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Recent advances of planar silicon APD technology

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Abstract

Radiation Monitoring Devices previously reported to have fabricated, using a planar processed, deep diffused silicon avalanche photodiodes (APDs) and position sensitive APDs (PSAPDs) that can be used for direct or scintillation-based spectroscopic and imaging applications. We have developed high gain (~1000), high quantum efficiency (40–70% in the 200–900 nm region) at unity gain, relatively low noise, and magnetically insensitive APDs up to $45\,cm^2$ in area and PSAPDs up to $2.8\times2.8\,cm^2$ in area. These detectors have begun to be implemented in applications such as positron emission tomography (PET) and single photon emission computerized tomography (SPECT) for medical imaging, high-energy physics experiments as water Cherenkov detectors and liquefied noble gas calorimeters, and receivers for long-range optical communication at near infrared (IR) wavelengths (1064 nm). Also, our PSAPDs have been combined with photocathode structures, similar to a photomultiplier tube (PMT), to fabricate hybrid devices. Here, we present a small review and a sample of results showing various applications utilizing our planar processed APDs and PSAPDs.

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Keywords: Silicon; APD; Position sensitive; Gamma rays; Imaging; Photodetector

1. Introduction

Silicon avalanche photodiodes (APDs) have been a desirable photodetector for many years. These devices can directly detect particles and low-energy X-rays in addition to being coupled to a variety of scintillation crystals, due to the APDs relatively high QE, to detect higher energy photons. With their compact design, ruggedness, magnetic insensitivity, relatively high QE, and high gain performance, these solid-state devices are a competing photodetector for photomultiplier tubes (PMTs). APD technology is now reaching a level of maturity where considerations are being made to employ their use in applications that PMTs have traditionally been used. Future next generation experiments in applications such as medical imaging, astronomy, high-energy physics, and nuclear safeguarding that need spectroscopic and/or imaging capabilities have found APDs to be of particular interest over PMTs.

Radiation Monitoring Devices, Inc. (RMD) deep diffused APDs were previously fabricated using a beveled edge structure that was created manually. To reduce the cost of manually beveled APDs, a planar process was developed to simplify the fabrication. This process has reduced the technical difficulty associated with manual beveling without any compromise in performance [1]. Position sensitive APDs have also been fabricated using the same planar process. Rather than placing one collecting electrode on the back APD surface, a resistive layer is placed on the back surface on which four collecting electrodes are then installed—one electrode in each corner. Charge sharing amongst the back contacts allows the detection of the interaction location using a simple algorithm, however, the algorithm creates a pincushion distortion to the image. This distortion can be removed using a look-up table or some other software based correction. These devices provide both direct interaction or scintillation based spectroscopic and spatial information [2].

Discrete APDs, APD arrays, and position sensitive APDs (PSAPDs) are now being realized for a variety of applications. PSAPDs with sensing areas ranging from $8\times8\,mm^2$

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(see Fig. 1) to $28 \times 28\,\text{mm}^2$ are currently being investigated for their use in small animal and clinical PET and SPECT instruments. We have fabricated large area APDs, up to $45\,\text{cm}^2$, which are being examined for their use in high-energy calorimeters, liquid xenon (LXe) detectors, and water Cherenkov detectors (see Fig. 2). Near-IR satellite optical communications is an application that APD arrays and PSAPDs are being examined for high-speed digital transmissions due to their good sensitivity at near-IR wavelengths and spatial information. We have also used our PSAPDs to fabricate a low light level spectroscopic and imaging hybrid photodetector [3]. These various applications exemplify the versatility of planar deep diffused APD technology.

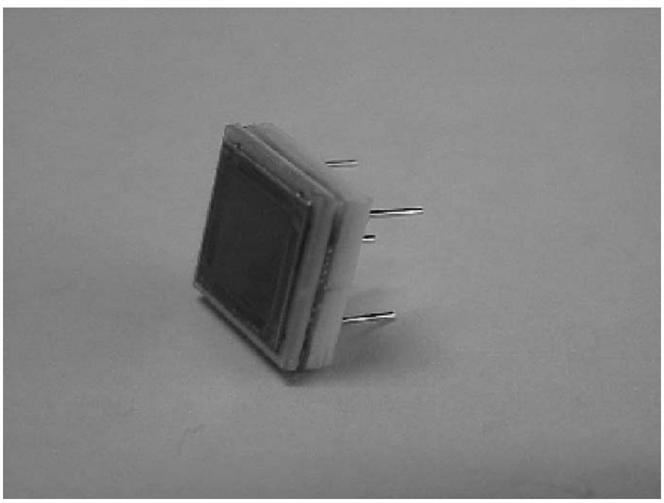

Fig. 1. A photograph of an $8 \times 8\,\text{mm}^2$ position sensitive APD.

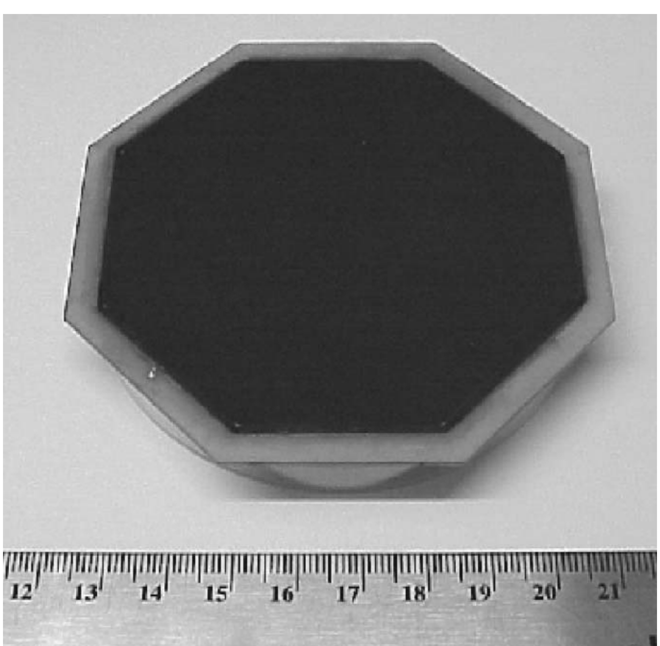

Fig. 2. A photograph of a $45\,\text{cm}^2$ APD.

This report provides an overview of APD technology performance in a wide-ranging area of photodetection applications.

2. APD applications

2.1. Positron emission tomography (PET)

Using PSAPDs in PET would increase the scintillation light collection due to a higher QE and because of their inherent compactness, reduce the over all size of the PET instrument. This is particularly attractive for traditional small animal PET where mechanical geometries often prevent the PMTs from being directly coupled to their scintillator. The 28×28 and $8 \times 8\,\text{mm}^2$ PSAPDs are currently being examined for clinical and small animal PET, respectively. These devices show good imaging capabilities, high spatial resolution, and good timing resolution when coupled to lutetium oxyorthosilicate (LSO), however, due to its large size, the $28 \times 28\,\text{mm}^2$ PSAPD must be cooled to reduce its noise level from the leakage current (see Fig. 3). The energy resolution is 15.5% at 511 keV when the $28 \times 28\,\text{mm}^2$ is cooled to $-20\,^{\circ}\text{C}$. The timing resolution of a device is an important parameter for PET. The ability to narrow the time interval when detecting coincident events improves the spatial resolution of the generated image. The timing resolution of our $8 \times 8\,\text{mm}^2$ device when using LSO is 1.6 ns (see Fig. 4). This is acceptable for current PET standards, however better timing resolution is desired.

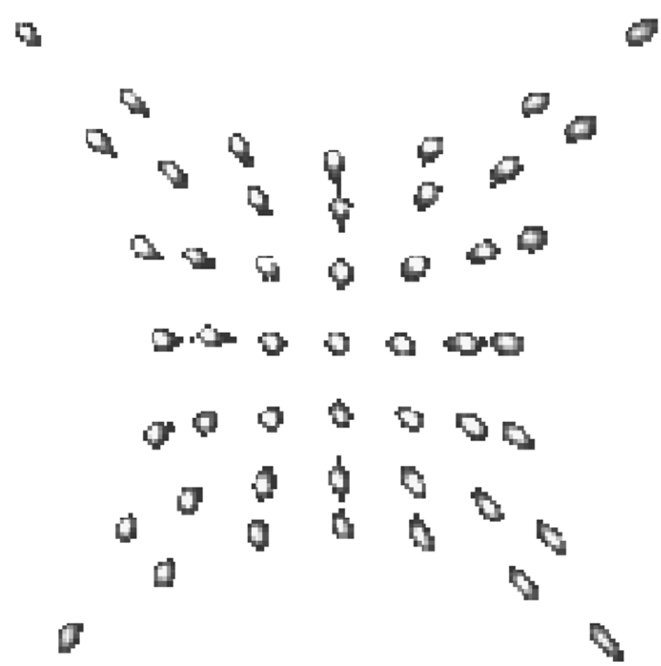

Fig. 3. A uniform flood histogram from a $28 \times 28\,\text{mm}^2$ PSAPD coupled to a 7×7 LSO array with 3 mm pixels while cooled to $-20\,^{\circ}\text{C}$ and irradiated with ^{22}Na (511 keV).