Comparison of power dissipation tolerance of InP/InGaAs UTC-PDs and pin-PDs

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Abstract: The power dissipation tolerances for InP/InGaAs uni-travelling-carrier photodiodes (UTC-PDs) and pin-PDs under high power optical inputs are compared. Catastrophic failures occur at constant power dissipations of 240 and 160 mW for the UTC-PDs and pin-PDs, respectively. Scanning electron microscope observations confirm that the areas of destruction are located in the high electric-field region in the depletion layer. Note: The contents are identical to a paper previously published in IEICE Trans. Electron. Copyright 2003 IEICE. All rights reserved.
Keywords: photodiode, uni-travelling-carrier photodiode, high power optical input, failure.
Classification: Photonic devices, circuits, and systems

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1 Introduction

There is an increasing demand for photodiodes (PDs) with a high output and a wide bandwidth because they will allow us to simplify the configu-

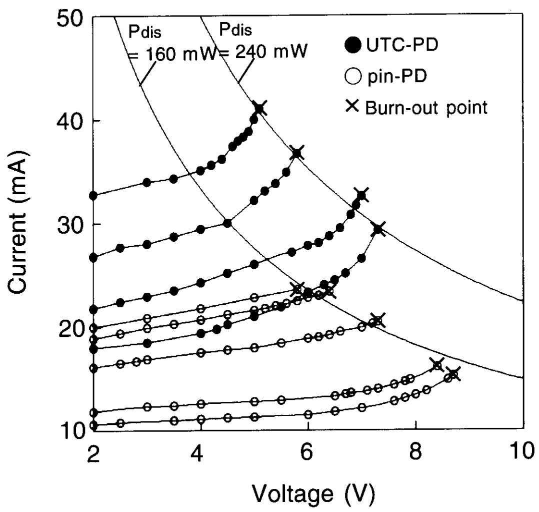

Fig. 1. Dependence of photocurrent on applied voltage for UTC-PDs and pin-PDs. Burn-out points and iso-power-dissipation curves are also plotted.

ration of receivers for broadband fibre-optic communications and ultrafast measurement systems. A uni-travelling-carrier photodiode (UTC-PD) [1] is a promising device because it has a higher output and a faster response than conventional pin-PDs, owing to its unique operation mode[2]. A very high output peak current of over 180 mA and a wide 3-dB bandwidth ($f_{3\mathrm{dB}}$) of 310 GHz have already been achieved in UTC-PDs[3, 4]. Because the UTC-PD is operated at a high input optical power, its power dissipation tolerance is of great interest. It has been reported that catastrophic failure of UTC-PDs occurs under a high-optical-input condition at a constant power dissipation[5]. However, precise mechanism responsible for the destruction has not yet been clarified. In this letter, we compare failures of UTC-PDs with those of pin-PDs under high input optical powers to reveal the mechanism dominating the power dissipation tolerance.

2 Experiment

We used UTC-PDs and pin-PDs having the same depletion layer thickness[2]. The epi-layers of the devices were grown on Fe-doped semi-insulating InP substrates by MOCVD. The UTC-PD has a p-InGaAs photoabsorption layer and an undoped InP collection layer, whereas the pin-PD has an undoped InGaAs absorption layer. The electric field is mainly applied on the InP collection layer in the UTC-PD, while it is applied on the InGaAs absorption layer in the pin-PD. Both types of PDs were fabricated using conventional photolithography, wet chemical etching, and lift-off metallization techniques. The active area of the fabricated devices was about 100 μm^2. The responsivities at 1.55 μm were 0.28 and 0.32 A/W for the UTC-PDs and pin-PDs, respectively.

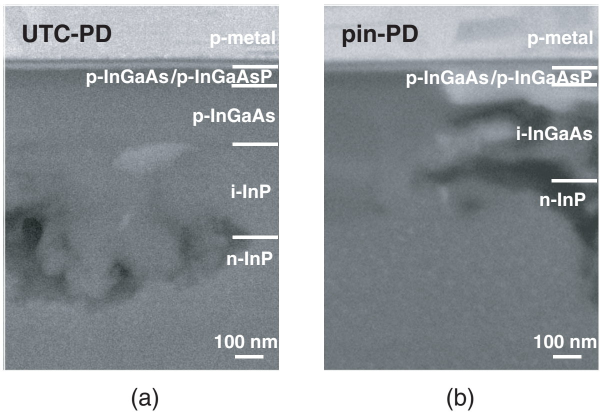

Fig. 2. Cross-sectional SEM photographs of (a) UTC-PD and (b) pin-PD after burn-out.

3 Results and discussion

Figure **1** shows the I-V characteristics of UTC-PDs and pin-PDs under several constant input optical powers. By increasing the applied voltage, the photocurrents of the PDs increased gradually, and catastrophic failure occurred at the burn-out points where the devices shorted. The burn-out points align well with the iso-power-dissipation line, which is defined as the product of the photocurrent and the potential drop in the depletion layer of each device. The fact that the burn-out occurs at the same power dissipation regardless of input optical power or bias voltage suggests that the failure is caused by an increase in device temperature as a result of self-heating. The power dissipation (Pdis) of the UTC-PD at the burn-out point is about 240 mW, whereas that of the pin-PD is about 160 mW. These results show that UTC-PDs have better power dissipation tolerance under high input optical powers than conventional pin-PDs.

In order to investigate the failure mechanism of the UTC-PDs and pin-PDs, we observed the failure regions using a scanning electron microscope (SEM). The SEM samples were prepared by the focused ion beam (FIB) etching technique. Fig. **2** shows the cross-sectional SEM photographs of the PDs after the burn-out. The dark area in each photograph is a vacancy, probably formed by the melting of semiconductor crystal due to heat generation. In the UTC-PDs, as shown in Fig. **2**(a), the destruction is mainly in the i-InP collection layer and at the boundary region of the i-InP collection layer and the n-InP contact layer, not in the p-InGaAs absorption layer. In contrast, in the pin-PDs, the i-InGaAs absorption layer is mainly damaged, as shown in Fig. **2**(b). In the UTC-PD, the electric field exists mainly in the collection layer, while it exists in the absorption layer in the pin-PD. These layers coincide well with the destroyed region shown above. Thus, it is suspected that the destruction occurs in the depletion layers, where the potential energies of the photogenerated carriers are mainly released to the lattice and heat is generated.

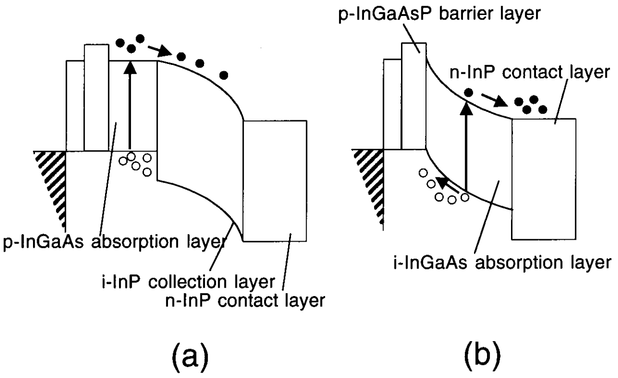

Fig. 3. Band diagrams of (a) UTC-PD and (b) pin-PD under a high optical input condition.

Figures **3**(a) and (b) show band diagrams of a UTC-PD and pin-PD under a high optical input condition. Under such a condition, band bending occurs in the depletion region due to the space charge effect [1]. This makes the electric field larger near the collection-layer/contact-layer interface in the UTC-PD, and near the absorption-layer/barrier-layer interface in the pin-PD. This is consistant with the SEM observation, where the destruction occurred near the i-InP/n-InP interface in the UTC-PD [see Fig. **2**(a)]. In the case of the pin-PD, however, the entire i-InGaAs region was destroyed. Since the thermal resistance of InGaAs (16 cmK/W at 300 K [6]) is about 10 times larger than that of InP (1.5 cmK/W at 300 K [6]), the temperature increase in the InGaAs absorption layer of the pin-PD due to the heat generation is much larger than that in the InP collection layer of a UTC-PD. In addition, the generated heat had to diffuse torward the substrate side, making the entire absorption layer hot. This can explain the SEM observation shown in Fig. **2**(b). These results indicate that the high power dissipation tolerance of the UTC-PD compared to that of the pin-PD originates from its unique layer structure, and thus the UTC-PD is advantageous for operation under a high-output condition.

4 Conclusion

We compared the power dissipation tolerances of UTC-PDs and pin-PDs under various input optical powers. It was found that UTC-PDs exhibit a higher power dissipation tolerance (240 mW) than pin-PDs (160 mW). SEM observations confirmed that device destruction occurred in the depletion regions in both types of PDs, implying that the temperature increase is responsible. The higher power dissipation tolerance of the UTC-PD is explained by the difference in the thermal resistance of the material used for the depletion region.

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