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SINGLE-PHOTON SYSTEMS APPLICATION NOTE

Silicon Avalanche Photodiodes in Dynamic Light Scattering

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Introduction

This application note describes the use of the ID100 single photon counting detector for the measurement of light scattered by small particles. By analyzing the fluctuation of the scattered light intensity it is possible to evaluate the particle size. ID Quantique offers compact and affordable state-of-the-art single photon counting detectors based on silicon avalanche photodiodes with best-in-class timing resolution and a short dead time, these are especially for dynamic light scattering applications.

Dynamic Light Scattering (DLS), also known as Photon Correlation Spectroscopy (PCS) or Quasi-Elastic Light Scattering (QELS) is a technique commonly used to determine the size of small particles in a solution [1, 2].

Shining a monochromatic light beam onto a solution with particles causes light to scatter. When the particles are much smaller than the incoming wavelength, this is predominantly Rayleigh scattering. This scattered intensity fluctuates with time. The time-dependent fluctuation occurs because the particles undergo Brownian motion and the distance between them is constantly varying [3]. From the time dependence of the scattering intensity fluctuation and knowing the temperature and viscosity of the medium it is possible to calculate the diffusion coefficient of the particles from which the hydrodynamic diameter can be derived.

The hydrodynamic diameter is that of a sphere that has the same translational diffusion coefficient as the particle being measured [3]. If a laser beam is applied to a solution with particles, the scattered light intensity can be measured at any time with the ID100 single photon counting detector and the size of the particles can be evaluated, as described in the following sections.

Dynamic Light Scattering and its Advantages

DLS is a non invasive technique and it is well established for measuring the size of molecules and particles in the submicron region.

This method offers several advantages:

- ✔ Measures particle sizes of 1nm to 1/10 of the wavelength of the light
- ✔ Typically ± 1% precision
- ✔ Short experiment duration (1-2min)
- ✔ Reliable and repeatable analysis
- ✔ Straightforward sample preparation
- ✔ Low sample volumes (as low as 2 uL)
- ✔ Modest development costs

ID100 Single Photon Counter

The ID100 single photon counters are based on a reliable silicon avalanche photodiode (APD) sensitive in the visible spectrum. The modules are able to detect weak optical signals down to the single photon level. With their very low dark count rates, timing resolution of 40ps and dead time of 45ns, the modules have an unmatched dynamic range.. The ID100 is easy-to-use, self-contained and can easily be integrated in every optical set-up. Besides a very narrow Instrument Response Function (IRF) it has an excellent timing stability up to count rates of at least 10MHz. The id100 is available in the following versions:

- ID100-20: free space coupling with 20mm active area
- ID100-50: free space coupling with 50mm active area
- ID100-SMF20: Single Mode Fiber coupling with 20mm active area
- ID100-MMF50: with 50/125µm FC/PC Multi Mode Fiber coupling
- ID100-MMF50: with 100/140µm FC/PC Multi Mode Fiber coupling

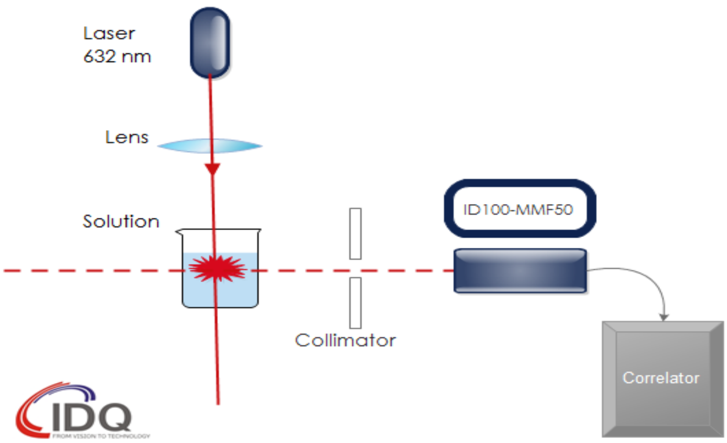
The ID100 modules exist in two grades, depending on the dark count rate specifications. For the Ultra-Low Noise grade, the dark count rate is less than 5Hz for the ID100-20 and less than 20Hz for the ID100-50 and ID100-MMF50. The key features are:

- ✔ Broad spectral range: 350 to 900 nm
- ✔ Best in class timing resolution of 40ps
- ✔ Low dark count rate of less than 5Hz
- ✔ Low dead time (45ns)
- ✔ Photon detection probability up to 35%
- ✔ Standard 50 Ω output with BNC connector
- ✔ Fast active quenching circuit
- ✔ Low bias voltage +5V
- ✔ Not damaged by strong illumination

For the measurements mentioned below, the ID100-MMF50 detector was used to compute the scattered light intensity.

Experimental Setup

Figure 1: Dynamic Light Scattering experimental setup.

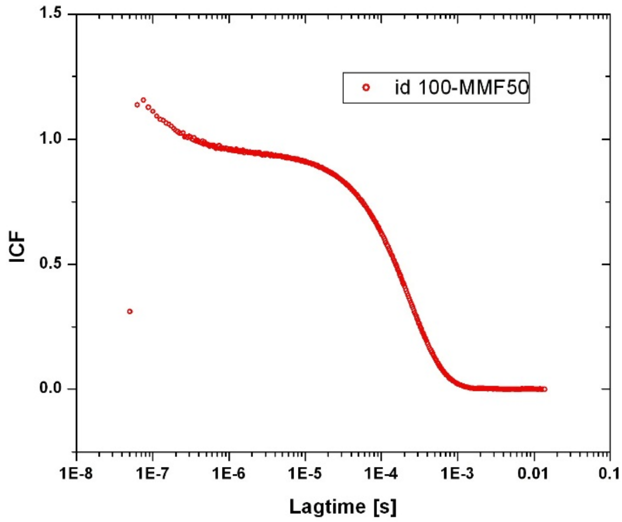


Auto-Correlation Measurements

The experimental setup is illustrated in figure 1. A 632nm He Ne laser is used for this measurement. The beam passes through collimation lenses, allowing the light to be focused onto the solution. The scattered light is then detected by the ID100-MMF50 single photon detector.

The output signal from ID100-MMF50 is sent to a correlator that computes the number of single photons detected as a function of time. The auto-correlation function is then calculated from the detected photon statistics. Figure 2 shows the normalized intensity correlation function (ICF) fluctuation with time. For a detector with zero after pulsing probability, the normalized ICF curve should go from 1 to zero with the increase of lag time. The deviation from 1 observed at short lag times in Figure 2 is due to to the after pulsing rate of the ID100-MMF50 that is typically 0.5% (you can find all details about its measurements in the annex document).

Figure 2. Intensity correlation function (ICF) dependence with time, in auto-correlation measurement. Courtesy of LS Instruments.



Cross-Correlation Measurements

The cross correlation measurement is performed with 2 single photon detectors (ID100-MMF50), as shown in figure 3. This measurement consists in illuminating the sample with a laser beam at 632nm and measuring the coincidence of the scattered light at a fixed angle. By performing a cross-correlation on the detected signal it is possible to eliminate the artefact created by the detectors' after pulse rate.

The specific cross-correlation setup of LS Instruments (figure 3) also allows suppression of photons that are scattered multiple times, which drastically interfere with measurements in turbid samples.

Figure 3: Cross-correlation experimental setup. Courtesy of LS Instruments.

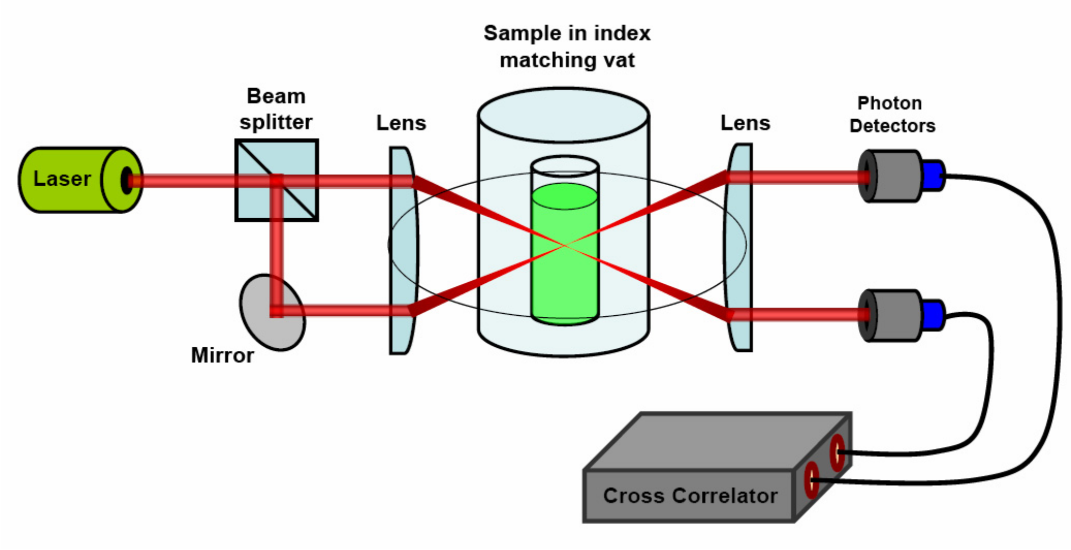
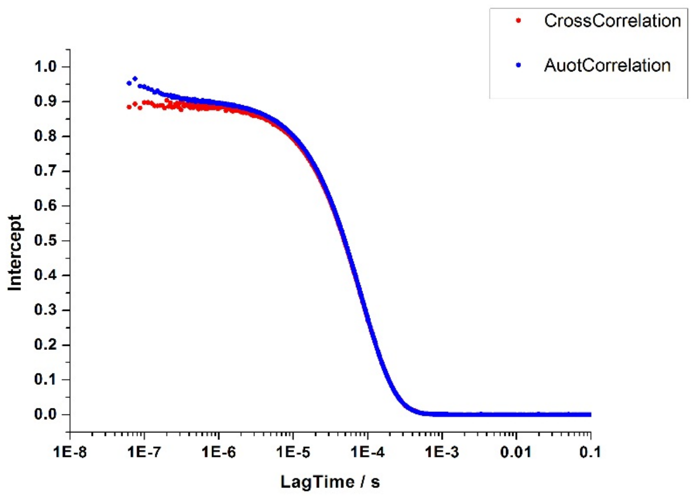


Figure 4 shows a comparison of the normalized intensity correlation function between the auto-correlation and cross-correlation measurements. Since the influence of the after pulses is eliminated, the cross-correlation curve has a flat behavior at short lag times. For longer lag times, both curves are similar. As the after-pulsing effect is suppressed reliable particle sizing is now feasible

Figure 4: Comparison between cross-correlation and auto-correlation measurements. Courtesy of LS Instruments.



Once the intensity correlation function is measured, the particle size can be calculated by fitting the data with mathematical models based on assumed particle size distributions [3]. With appropriate data analysis DLS is also a sensitive method to detect particle aggregation.

Industrial development

In the setups described above, the ID100 single photon detector module is used. ID Quantique also provides an OEM (original equipment manufacturer) version of ID100. The ID101 is the smallest, most reliable single photon detector on the market. It is low cost, and easy to integrate mechanically and electrically Thus, the ID101 can be easily mounted on a printed circuit board and integrated in equipment such as spectrometers or microscopes.

Conclusion

ID Quantique's ID100-MMF50 single photon detector is able to detect weak signals in the visible spectrum with a time resolution of 40ps and a 45ns dead time. The small influence of the after pulse rate is eliminated when performing cross-correlation dynamic light scattering (DLS) measurements. The ID100-MMF50 is an easy-to-use and self-contained detector that can be used for Dynamic Light Scattering DLS) experiments and be implemented in commercial setups thanks to the OEM version ID101.

References

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