Blue Sensitive Silicon Photomultipliers for Fast Timing Applications

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sensL sense light

ABSTRACT: SensL have developed a new Silicon Photomultiplier (SPM) process that delivers vastly improved timing and detection capabilities from 300nm to 450nm.

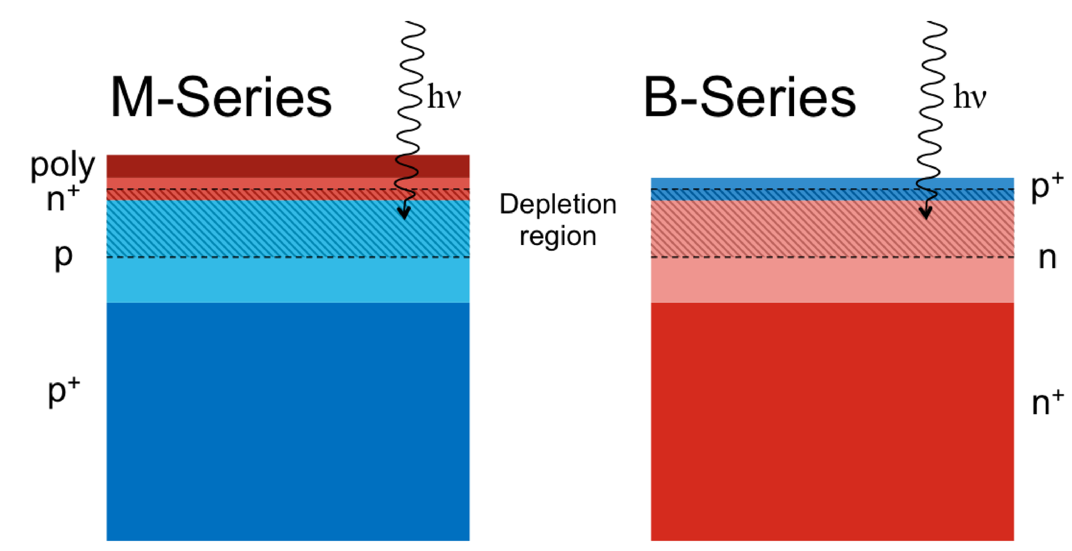
SPM technology is well established as an alternative to photodetectors such as the PMT, APD and photodiode. This is due to its combination of PMT-like performance such as high gain, photodetection efficiency (PDE) and fast timing with the practical benefits of solid-state detectors, which are rugged, compact, use a low bias and are magnetic-field insensitive. This technology is fabricated in high volume CMOS foundries to a custom SensL process based on N-type into P-type silicon wafers. This is a commercially proven technology with PET systems currently in FDA (510k) trials in the USA.

To achieve higher performance for applications requiring greater blue and UV sensitivity from 300nm to 450nm, SensL has developed a new process based on P-type into N-type silicon wafers. The resulting SPMs (referred to as "B-Series") feature significant improvements in both PDE and coincidence timing resolution. Both the maximum PDE (>40% at 420nm peak) and the wavelength range (down to ~300nm), are improved due to the newly-employed P-on-N structure. In addition, B-series detectors have extremely fast output pulses (<100ps-2ns rise times and 1-2ns pulse widths) through the fast output architecture that SensL has patented. For the first time, picosecond coincidence timing is possible from a technology that is manufactured in a commercial CMOS foundry.

This combination of high PDE and fast output signals leads to excellent timing performance, particularly for applications like time-of-fight PET (ToF PET) that use blue emitting scintillation crystals to make fast coincident timing measurements of 511keV annihilation radiation. Other applications that benefit from this new SPM technology are LiDAR, hazard and threat detection and biophotonics.

The results presented here are all made with a MiroFB-30035, which is a 3mm detector with 35mm microcells.

M-Series and B-Series Silicon from SensL

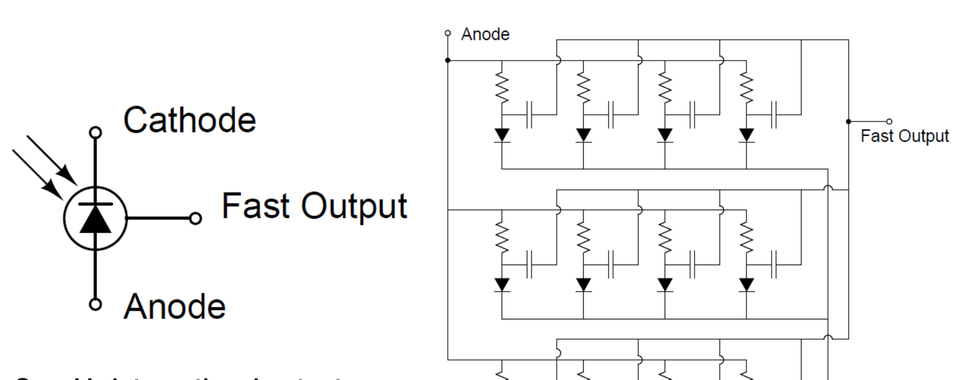


- N-on-P process
- Peak sensitivity at 500nm (green)
- Sensitive range 400nm - 1000nm

- P-on-N process
- Peak sensitivity at 420nm (blue)
- Sensitive range 300nm - 800nm

All SensL products are designed for high volume, low cost, and high uniformity, and are manufactured in a commercial CMOS foundry.

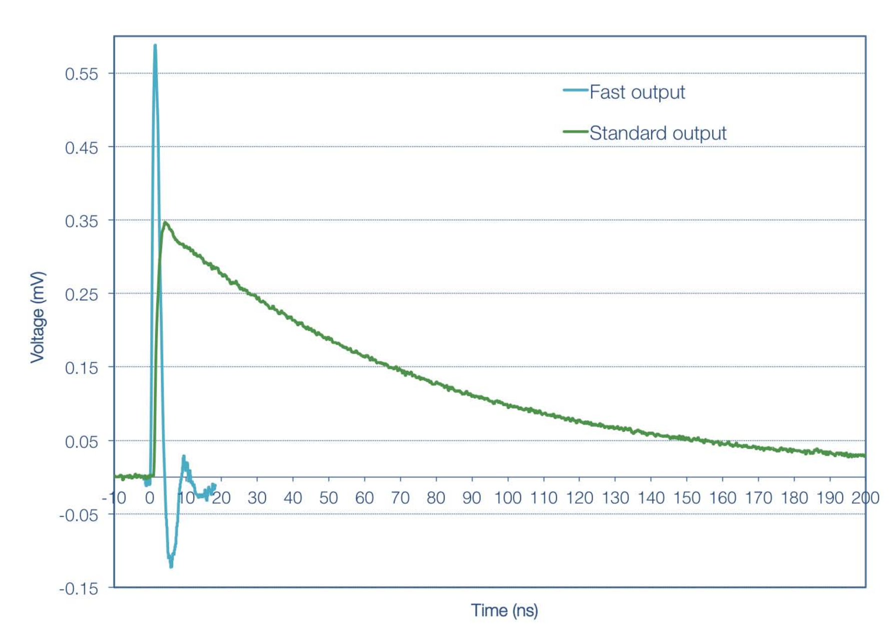
SPM Fast Output



SensL's international patent application no. WO2011117309

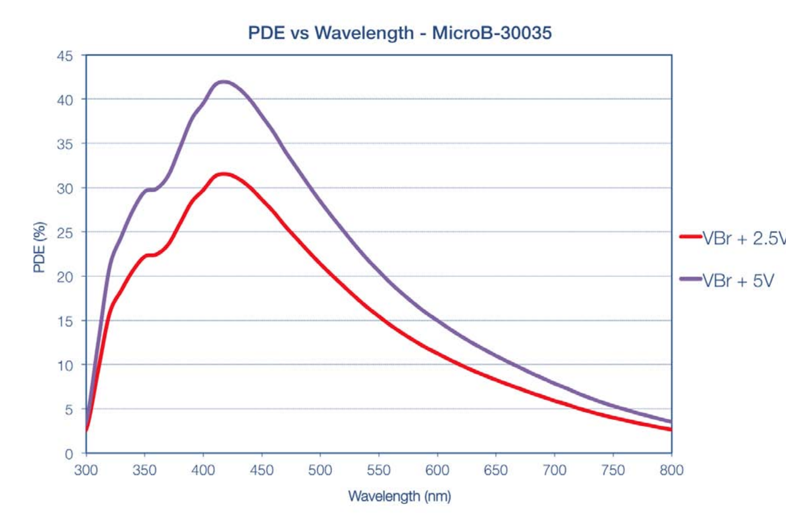
- SensL has developed a unique modification to the standard Silicon Photomultiplier structure that results in a third terminal carrying an ultra-fast output signal.
- The fast output is the derivative of the internal fast switching of the microcell in response to the detection of a single photon.
- Fast output is a low capacitance output.
- Rise times <100ps - 2ns
- Short pulse widths of 1-2ns FWHM
- Provides higher count rate ability or second photon timing capability.
- Improved ability to clearly distinguish the first photon arrival time.

Fast Output Compared with Standard Output



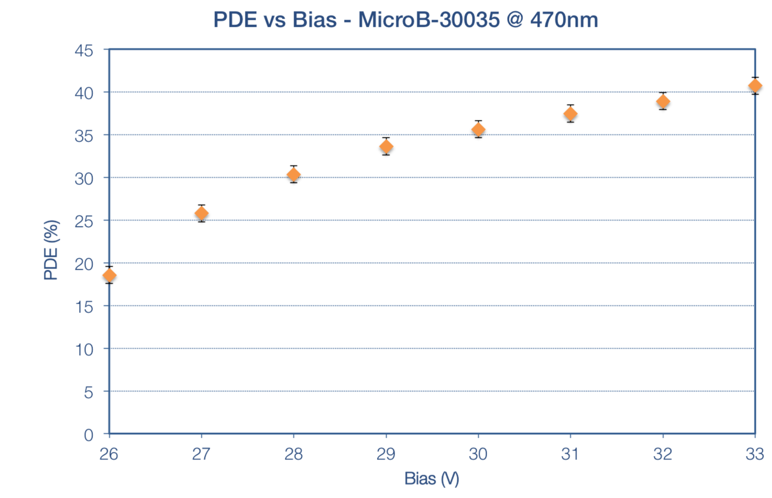
- The plot above shows the pulses resulting from the fast output and readout in standard mode for a MicroFB-30035 SPM (active area of 3mm x 3mm).
- The signals are the result of a 50ps pulse from a laser.
- The fast signal has a rise time of <1ns and a pulse width of ~2ns.
- The standard signal has a rise time of several ns and a decay time of several hundred ns.
- Smaller geometry detectors will have faster rise times, for example a 0.25mm SPM has a rise time of <100ps.

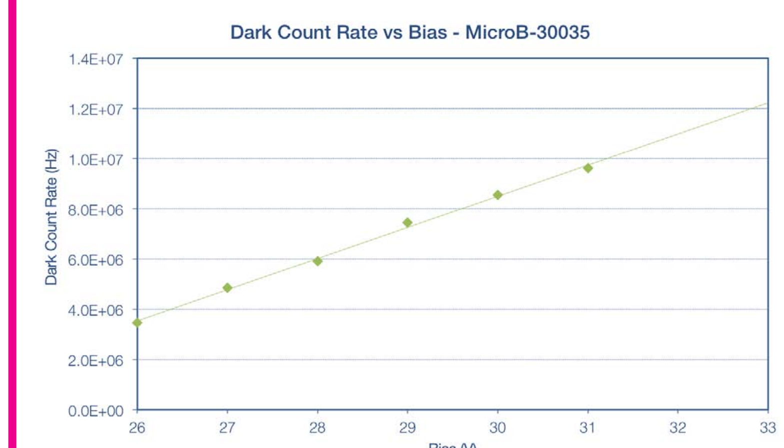
Photon Detection Efficiency and Dark Count Rate



- PDE measured using a monochromator with an integrating sphere and a reference photodiode.
- Plot shows 'true PDE' without contributions from cross-talk and afterpulsing.
- B-series SPMs show excellent blue and UV sensitivity.

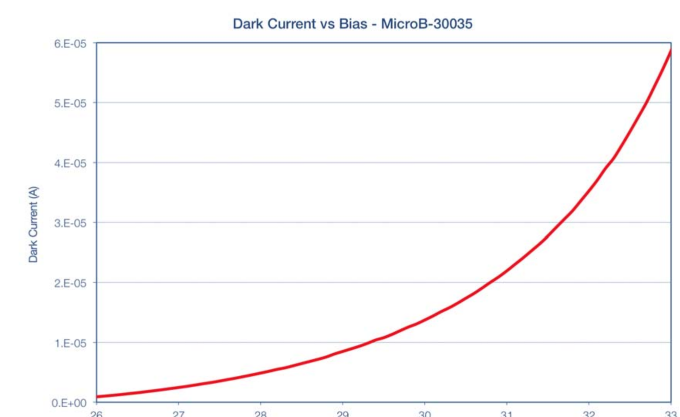
- PDE measured at a fixed wavelength of 470nm (**note this is not the peak wavelength of the device which is at 420nm**) using a pulsed LED.
- Plot shows 'true PDE' without contributions from cross-talk and afterpulsing.
- PDE improved with bias





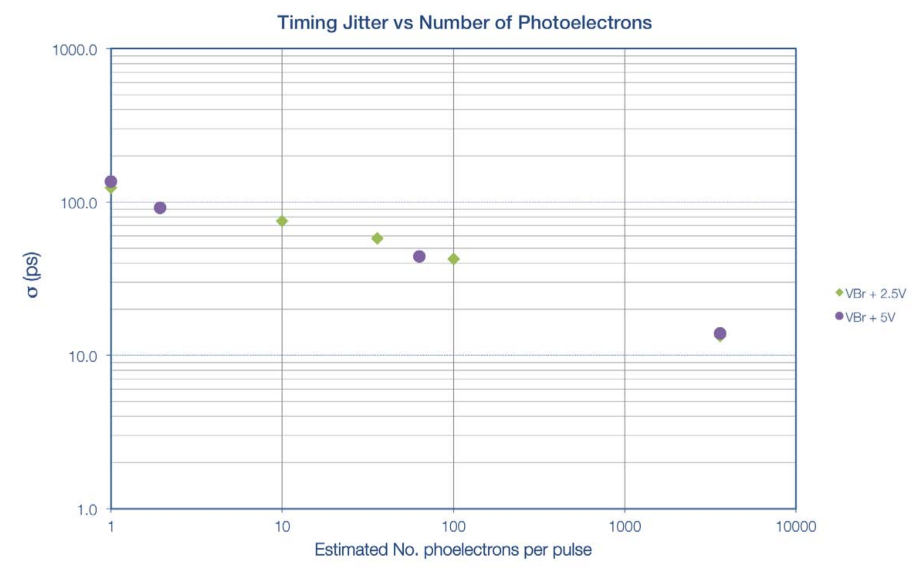
- Dark count rate (DCR) is the rate of pulses due to thermally induced carriers in the SPM.
- DCR increases linearly with bias.
- Measurement technique only allows measurement up to 31V.

- Gain increases linearly with bias.

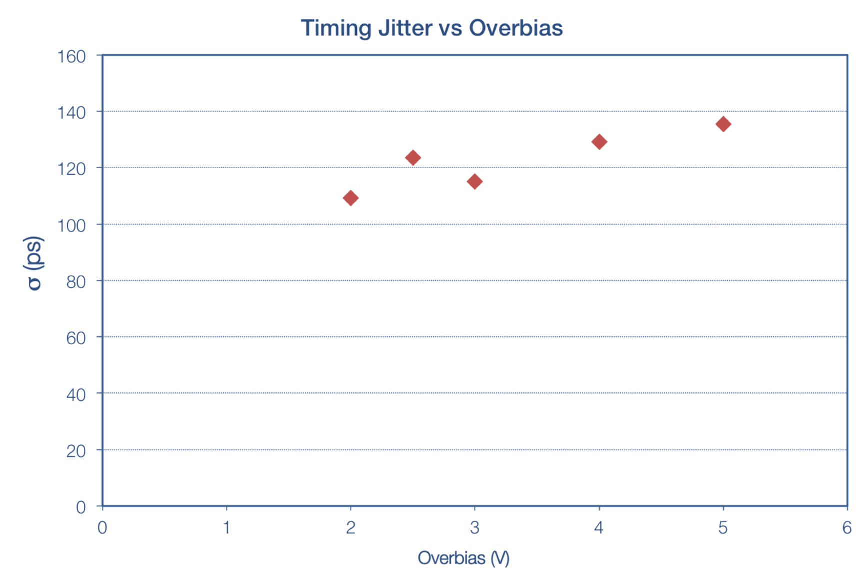


- The product of the gain and the DCR gives the total current.
- Both gain and DCR increase linearly with bias.
- Current vs bias plot goes as V^2.

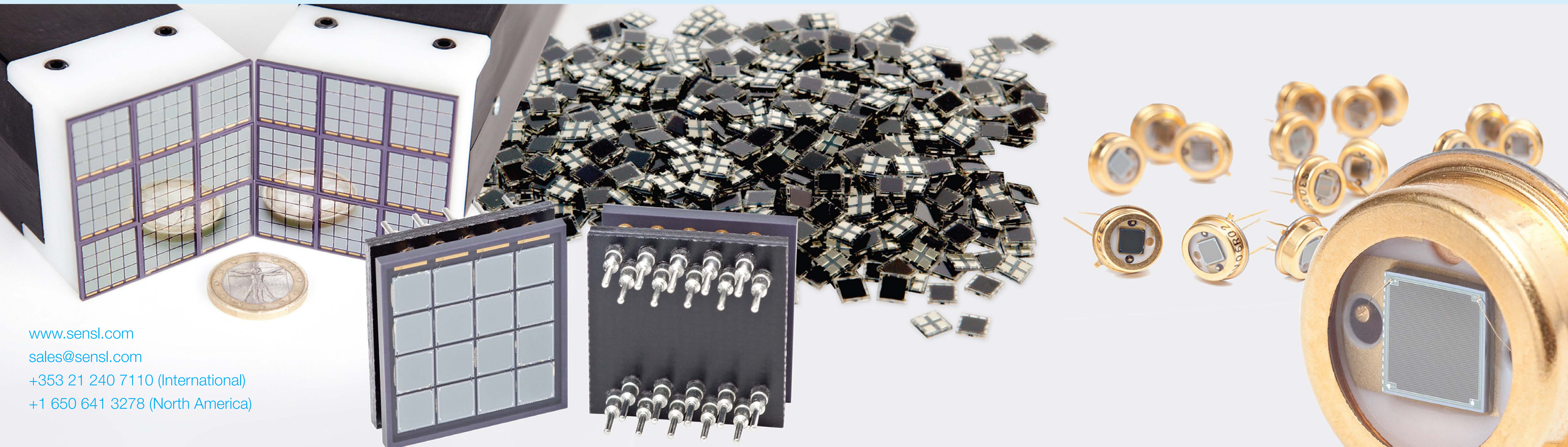
Single- and Multiple-Photon Timing Jitter



- Jitter is measured in relation to a 405nm Picoquant pulsed laser
- Multiple-photon data acquired using a WaveCatcher 12-bit digitizer.
- Single-photon data acquired using a Becker-Hickl card (SPC-140).
- For each signal level (number of photons), an optimal triggering threshold is used.



- Using the same set-up, jitter is shown to increase as a function of overbias.
- Data acquired using a Becker-Hickl card (SPC-140).



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