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Design and Characteristics of Low Noise and High Speed Silicon Avalanche Photodiodes

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Electric field distribution in avalanche photodiodes (APD) is required to be optimally designed in order to obtain low noise and high speed response characteristics. This paper discribes an optimum design and experimental results of silicon APD's at the wavelength corresponding to GaAlAs laser and light emitting diode.

Multiplication noise in silicon APD's with four types of impurity profile shown in Fig.1 is numerically calculated. Results on effective ionization coefficient ratio k_{eff} and depletion layer width w in Fig.2 show that reach-through types represented by C and D are suitable to obtain both low multiplication noise and wide depletion layer width at breakdown voltage around 100 V. On the other hand, type A, whose impurity density is uniform, does not have a wide depletion layer width, and the hyper-abrupt junction diode, type B, has a high k_{eff} value.

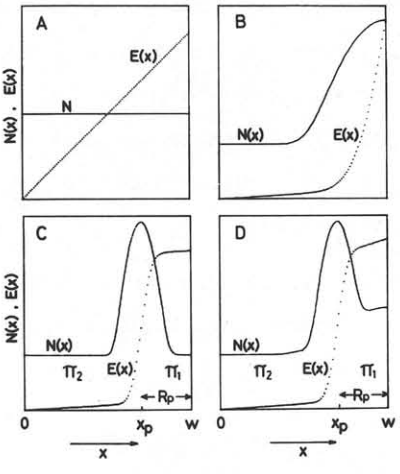

Fig.1 Four models of impurity density profile. The junctions locate at x = w.

High speed response can be obtained by reducing carriers which move by diffusion in a light absorption region. An impurity density gradient is provided in the absorption region to induce built-in electric field which drifts photocarriers with higher speed than that by diffusion.

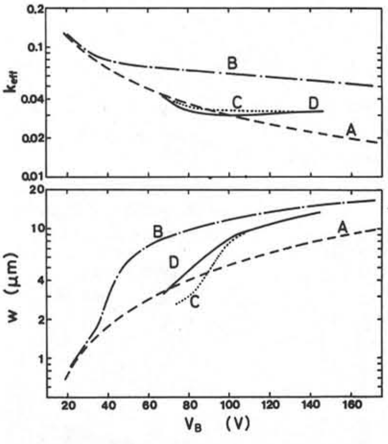

Fig.2 Calculated results of effective ionization coefficient ratio k_{eff} and depletion layer width w.

The impurity profile has been designed as shown in Fig.3. The profile at the avalanche multiplication region has a low-high-low structure, which is fabricated by boron ion implantation and epitaxial growth. Annealing at 1150 °C for 9 hours formed the impurity gradient by dopant diffusion from p^+-substrate to epitaxial p-layer. Impurity density is 7×10^{14} cm^{-3} in π_2 region and 1×10^{16} cm^{-3}

at the peak. The density in π_1 region is 7 x 10^{14} cm^{-3} for type C and 3 x 10^{15} cm^{-3} for type D. Breakdown voltage is in the range of 90 to 110 V, and its temperature coefficient is about 2 x 10^{-3} /degree. Dark current is less than 10^{-11} A at 85 % of the breakdown voltage. The quantum efficiency ranges 0.5 - 0.68 for wavelength 0.81 - 0.83 μm.

Measured excess noise factor F versus mutiplication factor M is shown in Fig.4. The excess noise factor calculated by McIntyre's equation(1) is also shown. The parameter k is the ratio of hole ionization coefficient to that of electron. Experimental results correspond to k = 0.04 for type C and 0.03 for type D. When k = 0.03, the excess noise factor at M = 100 is 7 dB.

Typical response waveform for mode-locked Nd:YAG laser pulses is shown in Fig.5. Observed pulse full width at half maximum ranges in 260 - 300 psec for multiplication factor of 2 - 200. Pulse width at 10 % of the pulse peak is 620 psec. Gain-bandwidth products are 150 GHz and 300 GHz at M = 100 and 400, respectively.

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Reference

(1) R.J. McIntyre, IEEE Trans. Electron Devices, ED-13, 164, 1966

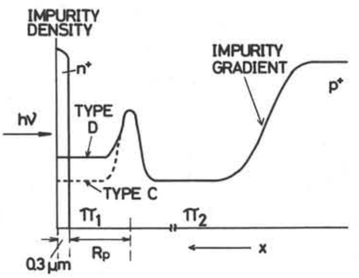

Fig.3 Impurity profile of fabricated diodes.

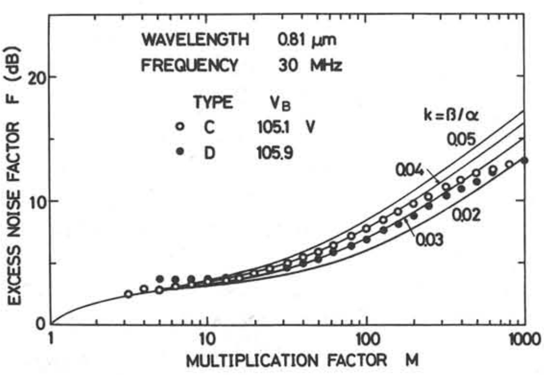

Fig.4 Measured excess noise factor.

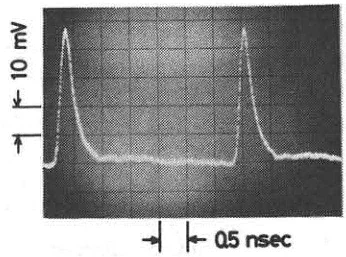

Fig.5 Response waveform for mode-locked Nd:YAG laser pulse.