A NEW DETECTOR FOR IRLED LIGHT

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A New Detector for IR LED Light

A new GaAlAs processing technique has led to a wavelength-specific detector for 880 nm light that requires no signal modulation or optical filtering to eliminate background illumination.

The standard device for detecting near IR light in the 850–950 nm region has for many years been the silicon photodiode or silicon phototransistor. These detectors are reasonably inexpensive and readily available from a number of suppliers. Their greatest disadvantage has been their broad spectral response, which often necessitates additional circuit components for source modulation and electrical filtering for the detector and/or external optical components for optical filtering. A new detector featuring limited spectral response completely eliminates the need for additional electrical or optical components.

The Silicon Photodiode

The silicon photodiode detector (see Figure 1) consists of a shallow diffused p-n junction. The planar junction edge emerges on the top of the chip, where it is passivated by a thermally grown oxide layer. The p-n junction and the depletion regions, particularly important to the operation of a photodiode, are created when the p-type dopant with acceptor impurities (excess holes) comes into contact with the n-type material, which is doped with donor impurities (excess electrons). The holes and the electrons, experiencing a lower potential on opposite sides of the junction, begin to flow across the junction into their respective areas of lower potential. This charge movement establishes a depletion region with an electric field opposite and equal to the low-potential field. Hence, no more current flows.

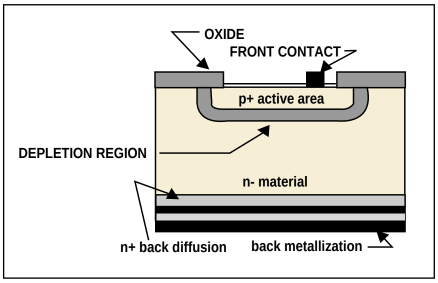

Figure 1. *Silicon photodiodes used for 880 nm detection will typically have a deeper diffused p-n junction. The reason is that 880 nm photons, due to their lower energy, are absorbed more deeply into the silicon.*

When photons of energy greater than that of the bandgap fall onto the device, they are absorbed and electron-hole pairs are created. The depth at which the photons are absorbed depends on their energy—the lower their energy, the more deeply they are absorbed. The electron-hole pairs drift apart, and when the minority carriers reach the junction they are swept across by the electric field. If the two sides are electrically connected, an external current flows through the connection. If the created minority carriers of that region recombine with the majority carriers of that region before reaching the junction field, the carriers are lost and no external current flows.

The GaAlAs Photodiode

Gallium-aluminum-arsenide (GaAlAs) has been in use for the past 20 years as an LED source. In laboratory studies it was recognized that GaAlAs could surpass silicon in detecting light from an 850–880 nm source. Until recently, GaAlAs was too expensive for general applications because of the size required (active areas >1mm^2 for the smallest detector vs. 0.13 mm^2 for most LEDs). The GaAlAs detector also had significantly higher noise than silicon photodiodes. Recent improvements in both materials and processing have enhanced the manufacturing yields, making GaAlAs an attractive IR detector (see Photo 1).

The photodiode region is formed and photons are converted to electrons in the same way as in silicon photodiodes. The difference is in the bandgap energy; silicon's is 1.1 eV and the GaAlAs detector's is ~1.3 eV, which is 0.1 eV lower than an 880 nm GaAlAs IR LED. The higher bandgap limits conversion to those photons that exceed 1.3 eV, resulting in a long cutoff wavelength of ~950 nm. The cutoff wavelength isn't so sharp as silicon's because the bandgap energy varies monotonically along the same curve as the aluminum concentration profile. Silicon, with its 1.1 eV bandgap energy, converts photons with a wavelength up to 1100 nm.

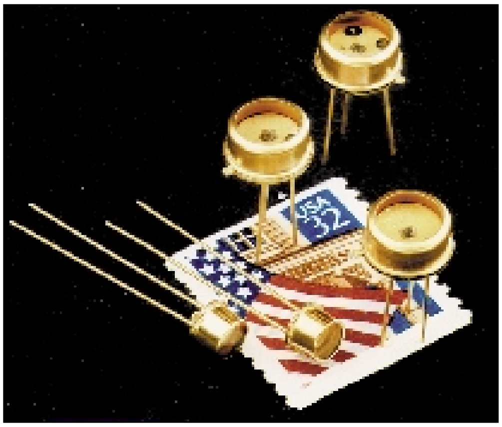

Photo 1. *Improvements in fabrication materials and processing techniques have secured GaAlAs photodetectors a place in the IR detector market.*

The GaAlAs photodiode consists of an epitaxially grown, graded-bandgap structure with two semiconducting regions that form a p-n junction (see Figure 2, page 24.). The aluminum concentration in the structure

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varies uniformly through the cross section from high at the top of the n layer to extremely low at the bottom of the p layer (see Figure 3). The high aluminum content in the n layer creates a window structure for transmission of longer wavelengths.

It is interesting to note that for an LED to penetrate the window layer, the photons must have an energy lower than that of the bandgap, but for a detector, the photon energy must be higher than the bandgap. (The GaAlAs detector could be used as an IR LED as well, but the peak wavelength would shift and become ~30 nm longer due to the lower energy required to penetrate the window layer of the device.) The GaAlAs detector's junction is buried ~100 µm into the material, while silicon detectors have their junction within 10 µm of the top surface. The additional material creates a unique optical filter that passes <2% of the light at 750 nm and <1% at 650 nm. Longer wavelengths, up to 1.3 eV (950 nm), are absorbed at varying efficiencies and converted to electrons. The combination of the higher bandgap of GaAlAs and the buried junction creates a 60 nm full-width half-maximum response curve.

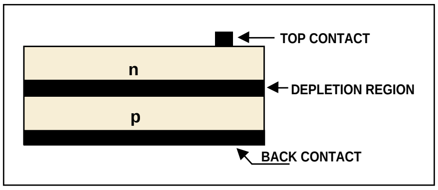

Figure 2. *In contrast to the silicon photodiode, the thick layer of material above the depletion region in a GaAlAs photodiode provides short wavelength blocking throughout the UV and visible regions.*

With the graded-bandgap process, the depth of the junction and bandgap can be controlled to vary the peak responsivity from 850 nm to 905 nm.

Standard Near IR Detectors

The spectral responses of the detectors listed in Table 1 are plotted in Figure 4. As can be seen, the greatest difference between silicon and GaAlAs detectors is silicon's much broader spectral response. Although such a broad response is advantageous and even mandatory in some applications, its effect of reducing the system SNR causes problems for the designer trying to detect a narrow band source in the near IR (such as an LED). Figure 5 (page 26) shows the response of GaAlAs and silicon detectors, the emission spectra of the sun, an 880 nm IR LED, and a 905 nm laser.

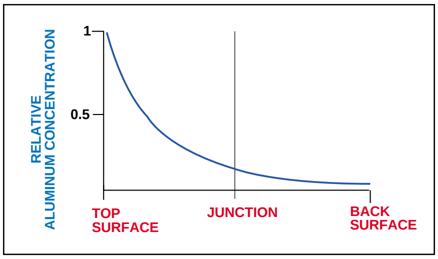

Figure 3. *Profiling the semiconductor from front to back illustrates its relative aluminum concentration and bandgap. As can be seen, the GaAlAs photodiode does not have a single bandgap energy level within the depletion region.*

TABLE 1

Standard Detector Choices for Near IR Detection

Detector	Spectral Region (23°C)	Peak Spectral Response	Responsitivity @ 880 nm	NEP (Typ @ 880 nm)	Risetime (Typ)
Silicon	300–1100 nm	950 nm	0.5 A/W	1×10^{-14}	100 ns
GaAlAs	850–910 nm	880 nm	0.6 A/W	1×10^{-14}	700 ns
Ge	700–1600 nm	1550 nm	0.2 A/W	8×10^{-13}	7 µs
InGaAs	850–1700 nm	1600 nm	0.2 A/W	6×10^{-14}	10 ns

Background Measurements with GaAlAs and Silicon Detectors

Table 2 compares only the GaAlAs and the silicon detectors because their prices are comparable, both types are available in a variety of sizes, and neither requires additional biasing voltages or cryogenic temperatures. The measurements, taken under various conditions, show typical currents generated by unfiltered GaAlAs and silicon detectors, and by the same silicon detector with three types of optical filtration, two longpass glasses, and a bandpass. Both detector types have active areas of 5 mm^2.

The test conditions were:

- Outdoor 1. Midday, clear sky, looking directly at the sun
- Outdoor 2. Midday, clear sky, looking away from the sun, parallel to the horizon
- Outdoor 3. Midday, overcast sky, looking away from the sun, parallel to the horizon
- Indoor 1. Normal office environment illuminated at regular intervals by 40 W fluorescent lights
- Indoor 2. The same as Indoor 1, with the addition of a nondirectly illuminating 75 W tungsten source about 8 ft away

The spectral response for the RG830, RG850, and the bandpass filter are shown in Figure 6.

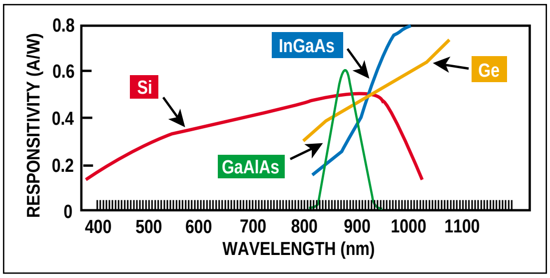

Figure 4. *Various detectors suitable for detecting 880 nm light exhibit a broad range of responses; the GaAlAs's bandgap energy and depth of junction provide a wavelength-specific performance.*

Signal Measurements

To compare the various silicon/filter combinations and the GaAlAs photodiode, an 880 nm source was positioned 4 ft away from the detector and forward biased to produce 200 nW at the detector. To establish the baseline background measurement, each detector was first tested without powering the LED and under the conditions listed in Table 2 (Indoor 1, Indoor 2). The LED was then powered to illuminate the detector and the background measurement was subtracted to determine the signal current. A ratio was

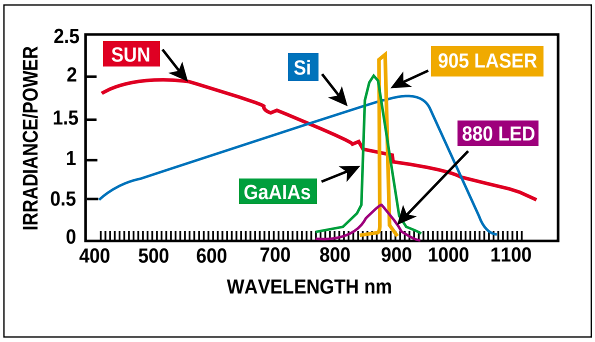

Figure 5. *To be successfully detected, light emitted by an 880 nm LED or an 805 nm laser diode must compete with the sun and other unwanted background light sources. With a broadband detector (silicon), the signal from the integrated energy of all the background sources can far exceed the signal from source.*

TABLE 2

Background Measurements Using GaA1As and Silicon Detectors

Detector	Detector Output				
	Outdoor 1	Outdoor 2	Outdoor 3	Indoor 1	Indoor 2
GaAlAs	207 µA	185 µA	149 µA	13 nA	27 nA
Bare silicon	874 µA	603 µA	368 µA	537 nA	233 nA
Si with RG830	500 µA	298 µA	189 µA	32 nA	80 nA
Si with RG850	450 µA	290 µA	180 µA	20 nA	92 nA
Si with BP filter	250 µA	240 µA	150 µA	15 nA	30 nA

established by dividing the signal current by the background light current. Table 3 illustrates the relative in-spectral-band responsivity vs. the out-of-spectral-band blocking for each detector configuration.

Conclusions

It is interesting to note that the ratio of signal current to background current in an optically filtered silicon detector under fluorescent lights is approximately the same as that for the optically unfiltered GaAlAs under a combination of fluorescent and tungsten lights. In all cases, the GaAlAs signal current to background current ratio is at least 2 × that of silicon with any combination of optical filters.

It would appear that the best silicon signal ratio is achieved by using the RG850 glass, probably because of signal loss caused by the long wavelength slope of the bandpass filter and the higher pass band transmittance of the longwave pass glass. If the filter were manufactured with a slightly wider half bandwidth, albeit with a lower pass band transmittance, the ratio of signal current to background current should be better than that of the longwave pass glass alone. However, the signal-to-background ratio would still not approximate that of the GaAlAs.

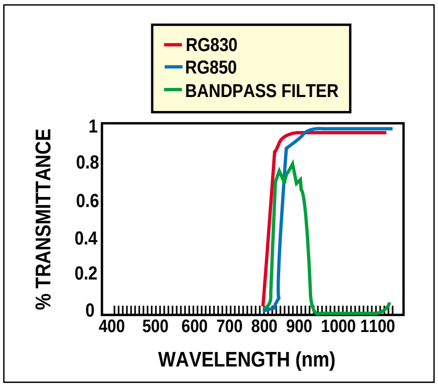

Figure 6. *In reducing the background light when making an 880 nm measurement, the two longwave pass filters will attenuate the visible spectrum by about a factor of 10,000, but allow transmittance of all IR light to ~2 µm. The bandpass filter will eliminate both the shortwave and long-wave energy, and the optical cavity can be tuned for both wavelength and bandwidth.*

TABLE 3

Signal Measurements

Detector	Detector Output Current/Signal Current to Background Current Ratio		
	Signal Current	Condition 1	Condition 2
GaAlAs	106 nA	121 nA/7:1	148 nA/2.5:1
Bare silicon	100 nA	650 nA/0.2:1	783 nA/0.15:1
Si with RG830	88 nA	120 nA/2.8:1	170 nA/1:1
Si with RG850	80 nA	102 nA/3.6:1	176 nA/0.83:1
Si with BP filter	39 nA	57 nA/2.2:1	70 nA/1.25:1

The additional cost of adding the spectral filtering was not taken into account. The additional cost for optical filtering depends on the size of the detector and the type of filtering desired. In many cases, a doubling of the sensor cost is not an unreasonable assumption.

An additional benefit of the GaAlAs detector is space. The designer can incorporate a wavelength-specific detector in a space no greater than 2 mm^2 (detector chip and mounting ceramic). The same wavelength-specific silicon device would require the same thickness with an additional 1–5 mm^2 for the optical filter.

The data indicate that if the designer needs to measure 880 nm LEDs in environments where background light could be a problem, the best solution is the GaAlAs detector.

The following devices, instruments, and parts were used in the test:

GaAlAs Detector. Model ODD-95W. Opto-Diode Corp., Newbury Park, California

Silicon Detector. Model OSD5-5T. Centronic Inc., Newbury Park, California

Amplifier/Current Meter. Model OT-100. On-Trak Photonics, Lake Forest, California

The RG830/RG850 color glass. Schott Glass Works, Duryea, Pennsylvania

Wideband filter. Spectro-Film, Inc., Woburn, Massachusetts

IR LED. Model OD-880-F. Opto Diode Corp., Newbury Park, California

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