can be generated is limited. Since most photodiodes use band-to-band photoexcitation (except for photoexcitation over the barrier in metal-semiconductor photodiodes), the long-wavelength cutoff λ_c is established by the energy gap of the semiconductor, Eq. 1, for example about 1.7 μm for Ge and 1.1 μm for Si. For wavelengths longer than λ_c, the values of α are too small to give appreciable absorption. The short-wavelength cutoff of the photoresponse comes about because the values of α are very large ($\geq 10^5$ cm^{-1}), and the radiation is absorbed very near the surface where recombination is more likely. The photocarriers thus recombine before they are collected in the *p-n* junction. In the near-infrared region, silicon photodiodes with antireflection coating can reach 100% quantum efficiency near 0.8 to 0.9 μm. In the 1.0- to 1.6-μm region, Ge photodiodes, III-V ternary photodiodes (e.g., InGaAs), and III-V quaternary photodiodes (e.g., InGaAsP) have shown high quantum efficiencies. For longer wavelengths, photodiodes are cooled (e.g., 77 K) for high-efficiency operation.

Response Speed. The response speed is limited by a combination of three factors: (1) drift time in the depletion region, (2) diffusion of carriers, and (3) capacitance of the depletion region. Carriers generated outside the depletion region must diffuse to the junction resulting in considerable time delay. To minimize the diffusion effect, the junction should be formed very close to the surface. Most light will be absorbed when the depletion region is sufficiently wide (of the order of $1/\alpha$); with sufficient reverse bias the carriers will drift at their saturation velocities. The depletion layer must not be too wide, however, or transit-time effects will limit the frequency response. It also should not be too thin, or excessive capacitance C will result in a large R_LC time constant, where R_L is the load resistance. The optimum compromise occurs when the depletion layer is chosen so that the transit time is of the order of one-half the modulation period. For example, for a modulation frequency of 10 GHz, the optimum depletion layer thickness in Si (with a saturation velocity of 10^7 cm/s) is about 5 μm.

Device Noise. To study the noise properties in a photodiode, we will consider the generalized photodetection process shown in Fig. 5a. An optical signal and background radiation are absorbed by the photodiode, whereby electron-hole pairs are generated. These electrons and holes are then separated by the electric field and drift toward the opposite sides of the junction. In the process, a photocurrent is induced in the external load resistor. Since noise is frequency dependent, to determine the currents generated by this photoelectric process, we will consider an intensity-modulated optical signal given by Eq. 12. The average photocurrent I_P due to the optical signal is given by Eq. 10. For the modulated optical signal, the rms signal power is $mP_{\text{opt}}/\sqrt{2}$, and the rms signal current is obtained from Eq. 13 with the gain set to unity,

$$i_p = \frac{q\eta m P_{\text{opt}}}{\sqrt{2}h\nu}. \tag{17}$$

We designate the current resulting from the background radiation to be I_B, and the dark current due to thermal generation of electron-hole pairs in the depletion region