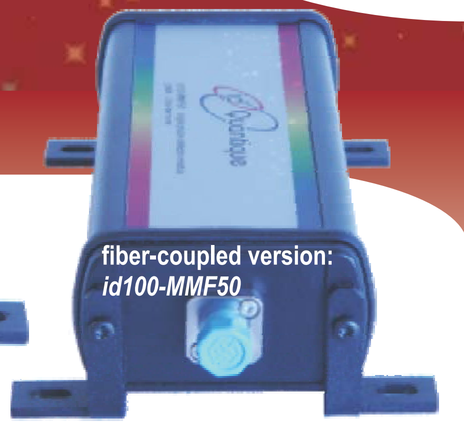
id100



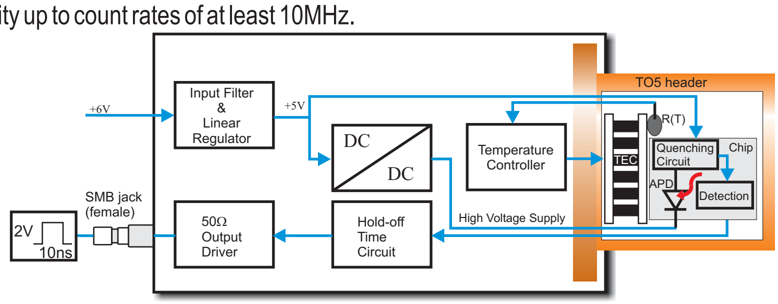
Detect visible photons with high timing accuracy

id Quantique's *id100 series* consists of compact and affordable single-photon counting 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, these modules are able to detect weak optical signals down to the single photon level. The *id100 series* includes:

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

The modules are available in two grades depending on the dark count rate specifications. For the Ultra-Low Noise grade, the dark count rate is less than 1Hz for the *id100-20*, less than 20Hz for the *id100-50* and *id100-MMF50*.

The free-space and fiber-coupled modules are easy-to-use, self-contained and can be integrated in every optical set-up. 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. Besides an extremely fast IRF (Instrument Response Function), the modules have an excellent timing stability up to count rates of at least 10MHz.



Block diagram of the id100 (free-space version).

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 reflects 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. No user adjustement is necessary. In the fiber-coupled version, the TO5 header and the optical fiber are included in the housing. The optical input consists of a FC/PC connector on the front side of the module.

Beside the *id100*, the *id101* series includes miniaturized versions intended for large-volume OEM applications (*http://www.idquantique.com/products/files/id101-specs.pdf*). The *id101-20* and *id101-50* have an active area diameter of 20µm and 50µm, respectively. The *id101-MMF50* is fiber-pigtailed with FC/PC connectors.

Ordering information and sales contact

id100-20-XXX: Single photon detection module with 20µm active area .

id100-50-XXX: Single photon detection module with 50µm active area .

id100-MMF50-XXX: Single photon detection module with multimode fiber input (50/125µm, FC/PC connector).

Please insert dark count rate grade code: XXX=STD for standard, XXX=ULN for Ultra-Low Noise .

For further information, please contact id Quantique by phone: +41 (0)22 301 83 71, fax: +41 (0)22 301 83 79, or email: sales@idquantique.com.

New

Ultra-Low Noise Modules Available

Features

- Best-in-class timing resolution (40ps)
- Small IRF shift at high count rates
- Standard and Ultra-Low Noise grades
- Low afterpulsing probability
- Low dead time (45ns)
- Peak photon detection at λ = 500nm
- Active area diameter of 20µm or 50µm
- Free-space or multimode fiber coupling
- Compact, easy-to-use and reliable
- Standard 50Ω output with BNC connector
- No DC power supply required
- Not damaged by strong illumination
- Highly reliable

Applications

- Photon counting, time correlated photon counting (TCSPC)
- Fluorescence and luminescence detection
- Single molecule detection, DNA sequencing
- Fluorescence correlation spectroscopy
- Decay and multiple decay time measurements
- Flow cytometry, spectrophotometry
- Environment analyses
- LIDAR, optical range finder
- Non contact profilometry
- Laser scanning microscopy
- Adaptive optics, astronomical instrumentation
- Quantum cryptography, quantum optics
- Optical time domain reflectometry
- Educational experiments

id Quantique

id100

Detect visible photons with high timing accuracy

General Specifications at T=25°C

Parameters	Minimum	Typical	Maximum	Units
Spectral range	350		900	nm
Timing resolution [FWHM] [1] [2] (1)		40	60	ps
Photon detection probability [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)	9	10	15	ns
Output pulse amplitude [5]	1.5	2	2.5	V
Dead time [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: id Quantique 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	< 1Hz
id100-50	50 µm	yes	< 80Hz	< 20Hz
id100-MMF50	(3)	yes		

(1) The optimal timing resolution is obtained when the incoming photons are focused on the photosensitive area.

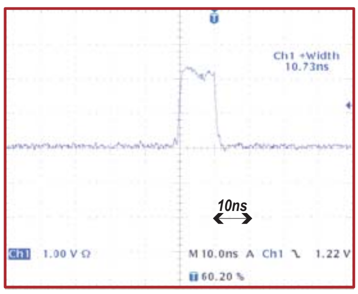
(2) The *id100* is free of indicating LEDs to maintain complete darkness during measurements.

(3) The *id100-MMF50* comes with a 50/125µm multi-mode fiber optimized for the visible spectral range. The numerical aperture is 0.22. The coupling efficiency is larger than 80%.

(4) The detector output was designed to avoid distorsion and ringing when driving a 50Ω load. The *id100* is thus compatible with most instruments: correlators, time-to-amplitude converters, time-to-digital converters, counters, oscilloscopes, etc.

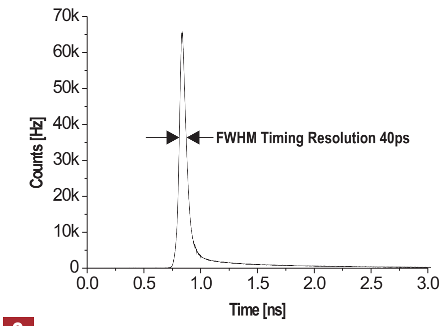
(5) Universal network adapter provided (110/220V).

5 Output Pulse

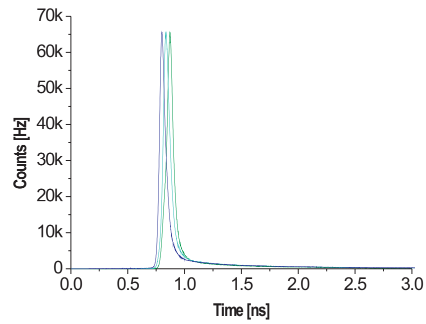


A typical pulse of 2V amplitude and 10ns width is observed at the output of the *id100 series* terminated with a 50Ω load. The recommended trigger level of the measurement device is 1V. For counting applications, the trigger slope can be negative or positive. For timing applications, the trigger slope must be positive in order to take full advantage of the *id100-series* timing resolution.

1 Timing Resolution

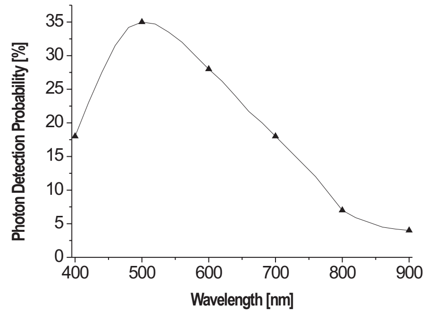


2 IRF Shift with Output Count Rate

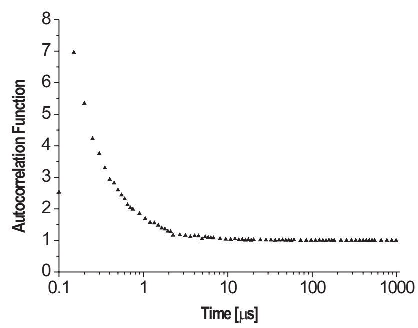


The shift of the instrument response function with the output count rate is small. As shown above, it is less than 70ps from 10kHz to 8MHz count rates (http://www.idquantique.com/products/files/id100-becker.pdf).

3 Photon Detection Probability versus λ



4 Afterpulsing

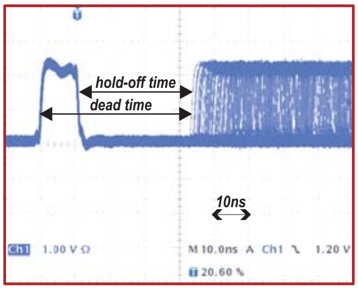


Typical autocorrelation function of a constant laser signal, recorded at a count rate of 10kHz.

id100

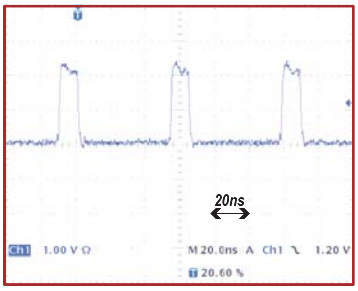
Detect visible photons with high timing accuracy

6 Dead Time



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

7 Maximum Count Rate - Pulsed Light



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

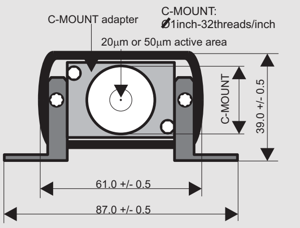
Mounting options

The ***id100 series*** comes with different mounting options:

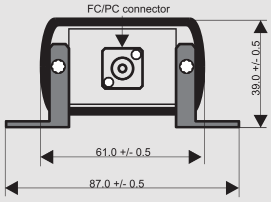
- use four mounting brackets supplied with the module. The brackets accept screws with diameters up to 4mm.
- use a standard optical post holder (not supplied). A M4 mounting hole placed on the bottom side of the *id100-20* & *id100-50* allows its mounting using a standard set screw (not supplied).
- for the free-space version only, a C-MOUNT adapter is added on the module front side.

Dimensional Outline

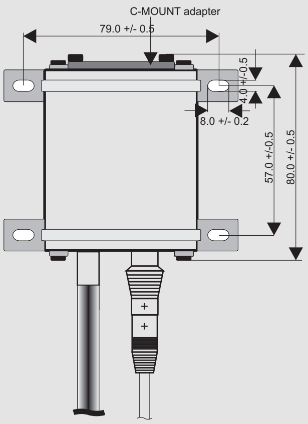
id100-20 / id100-50 Front View



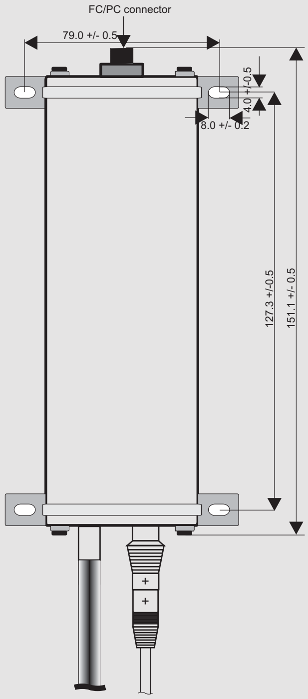
id100-MMF50 Front View



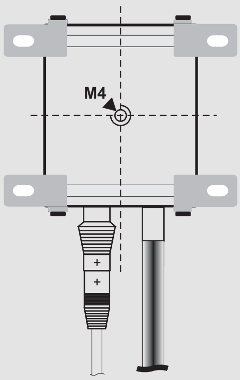
id100-20 / id100-50 Top View



id100-MMF50 Top View



id100-20 / id100-50 Bottom View



UNIT: millimeters

Accessories supplied

- single photon detection module with four mounting brackets and a C-MOUNT adapter (except for *id100-MMF50*)
- 1m coaxial cable with BNC and SMB connectors
- power supply with universal range of input plugs
- operating guide
- angled 2.5 mm hexagon key (except for *id100-MMF50*) supplied in order to remove the C-MOUNT adapter if required
- angled T10 Torx key supplied in order to remove the mounting brackets if required

fiber-coupled version:
id100-MMF50

free-space version:
id100-20 & id100-50

C-MOUNT

The worlds smallest photon counter

id101 series

For large-volume OEM applications, idQuantique offers the *id101 series*. The *id101* consists of a standard TO5 - 8pins optoelectronic package. The CMOS silicon chip combining a single photon avalanche diode and a fast active quenching circuit is mounted on top of a one-stage thermoelectric cooler. A thermistor is placed on the TEC cold side and accessible externally if temperature control is required. The *id101* is sold as an electronic component, free of external printed circuit board. It can be mounted by the customer on a custom printed circuit board. An evaluation board is available upon request. When properly biased, the performance is comparable with that of the *id100-50*. idQuantique's engineering team offers technical support for the proper integration of the *id101* in customer's commercial products. A fiber coupled version, the *id101-MMF50*, is also available. See the *id101* datasheet for more information.

Custom Design Service

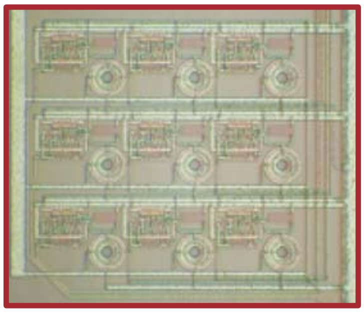
id Quantique SA designs and manufactures hardware products serving two main markets: network security and optical instrumentation. In the latter, the company offers innovative solutions for single photon detection. The company’s product portfolio includes the id100 and id150 single-photon detection modules for the visible spectral range. Over the years the company has acquired a broad expertise in the design of silicon photodetectors, operating in linear and Geiger mode.

id Quantique offers a design service to customers with non-standard detector needs. When photomultiplier tubes (PMTs) and silicon-based hybrid solutions (silicon APDs combined with discrete electronic circuits) do not meet your needs, id Quantique provides innovative solutions for industrial, commercial and research applications.

id Quantique's technology offers the possibility to fabricate compact modules, including large 1D and 2D arrays, with superior timing performances. These modules are used in biological/chemical instrumentation, quantum optics, aerospace and defense applications. The company is working with selected CMOS (Complementary Metal Oxide Semiconductor) foundries for the fabrication of its silicon detectors. The CMOS technology is widely recognized in the silicon industry as the most reliable way to fabricate ICs and sensors. Using this technology, detectors and front-end electronics can be integrated on the same silicon chip. Many of the functionalities (e.g. voltage conversion and read-out) are done directly at the chip level, thus almost completely removing the need for discrete electronic components and expensive assembly. Because only a very small number of external components are needed, the size of the module can be greatly reduced.

Our Custom Design Service includes:

- fabrication of 1D or 2D single photon detector arrays,
- design of photon detectors with custom shape and active area diameter,
- integration of dedicated quenching and recharging circuits exhibiting a dead time as short as 10ns,
- on-chip integration of data processing functionalities,
- design optimisation to fit your packaging needs,
- consulting services for the design of custom PIN photodiodes, as well as linear and avalanche-mode photo diodes.



custom design example: 3x3 single photon avalanche diode array

Other Products (please visit our website http://www.idquantique.com)

id101:	**miniature single photon counter for the visible spectrum**
id150:	**1x10 linear array of single photon detectors for the visible spectral range**
id201:	**single photon counting module for the spectral range between 900 and 1700 nm**
id300:	**sub-nanosecond laser source at 1310 or 1550 nm**
Quantis:	**Quantum Random Number Generator**
Clavis:	**Quantum Key Distribution for secure cryptographic communication**
Vectis:	**Point-to-point link encryption appliance**

Disclaimer
The information and specification set forth in this document are subject to change at any time by id Quantique without prior notice.

id Quantique SA, ch. de la Marbrerie 3, 1227 Carouge, Switzerland, Tel. +41 (0)22 301 83 71, Fax +41 (0)22 301 83 79
sales@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).

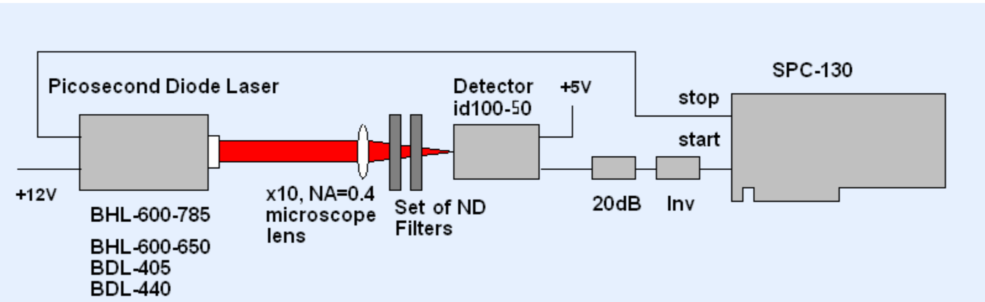
Detector

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.

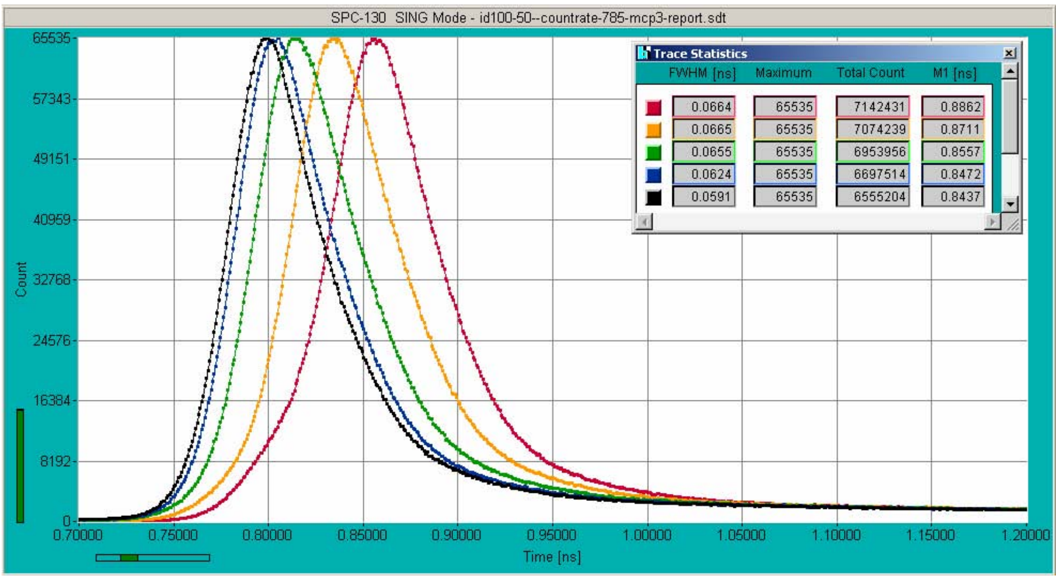


Fig. 2: IRF of the id100-50 at 785 nm. Detector count rates 8.1 MHz (red), 5.15 MHz (yellow), 2.1 MHz (green), 0.5 MHz (blue) and 62 kHz (black). Time scale 50 ps per division. The FWHM and the first moment of the IRF curves are shown in the insert.

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.

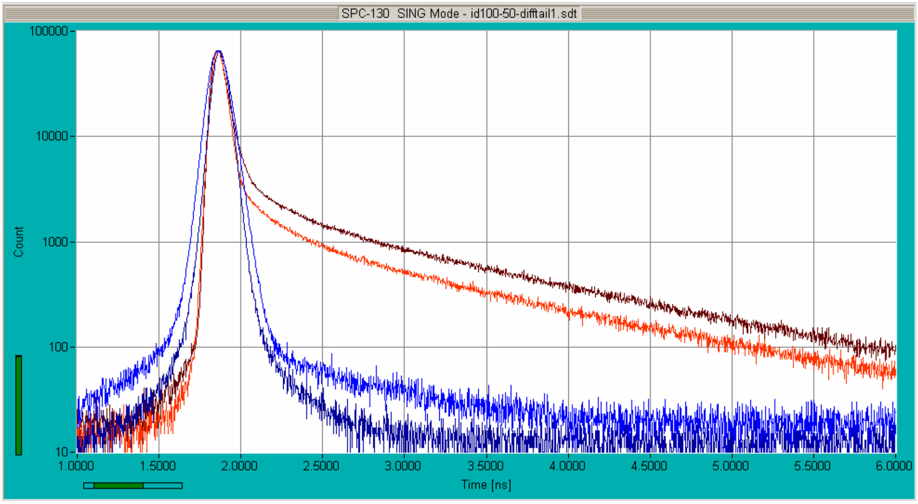


Fig. 3: Diffusion tail in the IRF of the id-100-50. 785nm (dark red), 650 nm (red), 444 nm (light blue), 405 nm (dark blue). The amplitude of the tail is about 5% and 3% at 650 and 785 nm. At 444 nm the tail is at the limit of detection, at 405 nm it is not detectable.

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.

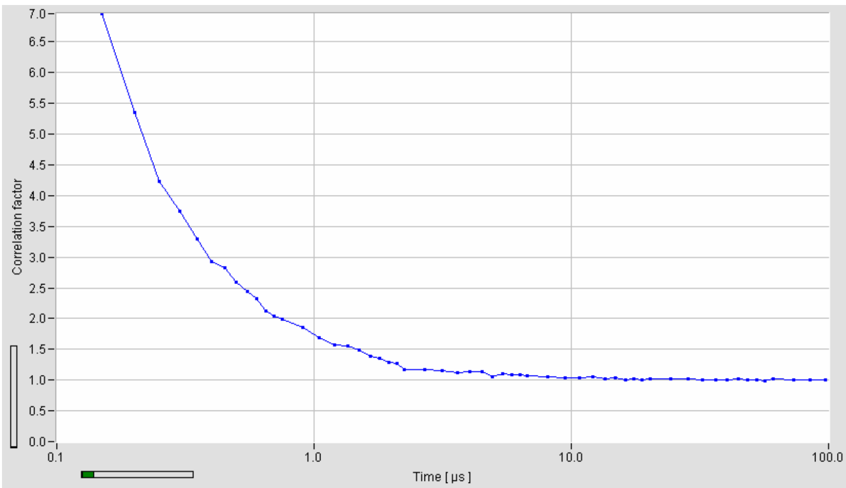


Fig. 4: Autocorrelation function of a light signal of constant intensity, recorded at a count rate of 10 kHz.

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

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

Performance of the id100-20 Detector in B&H TCSPC Systems

This report summarizes the results of Becker&Hickel's evaluation of the id100-20, a single photon counting module manufactured by id Quantique (www.idquantique.com)

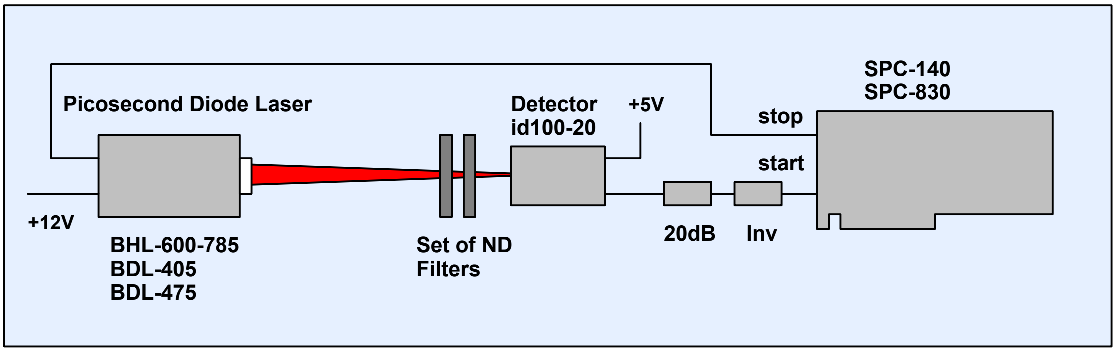
Detector

The id100-20 of id Quantique is an actively quenched single-photon APD (SPAD) module. The quenching circuit is integrated on the diode chip. The key parameters are (typical values):

Spectral range	350 to 900 nm
Diameter of the active area	20 µm
Timing resolution (fwhm)	40 ps
Detection probability at 500 nm	35 %
Dark count rate	200 s^{-1}
Output pulse amplitude	+ 2 V

Test Setup

The id100-20 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 sent directly to the SPAD module. The output pulses of the detector are 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 come directly from the laser.

For measurements at various wavelengths we used three different lasers. A BHL-600-785 was used at 785 nm. This laser has an exceptionally short pulse width of the order of 24 ps. The BDL-405 and the BDL-475 were used at 405 nm and 468 nm. The pulse width was about 68 ps and 58 ps, respectively. The measurements of the instrument response functions were performed by an SPC-140 TCSPC module, the correlation measurement by an SPC-830 module. All lasers and TCSPC modules are Beckel&Hickl products.

Instrument Response Functions (IRFs)

Instrument response functions measured at 785 nm are shown in fig. 2. The response was measured at a count rate of 5 MHz, 2.7 MHz, and 62 kHz.

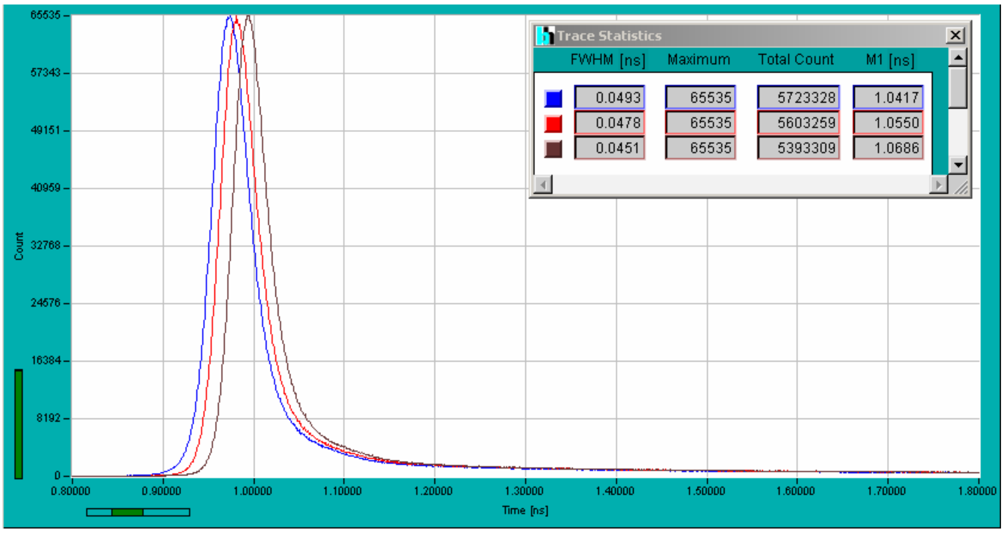


Fig. 2: IRF at 785 nm. Count rates 5 MHz (blue), 2.7 MHz (red), and 62 kHz (black). Time scale 100 ps per division. The FWHM and the first moment of the IRF curves are shown in the insert.

The measured width of the IRF (Instrument Response Function) varies from 49 ps to 45 ps. Corrected with an estimated width of the laser pulse of 24 ps, these values correspond to 43 ps to 38 ps, in agreement with 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 between 5 MHz and 2.7 MHz and 63 kHz is 13 ps and 26.9 ps. Compared to other APD modules, these values are exceptionally low. They are in fact smaller than for a XP2020 PMT with a standard voltage divider.

Fig. 3 compares the IRF of the id100-20 with the IRF of an R3809U-50 MCP-PMT operated at -3 kV. The measured FWHMs are 47 ps for the SPAD and 37 ps for the MCP-PMT.

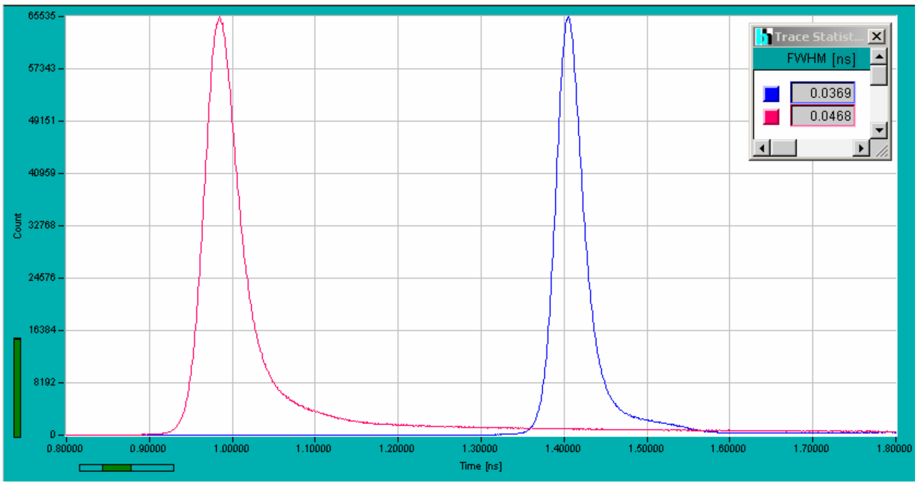


Fig. 3: Comparison of the IRF of the id100-20 (red, left) and the IRF of an R3809U MCP-PMT (blue, right). The measured FWHMs are 47 ps for the id100-20 and 37 ps for the MCP-PMT.

The true IRF width of the MCP-PMT is known to be about 28 ps. With this value, the width of the laser pulse can be estimated to be about 24 ps. The corrected IRF width of the SPAD is then 40 ps.

Fig. 4 shows measurements with the BDL-405 and BDL-475 lasers at the wavelengths of 405 nm and 468 nm.

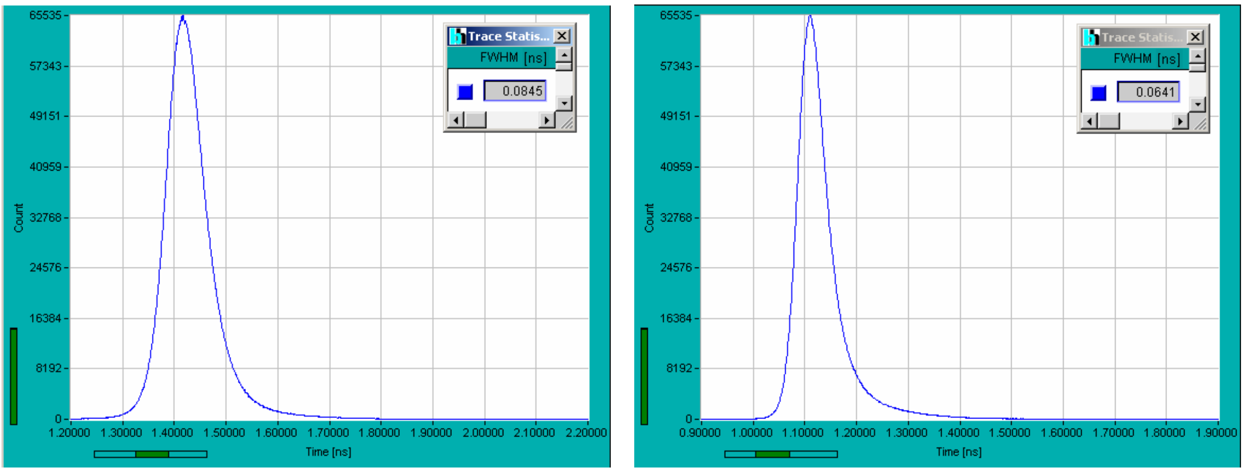


Fig. 4: Laser pulses recorded at 405 nm (left) and 468 nm (right)

The optical pulse width of these lasers is about 68 ps and 58 ps, respectively. Consequently, the recorded pulses are broader than the true IRF of the SPAD.

The comparison of the IRFs of the SPAD and the MCP PMT shows remarkable differences, see fig. 5.

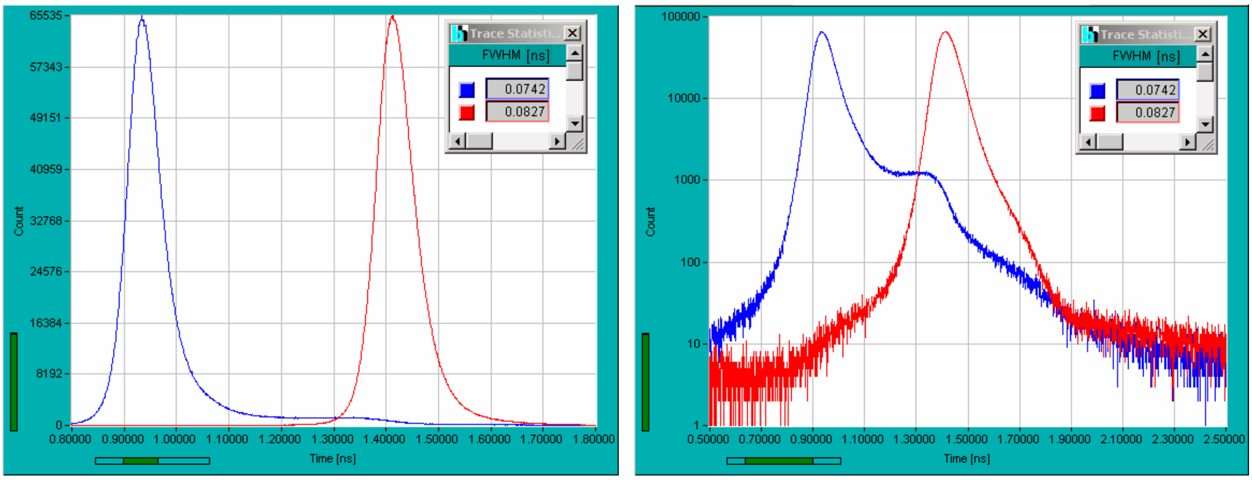


Fig. 5: Laser pulses recorded at 405 nm. Blue MCP PMT, red id100-20. Left linear scale, 100 ps / div, right logarithmic scale, 200 ps / div.

Although the SPAD records the pulse with a larger FWHM than the MCP PMT the response is cleaner and drops faster at longer times. Especially, the bump in the MCP measurement is not present in the SPAD measurement. The measurement shows indeed that the bump - which is usually attributed to the laser - is actually a feature of the MCP response.

With the known response width of the MCP of 28 ps, the true laser pulse width is about 68 ps. The same pulse is recorded with an FWHM of 82.7 ps by the SPAD. The estimated FWHM of the SPAD response is then 47 ps. However, the uncertainty of this result is large. It is therefore not sure whether or not the IRF is longer at 405 nm.

Afterpulsing

The afterpulsing of the id100-20 was checked by recording the laser 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. 6. 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 photons.

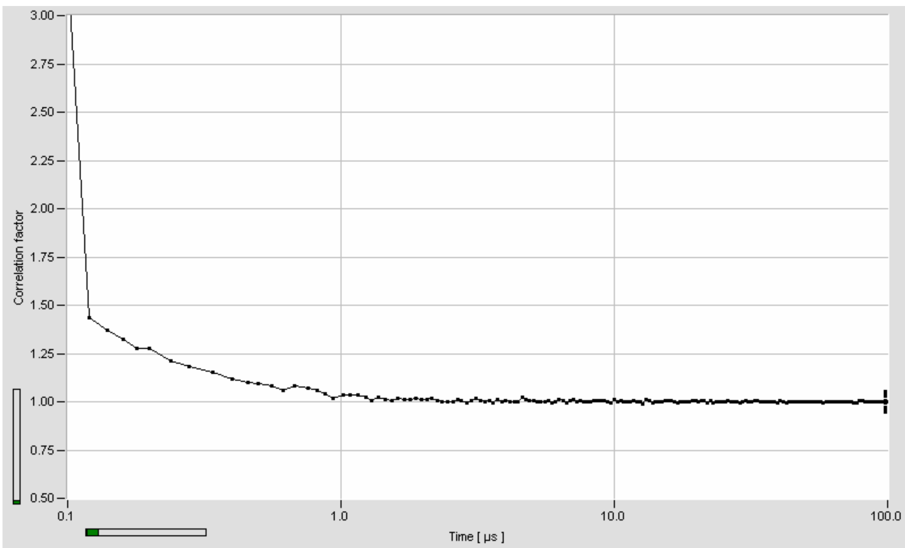


Fig. 6: Autocorrelation function of a constant laser signal, recorded at a count rate of 10 kHz.

Please note that, for a given afterpulsing probability, the amplitude of the autocorrelation curve is proportional to the reciprocal count rate.

The size and the duration of the afterpulsing is comparable to that of a good PMT. In particular, the afterpulsing ceases after about 1 µs. Typical intersystem crossing effects and diffusion times can therefore be measured with a single detector.

Conclusions

The id100-20 of id Quantique has an extremely fast IRF and an excellent timing stability up to count rates of at least 10 MHz. The IRF is free of bumps and prepulses, and drops smoothly at longer times. The IRF at long times is in fact better than that of the Hamamatsu R3809U MCP PMT. The id100-20 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. 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 with relatively high light levels. It is then not necessary to focus the light perfectly on the active area. These applications include a large number of standard fluorescence lifetime experiments and laser test setups.

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