

# Photodiode-Based Detector Operates at 60 GHz

*Careful design of device structure and drive circuitry yield high speed photodetector for optical detection*

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With the recent advancement of gigabit fiber communication and the photonic distribution of microwave signals, there is a growing need to characterize the high-speed optical signals found in such systems. This task is typically accomplished with a high-speed photodetector followed by an instrument such as a sampling oscilloscope, a radio frequency (RF) spectrum analyzer, or a vector network analyzer. For the measurement to be a true representation of the actual signal, the speed or bandwidth of the combined measurement system should exceed that of the signal under test. The high-speed photodetector is thus an essential part of the system.

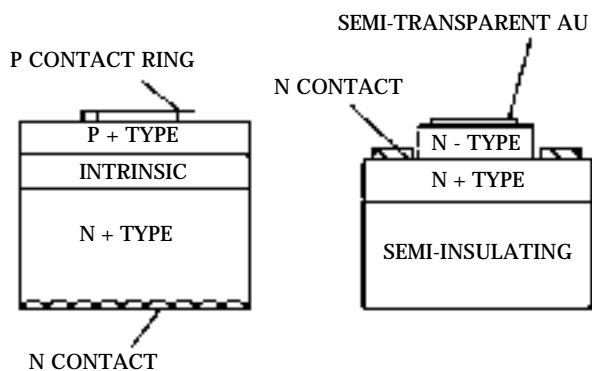
## Designing a high-speed detector

Two types of photodetectors commonly used for high-speed applications are *p-i-n* and Schottky photodiodes (see Figure 1). In both devices, photon absorption in the depletion region of a reverse-biased junction creates electron-hole pairs. These carriers are swept out of the high-field region to create a current in an external circuit.

The speed of these photodiodes is limited by depletion region transit time and capacitance. Transit time refers to the time required for the electrons and holes to drift across the high-field depletion region. It is determined by carrier velocity, which is constant ( $\sim 3 \times 10^6$  cm/s) and the depletion region thickness  $t$ , which can vary. Depletion region thickness is thus the design parameter controlling transit time, and should be made inversely proportional to the desired bandwidth.

Capacitance slows the device via an RC time constant where the resistance is that of the device load impedance. The capacitance is proportional to the active area and inversely proportional to depletion region thickness. For high-speed operation, then, both the active area and depletion region thickness should be minimized. A small active area, however, places demanding requirements on the focusing optics for the detector. A thin depletion region means only a fraction of the incident photons will be absorbed. To optimize speed while maintaining performance, designers generally make the active area and depletion region thickness just small enough to satisfy the speed requirements; transit time is typically made comparable to the RC time constant. Using this simple approach, engineers at New Focus have designed high-speed Schottky detectors that can achieve bandwidths as high as 60 GHz.

The design team chose a Schottky configuration because it is the faster of the two designs — in the case of a *p-i-n* diode, if the top *p*-layer is absorbing, the carriers generated in this undepleted, low-field region must diffuse out at slow speeds. Schottky photodiodes also offer lower parasitic resistance. The *n*-type Schottky diode, for example, has only an *n*-layer and no *p*-layer. In a top-illuminated *n*-type diode, the carriers are created near the top metal contact; the holes, which are the slower carriers,

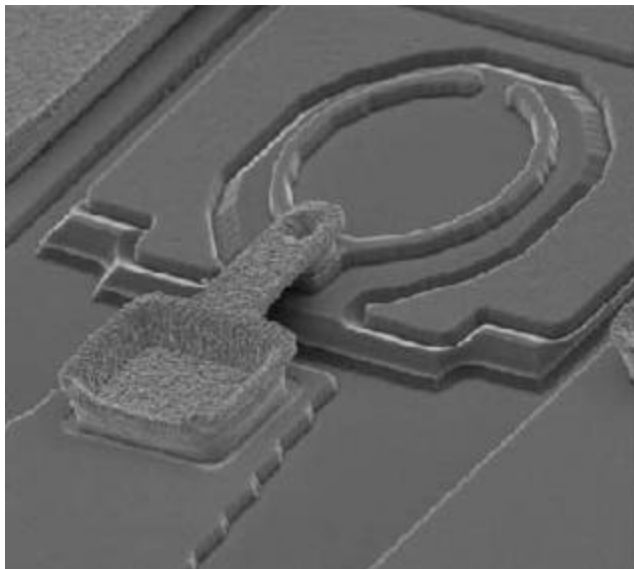


**FIGURE 1:** The high-field region is the intrinsic layer in the *p-i-n* photodiode (left) and the *n*-region in the Schottky photodiode (right).

travel just a short distance to the metal.

The detectors have been designed for both back-side and front-side illumination. For back-side illumination, light is incident through the transparent indium phosphide (InP) substrate and absorbed in the indium gallium arsenide (InGaAs) active region, permitting detection of wavelengths from 950 nm to 1650 nm. The top Schottky contact serves as a mirror, allowing a double-pass through the absorbing layer to enhance quantum efficiency.

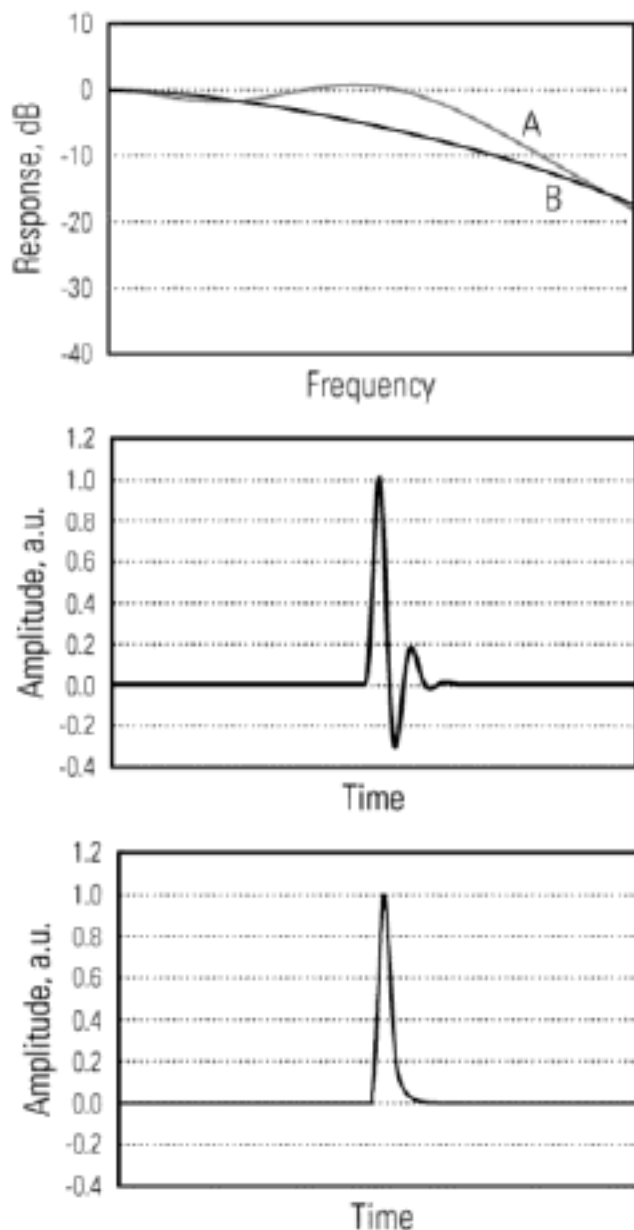
The front-illuminated devices are fabricated with both InGaAs and gallium arsenide (GaAs) absorbing layers and have a thin, semi-transparent gold (Au) Schottky metal. The sheet resistance of the gold is detrimental to the high-speed performance, so a current-collecting ring of thick gold is added to the periphery of the active area to minimize this resistance (see Figure 2). The devices are sensitive for wavelengths ranging from 400 nm to 1650 nm.



**FIGURE 2:** SEM of a front-illuminated InGaAs Schottky photodiode. Photo Courtesy of New Focus

### Flat frequency response and ring-free impulse response detectors

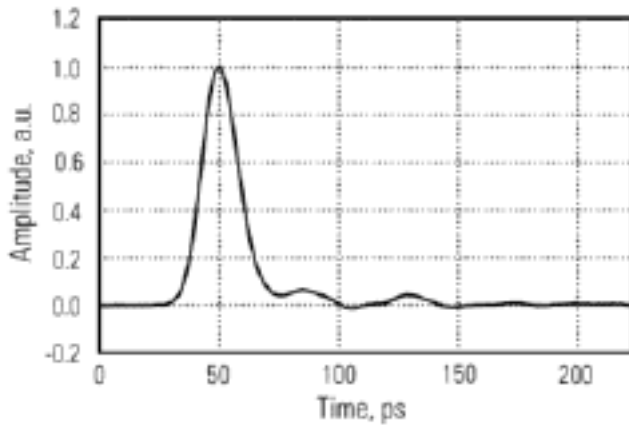
An intrinsic photodiode designed for high-speed operation is necessary, but not sufficient, for high-speed optical detection. The bias circuitry and the high-speed connection to the 50-ohm output transmission line must also be carefully designed to produce the desired response. This response is dictated by the application and is generally either a flat frequency response, with the responsivity varying only slightly across the operating bandwidth, or a fast, ring-free impulse response. Fourier transform techniques show



**FIGURE 3:** Detector designed for enhanced responsivity at high frequencies provides a nearly flat frequency response (top, curve A), but suffers from ringing in the temporal domain (middle). Detector with a clean, ring-free impulse response in the temporal domain (bottom) experiences roll off in the frequency domain, reducing the 3-dB frequency.

that the flat frequency response suffers from controlled ringing in the temporal domain (impulse response, see Figure 3). The ring-free impulse response, on the other hand, corresponds to a characteristic roll-off in the frequency domain and a corresponding reduction in the 3-dB frequency.

Recently developed time-domain optimized detectors with a fast, minimal-ringing impulse response are especially useful for digital com-



**FIGURE 4:** Impulse response of the Model 1444 measured with a 50-GHz scope and a 150-fs full-width-at-half-maximum input pulse at 1.06  $\mu\text{m}$  shows only slight amounts on ringing.

munications applications in which spurious ringing can degrade an eye diagram and bit error rate (BER). These detectors have been designed with a resistive matching network that presents the diodes with a constant 50-ohm impedance to eliminate unwanted reflections, and also terminates the detector so that its impedance is 50 ohms. The internal 50-ohm termination makes the detectors directly compatible with BER testing using switched digital hierarchy and SONET filters. The detectors are also fabricated with on-chip bias circuitry, such as integrated bypass capacitors which provide near-ideal performance to well beyond 60 GHz.

The impulse response of a detector with an 18-ps full-width-at-half-maximum shows only a slight amount of ringing (see Figure 4). The measurement has been made with a 50-GHz

sampling oscilloscope and short (less than 200 fs) pulses from a diode-pumped neodymium-doped glass (Nd:glass) laser operating at 1.06  $\mu\text{m}$ . Connecting the detector module directly to the input of the oscilloscope eliminates RF cables, and the detector's fiber-optic input then receives signals from the system under test.

Detectors with a flat frequency response can be implemented with some slight inductive peaking to enhance the responsivity at higher frequencies. Such detectors are useful for applications involving the optical transmission of microwave and millimeter wave RF signals, such as wireless cellular networks or antenna remoting in military or commercial communication satellite systems.

High-speed detectors are an important component in characterizing high-bandwidth optical communications. By optimizing the photodiode for high-speed operation, and by designing the microwave circuitry to produce either a ring-free impulse response or a flat frequency response, a wide range of measurement needs can be addressed.

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