Application Note

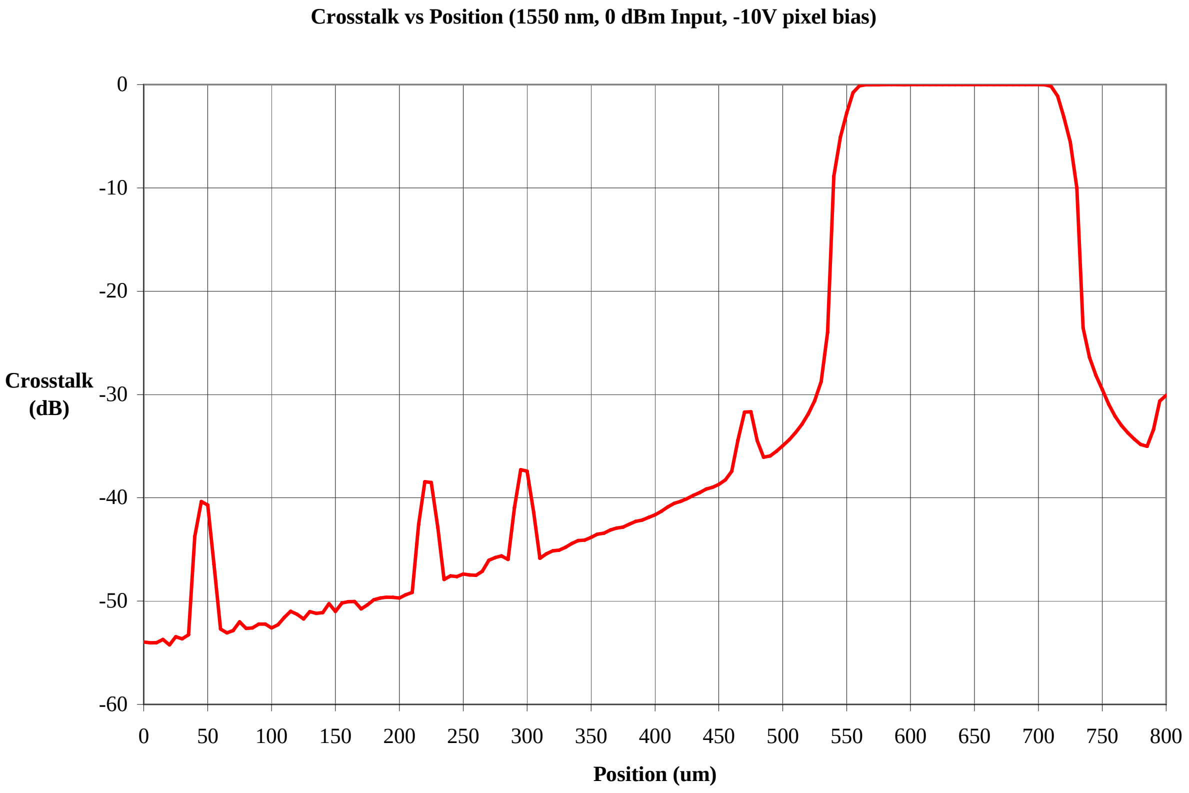
Cross-talk Limits in Monolithic InGaAs Photodiode Arrays

Summary

The primary factors determining the minimum achievable DC crosstalk of monolithic InGaAs photodiode arrays are carrier diffusion between pixels and optical crosstalk within the array.

The graph below shows how crosstalk in a common-cathode monolithic InGaAs detector array varies with the distance between the incident light spot and the measured pixel. The abscissa of the graph represents the position of a light spot scanned along the array axis, and the ordinate represents the electrical signal produced in the pixel at the extreme right (centered at a position of 635 microns on the graph). The array pitch was 250 microns, and the active area of each pixel was 150 microns wide along the scanned axis. The illumination source was a single-mode optical fiber placed within a few microns of the array surface; in this configuration optical crosstalk external to the array was less than -60 dB.

As expected, the signal level is constant as the light is scanned within the active area of the measured pixel (from 560 to 710 µm). Nearly all incoming photons that are absorbed anywhere within the depletion

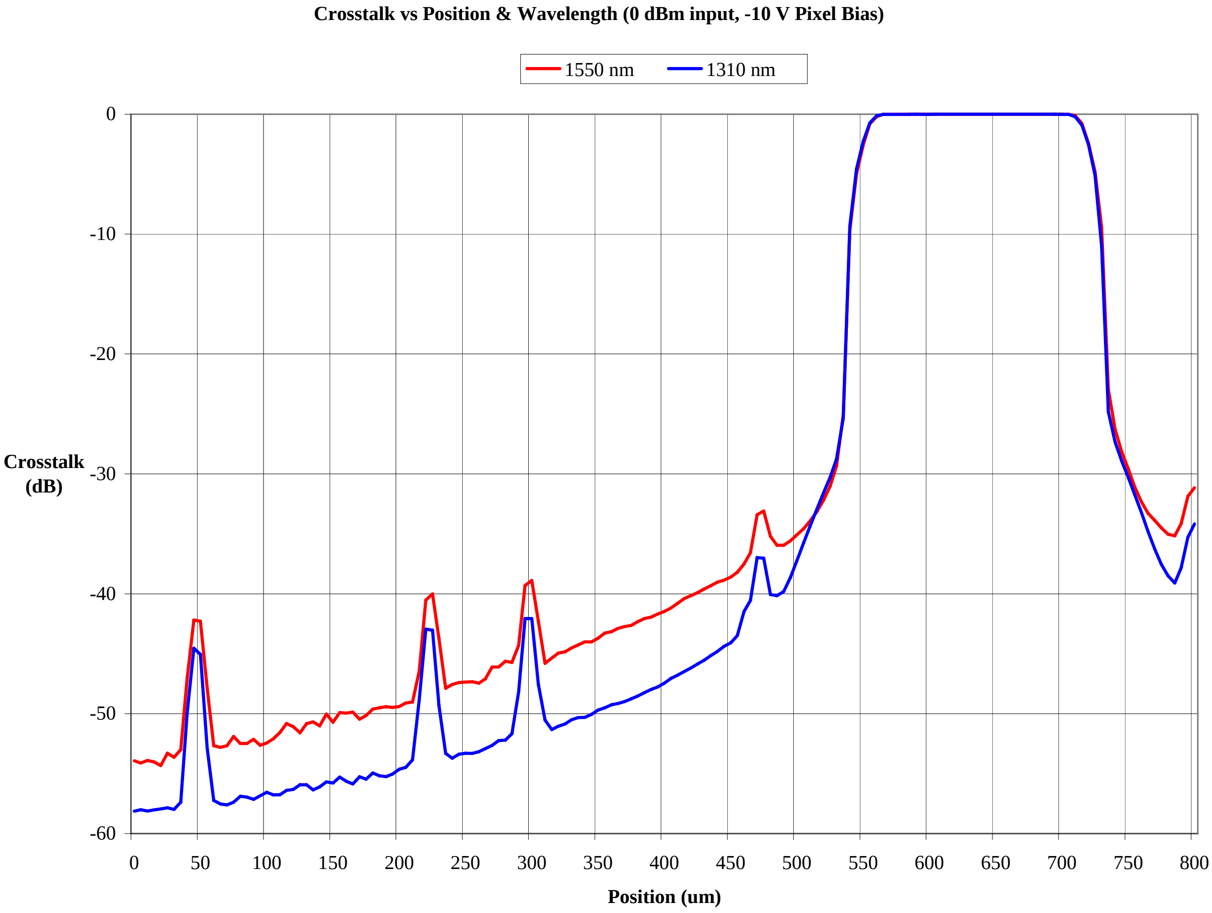


region of the diffused junction generate carriers that are separated by the electric field and collected at the anode and cathode.

However, when light is incident outside this active area, the crosstalk signal does not remain constant as the beam moves within the adjacent pixel active area (from 310 to 460 µm), nor within the active area of the non-adjacent pixel (from 60 to 210 µm). Rather, crosstalk decreases monotonically with distance between the light spot and the measured pixel, except for the small peaks located between the active areas. (These crosstalk peaks correspond to regions with no diffused junction and therefore no significant electric field at any point along the light path. This allows a larger fraction of the photo-generated carriers to contribute to the diffusion current that is independent of electric field.)

When the above experiment is repeated at various photodiode reverse bias voltages from zero to near breakdown, it is found that crosstalk at first decreases with increasing reverse bias, then becomes independent of bias voltage when the device becomes fully depleted (typically at 5 to 10 Volts). This effect is not strong: varying the reverse bias on the pixels from zero to -15 Volts reduces crosstalk at 1550 nanometers by about 2 dB.

Crosstalk also varies with wavelength: the crosstalk at 1310 nm is approximately 6 to 8 dB lower than the crosstalk at 1550 nm, as shown below.



Cross talk also varies slightly with the doping of the InGaAs active layer. Within the range of practical doping levels, crosstalk is roughly 3 dB lower for the highest resistivity active layer than for the lowest resistivity active layer.

What is the physical origin of crosstalk? Resistive leakage between the device terminals cannot explain the variation with wavelength, the variation with the position of the incident light inside a single active region, or the non-linear variation with bias voltage. The most plausible explanation for the origin of crosstalk is a combination of carrier diffusion and optical crosstalk within the array.

Diffusion can generate crosstalk when photo-generated carriers are not captured by the anode and cathode contacts closest to the incident light spot, but rather diffuse over relatively long distances to be collected by more distant contacts. These may be carriers that originate within the depletion region of a particular pixel but diffuse out of the depletion region before they can drift to the contacts, or they may be carriers that originate outside the depletion region and thus are free to diffuse along the concentration gradient.

Diffusion effects can explain the main features of the two graphs above. First, the generally decreasing crosstalk with distance, even when the incident light is scanned across a pixel, is consistent with a diffusion effect. Diffusion can also explain the crosstalk peaks observed in the zero-electric-field regions. In this regard, note that the 1550 nm crosstalk levels are the same when the light is incident at 50 microns and at 400 microns, even though the carriers responsible for crosstalk must move laterally by 510 microns in the former case and only 160 microns in the latter. When light is incident at 50 microns, the electric field is essentially zero in the region between anodes where the light is absorbed, so all of the light-generated carriers are free to diffuse away from the generation point. However, when light is incident at 400 microns, most of the carriers are generated within the depletion region of the photodiode located between 310 and 460 microns and are therefore collected by the contacts, leaving relatively few available to diffuse laterally in order to be collected by the adjacent pixel as crosstalk. This effect may be enhanced at longer optical wavelengths, where the mean absorption depth is larger and more carriers may be generated in lower-field regions. Note that if internal optical crosstalk were the sole contributing factor, crosstalk would be independent of electric field.

Optical crosstalk can arise within the array when a small fraction of the diverging incident light (of the order of 0.1% to 10%) passes through the depletion region, reflects from the interior surface of the cathode contact metal, and is absorbed in the depletion region of an adjacent pixel. The ratio of crosstalk at 1310 and at 1550 nm shown above is consistent with the wavelength dependence of light transmission through the active layer calculated for the actual device structure used in the experiments.

Based on the experiments conducted to date, the relative magnitudes of the optical and diffusion effects cannot be quantitatively determined.

Another consideration in the control of crosstalk in monolithic arrays is the use of guard ring structures. In common-cathode arrays, guard rings are p-type diffusions identical to the active pixels, but forming a single structure laid out in a lattice geometry surrounding the active pixels. When light is incident within a single pixel, the presence of a surrounding guard ring has no effect on crosstalk between pixels: crosstalk is purely a function of the electric field at the location of the incident light and the distance between the incident light and the measured pixel, as shown in the data above. One benefit of a guard ring is to prevent light striking the areas covered by the guard ring from generating a primary photocurrent in any pixel; this increases the modulation transfer function (MTF) of an array without reducing the pixel pitch. When a guard ring is used, the array is more sensitive to bias voltage: crosstalk arising from light incident within a pixel varies by about 2 dB between zero and 15 Volts reverse bias, but crosstalk arising from light incident within the guard ring varies about 25 dB between zero and 15 Volts reverse bias. When a guard ring is present, it should be reverse-biased by at least 5 Volts if light can strike the guard ring area.

If you need further technical support, please contact our sales department via email sui_support@goodrich.com or call us at 609-520-0610.

About Goodrich's SUI Team: Founded in 1991, SUI (Sensors Unlimited, Inc.) is the leading manufacturer of indium gallium arsenide (InGaAs) PIN and avalanche photodiode arrays that are used in shortwave and near infrared imaging for military, industrial, spectroscopic, machine vision, and telecommunications applications. SUI provides InGaAs photodiode array processing as a foundry service and designs custom readout integrated circuits for unique imaging applications within its ISO 9001 certified facility. For more information, visit www.oss.goodrich.com/sui.