Two Notable APDs for Fast X-ray Detection

A.Q.R. BARON, M. YABASHI, T. KUDO and T. ISHIKAWA

SPring-8/JASRI

We have investigated two types of avalanche photodiodes (APDs) that have relatively recently become available. Each one has unique characteristics that make it interesting as an x-ray detector for medium energy x-rays (say ~6 to 30 keV). One device, from Perkin-Elmer (formerly EG&G) has both a large active area (10×10 mm^2) and a large active thickness (where "active thickness" is used to mean that region of the APD where x-ray absorption leads to counting a photon), making it, to these authors' knowledge the most efficient device presently available for higher energy x-rays. This APD is interesting as a general purpose fast photon-counter and for use in inelastic nuclear absorption measurements. The other device, from Hamamatsu Photonics, is thinner, and much smaller in area, but has very good (<0.2 ns, FWHM) time resolution and an exceptionally good signal to noise ratio, possibly making it usable at energies as low as 1 or 2 keV (ϕ1mm and ϕ3mm devices, respectively). This APD is interesting as a fast photon counter at low energies, and, as a detector for nuclear forward scattering measurements. Each device will be discussed in turn. For a more general review of possible APDs, please see [1].

The Perkin-Elmer device is an improved model of an APD [1,2] (the C30703F) now commonly used in the US and Europe. Its good points include its large area (10×10 mm^2), its reliability, and a good (~100 um) active thickness. However, the large area leads to a relatively large capacitance that reduces the signal height and makes this device a little difficult to use below 10 keV (one can select better diodes to go to lower energies...). The new version of the C30703F is thicker (based on a 200 µm wafer), leading to both an improved active thickness (~185 µm) and a reduction in the capacitance, which improves the signal to noise ratio. Figure 1 shows the output of one such APD into a scope after a fast amplifier [3].

One slightly negative aspect to increasing the active thickness of this device is that its time resolution becomes slightly worse, changing from ~0.8 ns for the 100 mm active thickness to ~1.6 ns for the new device (see Fig. 2). This follows from the saturation of the electron drift velocity in silicon (about 100 µm./ns) and is not really avoidable, in a single silicon device. One notes, however, that for nuclear inelastic absorption experiments, this is not so important.

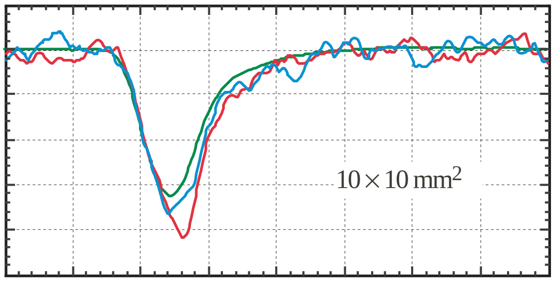

Fig. 1. Response of a 10×10 mm^2 × 185 µm APD to 5.9 keV x-rays. The average over many events is shown (smooth curve) as well as two single-photon events to show an indication of the noise level Scale: 50 mV and 5 ns /div.

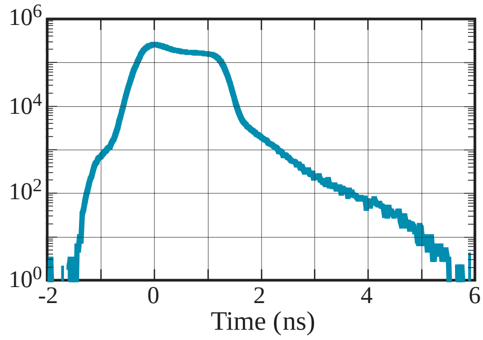

Fig. 2. Time response of the thick 10×10 mm^2 device to x-rays. The FWHM is about 1.6 ns.

A notable point about these devices is that they are readily available without a back - making it possible to stack them, one after another and thereby improve the efficiency at higher x-ray energies. While some care must be taken to prevent exposure to moisture (practically a Be window on the back may be used) this is possible and relatively inexpensive.

As a caution, we point out that some of the devices tested exhibit a slow increase in dark current. It is not clear if this is due to the unsealed delivery of the device or if it is some more fundamental instability. None of the devices tested (seven devices tested for between 10 and 800 hours each) has failed and some have appeared to improve with baking (~85C in a vacuum oven for ~1 day), but the problem persists in about half of the devices tested.

The new device from Hamamatsu is an improved model of a previous device. The earlier device (534X series) had an active thickness of ~10 µm and was used for experiments requiring especially good time resolution, with resolutions as low as 100 ps, FWHM, being obtained [4]. However, the earlier device had a relatively large capacitance (poor signal to noise ratio) making it awkward to use in larger area versions with lower energy x-rays. Likewise, while the thinness of the device allowed good time resolution, it also made for poor efficiency. The new "low capacitance" (LC) version of the device increases the active thickness to 20 to 25 µm, leading to a factor of two increase in efficiency in many cases, and decreases the capacitance, leading to a very nice signal to noise ratio (see Fig. 3).

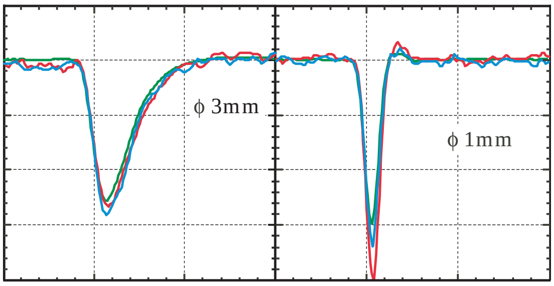

Fig. 3. Traces from ϕ1mm and ϕ3mm 534X LC devices showing the response to 5.9 keV x-rays. The average over many events is shown (smooth curve) as well as two single-photon events to show an indication of the noise level. Scale: 100mV and 5ns /div.

This device is especially interesting as a photon counter at lower energies (where it still has good efficiency at normal incidence) and for nuclear forward scattering experiments when relatively good time resolution is needed. Of course, the 160 ps resolution of the LC device is not as good as the ~100 ps of the earlier device, but, in many cases, the factor of two in counts rate easily makes up for the poorer time response. The time response is shown in Fig. 4.

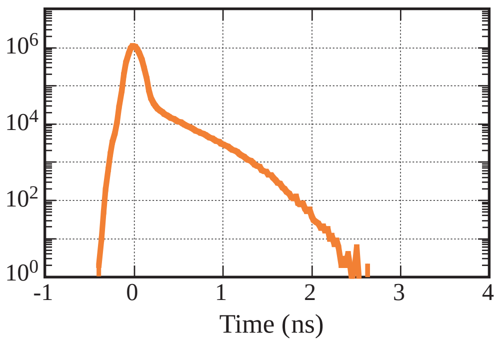

Fig. 4. Time response of the ϕ 3mm × 25 µm active thickness diode. Note the FWHM of 160 ps and the short tail.

Finally we note that while there has been no problem with the ϕ1mm device, one of two ϕ3mm devices failed after sitting on the shelf for about six months.

References

[1] A. Q. R. Baron, Hyp. Int. **125** (2000) 29.

[2] A. Q. R. Baron, Nucl. Instr. and Meth. **A352** (1994) 665.

[3] The amplifier is based on the MAR-6 chip of Minicircuits. More details can be found in A. Q. R. Baron, R. Rüffer, and J. Metge, Nucl. Instr. and Meth. **A400** (1997) 124

[4] S. Kishimoto, Nucl. Instr. and Meth. **A351** (1994) 554.