Modeling Internal Heating of Optoelectronic Devices Using COMSOL

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Introduction:

A model of heating in an Avalanche Photodiode (APD) due to current is desired. Resistivity through the device depends on charge carrier concentrations and induced photocurrent across this resistance results in Joule heating of the device. Excessive heating can result in failure of the device, so modeling with lab test parameters can show if heat is a cause of failure at certain illumination powers, and can estimate maximum incoming power ranges.

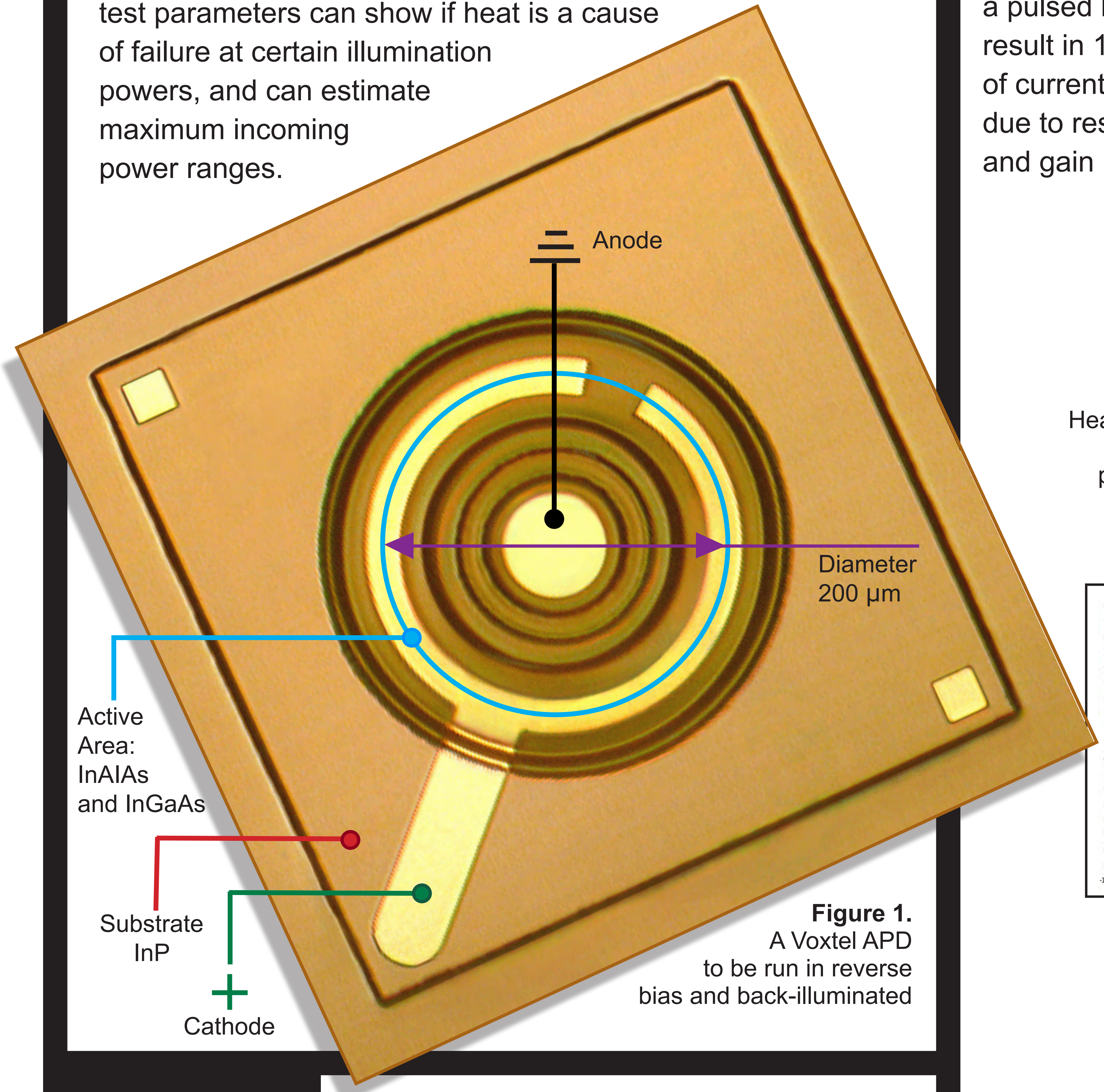

Figure 1. A Voxtel APD to be run in reverse bias and back-illuminated

Resistivity:

Heating is calculated by simulating photocurrent over the resistance within the device. Conductivity in a semiconductor depends on electron (n) and hole (p) concentrations as well as mobilities and is defined as:

$$\sigma = q\,(\mu_n n + \mu_p p)\ ^{1}$$

Resistivity (ρ) is the inverse of this equation and has units of Ωm. Due to the complex geometry of our device an estimate is used in place of a full charge-carrier solution. Carrier levels are estimated from a 1-d simulation in Sim Windows[2] which shows they are a few orders of magnitude lower (~1E14 cm^{-3}) than the dopant level in the depletion region and equal to the dopant level elsewhere (~1E18 cm^{-3}).

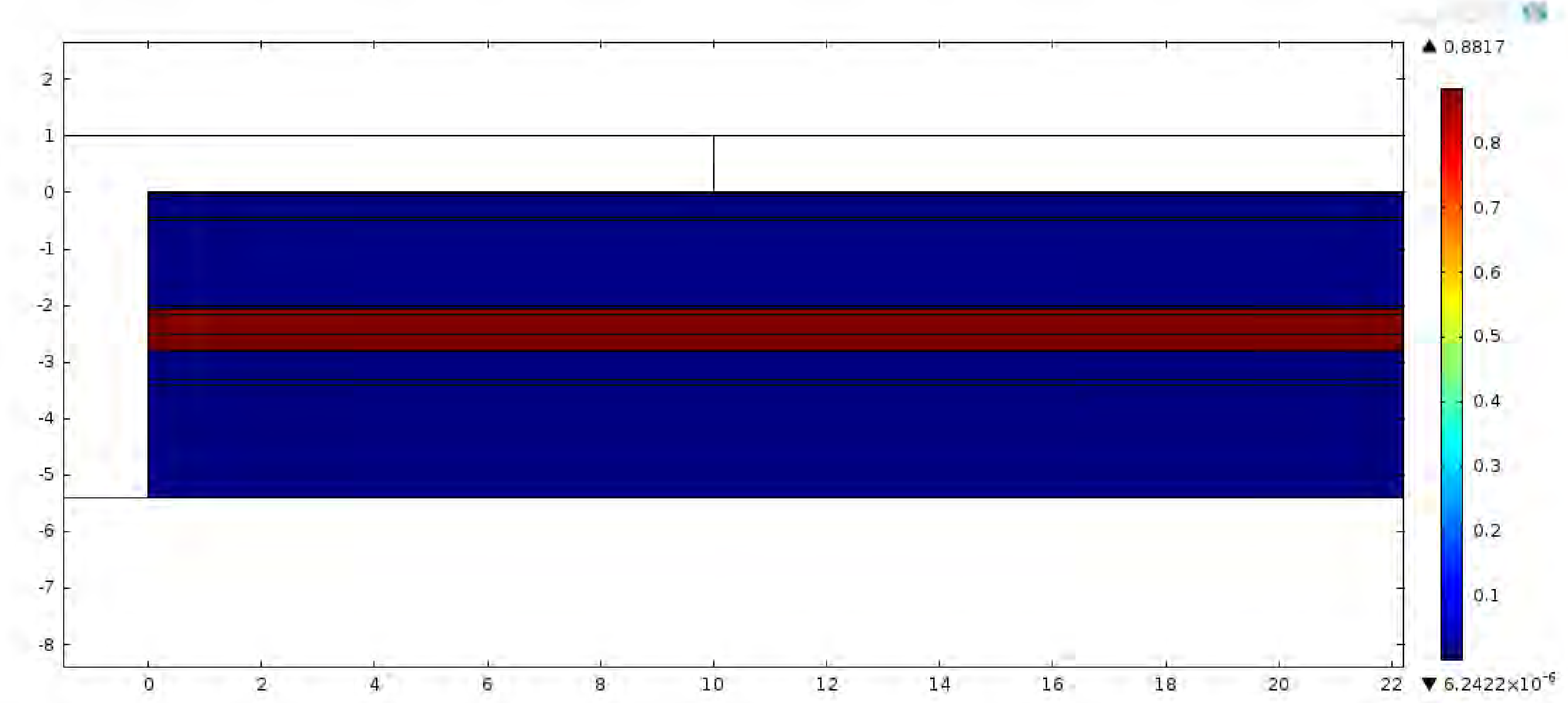

Figure 2. Resistivity in the active area of the APD

Joule Heating:

The equation utilized for the heating device is:

$$\rho C_p \mathbf{u} \cdot \nabla T = \nabla \cdot (k \nabla T) + Q$$

where ρ, C_p, and k are material parameters for density, heat capacitance and thermal conductivity. Q is heat energy from current flow. In testing we used a pulsed laser along a range of peak powers. 10 Watts of peak power will result in 100 amperes of current over 3 ns due to responsivity and gain in our device.

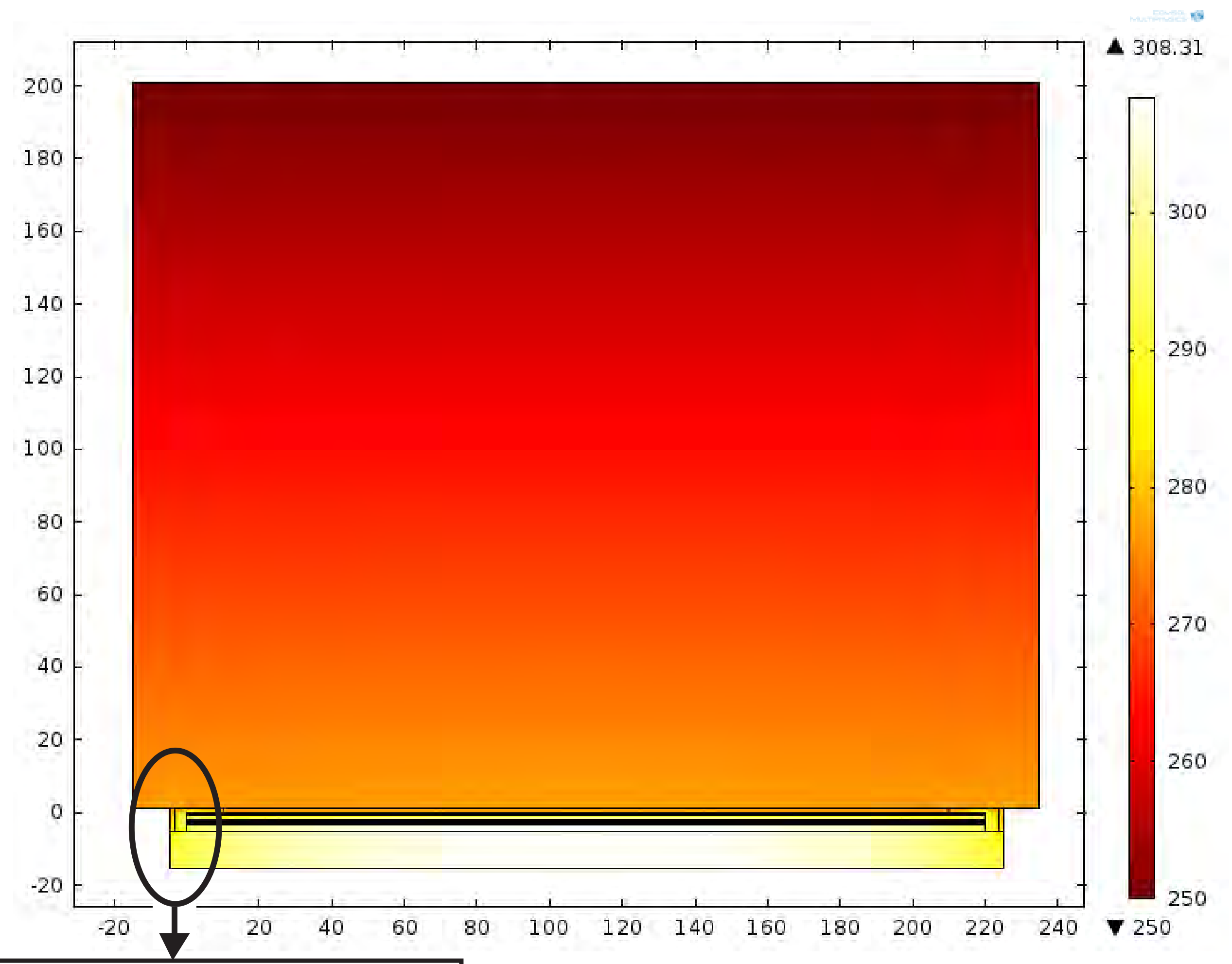

Figure 3. Heatmap of an APD with 10W peak power laser input

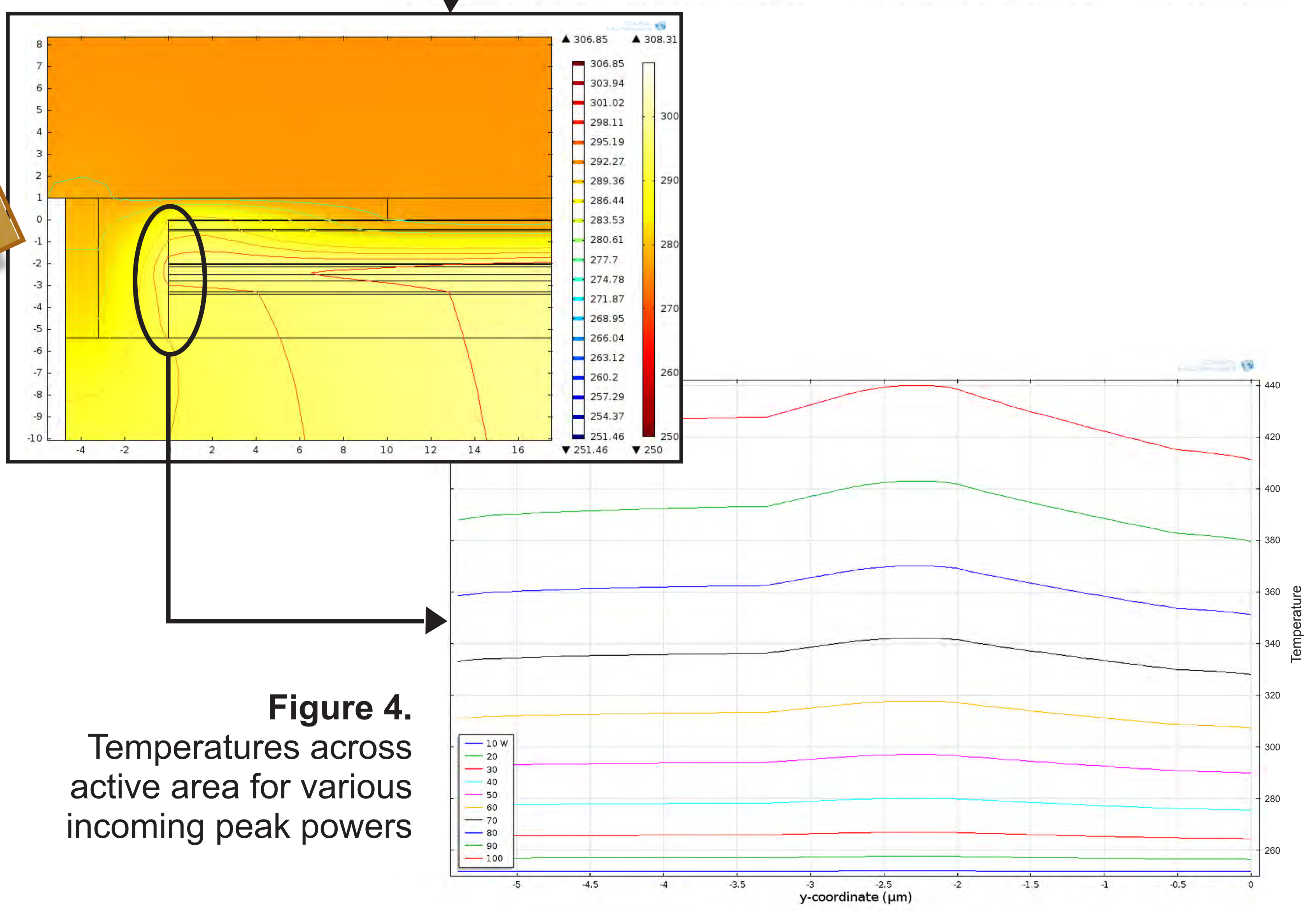

Figure 4. Temperatures across active area for various incoming peak powers

Conclusion:

The dielectric used on these devices is cured at 450 K, the highest known safe temperature for our APDs. Temperatures in this model do not indicate device failure, as they are below the safe point. However, the temperature scales faster than linearly with incoming power, and any increase in power may result in failure of the dielectric above its 650 K glass transition temperature.

Future tests should include a more advanced estimation in the depletion layer, if not a full convergence model of charge carrier distribution and electric field, as done in the p-n junction example. It would be ideal to incorporate the absorbed light into the current flow in the charge carrier model via a generation term.

References:

1. S.M. Sze, Semiconductor Devices 2nd Edition, p 53, John Wiley & Sons, Inc., Hoboken, NJ (2002).
2. David Wells Winston, Physical Simulation of Optoelectronic Semiconductor Devices, Unpublished doctoral thesis, ECE, University of Colorado (1996) www.SimWindows.com last accessed 8/21/12.