

Large-signal response of high speed $p-i-n$ photodetectors to short pulses with small spot sizes

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Abstract: We investigated the spatio-temporal response of high-speed $p-i-n$ photodetectors to high-energy short pulses with small spot sizes. We found that small spot sizes cause negligible additional field screening for properly designed photodetectors for a given input power.

Surface-normal photodiodes are commonly illuminated with spot sizes smaller than the diode mesas to prevent the optical power loss and slow diffusion tail that occur when the photodiodes are overfilled. It is, therefore, critical to understand $p-i-n$ photodetector response to high-power, small spot size optical inputs, particularly because field bleaching due to photogenerated carrier separation can significantly degrade detector response.

Typically detector dynamics are modeled by treating the photodiode as a lumped element (a current source with an effective lumped C and R). [1] To study the effects of small spot sizes, we have developed a model of the large-signal temporal-spatial behavior that accounts for the 2D distributed RC nature of the photodiode, which, to the best of our knowledge, has not previously been quantitatively investigated. Here we report measured and simulated response of surface-normal $p-i-n$ photodiodes using short pulses (~ 100 fs) with small beam spot sizes ($\sim 5\mu\text{m}$ radius) on large photodiode mesas ($300\times 300\mu\text{m}$).

To determine the spatio-temporal behavior, we monitored the voltage change across the photodiode in response to the incident pulse. For that, we used a dual-diode structure that was comprised of a $p-i-n$ photodiode with a bulk intrinsic region integrated with a $p-i$ (MQW)- n reflective electro-optical modulator diode on the bottom. Since the voltage across the bottom modulator diode is coupled to the voltage across the top photodiode [2], we could indirectly measure the local voltage across the photodiode by using a second, “probe” light pulse. One advantage of this optical probing technique is that it avoids parasitic loading effects.

Figure 1 shows this photodiode response of the photodiode to large input pulses. Dynamics are determined by two coupled processes: (1) vertical separation of the photogenerated carriers in the intrinsic region, strongly dependent on the (shielded) field in the vicinity of the incident spot, and (2) lateral voltage relaxation, primarily due to distributed-RC-decay. This hypothesis is supported by the fit between the data and simulation in Figure 2. Because the voltage shielding is constantly diffusing away, the “saturation” level of these devices is larger than might otherwise be expected. Lower internal resistance-per-square provides faster voltage relaxation yielding faster response and higher saturation power.

We simulated the behavior of a feasible photodetector: a $25\times 25\mu\text{m}$ $p-i-n$ diode with total resistance-per-square of 20Ω and capacitance-per-square-micron of 0.1fF . With 10V bias,

without considering the external RC decay, shining 0.81pJ evenly distributed across the entire device would reduce the bias to 1V once the carriers separated. As a limiting case, concentrated into a $1.5\mu\text{m}$ radius spot the same amount of photocarriers could shield a hypothetical 795V bias, suggesting that such a small spot would give total field screening and possibly very slow detector response. However, when distributed RC decay is accounted for, simulations show that at no point does the shielding voltage drop below 0.9V , which is sufficient to maintain small-signal operation and avoid field-bleaching effects.

We thus conclude that, by engineering distributed RC decay, it is possible to make the input power at which field bleaching occurs become effectively independent of spot size, enabling the use of small spots in a properly designed photodetector.

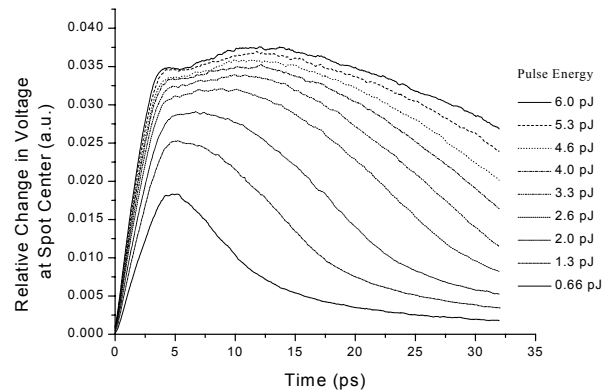


Figure 1. Large signal response ($5\mu\text{m}$ spot size radius, 5V reverse bias)

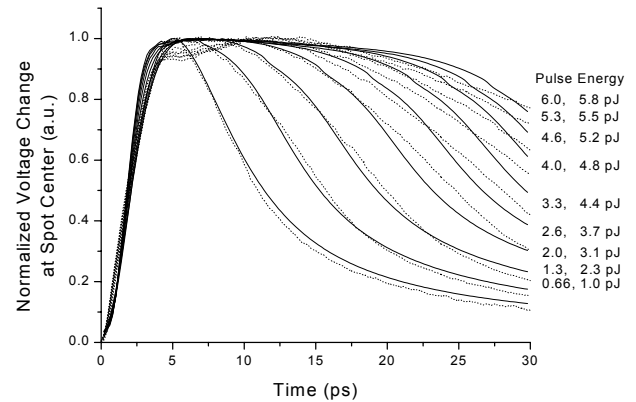


Figure 2. Normalized voltage change. Values of the actual (left column) and simulated (right column) incident power are presented in the legend

[1] M. Dentan and B. de Cremoux, "Numerical Simulation of the Nonlinear Response of a p-i-n Photodiode Under High Illumination," *J. Lightwave Tech.*, v. 8, p. 1137-1144 (1990).

[2] M.B. Yairi, H.V. Demir, and D.A.B. Miller, "Optically controlled optical gate with an optoelectronic dual diode structure – theory and experiment," *Opt. and Quant. Elec.*, v. 33, p. 1035-1054, in press (2001).