B—3—9 Heterojunction Effect on Spectral and Frequency Responses in InP/InGaAsP/InGaAs APD

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Low noise and low dark current avalanche photodiodes (APDs) have been studied using a heterostructure of InP/InGaAsP[1] and InP/InGaAs,[2] where the InP layers are the avalanche region and the InGaAsP and InGaAs layers are the light absorption regions. To reduce multiplication noise, the avalanche and light absorption layers are required to be made of n-type materials because holes have higher ionization coefficients than electrons in InP. In these APDs, minority carriers of holes are injected from the narrow bandgap region (InGaAs(P)) to the widegap region (InP) through the heterointerface. Therefore, hole transportation is affected by the valence band discontinuity of InP/InGaAs(P). This influences the electrical and optical characteristics of InP/InGaAs(P) APDs. In this paper, we discuss the influence of valence band discontinuity on spectral and frequency responses of heterostructure APDs. These two responses are the most important factors in APDs for practical use.

Heterostructure InP/InGaAsP/InGaAs planar APDs with a two-step guardring[1] were fabricated by using liquid phase epitaxy and Be ion implantation. These APDs are suitable for studying the influence of the valence band discontinuity on APD characteristics because the diode has two heterojunctions and two light absoption layers with different bandgap energies. Figure 1 shows a cross-sectional view of an InP/InGaAsP/InGaAs APD. The carrier concentration of the ternary and quaternary light absorption layers was $8\times10^{15}cm^{-3}$ and the thicknesses were 2.0 and 0.8μm respectively; the n-InP multiplication layer was $1\times10^{16}cm^{-3}$ and 1.5μm. The p^+-InP (Cd diffusion) and p-InP (Be ion implantation) regions were formed in the n^--InP layer. By combining the linear-graded junction of the Be-implanted region and two-step InP layers (n and n^-), a successful guardring effect was attained, resulting in fabricating a planar APD. The breakdown voltage (V_B) was about 100V and the dark current was 0.2μA at $0.9V_B$; a maximum gain of 10 was obtained.

The spectral responses were measured by focusing a monochromated light onto the p^+-InP region; Figure 2 shows the results obtained in which two special features were obtained: The photocurrents in the wavelength range exceeding 1.37μm show higher values than those in shorter range and the photocurrents increase gradually in the wavelength range from 1.0 to 1.37μm despite decreasing of absorption coefficients in this wavelength range.

The frequency responses were measured under the illumination of a sinusoidally modulated laser light having a wavelength of 1.3μm. Figure 3 shows the results. Flat responses of up to 500MHz were obtained at above 90V, but the response shows two-step degradations at 70V. The depletion edge, determined from C-V measurement, was just at the InGaAsP/InGaAs interface. The first degradation starts near 5MHz, which is attributed to the diffusion effect in the ternary layer. The other degradation starts at 300MHz; this degradation is considered not due to the effect of carrier transit time because the quaternary layer is very thin (0.8 μm).

The special features of spectral response and the degradation of frequency response at above 300MHz are attributed to the effect of valence band discontinuity as described below. The energy band diagram is estimated in the higher bias voltage range (see Fig. 4).[3] When holes are generated near the InP/InGaAsP hetero-interface, they cannot gain sufficient energy to run over the heterobarrier ΔE_1 and pile up there. This leads to decreased photocurrent in the shorter wavelength region and degradation of frequency response at 300MHz. Conversely, if carrier generation occurs around and beyond the InGaAsP/InGaAs interface, the generated holes gain enough energy and pass through the InP/InGaAsP interface, so that a higher photocurrent is obtained in the longer wavelength region (≥1.37μm). At a higher bias voltage, however, holes gain enough energy in a short interval, resulting in a flat frequency response.

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1) T.Shirai et al: Appl. Phys. Lett. 40 (1982) 532
2) N.Susa et al: IEEE J. Quant. Electron. QE-16 (1980) 868
3) A.B.Chen etal: Phys. Rev. B19 (1979) 3057

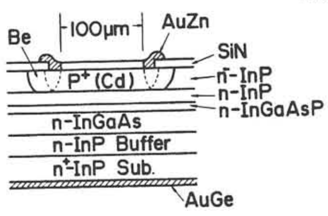

Fig. 1 Cross-sectional view of APD

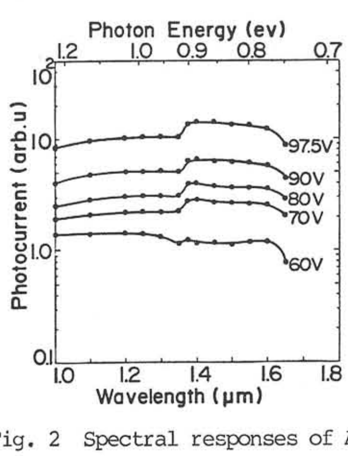

Fig. 2 Spectral responses of APD

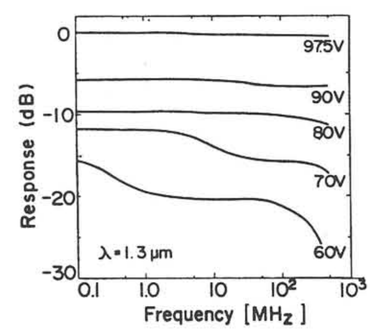

Fig. 3 Frequency responses of APD

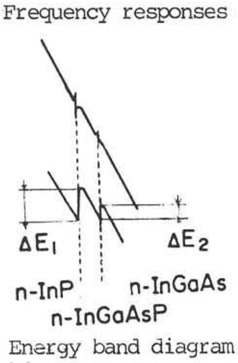

Fig. 4 Energy band diagram in the higher bias voltage