

# Low-Timing-Jitter Near-Infrared Single-Photon-Sensitive 16-Channel Intensified-Photodiode Detector

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**Abstract:** We developed a 16-channel InGaAsP photocathode intensified-photodiode (IPD) detector with 78 ps (1-sigma) timing-jitter, < 500 ps FWHM impulse response, >15% quantum efficiency at 1064 nm wavelength with 131 kcps dark counts at 15 C.

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## 1. Introduction

Laser-based instruments require single-photon-sensitive detectors to minimize resource requirements (size, weight, power and cost). This is particularly critical for space-based science instruments and optical communications terminals, but is also important for many airborne and ground-based systems. A detector with low timing jitter (<100 ps) is vital for high-precision micropulse lidar topographic mapping systems [1] and high-data-rate (short time slot-width) pulse-position-modulation (PPM) free-space optical communication systems [2]. The most cost-effective practical high-peak power pulsed laser systems (e.g. Nd, Yb and Er) operate at near-infrared wavelengths where space-qualified single-photon detectors have not been available.

The intensified photodiode (IPD) detector, (a.k.a hybrid photomultiplier tube (HPMT) or hybrid photodetector (HPD)), provides high-gain with low-noise suitable for single-photon sensitivity via electron bombardment of an avalanche diode. Advantages of the IPD include large detector area (1 mm for a single channel device), high maximum count rates (> 200 Mcps), high bandwidth (GHz), low afterpulsing, and near room temperature operation. Further features include low dark noise, large dynamic range for full analog pulse received waveform preservation and photon number resolution. Operating principles and performance results of previous IPDs have been reported for use at visible [3, 5], and near-infrared [4, 5, 6], wavelengths.

## 2. Achieving low timing jitter

In this work, we produced a 16-channel IPD with an InGaAsP photocathode for use at 1064 nm wavelength. Each channel has a 159  $\mu\text{m}$  x 159  $\mu\text{m}$  sensitive detection area at the photocathode. The overall IPD timing jitter is dominated by the random walk of the minority carrier electron across the InGaAsP absorber layer inside the transferred-electron photocathode. The contribution of this photocathode timing jitter,  $\sigma_j$ , is given [2], by:

$$\sigma_j = \frac{W^2}{2.62D_n} \quad \text{where } W \text{ is the InGaAsP absorber thickness and } D_n \text{ is the electron diffusion coefficient. A}$$

2.5  $\mu\text{m}$  lattice matched InGaAsP absorber layer with a mobility of 3000  $\text{cm}^2/\text{V}\text{-s}$ , gives a photocathode timing jitter of 307 ps. A single-channel device [4] with this geometry had an overall timing jitter of ~ 500 ps with 26% quantum efficiency (QE). A four-channel IPD [2] with similar timing jitter was previously demonstrated. For our 16-channel device, we reduced the InGaAsP layer thickness to 0.8  $\mu\text{m}$  that provides a measured QE of 15% at 1064 nm wavelength. Figure 1 shows the timing jitter (188 ps FWHM, 78 ps one-sigma) measurement results for our 0.8  $\mu\text{m}$  thick photocathode. We measured the timing jitter using two independent instruments 1) the Picoquant HydraHarp 400 multichannel scaler providing 188 ps FWHM measurement and an Agilent Model DSA91304A (13GHz BW) oscilloscope that calculated the one sigma jitter directly from the waveform histogram as 78 ps. This is an upper limit on the timing jitter because it includes the photon timing uncertainty associated with the 100 ps pulse width of the experimental test laser. For further context, a visible single-channel HPD with a 1 mm diameter photocathode has 28 ps timing jitter with 46% QE at 500 nm wavelength [3].

### 3. Additional 16-channel IPD measured characteristics

The single photon impulse response has a pulse width of 550 ps. The adjacent pixel cross talk was than 1.1% for any pair of adjacent pixels. The internal gain is  $>10^4$  for each pixel. Figure 2 shows the measured reduction of dark counts per channel with decreasing temperature and the extrapolation prediction of less than 10 keps at -20 C.

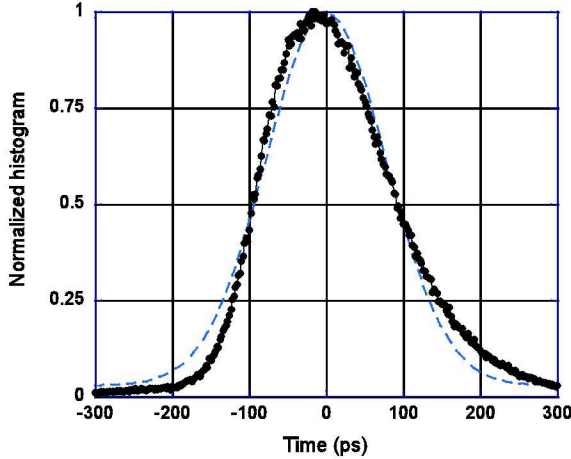


Fig. 1. Single-photon timing jitter measurement results for IPD with 0.8  $\mu\text{m}$  InGaAsP layer thickness. FWHM = 188 ps. Dashed line is Gaussian fit with  $\sigma = 78$  ps.

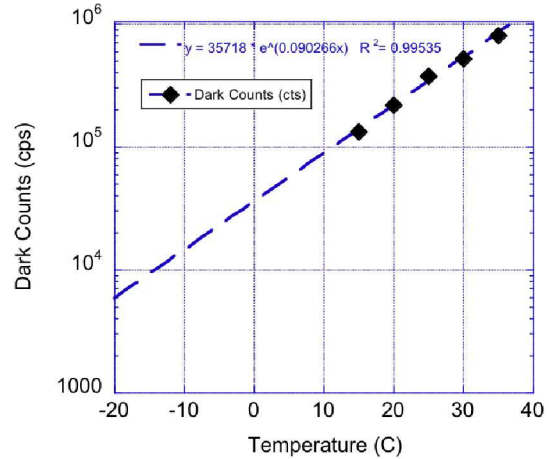


Fig. 2. IPD dark counts per channel vs. Temperature. Experiment ( $\blacklozenge$ ) and extrapolation (dashed line).

An excess noise factor of 1.2 was measured from the pulse height amplitude distribution. Figure 3 shows excellent agreement for two independent sets of measured photon number resolution (scaled pulse height distribution

histogram) and the Poisson probability mass function  $f(k, \lambda) = \frac{\lambda^k e^{-\lambda}}{k!}$  theory with a)  $\lambda=1.6$  and b)  $\lambda=3.3$ .

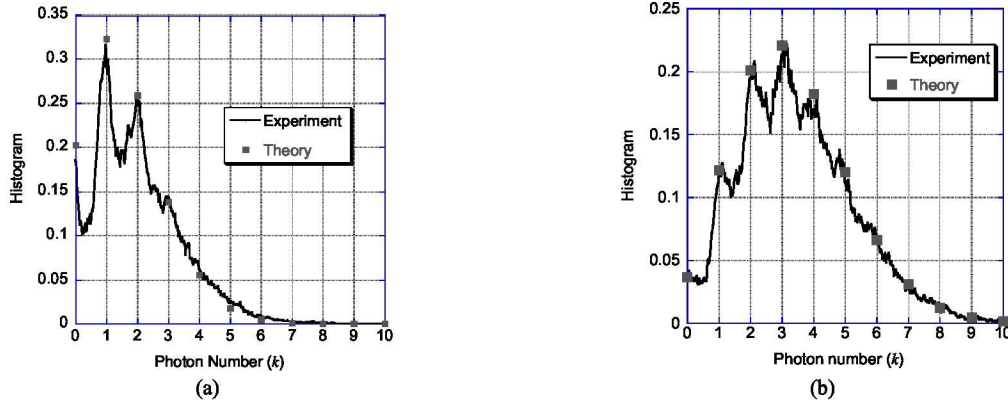


Fig. 3 Measured scaled histogram of the pulse height distribution and Poisson theory for (a)  $\lambda=1.6$  and b)  $\lambda=3.3$ .

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