2. HIGH-POWER GERMANIUM/SILICON PHOTODIODE ARRAYS

Recently, there has been an increasing interest in integrated microwave photonics systems, which take advantage of the silicon photonics platform to enable reliable, compact and low cost solutions [7]. These photonic integrated circuits benefit from high-power high-linearity waveguide photodiodes that can be monolithically integrated onto Si. While high-speed Ge/Si PDs with low dark current at low bias and high responsivity are well-developed for digital applications, only few high-power Ge-on-Si PDs have been reported to date [8-11].

Recently, we have demonstrated Ge/Si waveguide photodetector arrays for high-power analog applications utilizing the AIM Photonics silicon foundry [12]. Figure 2 shows a summary of the RF output power and compression measured at the 3-dB bandwidth for PD arrays and single PDs. PD arrays with 8, 4, and 2 elements have output powers of 14 dBm, 10 dBm, and -0.4 dBm at 5 GHz, 12 GHz, and 18 GHz, respectively. In comparison, single photodiodes with and without spiral inductor for inductive peaking reached -5 dBm at 34 GHz and 21 GHz, respectively.

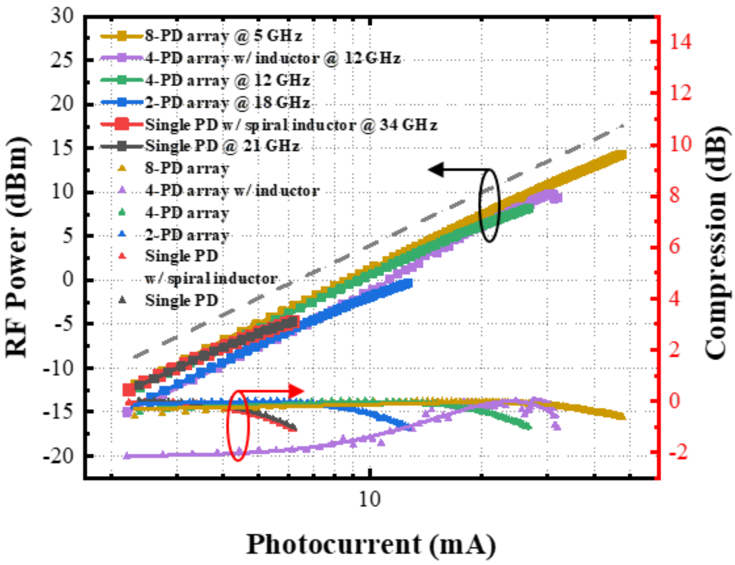

Figure 2. Summary of output RF power and compression measured at each photodetector’s 3-dB bandwidth and -5 V bias.

ACKNOWLEDGEMENTS

Part of this work was supported by DARPA, the Naval Research Laboratory, and the Air Force Research Laboratory.

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