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TCSPC Performance of the id100-50 Detector

This report summarizes the results of Becker&Hickel's evaluation of the id100-50, a single photon counting module manufactured by id Quantique (www.idquantique.com).

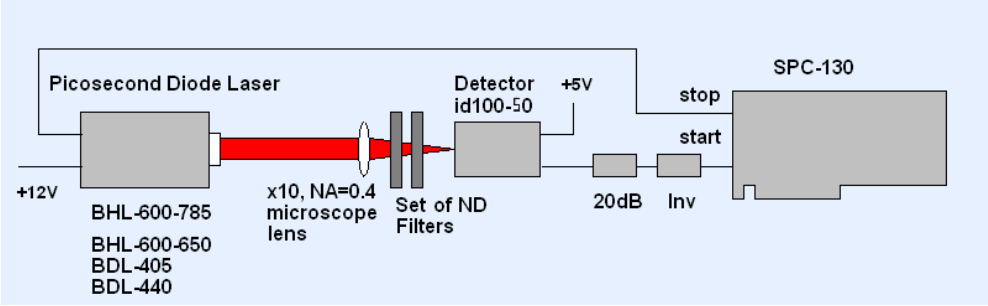
Detector

The id100-50 of id Quantique is an actively quenched single-photon APD (SPAD) module. The quenching circuit is integrated on the diode chip. Compared with the id100-20, the id100-50 has a 6.25 time larger active area. The larger area simplifies optical alignment and focusing while maintaining the low dark count rate and the good time resolution of the id100-20. The key parameters are:

Spectral range	350 to 900 nm
Diameter of the active area	50 µm
Timing resolution (fwhm)	55 ps
Detection probability at 500 nm	35 %
Dark count rate	< 200 s^{-1}
Output pulse amplitude	+ 2 V

Test Setup

The id100-50 was tested in the setup shown below.



Light pulses of a picosecond diode laser were attenuated by a package of neutral density (ND) filters and focused directly to the SPAD module. The output pulses of the detector were sent to the start input of a TCSPC module. To transform the pulse polarity and the pulse amplitude into the standard

input range of the TCSPC module a 20 dB attenuator and a passive pulse inverter were inserted in the signal line. The timing reference pulses at the stop input of the TCSPC module came directly from the laser.

For the measurement of the TCSPC instrument response function we used a BHL-600-785 diode laser. This laser has an exceptionally short pulse width of the order of 24 ps. For the measurement of the diffusion tail at various wavelengths a BHL-600-650 (650 nm), a BDL-440-SM (444 nm), and a BDL-405-SM (405 nm) were used. The measurements of the instrument response functions (IRFs) were performed by an SPC-130 TCSPC module. All lasers and TCSPC modules are Beckel&Hickl products.

Instrument Response Functions (IRFs)

IRF recordings measured at a wavelength of 785 nm are shown in fig. 2. The curves were measured at detector count rates from 214 kHz to 8.1 MHz. The maximum ADC resolution and TAC gain of the SPC-130 was used, resulting in a time channel width of 813 fs.

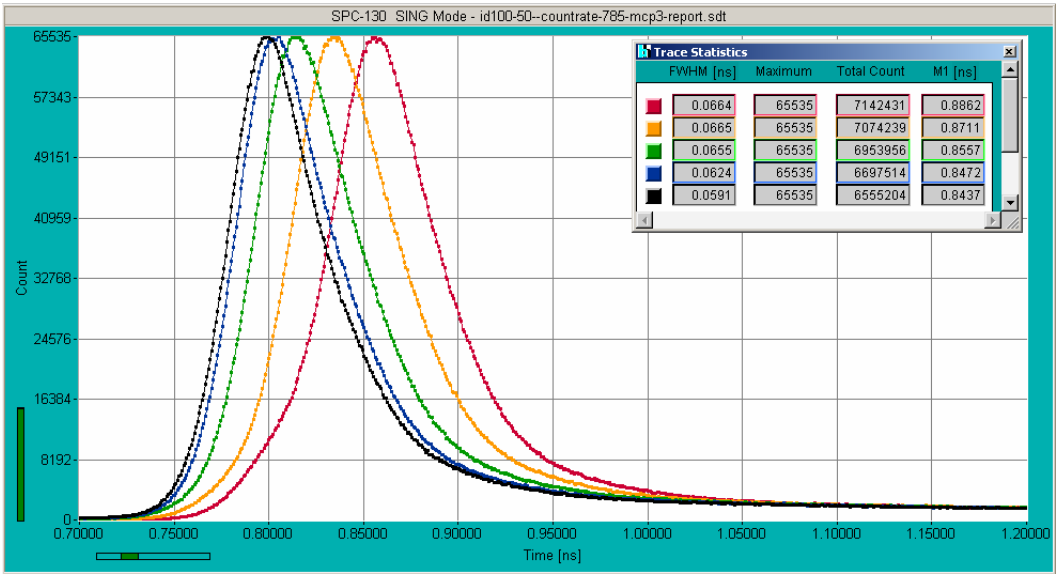


Fig. 2: IRF of the id100-50 at 785 nm. Detector count rates 8.1 MHz (red), 5.15 MHz (yellow), 2.1 MHz (green), 0.5 MHz (blue) and 62 kHz (black). Time scale 50 ps per division. The FWHM and the first moment of the IRF curves are shown in the insert.

The measured width of the IRF (Instrument Response Function) varies from 66 ps to 59 ps. Corrected with an estimated width of the laser pulse of 24 ps, these values correspond to 55 ps to 61 ps, in agreement with the id Quantique specifications.

To quantify the shift of the IRF with the count rate, the first moments, M1, of the IRF curves were calculated. The shift of the first moment is

Count Rate (MHz)	0.2	0.5	2.1	5.15	8.1
Shift of M1 (ps)	0	3.5	12	28	42

Compared to other APD modules, these values are exceptionally low. It should also be noted that the IRFs remain free of satellite pulses or other artefacts up to the highest count rates applicable with currently available TCSPC techniques.

The IRFs of all single-photon APDs have a ‘diffusion tail’ caused by carrier generation in the neutral layers below the avalanche region. The amplitude of the tail depends on the wavelength and

can reach 10 to 20% of the IRF peak. The diffusion tail of the id-100-50 for different wavelengths is shown in fig. 3.

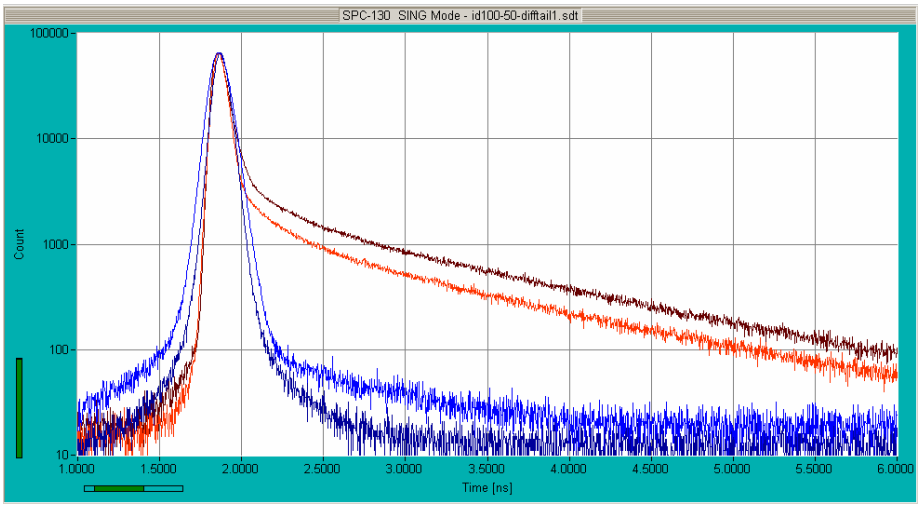


Fig. 3: Diffusion tail in the IRF of the id-100-50. 785nm (dark red), 650 nm (red), 444 nm (light blue), 405 nm (dark blue). The amplitude of the tail is about 5% and 3% at 650 and 785 nm. At 444 nm the tail is at the limit of detection, at 405 nm it is not detectable.

With 5% and 3% at 785 nm and 650 nm, respectively, the amplitude of the tail is relatively low. At 444 nm and 405 nm the diffusion tail is almost not detectable.

Afterpulsing

The afterpulsing of the id100-50 was checked by recording a continuous light signal in the time-tag (FIFO) mode of the TCSPC module. The time-tag data were used to record the autocorrelation function of the photon times. Consequently, the curve resembles the result of a fluorescence correlation (FCS) measurement. The result is shown in fig. 4. The autocorrelation function is normalised to the correlation expected for uncorrelated photon data, i.e. a correlation factor of 1 means that there is no correlation between the events.

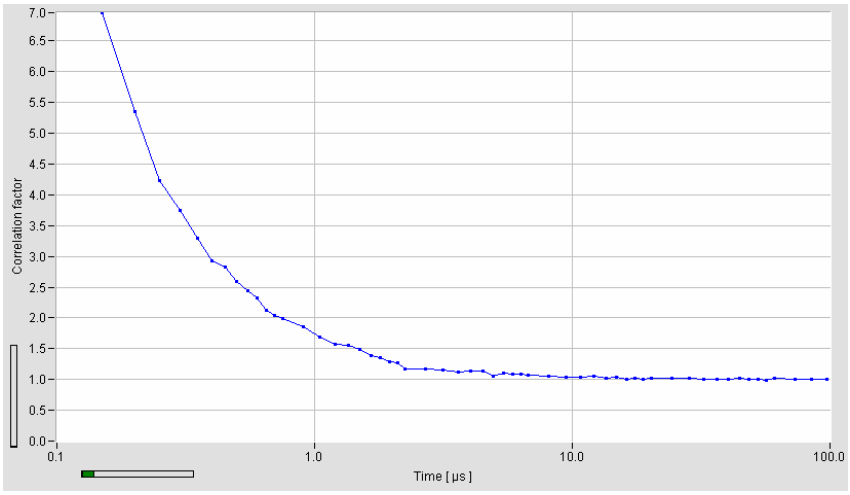


Fig. 4: Autocorrelation function of a light signal of constant intensity, recorded at a count rate of 10 kHz.

When comparing the autocorrelation curves of different detectors, please take into regard that the absolute amplitude of the autocorrelation curve is proportional to the reciprocal count rate.

Quantum Efficiency

We attempted to compare the quantum efficiency of the id100-50 with the quantum efficiency of a Hamamatsu H5773-20 PMT module. The H5773-20 has a 'high efficiency extended red' photocathode featuring exceptionally high quantum efficiency in the red and NIR range of the spectrum. At 650 nm, the efficiency of both the id100-20 and the id100-50 detectors were found about 3 times higher than for the PMT module. Based on the spectral sensitivity given for the H5773-20 the quantum efficiency of the id-100 can be estimated to be 25 to 40% at 650 nm. These values are similar or even better than the 'detection probability' (22% at 650 nm) specified for the id100-50 and -20.

Conclusions

The id100-50 of id Quantique has an extremely fast IRF and an excellent timing stability up to detector count rates of at least 8 MHz. The IRF is free of bumps and pre-pulses, and drops smoothly at longer times. The timing performance comes close to that of the smaller id100-20 module. The id100-50 is a wonderful detector for all applications in which the light can be concentrated on a small detector area. The good timing stability at high count rates then makes the id100-20 a real alternative to the R3809 MCP PMTs commonly used in TCSPC experiments. Potential applications are single-molecule spectroscopy, time-resolved confocal microscopy, and experiments of quantum-key distribution. Moreover, the detector is particularly suitable for a large number of applications at relatively high light intensity.

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