Dual-Drifting-Layer Uni-Traveling Carrier Photodiode for Wide Bandwidth and High Power Performance

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Abstract: Uni-traveling-carrier photodiodes with novel dual-drifting-layer structure is proposed to realize wide bandwidth and high saturation power performance. High-speed operation at high bias voltage is demonstrated by optimizing the electric field profile within the dual-drifting-layer structure.

OCIS codes: (040.5160) Photodetectors, (230.5170) Photodiodes

1. Introduction

High-speed and high saturation power uni-traveling photodiodes (UTC-PDs) are important components for many applications, such as radio over-fiber and phased array antenna systems [1]. In these applications, high power or high photocurrent characteristics of UTC-PDs are often required to improve system performances including wide dynamic range and low noise figure. But at high photocurrent level, the voltage swing effect induced by the alternating current delivered to the load will be superimposed on the PD bias. Therefore, the electric field in the depletion region will redistribute and cause obvious performance degradation in conventional UTC-PDs [2]. In order to reduce such load voltage swing effect, a higher reverse bias voltage is necessary for high saturation performance. The addition of a thin p-doped layer beneath the thin depletion layer was adopted to solve this problem, and UTC-PD operating at a high bias voltage of about 5 V was demonstrated [3]. However, increasing the bias voltage to over 10 V would cause bandwidth degradation under high output photocurrent.

To achieve both high-speed and high saturation power performance, a novel dual-drifting-layer (DDL) UTC-PD has been proposed and fabricated, in which a thin p-doped layer is inserted into a thick depletion layer, and the electric field profile is optimized to ensure electron velocity overshoot and to reduce the load voltage swing effect. Significant electron velocity overshoot can still be maintained in the depletion layer under high reverse bias. The device exhibits a responsivity of 0.44 A/W at 1.55 μm wavelength, and a 3-dB bandwidth over 25 GHz. A high saturation photocurrent of 60 mA to a 50 Ω load is demonstrated under high bias voltage of –11 V at 20 GHz.

2. Device Structure and Simulation Results

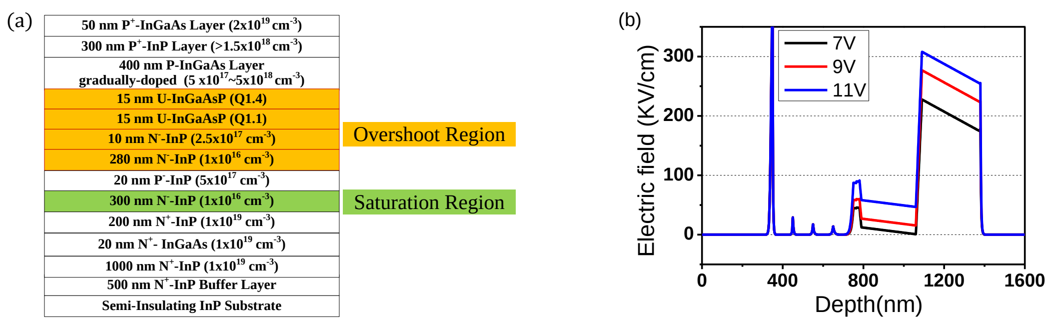

Fig.1. (a) DDL UTC-PD epitaxial structure, and (b) electric field profiles under different reverse biases at 25 mA photocurrent.

The epitaxial structure of the DDL UTC-PD is shown in Fig. 1(a), which includes a 400-nm-thick p^+-type graded doped InGaAs absorption layer and a 640-nm-thick dual-drifting InP depleted collector. The dual-drifting region consists of a 320-nm-thick electron velocity overshoot region and a 300-nm-thick electron velocity saturation region, with a 20-nm-thick p-doped charge layer in between. The electric field distribution in the dual-drifting region should be optimized to achieve a short transit time and a small capacitance simultaneously.

Figure 1(b) shows the calculated electric-field distribution in the depletion region under different reverse bias voltages. As can be seen, the electric field in the depletion region was controlled by the 20 nm p-doped charge layer with a doping density of 5.0×10^{17} cm^{-3}. The electric field in the velocity overshoot region should be in the range of the critical field for overshoot transport [3, 4]. It should be noted that the actual electric field would be smaller than the simulated value, because of electron accumulation at the InGaAs/InGaAsP/InP interfaces. The electric field distribution is designed to help the photogenerated electrons drift at overshoot velocity in the low electric field region, whereas the electron velocity drops to the saturation velocity in the high electric field region. The overshoot velocity can reach 4.0×10^7 cm/s, which is much higher than the saturation velocity 1.0×10^7 cm/s [4], thus the transit time over the entire depletion region can be significantly reduced. When the reverse bias is increased to 11 V, the electric field mainly falls on the electric field suffering layer, whereas the electric field within the velocity overshoot layer still remain around the critical value, and the electrons drift at overshoot velocity in this region. Consequently, the high-speed performance of our DDL UTC-PD will be less influenced by the high bias voltage, and has the potential to achieve higher saturation power.

3. Measurement Results

The frequency response of the device is measured using the heterodyne-beating method [2]. The measured frequency responses of a 22-μm-diameter DDL UTC-PD at different reverse bias voltages are plotted in Fig. 2(a). A 3-dB bandwidth of 25 GHz has been achieved under −11 V bias and 25 mA photocurrent. It is seen that the optimized DDL structure helps ensure wide bandwidth performance under a high reverse voltage. The frequency response degrades when the bias is decreased to −7 V, as the reduced electric field in the overshoot region no longer support overshoot transport. These results indicate that our device exhibits advantages over conventional UTC-PDs, in which the bandwidth decreases significantly under high reverse bias [5].

The output radio frequency (RF) power versus photocurrent of the device at 20 GHz frequency under −11V is plotted in Fig. 2(b). The maximum photocurrent is measured to be 60 mA under −11V reverse bias voltage, with a corresponding output RF power of 16 dBm. Higher output RF power and saturation photocurrent can be expected with flip-chip bonding technique to solve the thermal failure problem under high bias voltage [3].

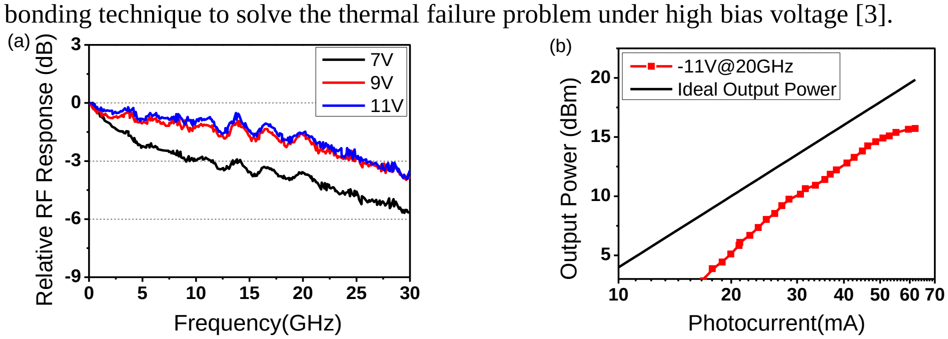

Fig.2. (a) Frequency response of 22-μm diameter DDL UTC-PD at 25 mA photocurrent under different biases. (b) Output RF power versus output photocurrent at 20 GHz under −11V bias voltage.

4. Summary

A novel DLL UTC-PD with capability of high power and high speed performance has been proposed and demonstrated. By adopting a dual-drifting-layer structure in which the electron maintains high drifting velocity under high reverse bias voltage, a 3-dB bandwidth of 25 GHz is attained. The device also achieves a saturation photocurrent up to 60 mA under −11 V bias, with a corresponding output RF power of 16 dBm at the frequency of 20 GHz.

5. Acknowledgement

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6. References

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