80 ps FHWM Instrument Response with ID230 InGaAs SPAD and SPC-150 TCSPC Module

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The new ID Quantique ID230 InGaAs SPAD delivers an instrument response width of 80 ps FWHM with the bh SPC-150 TCSPC module. This is the fastest TCSPC response reported for InGaAs SPADs so far. Compared to its predecessor the new InGaAs SPAD also has a much lower dark count rate. The detector we tested had less than 300 dark counts when operated with a dead time of 40 µs. Optical signals as weak as 800 photons per second count rate could thus be detected at high signal-to-background ratio. Results are presented in this application note.

TCSPC With InGaAs SPADs

Single-photon avalanche diodes (SPADs) based on InGaAs material achieve high detection efficiency in the wavelength range from 900 nm to 1700 nm. A problem of early InGaAs SPADs was the high dark count rate, and the strong afterpulsing. To avoid instability, the devices could only be operated in a gated mode: The reverse voltage is increased above the breakdown level for a period of 10 to a few 100 ns, and then decreased below the critical level for several microseconds. Gated operation may be a solution for general photon counting in combination with low-repetition rate light sources. It is, however, not acceptable in combination with TCSPC: TCSPC works best at high repetition rate of the light signals, and requires the detector to be active continuously. With early InGaAs SPADs pseudo-continuous operation at low dark count rate could be obtained by gating the detector with an asynchronous HF signal. However, this reduces the effective detection efficiency by several orders of magnitude. Efficiencies and dark count rates reported for this kind of operation should therefore considered with reservation.

The first InGaAs SPAD for true continuous operation was the id220 detector of ID Quantique [1]. The ID220 delivers an IRF width of about 220 ps with the bh TCSPC modules. The dark count rate is on the order of a few 1000 to a few 10,000 counts per second, depending on the detector parameters selected. Results for fluorescence-decay recording and confocal FLIM have been presented in [3] and [6]. In 2015 ID Quantique released a new InGaAs SPAD, the ID230, with substantially improved performance [2]. The detector is shown in Fig. 1. We have tested the ID230 in combination with a bh SPC-150 TCSPC module and a bh BDS-SM-1064 nm picosecond diode laser. Results are presented in this application note.

Fig. 1: ID230 InGaAs SPAD detector

Results

For characterising the id230 in combination with the bh TCSPC modules we used the setup shown in Fig. 2. A BDS-SM picosecond diode laser [7] generates a 50 MHz train of picosecond light pulses at a wavelength of 1064 nm. The BDS-SM laser has a single-mode fibre output. The light from the laser fibre was injected into the multi-mode input fibre of the ID230 through a package of ND filters. The fibres were aligned face-to-face without any focusing optics in between. The input fibre of the detector was thus illuminated at low numerical aperture. This is important to minimise pulse dispersion in the fibre. One meter of multi-mode fibre can introduce almost 100 ps of pulse dispersion when used at maximum NA [5]. This is on the same order as the expected IRF width of the id230 detector. An optimum IRF width can thus only be achieved by keeping the NA at the input of the detector fibre low.

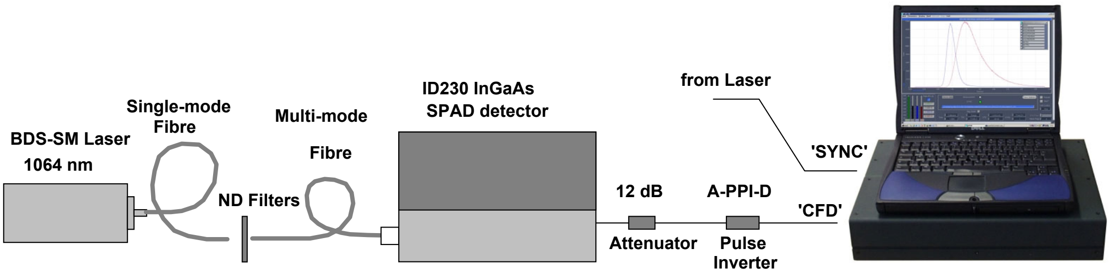

Fig. 2: TCSPC setup for characterising the id230 detector

The TCSPC system was a standard bh Simple-Tau 150, containing an SPC-150 TCSPC module [6]. The detector output pulses were adapted to the input voltage range of the SPC module by an attenuator and an A-PPI-D pulse inverter. The synchronisation signal for the TCSPC module was obtained directly from the Sync output of the BDS-SM laser. A typical laser pulse shape recorded with this setup is shown in Fig. 3.

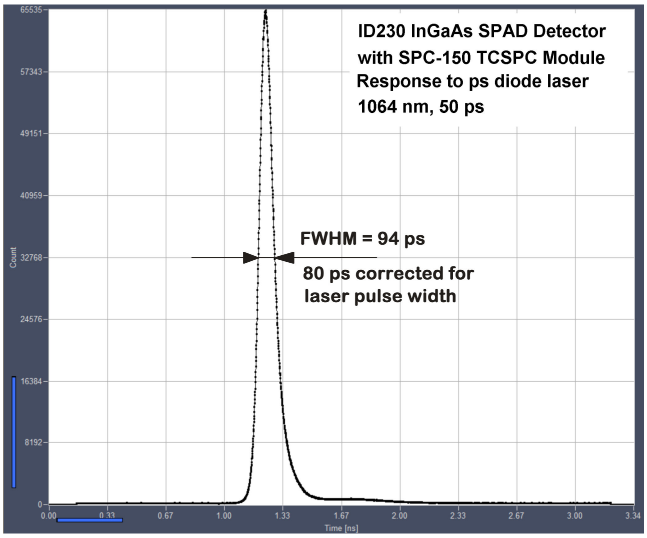

Fig. 3: Laser pulse recorded with the Id230 SPAD. BDS-SM-1064nm ps diode laser, SPC-150 TCSPC module. Detection efficiency 25%, dead time 5 µs. Laser pulse width is 50 ps to 60 ps.

The width of the recorded photon distribution is 94 ps. These 94 ps necessarily contain a contribution from the laser pulses. The width of laser pulses is not exactly known since we had no fast reference detector for a wavelength of 1064 nm. However, BDS-SM lasers of sub-1000 nm wavelength have pulse widths in the range of 50 to 60 ps. Assuming the same width for the pulses at 1064 nm the real IRF width of the detector-TCSPC combination can be expected in the range of 72 ps to 80 ps. To our knowledge, this is the fastest TCSPC response reported for an InGaAs SPAD yet.

Operating Conditions of the Detector

The ID230 detector comes with software that allows the user to adapt the detector parameters to the conditions of the experiment. Both the detection efficiency and the dead time (quenching time after detecting a photon) can be modified. The best TCSPC results were obtained with the detection efficiency set to the maximum of 25%. Reducing the detection efficiency results in a broader IRF and is therefore not recommended.

Unlike the detection efficiency parameter, the dead time selection in the ID230 software is important to optimise the TCSPC performance for different experiments. Shorter dead time results in higher saturated count rate and less counting loss but also in higher background and stronger afterpulsing. For typical applications with count rates in the 10 kHz to 100 kHz range a dead time of 5 µs was found to be the best compromise. For low-count-rate applications longer dead times should be used. At count rates in the range of a few kHz or below an increase in dead time does not cause noticeable loss of photons. It does, however, result in a dramatic decrease of the counting background. An increased dead time thus increases the dynamic range of the recording.

An example is shown in Fig. 4. A signal that delivered only 800 counts per second was recorded with a dead time of 40 µs. At 800 counts per second, the loss of photons in the 40 µs following a previously recorded photon is negligible. However, the increased dead time reduces the dark count rate from several 1000 down to less than 300 counts per second. The dynamic range therefore increases, and the signal is recorded at high signal-to-background ratio. The result shows that the ID230 can be used down to extremely low light intensities.

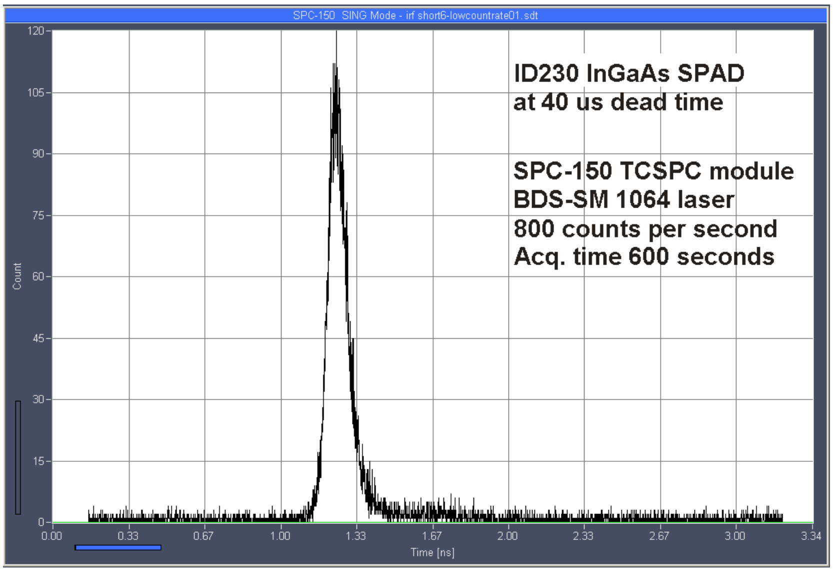

Fig. 4: Laser pulse recorded at a count rate of 800 photons per second. ID230 dead time 40 µs, acquisition time 600 seconds. The long dead time decreases the counting background and thus results in a high signal-to-background ratio.

Summary

With its 80 ps IRF width and 25% detection efficiency the combination of the ID230 InGaAs SPAD and the bh SPC-150 TCSPC module records optical signals in the IR at unprecedented time resolution and sensitivity. Faster detection at IR wavelengths has only been obtained with superconducting detectors [4].

References

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