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Enhanced frequency response associated with negative photoconductance in an InGaAs/InAlAs avalanche photodetector

Gyungock Kim, In Gyoo Kim, Jong Hyeob Baek and O Kyun Kwon
Electronics and Telecommunications Research Institute
Yusong P. O. Box 106, Taejon, Korea 305-600, gokim@etri.re.kr

1. Introduction

The avalanche photodetector (APD) with the merit of internal current-gain (DC-gain), is widely used in many areas [1]. One of the most important aspects of a high-performance APD is its 3-dB bandwidth (f_{3dB}) as a function of its current-gain. However, the high current-gain in an APD limits the high-speed performance due to the relatively slow avalanche build-up process, and therefore, it is difficult to significantly enhance the frequency response of an APD, while maintaining the high current-gain. Further mechanism is required to achieve the high-speed response and the high current-gain simultaneously.

In this paper, we report the negative photoconductance characteristics and the enhanced frequency response at high current-gains in an InGaAs/InAlAs APD. The measured internal RF-gain effect in the avalanche region demonstrates that the avalanche process does not limit the bandwidth of an APD.

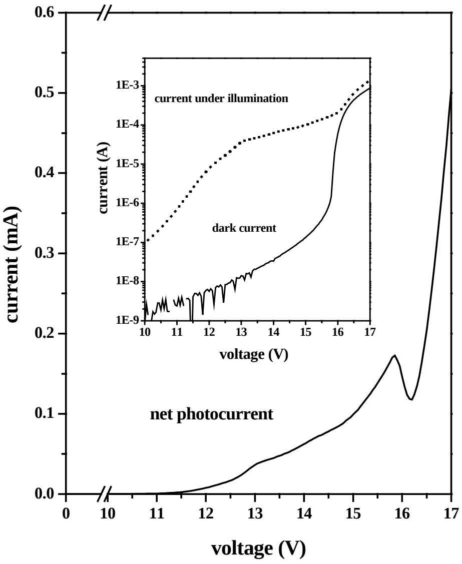

Fig. 1 DC photoresponse of an APD with a NDR characteristic of the net photocurrent. Inset depicts the measured I-V curves in log scale.

2. Experiment

The samples were grown by MOCVD or MBE on Fe-doped (100) InPs. The APD employed the resonant-cavity type structure. The 10 to 30 pairs of undoped $\mathrm{In_{0.53}Al_{0.13}Ga_{0.34}As/In_{0.52}Al_{0.48}As}$ were grown on InP substrate as a bottom reflector. A Si-doped n^+ $\mathrm{In_{0.52}Al_{0.48}As}$ contact layer was followed by a 150 nm $\mathrm{In_{0.52}Al_{0.48}As}$ multiplication layer. A 50 nm p-$\mathrm{In_{0.52}Al_{0.48}As}$ charge layer was followed by the undoped $\mathrm{In_{0.52}Ga_xAl(_{0.48-x})As}$ graded layer. A 55 nm $\mathrm{In_{0.53}Ga_{0.47}As}$ absorption layer was followed by an $\mathrm{In_{0.52}Al_{0.48}As}$ spacer layer. This was followed by a p^+-$\mathrm{In_{0.52}Al_{0.48}As}$ layer and a p^+ $\mathrm{In_{0.52}Al_{0.48}As}$ cap layer. Mesas with diameters varying from 10 µm to 50 µm were defined by wet etching. The frequency responses of the APDs were measured using HP lightwave component analyzer or by impulse response experiment with h a 1.55 µm 700-fs fiber pulse laser.

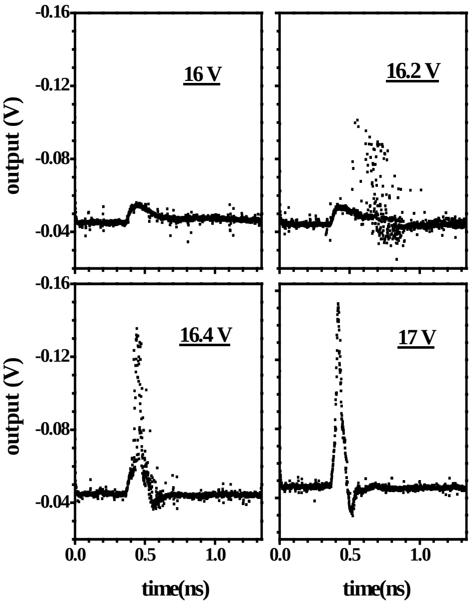

Fig. 2 The time-domain pulse measurement, which shows the formation process of a high-speed response signal near the threshold voltage in the avalanche region.

3. **Results and discussion**

Figure 1 shows the typical experimental I-V characteristics for the APD. The net photocurrent exhibits a negative differential resistance (NDR, negative photoconductance) in the avalanche region. This NDR is attributed to the internal space charges, i.e., excess electrons generated from the impact ionization transferring to low mobility (L- and X-) states, which can cause strong space-charge instability.

Figure 2 shows the experimental time-domain pulse response with varying bias voltage at a low quantum-efficiency condition. The measurement detects the formation process of the high-speed response signal near the threshold voltage in the avalanche region. This reflects the established traveling space-charge effect in the avalanche region, which can produce the enhancement exceeding unity for the resonance frequencies resulting in internal RF-gains. The formation depends on the conditions of the charge concentration and the length of the active region. The experiments indicate that the number of carriers (carrier concentration) in the multiplication layer is an important factor for the internal RF enhancement, and affects the shape of the frequency response of a device.

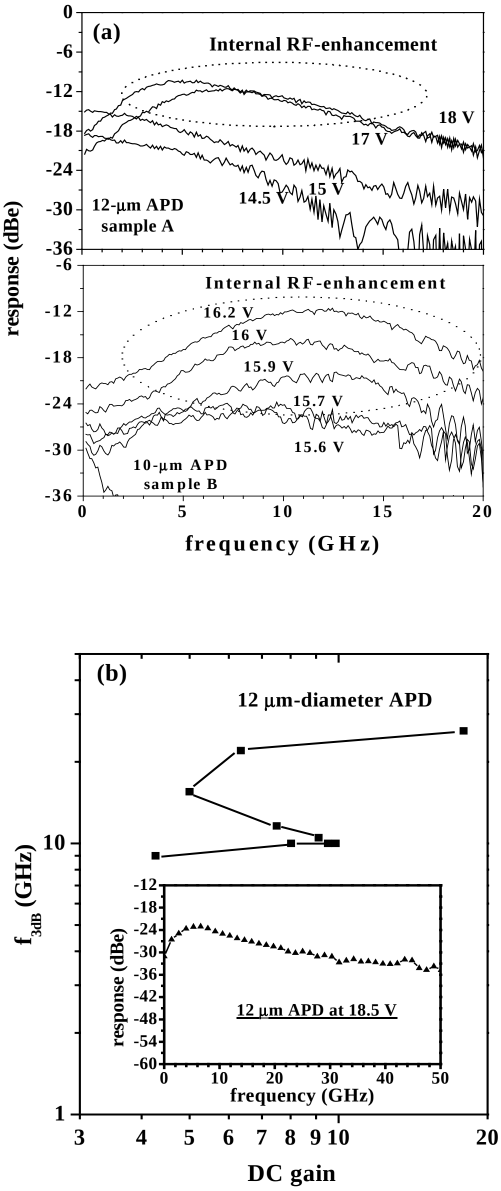

Fig. 3 (a) Frequency responses exhibiting the RF enhancement effect at higher biases. (b) The experimental multi-valued f_{3dB} versus DC-gain curve. Inset shows the maximum f_{3dB} greater than 40 GHz in the avalanche region.

Fig. 3(a) shows the measured frequency responses of the APDs, grown by MOCVD (sample A) and MBE (sample B) at various biases using a HP 20 GHz lightwave component analyzer, which displays the RF-enhanced effect in the higher-frequency range as the applied bias level increases in the avalanche region. The RF-gain peak occurs at progressively higher frequencies as the applied bias increases from the threshold voltage that occurs in the NDR region of the I-V curve. In Fig. 3(b), the APD displays a multi-valued f_{3dB} versus DC-gain curve. The measured internal RF-gain effect demonstrates that the avalanche process does not limit the device speed, which is in contrast to the conventional APD. The higher input power results in the better f_{3dB} of a device, implying that better quantum efficiency can improve the device performance further. Inset shows the frequency response of a 12-µm APD obtained from the Fourier transform of the pulse response at a high bias voltage, exhibiting the maximum f_{3dB} greater than 40 GHz at DC-gains over 10 in the avalanche region.

3. Conclusions

In summary, the InAlAs/InGaAs avalanche photodetector with a NDR characteristic is presented. The device exhibits the internal RF-gain effect in the avalanche region. The RF-gain peak occurs at progressively higher frequencies with increasing bias, demonstrating that the avalanche process does not limit the f_{3dB} of a device, in contrast to the conventional APD. The experimental result indicates that the NDR effect utilized and optimized in a high-performance APD can enhance the high-speed response at high current-gains.

Acknowledgements

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