IDQ
FROM VISION TO TECHNOLOGY

REDEFINING PRECISION

id100 SERIES

SINGLE-PHOTON DETECTOR FOR VISIBLE LIGHT WITH BEST-IN-CLASS TIMING ACCURACY

IDQ's *id100 series* consists of compact and affordable single-photon detector modules with best-in-class timing resolution and state-of-the-art dark count rate based on a reliable silicon avalanche photodiode sensitive in the visible spectral range. The *id100 series* detectors come as:

- free-space modules, the *id100-20* and *id100-50* with a 20µm and respectively a 50µm diameter photosensitive area,
- a fiber-coupled module, the *id100-MMF50*, coming with a standard FC/PC optical input.

The modules are available in two dark count grades, with dark count rate as low as 2Hz.

With a timing resolution as low as 40ps and a remarkably short dead time of 45ns, these modules outperform existing commercial detectors in all applications requiring single-photon detection with high timing accuracy and stability up to count rates of at least 10MHz.

KEY FEATURES

- Best-in-class timing resolution (40ps)
- Low dead time (45ns)
- Small IRF shift at high count rates
- Standard and Ultra-Low Noise grades
- Peak photon detection at λ = 500nm
- Active area diameter of 20µm or 50µm
- Free-space or multimode fiber coupling
- Not damaged by strong illumination

APPLICATIONS

- Time correlated single photon counting (TCSPC)
- Fluorescence and luminescence detection
- Single molecule detection, DNA sequencing
- Fluorescence correlation spectroscopy
- Flow cytometry, spectrophotometry
- Quantum cryptography, quantum optics
- Laser scanning microscopy
- Adaptive optics

ID Quantique SA
Chemin de la Marbrerie 3
1227 Carouge/Geneva
Switzerland
T +41 22 301 83 71
F +41 22 301 83 79
info@idquantique.com
www.idquantique.com

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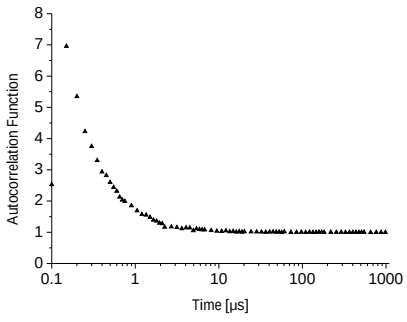
SPECIFICATIONS

Parameter	Min	Typical	Max	Units
Wavelength range	350		900	nm
Timing resolution [FWHM] 1 2 1		40	60	ps
Single-photon detection probability (SPDE) 3				
at 400nm	15	18		%
at 500nm	30	35		%
at 600nm	20	25		%
at 700nm	15	18		%
at 800nm	5	7		%
at 900nm	3	4		%
Afterpulsing probability 4			3	%
Output pulse width 5 4 6	9	10	15	ns
Output pulse amplitude 5	1.5	2	2.5	V
Deadtime 6		45	50	ns
Maximum count rate (pulsed light) 7		20		MHz
Supply voltage 5	5.6	6	6.5	V
Supply current		100	150	mA
Storage temperature	-40		70	°C
Cooling time			5	s

Dark count rate: IDQ´s modules are available in two grades: **Standard** and **Ultra-Low Noise**, depending on dark count rate specifications.

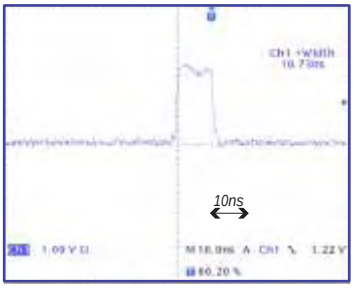
	Active Area Diameter	TE cooled	Standard	Ultra-Low Noise
id100-20	20 µm	yes	< 60Hz	< 2Hz
id100-50	50 µm	yes	< 80Hz	< 20Hz
id100-MMF50	3	yes		

4 Afterpulsing



Typical autocorrelation function of a constant laser signal recorded at a count rate of 10kHz.

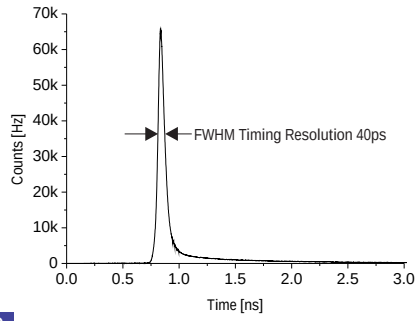
5 Output Pulse



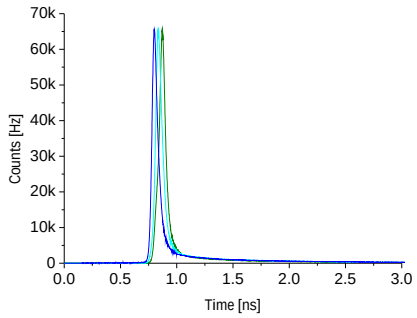
Typical pulse of 2V amplitude and 10ns width observed at the output of an *id100* terminated with 50Ω load. Recommended trigger level: 1V. For timing applications, triggering on rising edge is recommended to take full advantage of the detector´s timing resolution.

1. Optimal timing resolution is obtained when incoming photons are focused on the photosensitive area.
2. The *id100* is free of indicating LEDs to maintain complete darkness during measurements.
3. The *id100-MMF50* comes with a 50/125µm multi-mode fiber optimized for visible spectral range with 0.22 numerical aperture. The coupling efficiency is larger than 80%.
4. The detector output is designed to avoid distorsion and ringing when driving a 50Ω load.
5. Universal network adapter provided (110/220V).
6. See on page 4 the A-PPI-D pulse shaper for negative input equipment compatibility.

1 Timing Resolution

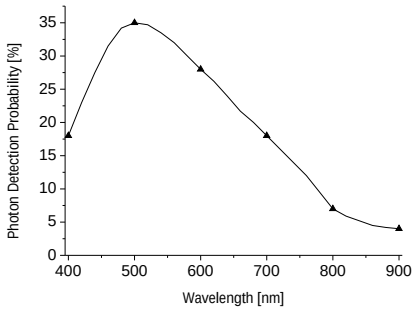


2 IRF Shift with Output Count Rate

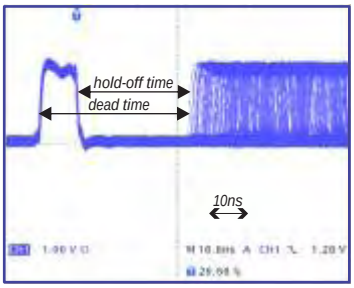


Extremely low shift of instrument response function with output count rate (less than 70ps from 10kHz to 8MHz).

3 Photon Detection Probability versus λ



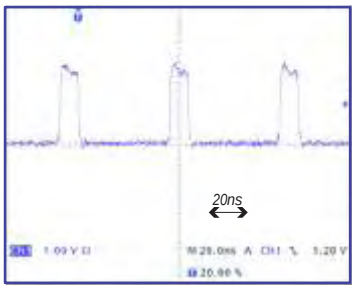
6 Dead Time



Measurement obtained with an oscilloscope in infinite persistance mode: the dead time consists of the output pulse width and the hold-off time during which the *id100* is kept insensitive.

ID Quantique SA
Chemin de la Marbrerie 3
1227 Carouge/Geneva
Switzerland
T +41 22 301 83 71
F +41 22 301 83 79
info@idquantique.com
www.idquantique.com

7 Maximum Count Rate - Pulsed Light



The short dead time of the *id100* allows operation at very high repetition frequencies, up to 20MHz.

MOUNTING OPTIONS

The *id100 series* comes with different mounting options:

- Use mounting brackets supplied with the module using screws with diameters up to 4mm.
- Use a standard optical post holder (not supplied)using the M4 thread located on the bottom side of the *id100-20 & id100-50* detectors.
- Use the C-MOUNT adapter to add optical elements in front of the detector (*id100-20 & id100-50* only).

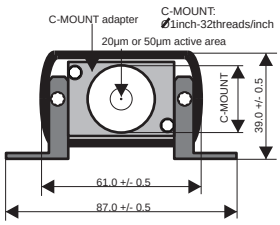
PRINCIPLE OF OPERATION

The id100 consists of an avalanche photodiode (APD) and an active quenching circuit integrated on the same silicon chip. The chip is mounted on a thermo-electric cooler and packaged in a standard TO5 header with a transparent window cap. A thermistor is used to measure temperature. The APD is operated in Geiger mode, i.e. biased above breakdown voltage. A high voltage supply used to bias the diode is provided by a DC/DC converter. The quenching circuit is supplied with +5V. The module output pulse indicates the arrival of a photon with high timing resolution. The pulse is shaped using a hold-off time circuit and sent to a 50Ω output driver. All internal settings are preset for optimal operation at room temperature.

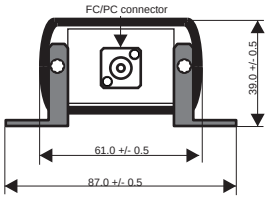
In the fiber-coupled version, a fiber pigtail with FC/PC connector is coupled to the detector.

DIMENSIONAL OUTLINE (in mm)

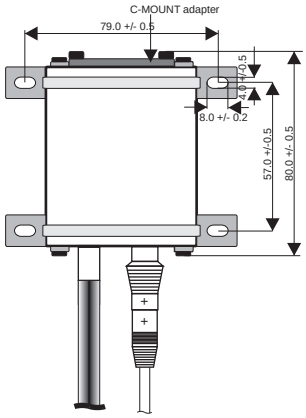
***id100-20 / id100-50* Front View**



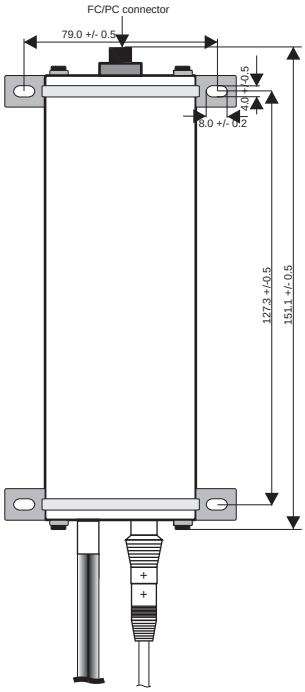
***id100-MMF50* Front View**



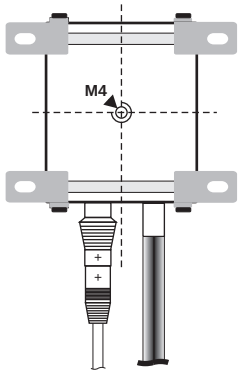
***id100-20 / id100-50* Top View**



***id100-MMF50* Top View**

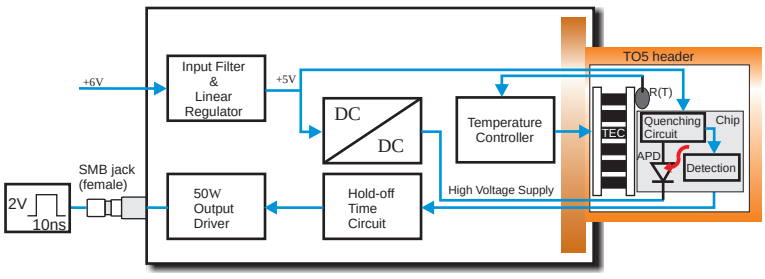


***id100-20 / id100-50* Bottom View**



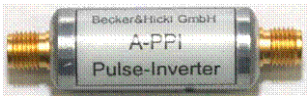
UNIT: millimeters

BLOCK DIAGRAM

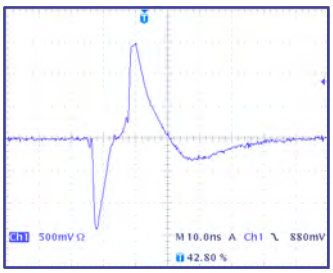


ID Quantique SA
Chemin de la Marbrerie 3
1227 Carouge/Geneva
Switzerland
T +41 22 301 83 71
F +41 22 301 83 79
info@idquantique.com
www.idquantique.com

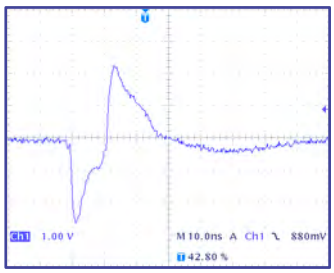
ACCESSORY - OPTIONAL PULSE SHAPER



IDQ provides as an option a pulse shaper (A-PPI-D) which can be used with equipments requiring negative input pulses. The id100 output pulse leading edge is converted in a sharp negative pulse of typical amplitudes 1.4V in 50Ω load and 2.5V in high impedance load. The pulse shaper is delivered with two SMA/BNC adapters.



Typical output pulse of an id100 equipped with a A-PPI-D pulse shaper in 50Ω load.



Typical output pulse of an id100 equipped with a A-PPI-D pulse shaper in high impedance load.

id101 SERIES - THE WORLD´S SMALLEST PHOTON COUNTER

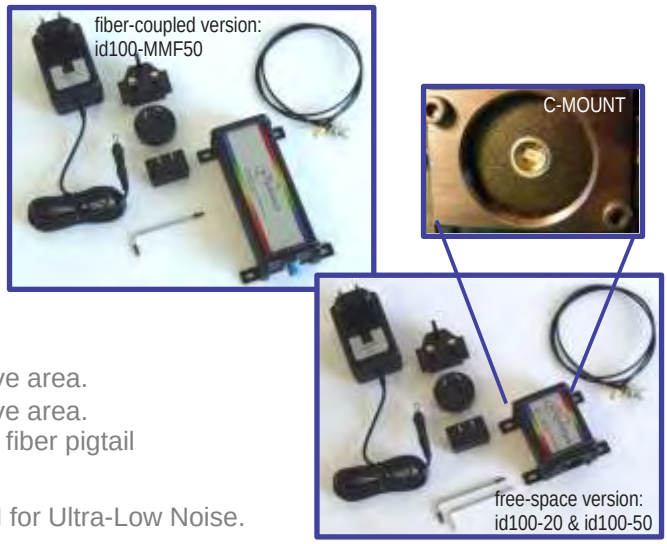
For large-volume OEM applications, IDQ offers the *id101 series,* consisting of a standard TO5 - 8pins optoelectronic package with a CMOS silicon chip (single photon avalanche diode and fast active quenching circuit) mounted on top of a thermoelectric cooler. A thermistor is available for temperature monitoring and control. An evaluation board is available upon request. When properly biased, the performance is comparable with that of the *id100-50*. IDQ's engineering team offers technical support to simplify integration. A fiber coupled version, the *id101-MMF50*, is also available. See the *id101* datasheet for more information.

OTHER PRODUCTS

- id101 — Miniature single-photon detector for the visible spectral range (see above)
- id150 — Monolithic linear array of single-photon detectors for the visible range
- id201 — Single-photon detector for telecom wavelenghts
- id300 — Short pulse laser source
- id400 — Single photon counting module for the 900-1150nm spectral range
- Quantis — Quantum Random Number Generator
- Clavis^2 — Quantum Key Distribution System for R&D
- Cerberis — Layer 2 encryptor with Quantum Key Distribution
- Centauris — Layer 2 encryptor

SUPPLIED ACCESSORIES

- Mounting brackets (4x)
- C-Mount adapter (except for id100-MMF50)
- Coaxial cable (1m, BNC-SMB)
- Power supply with universal input plugs
- Operating guide
- Angled 2.5mm hexagonal key to remove C-Mount adapter
- Angled T10 Torx key to remove mounting brackets



ORDERING INFORMATION

id100-20-XXX	Single-photon detector with 20µm active area.
id100-50-XXX	Single-photon detector with 50µm active area.
id100-MMF50-XXX	Single-photon detector with multimode fiber pigtail (50/125µm, FC/PC connector).

Select dark count grade: XXX = STD for Standard, XXX = ULN for Ultra-Low Noise.

ID Quantique SA
Chemin de la Marbrerie 3
1227 Carouge/Geneva
Switzerland
T +41 22 301 83 71
F +41 22 301 83 79
info@idquantique.com
www.idquantique.com

Becker & Hickl GmbH

Nahmitzer Damm 30
12277 Berlin

Fon +49 (30) 787 56 32
Fax +49 (30) 787 57 34

Email info@becker-hickl.com

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).

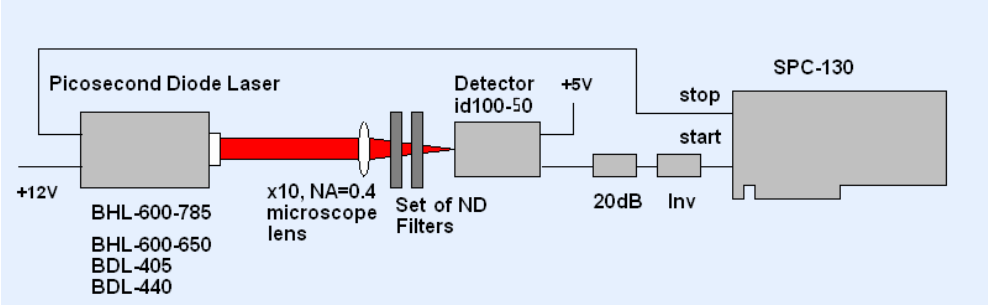
Detector

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.

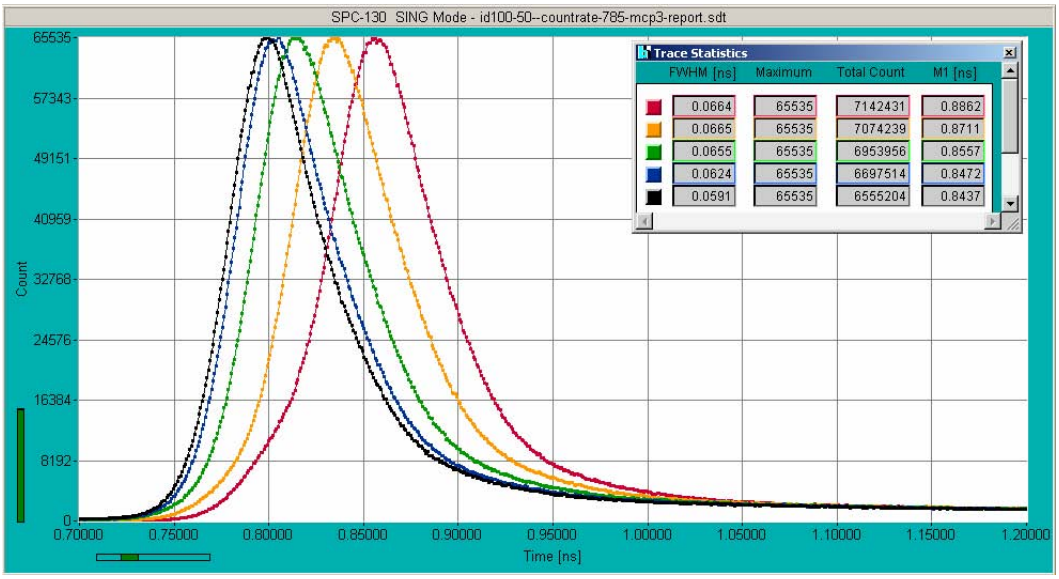


Fig. 2: IRF of the id100-50 at 785 nm. Detector count rates 8.1 MHz (red), 5.15 MHz (yellow), 2.1 MHz (green), 0.5 MHz (blue) and 62 kHz (black). Time scale 50 ps per division. The FWHM and the first moment of the IRF curves are shown in the insert.

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.

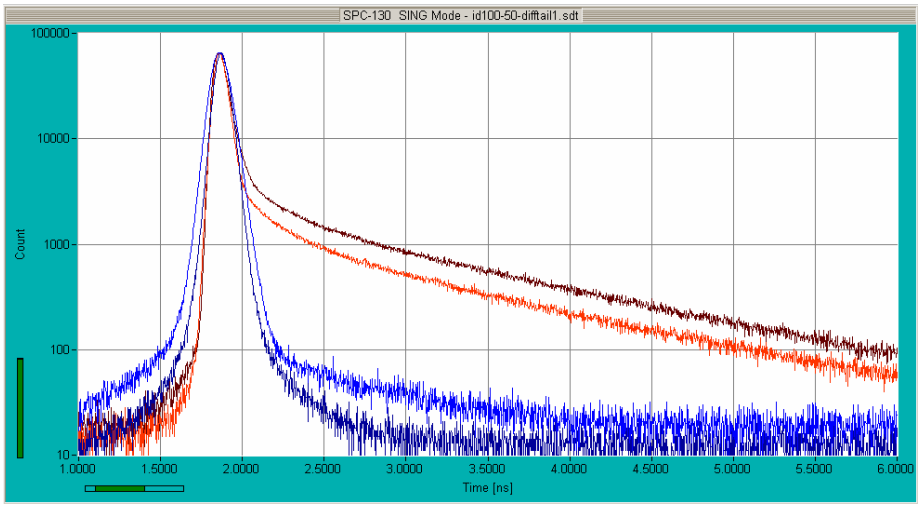


Fig. 3: Diffusion tail in the IRF of the id-100-50. 785nm (dark red), 650 nm (red), 444 nm (light blue), 405 nm (dark blue). The amplitude of the tail is about 5% and 3% at 650 and 785 nm. At 444 nm the tail is at the limit of detection, at 405 nm it is not detectable.

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.

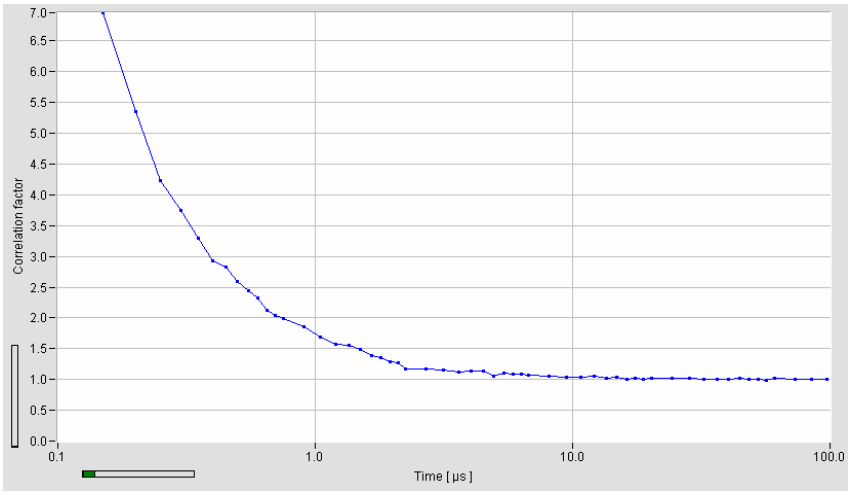


Fig. 4: Autocorrelation function of a light signal of constant intensity, recorded at a count rate of 10 kHz.

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.

Wolfgang Becker
Becker & Hickl GmbH
Nahmitzer Damm 30
12277 Berlin
Tel. +49-30-787 56 32
Fax +49-30-787 57 34
becker@becker-hickl.com
http://www.becker-hickl.com