Technical Brief: Slow Turn-Off of Silicon Photodiodes at Longer Wavelengths

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Silicon photodiodes do not turn always off immediately when incident light on them is removed. This tech brief explains why this is so and how to deal with it.

The slow turn off of some silicon photodiodes is due to a number of factors including the recombination time of the minority carriers in the bulk silicon. The slow turn-off tends to be wavelength dependent with wavelengths longer than around 800nm taking exponentially longer to be absorbed by the photodiode. See figure 3 in this article from Thorlabs that shows the rise time of a Thorlabs DET100A photodiode (9.8mm diameter) to be about 600us at about 1060nm versus about 750ns at 800nm for the same photodiode! Similar results were found with a Thorlabs PDA36A2 photodiode (4.1mm diameter); see *Figure 1* below. In this instance, the photodiode output took over a 100us to turn off at 1064nm versus perhaps 1us at 640nm.

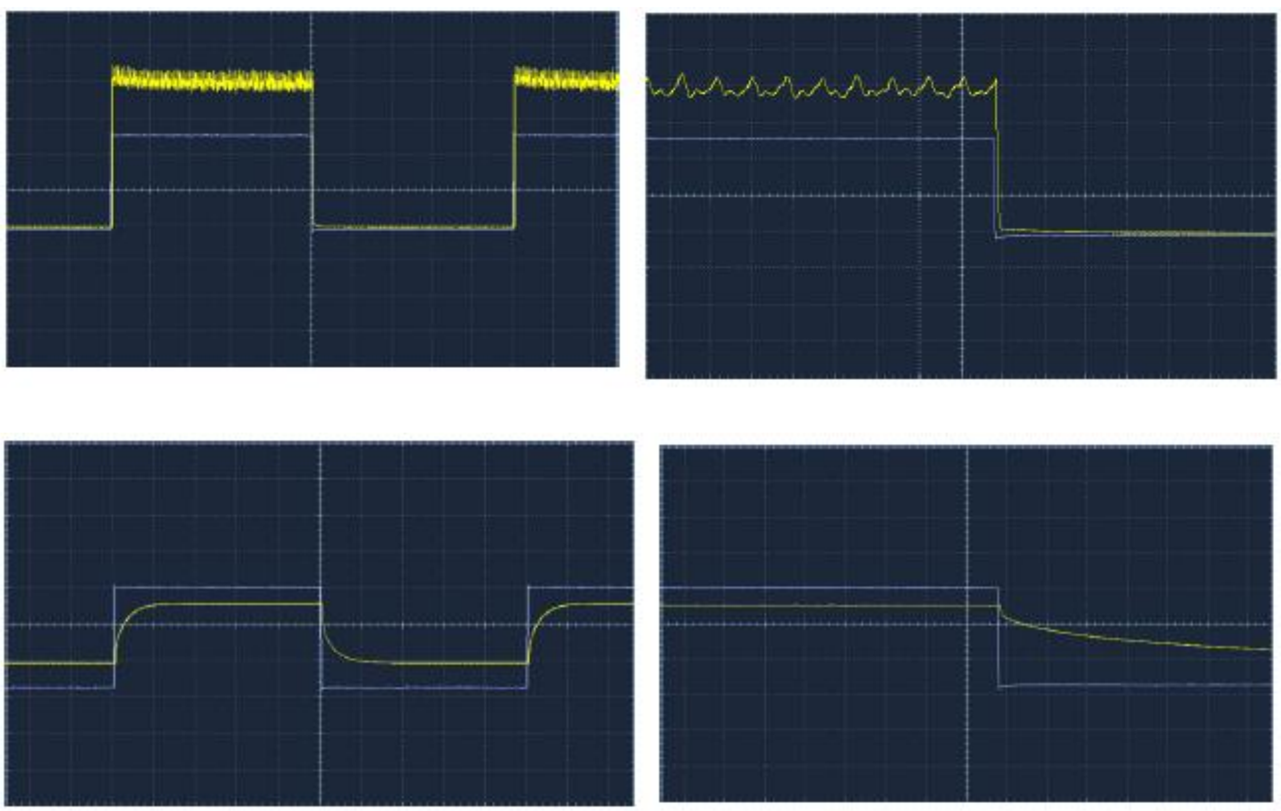

Figure 1: PDA36A2 photodiode turn-on and turn-off (yellow) at 640nm (top) and 1064nm (bottom); horizontal axis is time (5us/division for blown-up traces on right), and vertical axis is the output of a trans-impedance amplifier (TIA). The square blue traces are the laser diode turn-on and turn-off controls. In this application, the slow-tail response at 1064nm prevented a ring-down setup from yielding useful measurements. (Courtesy FiveNine Optics Inc.)

In this patent (6018674 (uspto.gov)), the problem of slow turn-off of silicon photodiodes is discussed and found to be greater at longer wavelengths (e.g., 980nm versus 635nm). The patent (now expired) describes a method of screening photodiodes so that they meet the necessary turn-off criteria. And indeed, for a given size, some silicon photodiodes may have a substantially slower turn-on and turn-off than others.

In the case described above with FiveNine Optics, the solution involved using an InGaAs photodiode instead of a silicon one. The InGaAs photodiode showed a relatively snappy response at 1064nm (although it didn't have a lot of responsivity at 640nm).

Several items may help somewhat to reduce the slow turn-off tail of a silicon photodiode with some tradeoffs. One can reverse-bias the silicon photodiode. This will significantly increase the response from 10% to 90% and from 90% to 10% but may not make much difference in terms of the long turn-off tail of the photodiode (and will increase the dark current). One can also use metal tape to mask off the edges of the photodiode as photons captured near the edges take longer to re-absorb. However, I have not found masking to make a significant difference. Using a smaller photodiode can definitely improve the turn-off, however many applications require a certain minimum size of active area.

The above discussion has been about using the PN type of silicon photodiode. One can also use a PIN photodiode which includes an intrinsic layer between the P and N layers of a photodiode (see PIN diode - Wikipedia). PIN photodiodes are often used in electro-optical communications circuits and may not have a significant turn-off tail at some wavelengths. However, PIN photodiodes tend to only be available in smaller sizes. Also note that communications circuits may not care about a slow turn-off tail as the photodiode output is usually only considered in a binary fashion.

Conclusions: Recognizing that you may have a problem with a slow turn-off (and possibly turn-on) time of a photodiode is the always the first step. (In silicon photodiodes, this tends to be above 800nm.) Part of this diagnosis may involve using light at shorter wavelengths and noting the faster turn-on and/or turn-off response. Once this diagnosis is made, the main solution generally involves experimentally finding a photodiode with an improved turn-on and/or turn-off time at the wavelengths of interest.