TECHNICAL NOTE

IRF Width & Minimum Measurable Lifetime in the FLS1000

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Instrument Response Function

Short lifetimes in the FLS1000 are measured using the time-correlated single photon counting (TCSPC) technique. The minimum measurable lifetime in TCSPC depends on the temporal width of the Instrument Response Function (IRF) which is a measure of the total response time of the TCSPC excitation and detection system.

The IRF has four main contributions and the total IRF temporal width can be calculated by the quadrature summation of the individual contributions. All widths are given as the full-width half maximum (FWHM) of their temporal distributions:

$$\mathrm{FWHM}_{\mathrm{IRF}} = \sqrt{\mathrm{FWHM}^2_{\mathrm{Source}} + \mathrm{FWHM}^2_{\mathrm{Detector}} + \mathrm{FWHM}^2_{\mathrm{Electronics}} + \mathrm{FWHM}^2_{\mathrm{Dispersio}}}$$

$\mathrm{FWHM}_{\mathrm{Source}}$ is the pulse width of the excitation source which is typically a pulsed laser. The pulse width depends on the type and model of the laser used.

$\mathrm{FWHM}_{\mathrm{Detector}}$ is the response width of the detector and depends on the type of detector used. This is often the dominant contribution to the total width of the IRF.

$\mathrm{FWHM}_{\mathrm{Electronics}}$ is the electronic jitter of the TCSPC timing electronics. The jitter of FLS1000 TCC2 counting electronics is 20 ps and electronic jitter is therefore only significant when the $\mathrm{FHWM}_{\mathrm{Source}}$ and $\mathrm{FHWM}_{\mathrm{Detector}}$ are small.

$\mathrm{FWHM}_{\mathrm{Dispersion}}$ is the temporal dispersion of the pulse as it passes through the emission monochromator. Dispersion is only significant when $\mathrm{FHWM}_{\mathrm{Source}}$ and $\mathrm{FHWM}_{\mathrm{Detector}}$ are small. When the FLS1000 is configured with a fast detector (small $\mathrm{FHWM}_{\mathrm{Detector}}$) a low groove density lifetime grating is added to the emission monochromator to minimise $\mathrm{FWHM}_{\mathrm{Dispersion}}$.

The source pulse widths, detector response widths and total $\mathrm{FWHM}_{\mathrm{IRF}}$ of the source and detector combinations that are possible in the FLS1000 are given in Table 1. The pulse widths of the sources are approximate as the exact pulse widths are dependent on the wavelength of the source.

		EPL[a]	HPL[a]	EPLED[a]	AGILE[b]	Ti:Saph
		75 ps	90 ps	900 ps	250 ps	150 fs
PMT-900	600 ps	610 ps	610 ps	1080 ps	650 ps	600 ps
PMT-980	600 ps	610 ps	610 ps	1080 ps	650 ps	600 ps
PMT-1010	800 ps	800 ps	810 ps	1200 ps	840 ps	800 ps
PMT-1400-LN2	800 ps	800 ps	810 ps	1200 ps	840 ps	800 ps
PMT-1700-LN2	800 ps	800 ps	810 ps	1200 ps	840 ps	800 ps
PMT-1400-TE	400 ps	410 ps	410 ps	990 ps	470 ps	400 ps
PMT-1700-TE	400 ps	410 ps	410 ps	990 ps	470 ps	400 ps
HS-PMT-850[c,d]	200 ps	220 ps	220 ps	920 ps	320 ps	200 ps
HS-PMT-920[c,d]	200 ps	220 ps	220 ps	920 ps	320 ps	200 ps
HS-HPD-870[d]	20 ps	80 ps	90 ps	900 ps	250 ps	30 ps

a. Typical value, the pulse width depends on the wavelength model of the source.

b. Typical value, the pulse width is wavelength dependent and varies between 200 ps – 350 ps.

c. The response width of the HS-PMT varies from 150 ps to 200 ps. A value of 200 ps was used for these calculations.

d. $\mathrm{FWHM}_{\mathrm{Dispersion}}$ was omitted from the calculations; this is justified if a low groove lifetime grating is paired with the HS-PMT and HS-HPD detectors. $\mathrm{FWHM}_{\mathrm{IRF}}$ will increase by approx. 30 ps with standard gratings.

Table 1: $\mathrm{FWHM}_{\mathrm{IRF}}$ of source and detector combinations in the FLS1000.

Minimum Lifetime

Short lifetimes are calculated using reconvolution fitting. In reconvolution fitting, the IRF is measured experimentally and convoluted with the chosen decay model prior to fitting to take into account the width and shape of the IRF during the fitting routine. The width and shape of the IRF determines the minimum lifetime that can be reliably extracted using reconvolution fitting.

$\mathrm{FWHM}_{\mathrm{IRF}}$ / 10

One-tenth of the $\mathrm{FWHM}_{\mathrm{IRF}}$ is the most often quoted minimum lifetime achievable via reconvolution fitting. While technically possible, this minimum lifetime is achievable only under ideal experimental conditions. The sample must be a solution and the decay to be fitted must exhibit single exponential kinetics, and even under these conditions careful measurements are required to reach this limit. Multi-component exponential fits are not possible at this limit as they have too many degrees of freedom and solid samples have unpredictable scattering properties during the IRF acquisition for the one-tenth limit to be reliable.

$\mathrm{FWHM}_{\mathrm{IRF}}$ / 3

One-third of the $\mathrm{FWHM}_{\mathrm{IRF}}$ is a more practical estimate of the minimum lifetime that can be achieved via reconvolution fitting. Staying within this limit increases the fit reliability when measuring solutions with single exponential kinetics and enables solutions with multiexponential kinetics to also be fit. Analysis of decays of solid samples with single exponential kinetics is also possible within this limit. In general, when analysis of samples with complicated kinetics is expected; configure the FLS1000 to have as narrow a $\mathrm{FWHM}_{\mathrm{IRF}}$ as possible to increase the reliability of the fitting and reduce the experimental complexity of the measurements.

Conclusion

The width of the IRF is the key metric that determines the minimum measurable lifetime in the FLS1000. The FLS1000 can be equipped with a wide range of sources and detectors that enable IRF widths as low as 30 ps to be achieved. It is recommended to configure the FLS1000 sources and detectors with at least the $\mathrm{FWHM}_{\mathrm{IRF}}$/ 3 minimum lifetime limit in mind.

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