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Tech Notes

Specialized Avalanche Photodiode Arrays Enable Adaptive Optics Uses

Adaptive optics requires detectors with high fill factor—as an incident light spot shifts, so does the pattern of detector responses. Lincoln Laboratory has demonstrated an array of GM-APDs specifically tailored for adaptive optics uses.

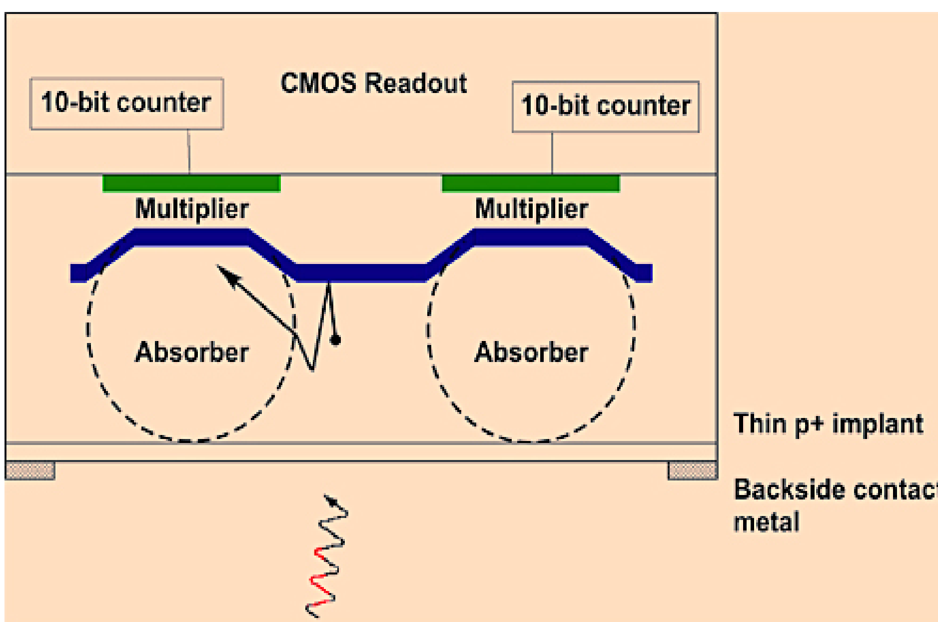
In optical ground-based astronomy and space surveillance, constantly changing aberrations introduced by atmospheric turbulence degrade image quality. One solution is to use adaptive optics, which corrects for these aberrations in real time.

Adaptive optics systems sense the distortion of the wavefront from a bright star or an artificial beacon (created by projecting a laser through the atmosphere) and correct for this distortion using deformable mirrors. High quality wavefront sensors are key enablers for such adaptive optics systems.

One type of wavefront sensor, known as a Shack-Hartmann sensor, uses microlenses to convert the incoming light wave to an array of light spots. The location of each spot indicates the local wavefront tilt. Each light spot is measured by a 2x2 subarray of pixels behind each lens; its displacement from the center of the subarray is deduced from the relative detection signals from the four pixels. The subarray must have high fill factor in order to perform this function. Charge-coupled devices and other conventional photodetectors have been used for this application, but their performance is sometimes limited by analog circuit readout noise.

Light entering the wavefront sensor is transformed into an array of light spots whose locations indicate the wavefront's shape.

As a means of eliminating the this readout problem, the Advanced Imaging Technology Group at Lincoln Laboratory has fabricated arrays of high-fill-factor Geiger-Mode Avalanche Photodiodes (GM-APDs) for optical wavefront sensor applications. The specialized arrays are hybridized to all-digital CMOS photon counting circuits for wavefront sensing applications.



Cross-section view through two diodes in one quad cell of a high fill-factor APD array suitable for wavefront sensor applications.

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GM-APDs differ from conventional photodetectors because they produce a digital pulse in response to a single incoming photon, eliminating analog circuit readout noise and enabling sensitive photon counting. While GM-APDs have been used as photon-counting detectors for decades, Lincoln Laboratory was among the first to hybridize arrays of these detectors to CMOS readout circuits. Initially, this was done for laser radar imaging applications, whose requirements allow the APDs to be fairly small (30-micrometer-diameter) and sparsely spaced (50- or 100-micrometer pixel pitch). However, those devices had relatively low fill factor and were therefore unsuitable for applications as a wavefront sensor.

The new devices customized for wavefront sensing consist of 16x16 subarrays. Each subarray, known as a quad cell, is a 2x2 GM-APD array with high fill factor. Any photoelectron originating in the interior region of a quad cell is collected and detected by the closest APD. The presence of a photon is registered digitally by a 10-bit counter in the pixel circuit.

The information is digitized by the pixel and can be read out rapidly without noise penalty, enabling the wavefront to be sensed with low latency (< 20 microseconds). The four counter values are used to compute the displacement of the light spot from the center of the quad cell. The near 100% sensitive detection region of the unique APD structure ensures good centroid detection at low signal levels, allowing wavefront sensor phase distortion estimation.

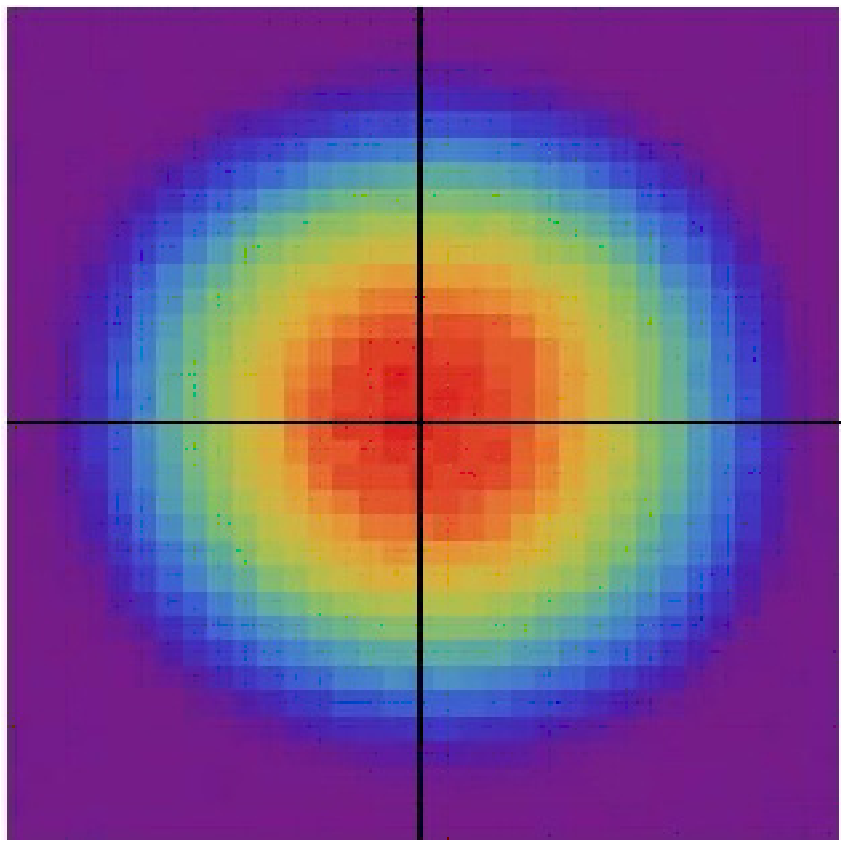
Since each photoelectron is counted, ensuring higher accuracy, these arrays can now be used in other new circumstances, such as science imaging and laser communications.

Future work will integrate these arrays in adaptive optics telescope systems and will speed up the image acquisition in large sky surveys while improving imaging performance. ■

Additional Reading

B.F Aull, A.H. Loomis, and D.J. Young, et.al., “Geiger-Mode Avalanche Photodiodes for Three-Dimensional Imaging,” Lincoln Laboratory Journal, vol. 13, no. 2, pp.335-350, 2002.

M.A. Albota, B.F. Aull, and D.G. Fouche, et. al., “Three-Dimensional Imaging Laser Radars with Geiger-Mode Avalanche Photodiode Arrays,” Lincoln Laboratory Journal, vol. 13, no. 2, pp. 351-370, 2002.



This false-color contour plot shows the total number of detection events from all four detectors in a quad cell as a function of the location of a small light spot. (Red denotes high counts, blue, low counts.) Photoelectrons incident on the boundary areas between adjacent APD regions are collected and detected smoothly, demonstrating that this design is well suited for wavefront sensor use.