B-4-1 Improved Avalanche Photodiodes for Long Wavelength Optical Fiber Systems (Invited)

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Optical fiber systems in the wavelength region of 1-1.6 μm, where silica fiber has low loss [1] and low dispersion [2], are promised to be future long haul, large capacity transimission systems. Many studies have been concentrated on realization of detectors which have as high performance as Si-APDs (avalanche photodiodes). Semiconductors investigated for APDs include germanium [3] and III-V compounds, such as InGaAsP [4]-[12], InGaAs [13],[14], AlGaAsSb [15], AlGaSb [16],[17], GaSb [18]. This paper reviews Ge-APDs and InGaAs/InP APDs with improved properties.

Improved Ge-APDs Two junction structures, p^+-n and n^+-n-p, have been developed so that hole injection into the avalanche multiplication region is predominant [19]-[22]. Since hole ionization rate is larger than that of electrons, the noise of the p^+-n diodes decreases by increasing wavelength, and that of the n^+-n-p diodes is nearly constant in the whole sensitive wavelength region [23]. Quantum efficiency, dark current, maximum avalanche gain, and response speed of the p^+-n diodes fabricated by fully-ion implantation [20] are comparable to, or better than those of the n^+-p diodes [3]. Figure 1 shows measured receiving optical power required for 10^{-9} error rate at data rates of 0.4-2 Gbit/s using the p^+-n Ge-APD [24]. Optical power of -32 dBm was obtained for 2 Gbit/s RZ signal.

InGaAs/InP APD Small band gap energy (E_g=0.75 eV) and small electron effective mass ($m^*=0.041m_0$) result in large tunneling current of $In_{0.53}Ga_{0.47}As$-APDs [25]-[27], that restricts obtaining high avalanche gain. The structure, which consists of an InGaAs light absorption region and an InP avalanche multiplication region, is proved to have low dark current and high multiplication gain [27]. Mesa structure [29],[30] of the SAM-APDs (Separated Absorption and Multiplication regions-APD) is shown in the inset of Fig. 2. Figure 2 shows dark current and photocurrent as functions of reverse bias voltage for the diode fabricated from liquid-phase epitaxial (LPE) InGaAs/InP wafer. Low dark current density of 4×10^{-4} A/cm^2 at 90% of breakdown voltage and high avalanche gain of 50-80 were obtained by the diodes. The multiplication noise for the InGaAs/InP SAM-APD is lower than that for Ge-APD. k value of the diode is 0.3-0.4, as shown in Fig. 3. Calculated receiving optical power for InGaAs/InP SAM-APD is shown in Fig. 1. Receiving power will be improved by 3.3 dB using the SAM-APD.

Planar structure SAM-APDs (Fig. 4) [31] are fabricated from vapor-phase epitaxial (VPE) InP/InGaAs/InP wafer [32] or LPE wafer with an anti-meltback layer of InGaAsP [33],[34] similar to 1.5 μm laser diode. Guardring structures by Zn or Cd diffusion [33],[35] and a new structure guardring [11] were also investigated. Detailed properties will be presented.

References
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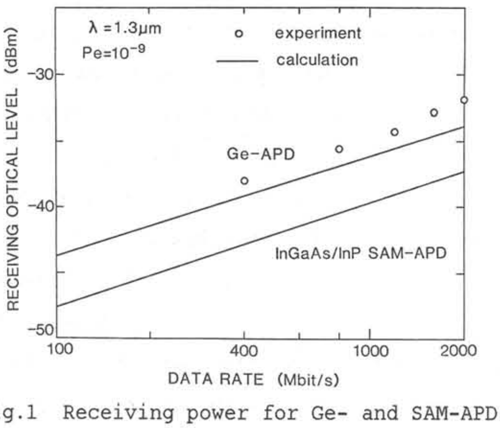

Fig.1 Receiving power for Ge- and SAM-APD.

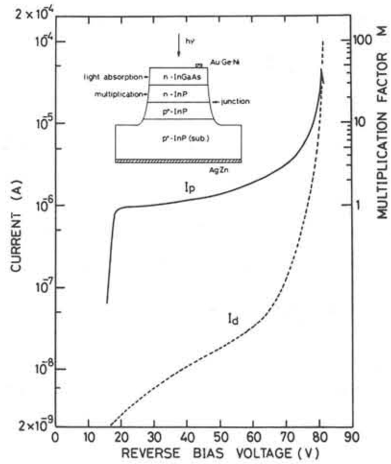

Fig.2 Dark- and photocurrent.

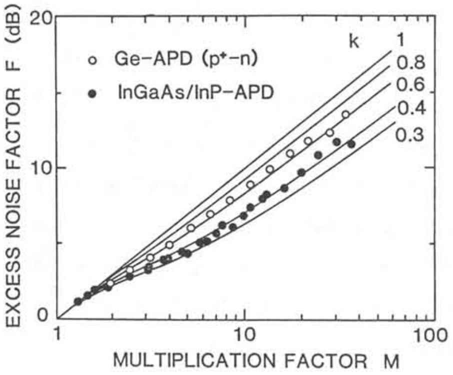

Fig. 3 Excess noise factor.

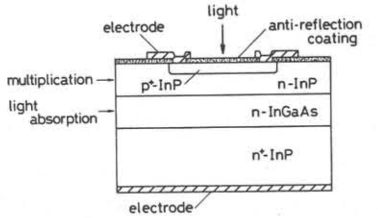

Fig. 4 Planar structure SAM-APD.