Simulation modelling of a micro-system for time-resolved fluorescence measurements

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Problem description

Area of our interest is CMOS single photon avalanche diode (SPAD) detectors applied to time-resolved fluorescence measurement. Many research groups develop CMOS SPADs but they mainly focus on the SPAD improvement using different performance metrics without consideration of the system context and specific application requirements.

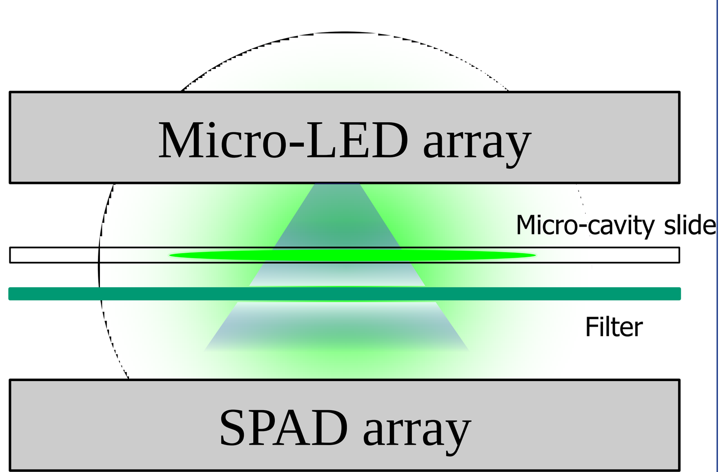
We propose to study the characteristics of SPAD-based detectors from a system perspective, taking into account the whole experimental setup and measurement technique. This approach will enable the development of electro-optical systems with the optimal performance for their target application.

Approach

The developed simulation model of a typical fluorescence measurement setup [1] takes into account:

- the geometry of the setup;
- power, time and frequency characteristics of the light source;
- filter transfer function;
- characteristics of fluorescence sample;
- the basic features of SPAD detectors and quenching circuits:
- time-correlated single photon counting and the time-gating technique.

Experimental system



The two-chip "sandwich" structure includes a blue micro-LED array and a CMOS SPAD detector array [2]. For this experiment a single pixel in the SPAD array and the nearest LED from the LED array have been selected. The sample (CdSe/ZnS quantum dots in toluene) in a micro-cavity slide and an excitation filter are placed in the gap between the excitation and detection planes. An external time-correlated single photon counting module is used to build fluorescence decay curves.

Results

A range of experiments with different light pulse width was carried out to examine the sensitivity of the simulator. The simulated and experimental results for 3.1ns, 3.15ns and 3.3ns pulse width with respectively 3.77μW, 6.47μW and 9.08μW average optical power per pulse are presented in Figure 1.

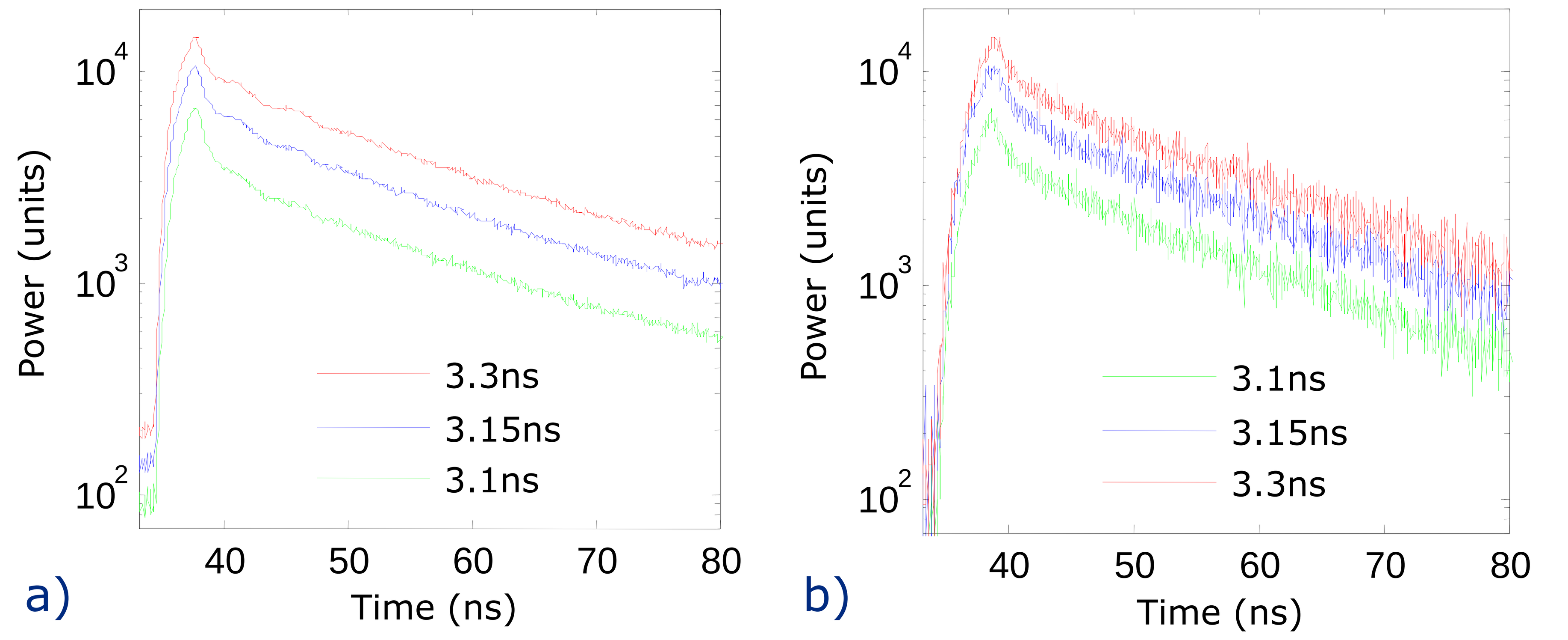


Figure 1. Experimental (a) and simulated (b) fluorescence decay with different light pulse width.

The second range of experiments was used to estimate the quantitative simulation ability of the model. Different setups with and without excitation filter and fluorescent sample have been established. Selected results are presented in Figure 2. Experimental and simulated data are in good agreement except in the peak area. This mismatch can be explained by the lack of exact LED time curve used in simulation (time curve shape with 2.2ns width has been squeezed to receive 2ns).

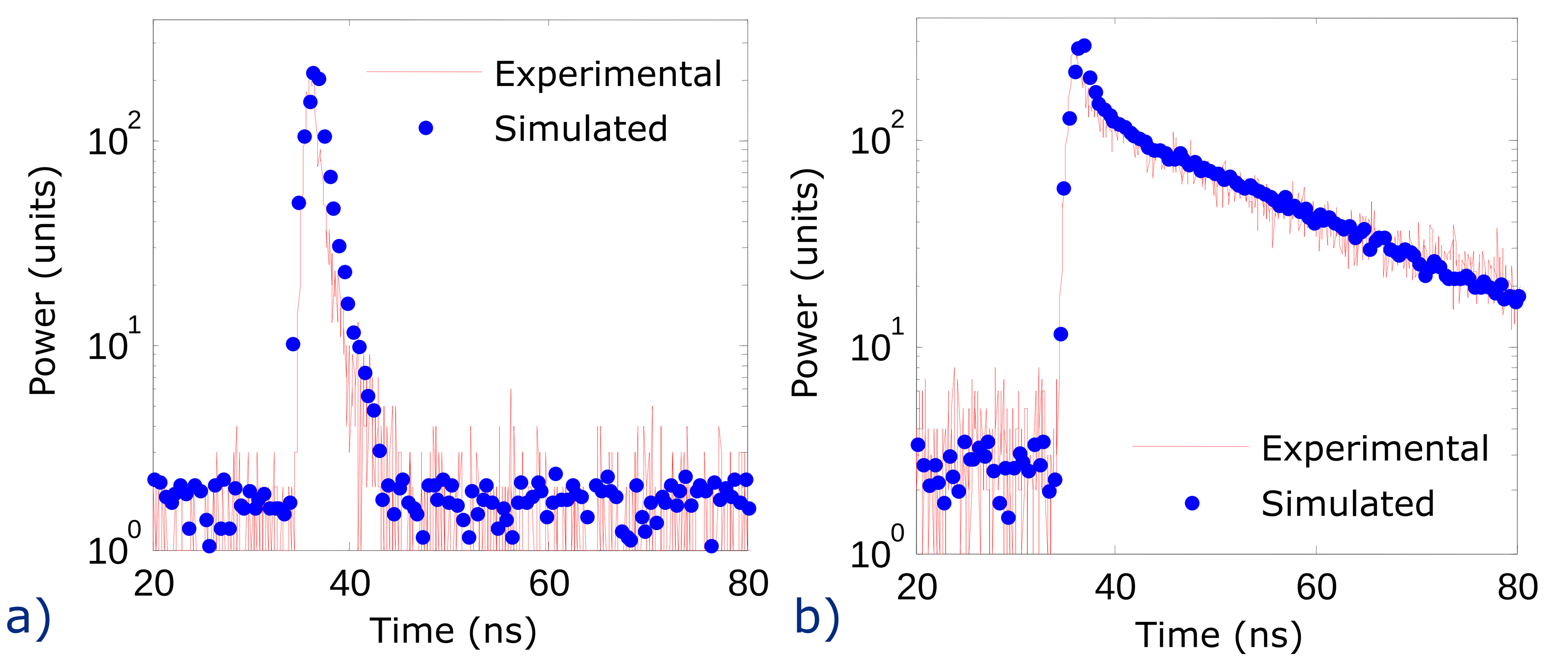


Figure 2. a) Experimental and simulated curves measured without fluorescence sample;
b) experimental and simulated fluorescence decay.

Conclusion

Our model can be used to predict qualitative and quantitative results for specific experimental setups, predict results of virtual experiments with a fictitious detector, light source, etc. This feature is applicable for investigation of the influence of individual system elements on the final results.

References

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[2] Rae, B. R., Muir, K. R., Renshaw, D., Henderson, R. K., Girkin, J., Gong, Z., McKendry, J., Gu, E. and Dawson, M. D., "A vertically integrated CMOS micro-system for time-resolved fluorescence analysis," Proc. IEEE BioCAS, pp. 85-88 (2009).

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