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High-Speed and High-Output Voltage Refracting-Facet Photodiode

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1. Introduction

A photodiode (PD) that can provide high speed, high responsivity and high saturation output is of great importance for the future large-capacity optical fiber communication systems [1]. An edge-illuminated refracting-facet photodiode (RFPD), in which the incident light parallel to the up-side surface is refracted at an inwardly angled facet and absorbed by an absorption layer [2], is a very attractive way to meet above requirements. To improve the high-speed characteristics, thinning the absorption layer is essential. In this RFPD, since the refracted light transits with a small angle to the absorption layer, the absorption length effectively increases, resulting in a high responsivity even with a thin absorption layer. This feature also produces a decrease in photon density (current density), resulting in a high-output current. In addition, thinning the absorption layer is effective in improving the saturation output characteristics because the influence of field modulation due to the space charge in the depletion region can be suppressed by applying low bias voltage.

In this paper, we describe a successfully fabricated thin-absorption-layer RFPD with a large 3-dB bandwidth of 66 GHz and a high output peak voltage over 2.5 V.

2. RFPD structure and fabrication

A schematic cross-sectional view of the fabricated RFPD is shown in Fig. 1. The incident light refracted at an angled facet (mesa angle θ) is absorbed at the absorption layer, which consists of a 0.4-μm-thick undoped-InGaAs and a 0.03-μm-thick p-doped InGaAs contact layer. Since the refracted light transits with a certain angle to the absorption layer, the absorption length effectively increases. In addition, since this RFPD successfully uses a p-metal as a reflector, the absorption length is doubled. These two factors result in an increase in internal quantum efficiency.

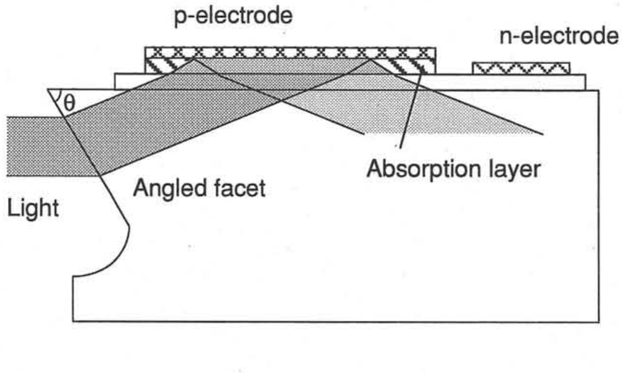

Fig. 1 Schematic cross-sectional view of the fabricated RFPD.

The mesa etching and metal formation for the p and n regions were done using conventional photolithography, wet chemical etching, and liftoff metallization techniques. After forming the pad electrode, mesa formation for the angled facet was carried out [3]. Finally, the incident facet was antireflection coated.

3. Results

The responsivity dependence on junction size measured for 1.55-μm light with a spot-size of 1.5 μm ($2w_s$=3.0 μm) is shown in Fig. 2. The responsivity is as high as 0.69 A/W for a 11 × 35 μm^2 RFPD even with an absorption layer as thin as 0.43 μm, and stays at 0.61 A/W even for an RFPD with a junction as small as 3 × 9 μm^2. The small signal frequency

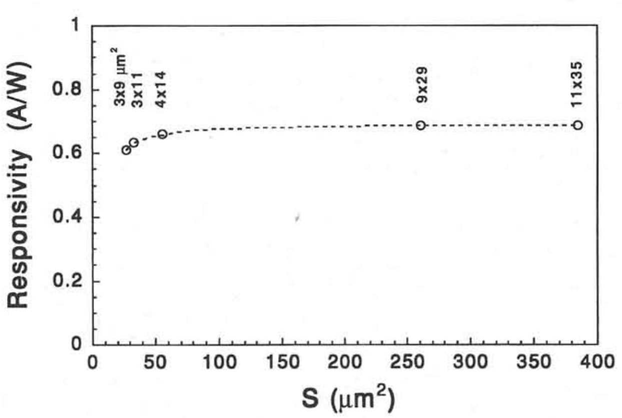

Fig. 2 Responsivity dependence on junction size for 1.55-μm light with a spot-size of 1.5 μm ($2w_s$=3.0 μm).

responses of the fabricated RFPDs were measured using a lightwave component analyzer (HP-83467C) up to 50 GHz. The 3-dB-down frequency (f_{3dB}) were estimated by fitting the empirical frequency response formula given by

$$R = R_0 \Big/ \sqrt{(1 + (f/f_{3dB})^2)}, \qquad (1)$$

where R_0 is DC responsivity. Figure 3 shows the f_{3dB} dependence on junction size (S) for RFPDs biased at -2V. The f_{3dB} increases with decreasing S due to the reduction of the CR time constant and reaches 66 GHz for an RFPD 3 × 9 μm^2 in size. Since the absorption layer is as thin as 0.43 μm, enough electric field to accelerate the photo-generated carriers is formed at

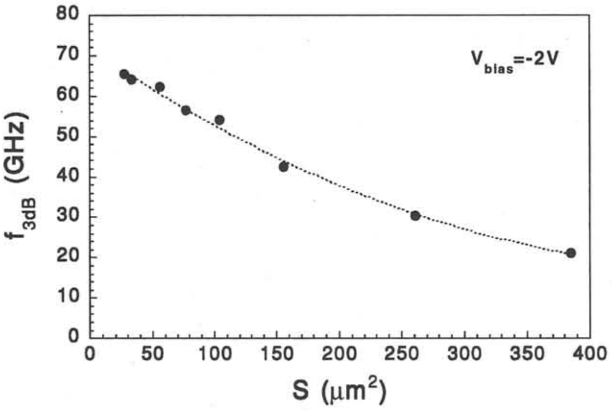

Fig. 3 f_{3dB} dependence on junction size (S) at the RFPDs biased at -2V.

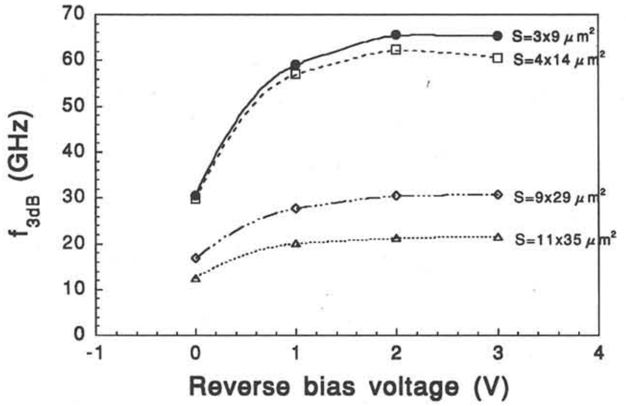

Fig. 4 f_{3dB} dependence on reverse bias voltage for different size RFPDs.

a low bias voltage. Figure 4 shows the bias dependence of f_{3dB} for the different-sized RFPDs. The f_{3dB}'s of more than 50 GHz were obtained at a reverse bias voltage of 1 V for the 3 × 9 and 4 × 14 μm^2 RFPDs.

The high output voltage characteristics under high power pulse irradiation were measured by employing an electrooptic (EO)-sampling technique [4] using an external CdTe probe tip. The RFPD output voltages were derived by calibrating the EO-signal intensity using a 50-GHz digital sampling oscilloscope. The f_{3dB} at high output voltage was estimated from the power spectrum obtained by the Fourier transform of the measured photoresponse. The f_{3dB} versus output peak voltage (V_p) with changing input power for a 4 × 14 μm^2 RFPD is shown in Fig. 5. The f_{3dB} tends to decrease with increasing output peak voltage (input power). This is considered to be due to the field modulation of the depletion layer induced by the space charge of photogenerated carriers [5]. However, by increasing the bias voltage of device, the high f_{3dB} is kept under the high V_p because of the increased electric field. An f_{3dB} of more than 40 GHz can be obtained at a V_p of 1 V when the RFPD is biased at -3 V and at a V_p of more than 2.5 V when biased at -7 V. These excellent high output voltage characteristics are attributed to the thin absorption layer and reducing the photon density (current density) by transiting the light with a small angle to the absorption layer. A uni-traveling-carrier photodiode (UTC-PD) structure in which only electrons are used as active carriers can enhance the saturation output current [5] and is easily employed in this RFPD. Its use is expected to further improve the high-output characteristics and results in better responsivity than can be obtained when using a surface-incident UTC-PD.

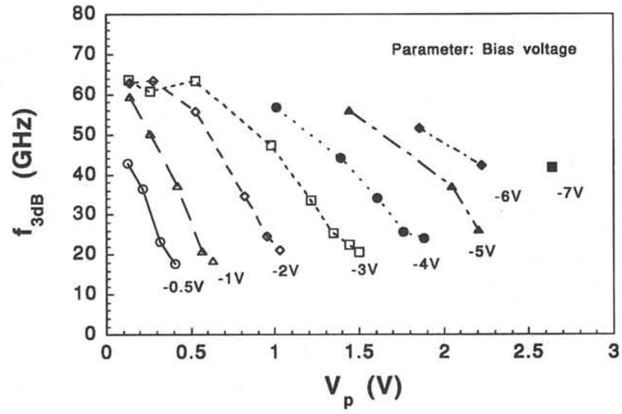

Fig. 5 f_{3dB} versus output peak voltage (V_p) with changing input power at a 4 × 14 μm^2 RFPD.

4. Conclusion

We have demonstrated a high-speed and high-output peak voltage refracting-facet photodiode employing a thin absorption layer. The fabricated RFPD showed a responsivity as high as 0.69 A/W even with an absorption layer as thin as 0.43 μm, a maximum 3-dB bandwidth of 66 GHz, and a high output peak voltage of over 2.5 V.

Acknowledgments

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