Zero-bias GaAsSb/InP Photodiode with 40 GHz Bandwidth

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***Abstract*—We demonstrate a back-illuminated modified uni-traveling carrier (MUTC) photodiode with 40 GHz bandwidth at zero bias. The photodiode has a responsivity of 0.2 A/W without anti-reflection (AR) coating and delivers -2.8 dBm RF output power.**

Keywords—Photodiode, Photodetector, zero-bias

I. Introduction

High power and high-speed photodiodes (PDs) are key components in ultra-broad-band analog photonic applications [1-2]. To achieve large bandwidth and high RF output power conventional PDs usually necessitate a bias circuitry and are driven under a high external reverse voltage. Together with large photocurrents, this can lead to device heating and eventually thermal failure. To reduce thermal stress on the PD and to minimize system complexity, zero-bias operation of the PD is desired. Previously, Umezawa et al. have reported a bias free InGaAs/InP uni-traveling carrier PD (UTC-PD) with an output power of -7 dBm at 100 GHz [3]. Jin-Wei Shi et al. have reported a GaAsSb/InP UTC-PD with - 13.9 dBm at 160 GHz in ref. [4].

In this paper we present a zero-bias GaAsSb/InP PD with 40 GHz bandwidth and high saturation power -2.8 dBm.

II. Device Design

Contact layer GaAsSb, p+, Be, $1x10^{19}$, 50nm
Un-depleted Absorber, GaAsSb, p+, Be, $5x10^{18}$, 30nm
Un-depleted Absorber, GaAsSb, p+, Be, $3x10^{18}$, 30nm
Un-depleted Absorber, GaAsSb, p+, Be, $1x10^{18}$, 35nm
Un-depleted Absorber, GaAsSb, p, Be, $8x10^{17}$, 35nm
Un-depleted Absorber, GaAsSb, p, Be, $7x10^{17}$, 35nm
Un-depleted Absorber, GaAsSb, p, Be, $6x10^{17}$, 35nm
Depleted Absorber, GaAsSb, p, Be, $1x10^{16}$, 50nm
Drift layer InP, n-, $1x10^{16}$, Si, 50nm
Drift layer InP, n-, $2x10^{16}$, Si, 50nm
Drift layer InP, n-, $2.5x10^{16}$, Si, 100nm
Drift layer InP, n-, $3x10^{16}$, Si, 150nm
InP, n+, $1x10^{18}$, Si, 75nm
Contact layer InP, n+, $1x10^{19}$, Si, 700nm
Semi-insulating InP Substrate

Figure 1. Epitaxial structure of the PD. All layers are lattice-matched to InP.

The epitaxial layer structure of the PD is shown in Fig. 1. In contrast to the high-power InGaAs/InP MUTC PD in ref. [5], here we used GaAsSb instead of InGaAs as the absorber material. This eliminates the discontinuity in the conduction band between the absorber and the InP drift layer which is known to impede electron transport across the interface at high photocurrent levels [5]. The epitaxial structure was grown on InP and consists of a 300 nm-thick lightly graded doped InP drift layer for space-charge compensation and a 250 nm-thick graded doped GaAsSb absorber. The simulated band diagrams at different photocurrents are shown in Fig. 2. In order to provide high bandwidth and high saturation power under zero-bias, the doping concentrations were carefully designed to achieve electron velocity over-shoot in the drift layer. The PDs were fabricated as double-mesa photodiodes by using conventional dry etching techniques. The PDs were connected to gold-plated coplanar waveguide (CPW) RF pads through an air-bridge.

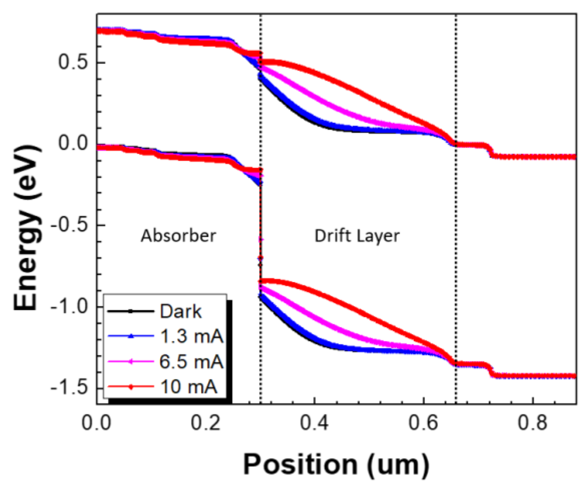

Figure 2. Simulated band diagram at 0 V at different photocurrents.

III. Characterization

The microscope picture of a 10 μm diameter PD and the dark currents of fabricated PDs with different diameters are shown in Fig. 3. We measured dark currents in the range of 100 nA at a bias of -3 V. The responsivity was measured at 1550 nm wavelength and 0 V bias and was 0.2 A/W. We expect that a responsivity of 0.27 A/W can be achieved once a single-layer anti-reflection coating is applied.

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Figures 4 and 5 show the measured frequency responses for different photocurrents at 0 V and -1 V bias, respectively. At 0 V bias, the bandwidth is 40 GHz up to 2 mA, and 35 GHz at 5 mA. The decrease of bandwidth with higher photocurrent can be explained by the space charge effect. At -1 V bias, the bandwidth remains over 50 GHz for all measured photocurrents. The capacitance of a 10 μm diameter PD measured at 0 and -1 V bias was 72 fF and 55 fF, respectively, corresponding to an RC-limited bandwidth of 44 GHz and 57 GHz assuming a 50 Ω load. The fact that the bandwidth is limited by RC implies that a higher bandwidth can be expected by reducing the PD area.

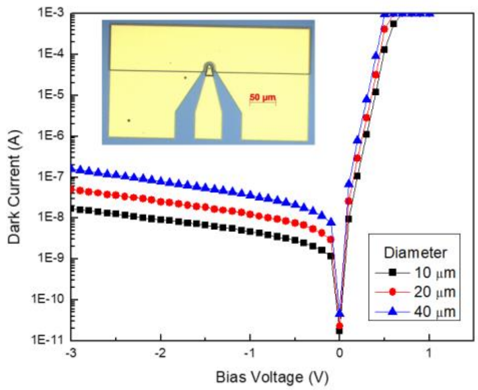

Figure 3. Top-view of a fabricated PD (inset) and dark current versus voltage for PDs with different diameters.

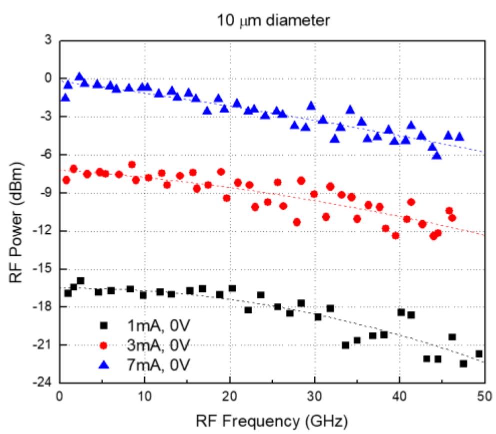

Figure 4. Measured frequency responses of 10 μm diameter PD at zero bias.

Figure 6 shows the saturation characteristics of a 10 μm diameter PD measured at 40 GHz at different voltages. We measured -2.8 dBm, 9.3 dBm, 12.5 dBm and 13.2 dBm at 0 V, -1 V, -2 V and -3 V, respectively. At a forward bias of 0.2 V we obtained -14.1 dBm at 40 GHz. The saturation current of the PD is 7.5 mA under zero bias. The results indicate that the output power is mainly limited by the space charge effect in the depletion region.

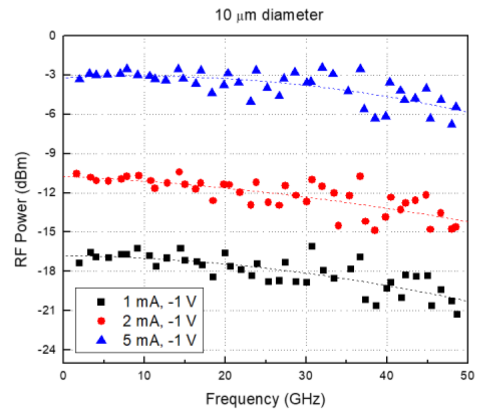

Figure 5. Measured frequency responses of 10 μm diameter PD at -1 V bias voltage.

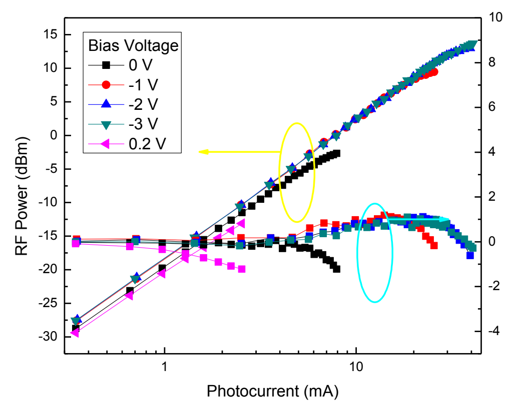

Figure 6. RF output power and RF compression at different bias voltages.

IV. Conclusion

By optimizing the doping concentration in a GaAsSb/InP modified uni-traveling carrier PD we demonstrated a 10 μm diameter PD with 40 GHz bandwidth, 7.5 mA saturation current and -2.8 dBm RF output power at zero-bias.

References

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