Low jitter SPADs meet Time Tagger Ultra HiRes

Two photons timing resolution of record-breaking low jitter SPADs measured by Time Tagger Ultra HiRes

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The accurate measurement of single photon arrival time is the key to improve applications such as fluorescence lifetime imaging (FLIM) and positron emission tomography (PET). The timing resolution of single photon avalanche diodes (SPADs) used in these cases is determined by the limitations of the different processing stages, including the SPAD, its quenching circuit (QC) and the time-to-digital conversion (TDC). The group of Jean-François Pratte at the University of Sherbrooke, Canada, developed a novel QC and SPAD implemented in a CMOS technology that provides a record-breaking low jitter of 7.8 ps full width at half maximum (FWHM) – at room temperature [1]. This calls for a TDC with outstanding performance: Using a pre-release unit of the new Time Tagger Ultra HiRes (will be introduced by the end of 2019) that provides timing resolution down to 3 ps (RMS)/7 ps (FWHM), we were able to perform a time-correlated single photon counting (TCSPC) measurement with two independent SPADs, proving a timing resolution of 12.5 ps FWHM for a single SPAD detector.

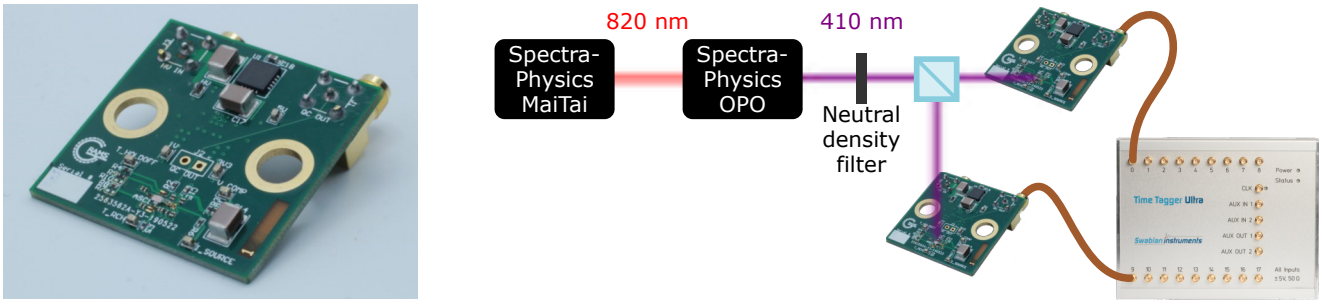

Figure 1. The SPAD detector provided by Sherbrooke University and a scheme of the setup. The setup consist of a Spectra Physics Mai Tai 80 MHz Ti:Sapphire femtosecond pulsed laser and a Spectra-Physics Inspire optical parametric oscillator (OPO) and a pre-release unit of the new Time Tagger Ultra HiRes.

EXPERIMENTAL SETUP

The setup is shown in Fig. 1. An attenuated femtosecond laser provides fast pulses with < 100 fs pulse width and negligible pulse-to-pulse jitter. The beam is strongly attenuated to photon starved level (< 1 photon per pulse). In contrast to Ref. 1 where the SPAD and the QC were read through a high-impedance differential probe, here the SPAD and QC modules provide signals to the 50 Ω inputs of theTime Tagger Ultra HiRes. The TCSPC measurement is performed using the Time Tagger correlation measurement class to sample the number of events for each signal delay.

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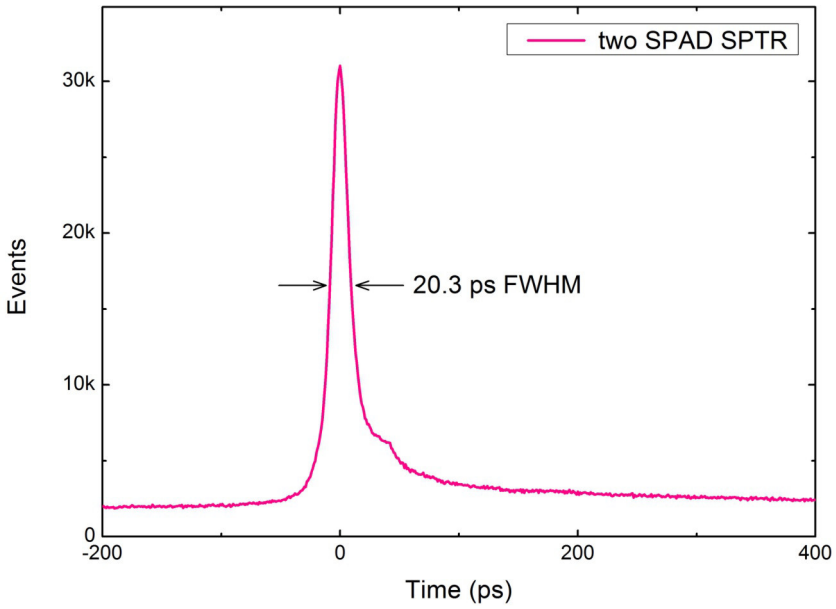

Figure 2. The TCSPC measurement provides the number of events over the measured photon arrival time difference. The FWHM is a measure for the timing resolution of the entire system.

Results

The TCSPC signal is displayed in Fig. 2. The histogram shows a timing resolution of 20.3 ps FWHM, including two SPADs and two TimeTagger contribution. The single SPAD and QC timing resolution can be determined by taking the Time Tagger Ultra HighRes jitter of (7.0 ps FWHM) into account. From

$$\mathrm{FWHM}_{\mathrm{meas}}^2 = 2\mathrm{FWHM}_{\mathrm{SPAD}}^2 + \mathrm{FWHM}_{\mathrm{TT}}^2$$

we can calculate $\mathrm{FWHM}_{\mathrm{SPAD}}$ = 12.5 ps. This low jitter makes these SPADs a promising option for any applications where the timing resolution has a higher priority than the quantum efficiency.

References

[1] F. Nolet et al., “Quenching Circuit and SPAD Integrated in CMOS 65 nm with 7.8 ps FWHM Single Photon Timing Resolution,” Instruments, vol. 2, no. 4, p. 19, Dec. 2018.

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