273 ps FWHM TCSPC Response with Hamamatsu H15620 NIR PMT

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The new Hamamatsu H15620 NIR PMT module delivers an instrument-response width of < 280 ps FWHM with the bh SPC-150NX TCSPC module. The module fits smoothly into the bh TCSPC systems. The supply voltage for the detector, the cooler current, and the gain control voltage are available from a DCC-100 detector controller module. In combination with a HFAC-26-1 preamplifier, the DCC-100 provides also for overload shutdown. We demonstrate the performance of the detector at the example of diffuse optical imaging experiments at a wavelength of 1300 nm.

TCSPC above 1000 nm

After more than 60 years of TCSPC development [1, 2] the detection of optical signals above a wavelength of 1000 nm is still a problem. InGaAs SPADs work in the range from 900 to 1700 nm. They have high quantum efficiencies and reasonably fast IRFs [3, 4] but the diameter of the active area is on the order of only 20 µm. The detectors are therefore well suited for systems that detect light from a diffraction-limited spot, such confocal microscopes or micro-spectrometers [2, 4] but they are not efficient in detecting light that emerges from a large area. An even wider wavelength range is available from superconducting single-photon detectors (SSPDs). With single-nanowire and meander-type SSPDs, bh TCSPC modules deliver IRF widths down to 4.4 ps and 17 ps (fwhm), respectively [5, 6]. However, with active areas of 0.2 µm x 2 µm and 4 x 4 µm, the detectors are extremely small, and even difficult to handle in diffraction-limited optical systems. The use in systems for diffuse optical experiments with biological tissue is therefore impossible. PMTs with IR-sensitive cathodes do exist and offer large active area. However, even with strong cooling the dark count rates are so high that they present a substantial fraction of the saturated count rate of a TCSPC device. This limits the dynamic range over which an optical waveform can be recorded. Recently, Hamamatsu have addressed the problem by building a compact cooled PMT module with an active area of 1.6 mm^2. On the one hand, this is small enough to keep the dark count rate at a reasonable level. On the other hand, it is large enough to capture enough light from a diffusely emitting object. This application note gives an overview on the essential parameters reached by a TCSPC system with this detector.

TCSPC Performance of the Hamamatsu H15620 Detector

The Hamamatsu H15620 detector contains a small PMT together with a high-voltage generator, a thermoelectric cooler, a heat sink, and a cooling fan. The active area is 2 mm^2. The detector needs a +5V power supply, a 0...+0.9V gain control voltage, and a 1...4 A current source for the thermoelectric cooler. These voltages and the thermoelectric-cooler current are supplied by a bh DCC-100 detector controller module. The only voltage which is not available from the DCC is the supply voltage for the cooling fan. Together with a bh HFAC-26-1 26-dB preamplifier the DCC-100 also provides for overload shutdown. The single-photon pulses from the preamplifier have an amplitude of -100 to -400 mV. This is compatible with the CFD input of the bh SPC series TCSPC / FLIM modules. The connection diagram is shown in Fig. 1.

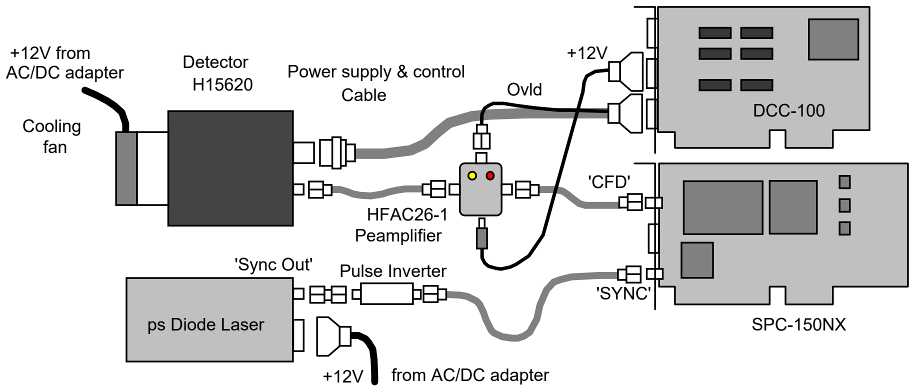

Fig. 1: Connection diagram, TCSPC system with H15620 detector

IRF

Our test device was a H15620-45, with a wavelength range from 950 nm to 1400 nm. For testing the IRF we used a BDS-SM, 1300 nm picosecond diode laser. The laser beam was projected through a set of ND filters to the photocathode of the detector. The beam diameter was 4 mm, i.e. the entire active area was illuminated. The IRF recorded this way is shown in Fig. 2.

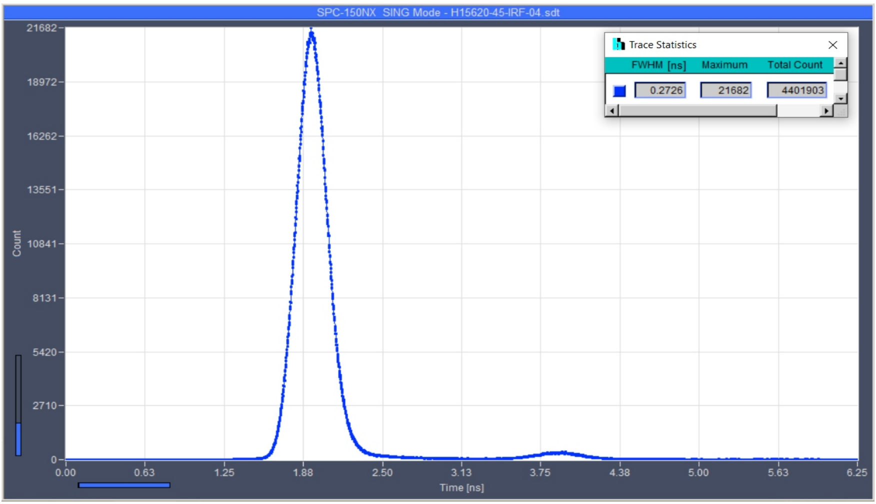

Fig. 2: IRF of the H15620-45 detector, recorded with SPC-150NX TCSPC module and BHL-150, 1300 nm picosecond diode laser. Full width at half maximum is 273 ps.

The IRF was recorded with a detector gain control voltage of 0.9 V. The CFD parameters of the SPC-150 module were optimised for best IRF shape and maximum detection efficiency. The CFD threshold under these conditions was -200 mV, the CFD zero-cross level +15 mV. No attempts were made to narrow the IRF on the expense of detection efficiency.

With a full width at half maximum (fwhm) of 273 ps, the IRF is surprisingly fast - Hamamatsu specifies a typical value of 400 ps. We do not know whether the fast IRF is a result of the extremely fast discriminator of the SPC-150 NX module or we just received an extraordinarily fast detector. Please note also that the IRF width is for the H15620-45. It may be different for the H15620-25 because of different electron diffusion times in the photocathodes.

Dark Count Rate

As expected, the dark count rate depends on the cooling current. The maximum cooling current for the H15620 is 5 A. The DCC-100 detector controller delivers a maximum current of 2 A. With the

2 A from the DCC-100 we obtained a dark count rate of approximately 4000 counts per second. The ambient temperature was 25 °C, the cooling fan was running at 12V. With a cooling current of 3 A (from an external power supply) the dark count rate dropped to about 2500 counts per second.

Diffuse Optical Imaging Experiments

The expected application of the H15620 is in diffuse optical tomography, or near-infrared spectroscopy (NIRS) and functional near-infrared spectroscopy (fNIRS) [1, 2]. Scattering and absorption in biological tissue decrease with increasing wavelength. Therefore, near-infrared light penetrates relatively thick layers of tissue. The wavelength range around 1300 nm is of special interest because the absorption of water has a local minimum at this wavelength.

A 'Distribution of Time of Flight' (DTOF) after propagation of 1300 nm light pulses through 25 mm of tissue (the palm of a human hand) is shown in Fig. 3. The incident power was about 200 µW, the pulse repetition rate 50 MHz.

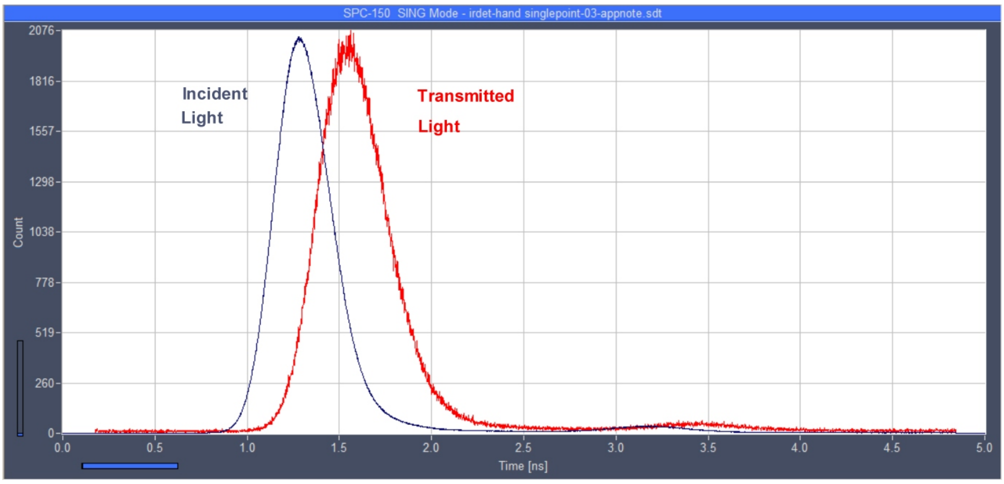

Fig. 3. Distribution of time of flight (DTOF) after propagation of ps light pulses through the palm of a human hand

Recording of DTOFs can be combined with imaging. The principle is shown in Fig. 4. The laser beam is scanned over the object of investigation by a galvanometer scanner, in our case a modified bh DCS-120 scan head [2].

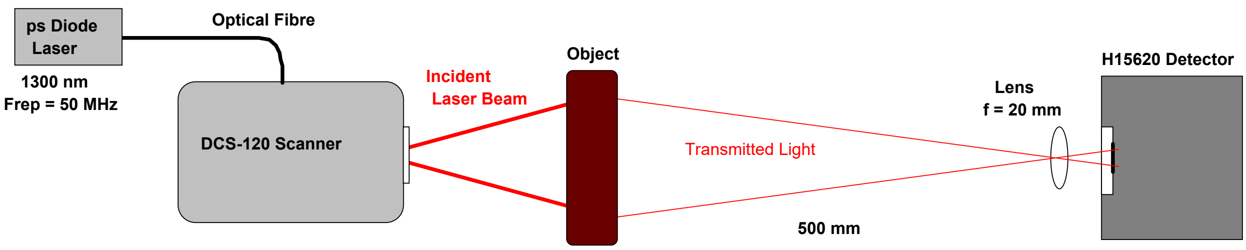

Fig. 4: DTOF scan of a diffusely transmitting object, optical principle

The photons emerging from the distant side of the object are transferred to a H15620-45 detector placed in a distance of about 50 cm. A 20 mm lens in front of the detector projects a de-magnified image of the object on the active area. The large distance is necessary to obtain an image small enough to fit into the active area of the detector. The photon pulses from the detector are recorded by the TCSPC module, which builds up the distribution of the photons over the time in the laser pulse period and the coordinates of the scan [2].

A scan of the palm of a human hand is shown in Fig. 5. The left image shows the intensity of the transmitted light. Additional information on scattering and absorption coefficients is obtained by moments of the DTOFs in the individual pixels [7]. Therefore, in the right images the first moment of the DTOFs has been calculated and an overlaid to the intensity data by false colour.

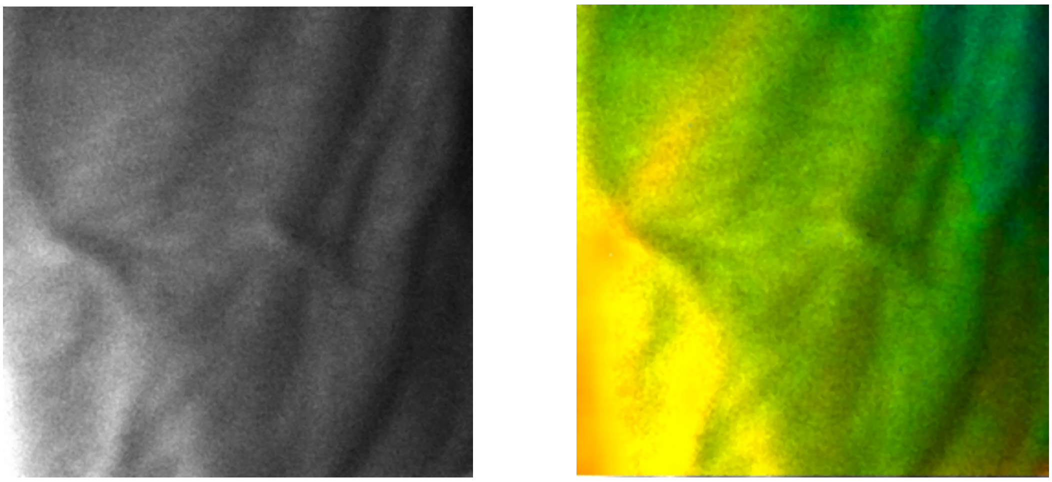

Fig. 5: DTOF scan of the palm of a human hand. Left: Intensity image. Right: Combined intensity / propagation-time image. Colour shows the average propagation time, yellow to green refers to 900 to 1100 ps.

Summary

The H15620 is fully capable of recording optical waveforms in combination with the bh TCSPC devices. With its fast IRF, relatively large area, and low dark count rate it is especially suitable for detecting signals from diffusely emitting objects. Applications are preferentially in the field of NIRS and fNIRs, including brain imaging and optical mammography, in the optical window around 1300 nm. Other applications may be in material sciences, especially in the investigation of novel solar cell materials.

Acknowledgement

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