Hybrid Single-Photon Detectors

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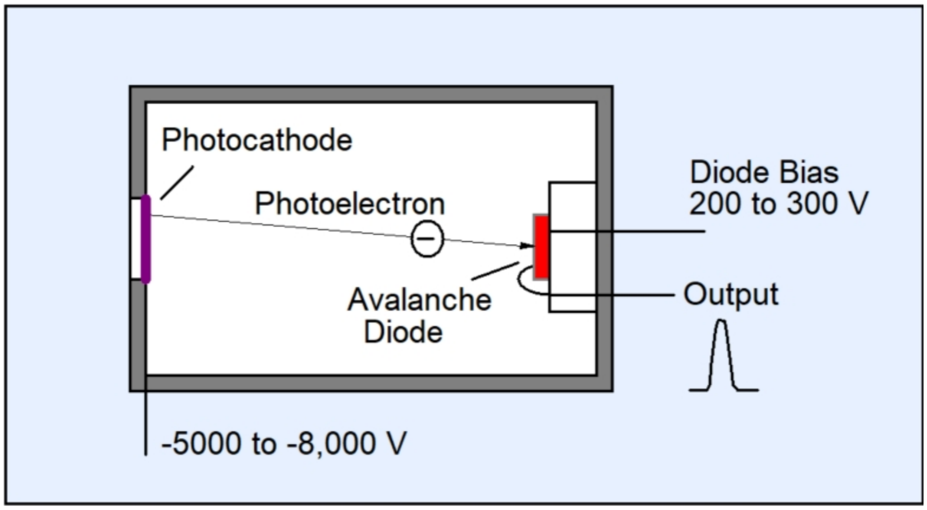
A hybrid photon detector consists of a photocathode, an electron acceleration system, and a silicon avalanche diode. Photoelectrons emitted by a photocathode are accelerated towards the avalanche diode by a strong electrical field and injected directly into diode material.



When an electron hits the avalanche diode it generates a large number of electron-hole pairs in the silicon. These carriers are further amplified by the linear gain of the avalanche diode. The total gain is on the order of 10^6, i.e. sufficient to generate a detectable current pulse at the output of the avalanche diode.

Important for TCSPC, the high acceleration voltage between the photocathode and the APD results in low transit time spread. With an acceleration voltage of 8 kV the transit-time spread of the electron time-of-flight is less than 20 ps. Hybrid detectors therefore deliver a very good time resolution in combination with TCSPC. In fact the intrinsic time jitter of the electron amplification system is so low, that the temporal instrument response function (IRF) of a hybrid detector is dominated by the dwell time of the photoelectrons in the photocathode. Detectors with GaAsP photocathodes deliver IRFs on the order of 90 to 120 ps (full width at half maximum, fwhm), detectors with GaAs photocatodes deliver IRFs of 120 to 200 ps fwhm. Bi-alkali and multi-alkali cathodes do not have noticeable electron dwell times. With the bh TCSPC devices such detectors deliver IRF widths of 16 to 20 ps fwhm.

Compared with a conventional PMT, the hybrid PMT has also an advantage in terms of counting efficiency. In a conventional PMT, a fraction of the photoelectrons is lost on the first dynode of the electron multiplication system. There are no such losses in the hybrid PMT: A photoelectron accelerated to an energy of 8 keV is almost certain to generate a carrier avalanche in the avalanche diode. With a high-efficiency GaAsP cathode a hybrid photomultiplier reaches the efficiency of a single-photon avalanche photodiode (SPAD), but with a cathode area several orders of magnitude larger.

The perhaps most significant advantage of the hybrid detector has only been recognised recently: The hybrid PMT is virtually free of afterpulsing. Afterpulsing is the major source of counting background in high-repetition-rate TCSPC applications, and a known problem in fluorescence-correlation (FCS) measurements. The absence of afterpulsing results in high dynamic-range fluorescence-decay recording, and in artefact-free recording of autocorrelation FCS with a single detector.

bh were the first to recognise the potential of hybrid detectors in TCSPC applications. bh were also the first to make the detectors applicable to TCSPC by combining the detector tube, the high-voltage generators, and the low-noise preamplifier in a perfectly shielded metal case.