Simulation and Measurement of High Speed Germanium Photodiodes

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Abstract

Imaging of high density targets fusion targets at peak compression requires the use of hard x-rays. In addition high temporal resolution to gate out background x-rays requires a temporally gated hard x-ray detector (8-70KeV). Device physics and response of germanium photodiodes for high temporal resolution (~1ns) detector are investigated in this poster.

Motivation

NIF energy efficiency is strongly limited by the inefficient (≤10%) hohlraum to target transfer of x-rays [1]. This is determined by both hohlraum shape and laser alignment. Current hard x-ray imaging systems have limited spatial and temporal resolution, allowing for poor viewing of target evolution near peak compression. Germanium photodiode arrays have superior electronic properties to silicon, providing imaging systems with superior stopping power and faster temporal response (~1 ns). This will lead to a better understanding of process dynamics, and ultimately, higher efficiency.

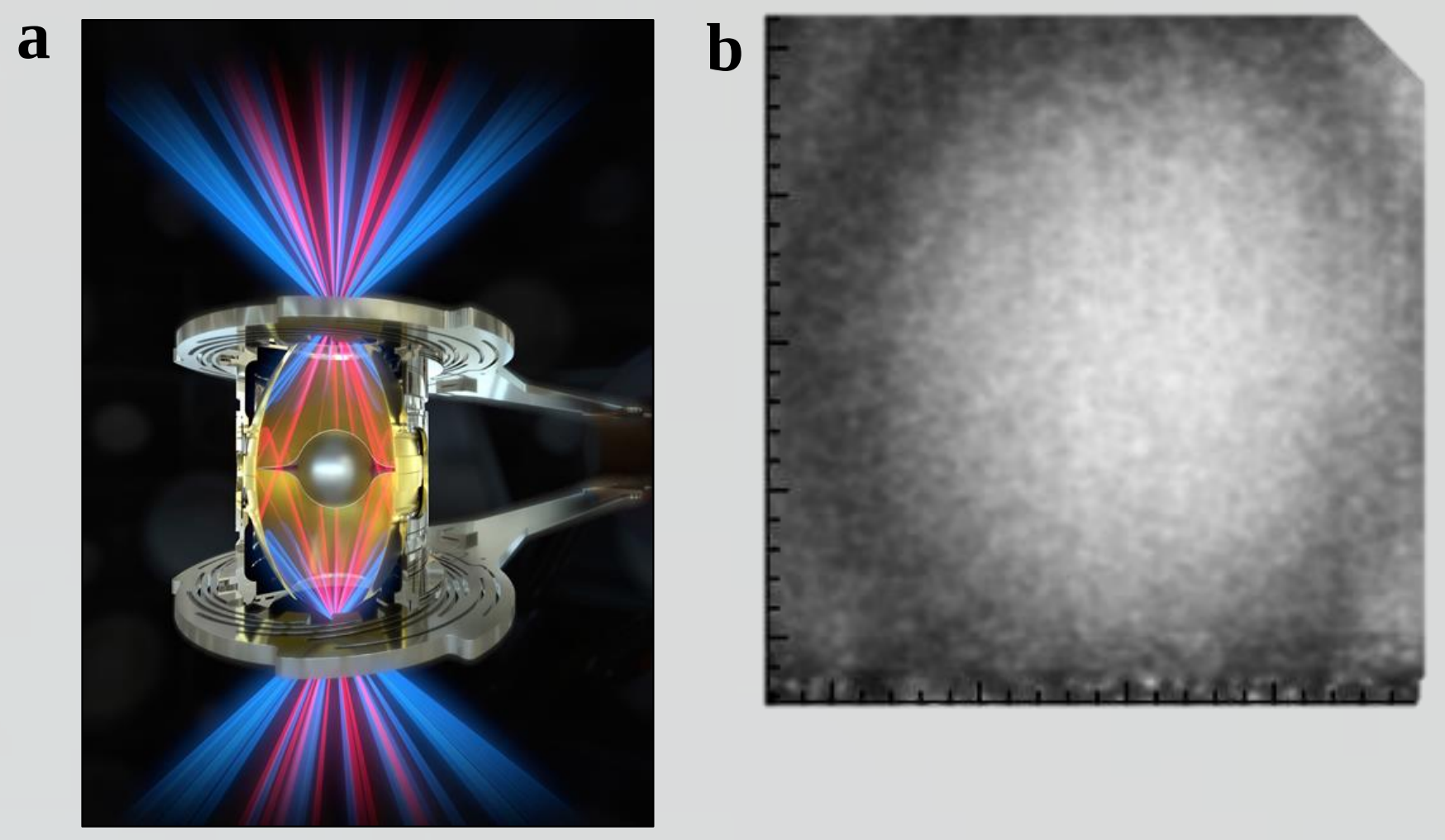

Figure 1. **(a.)** Artist's depiction of hohlraum target housing being bombarded with laser radiation. **(b.)** Image of deuterium-tritium target with modern radiographic imaging system (target ~1 mm in diameter).

Device Architecture

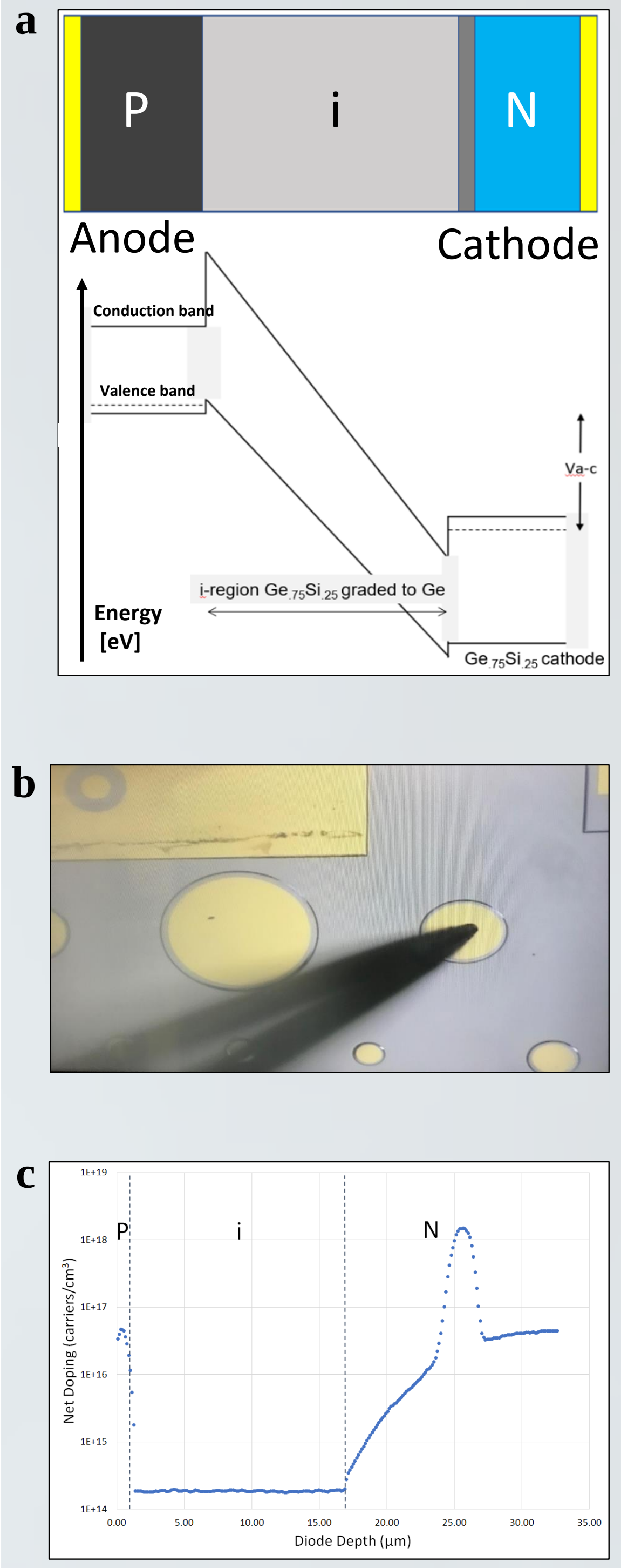

Figure 2 (left) **(a)** Individual pin diode structure. Photosensitive element of device that will be stacked in array to produce image (see Figure 3). **(b)** Physically implemented mesa pin diode under microscope. Au/Pd plated anode visible. Rest of the device extends into plane of viewing. **(c)** Measured SRP doping profile of photodiodes from part b.

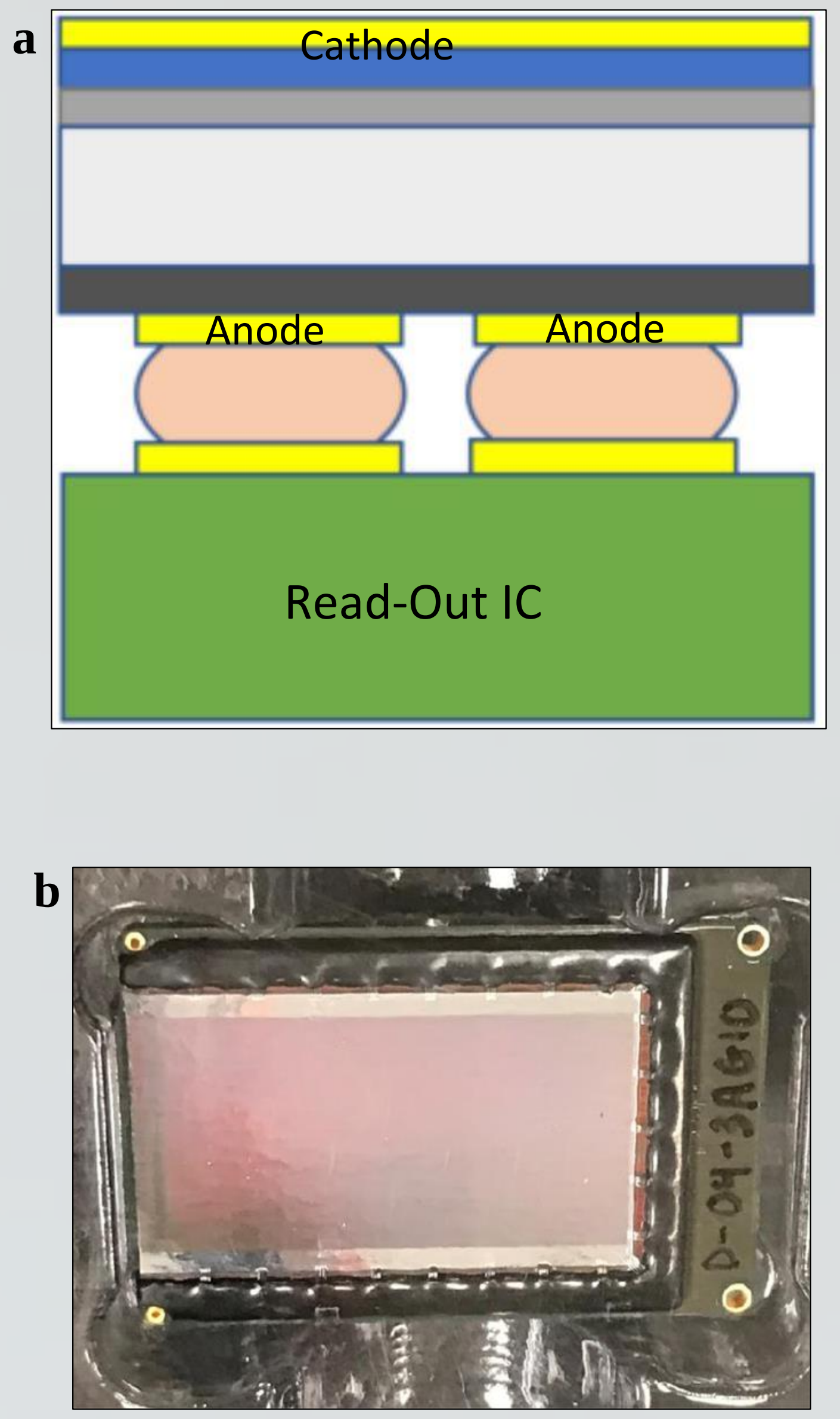

Figure 3 (right). **(a)** Two pin diodes in a 2D common cathode camera architecture. **(b)** Daedalus image sensor with silicon photodiode array. Demonstrates target final 3D array design of camera.

Device Characterization

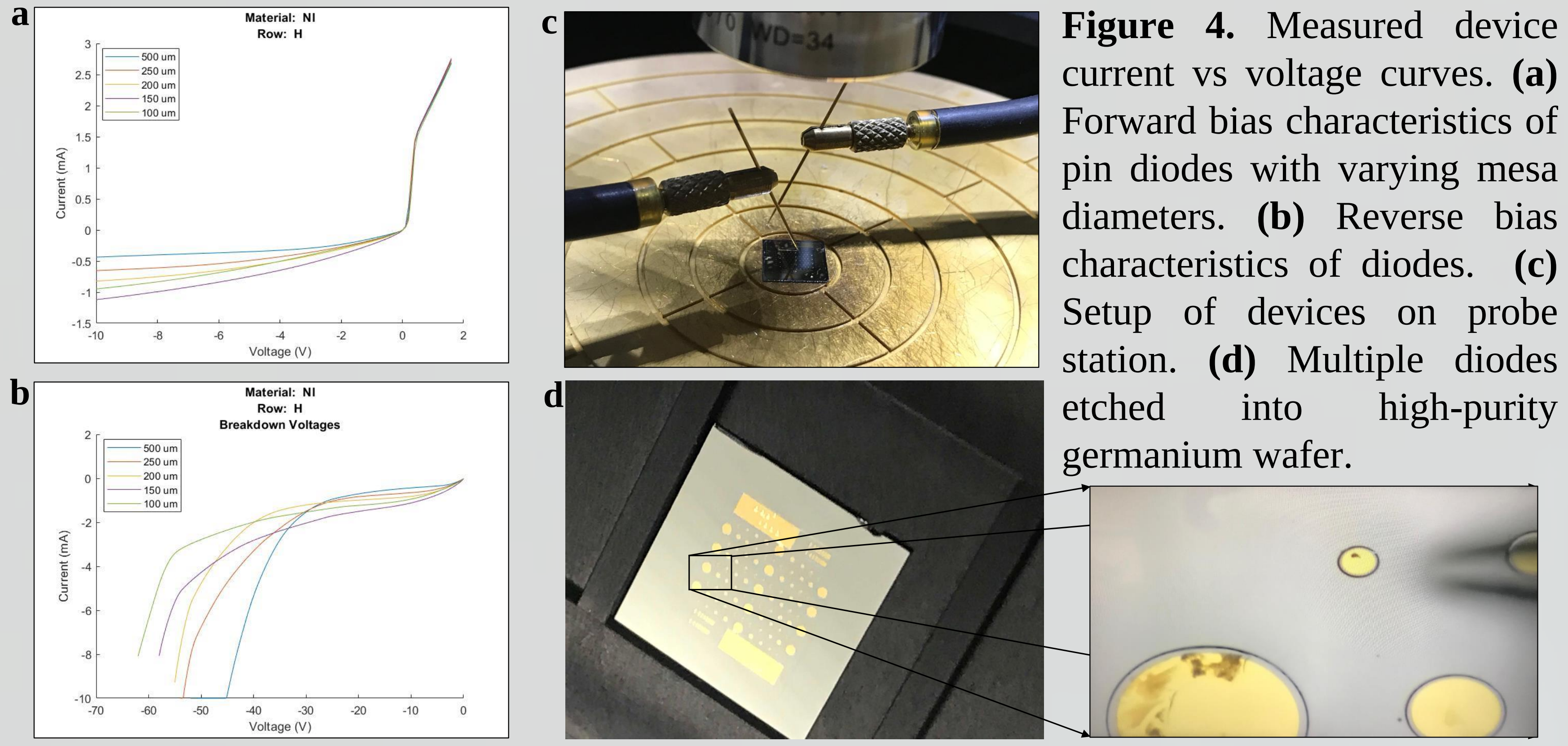

Figure 4. Measured device current vs voltage curves. **(a)** Forward bias characteristics of pin diodes with varying mesa diameters. **(b)** Reverse bias characteristics of diodes. **(c)** Setup of devices on probe station. **(d)** Multiple diodes etched into high-purity germanium wafer.

Key Simulation Results

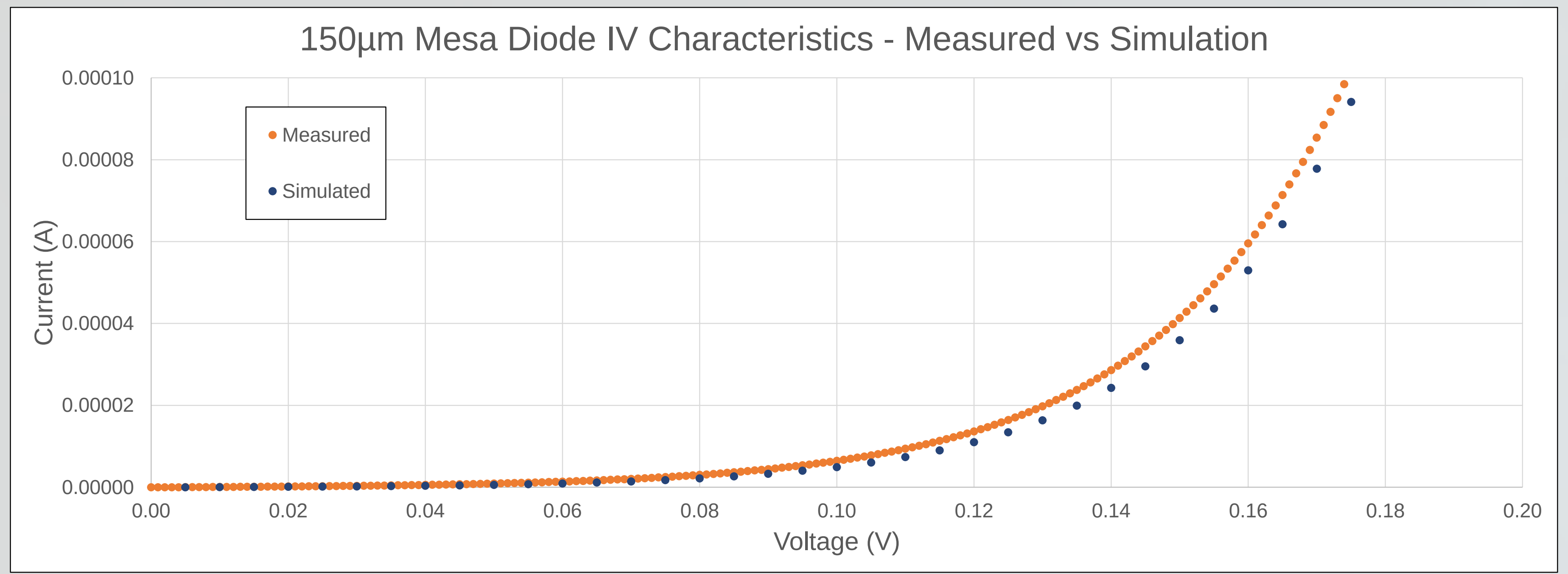

Figure 5. **S**imulation data of 3D diode overlayed on physical device IV curve. Demonstrates the degree of agreement between physical mesa diodes above and simulations, which is key to understanding reliability of simulation results and their predictions.

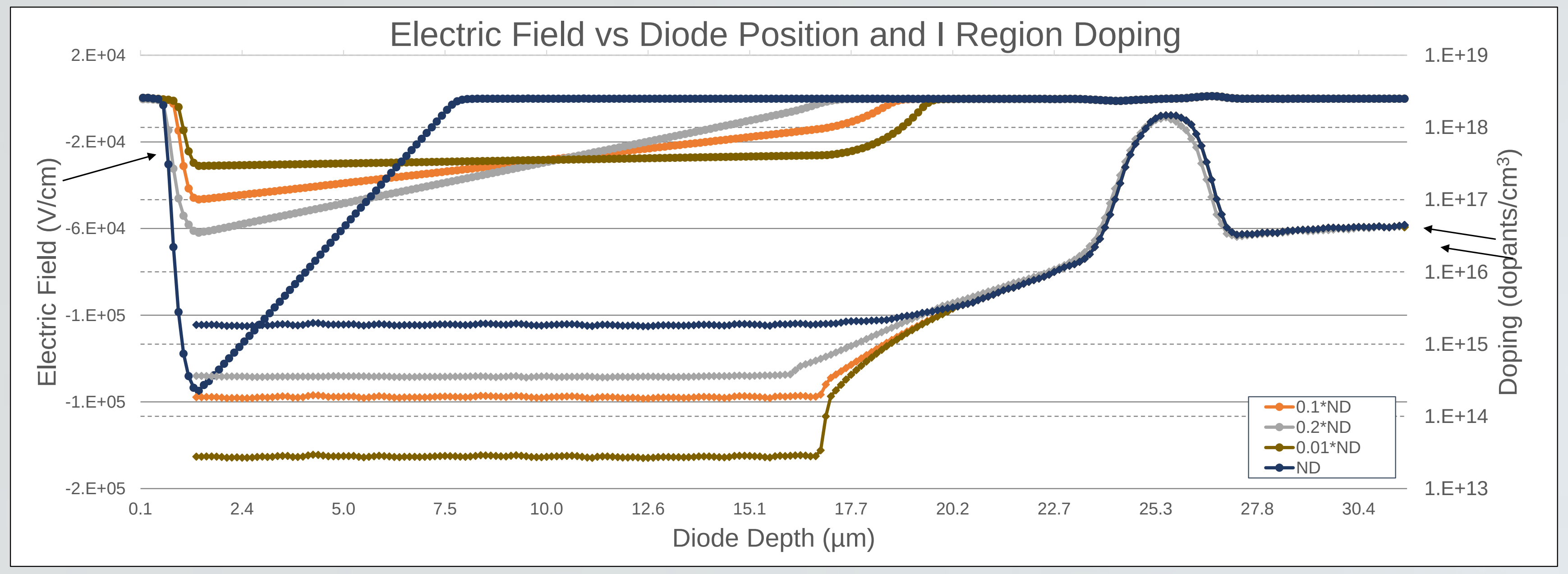

Figure 6. Internal electric field as a function of 17 µm intrinsic region donor doping when biased at -50V of a pin diode. This simulation demonstrates a fully depleted and uniform intrinsic region is possible by decreasing the doping by two orders of magnitude. This forms a major part of an effective proof of concept of the device as a fully depleted I region combined with the long carrier lifetime is guaranteed to sweep away all electron-hole pairs generated, producing a pulse at the anode.

Future Work

Outstanding Questions:

- Which doping level produces the least distorted signal (see Figure 6)?
- What is the shape of the internal generated carrier cloud when photodiode struck by x-ray?
- How many x-ray photons does it take to saturate the photodiodes?
- Is the transient response as fast as theory and simulations predict (see Figure 7 below)?
- Is the quantum efficiency as high as theory and simulations predict (see Figure 8 below)?
- What is the expected dark current of the camera? Will it allow for single photon detection?
- Is decreasing the intrinsic region doping by two orders of magnitude possible (see Figure 6)?

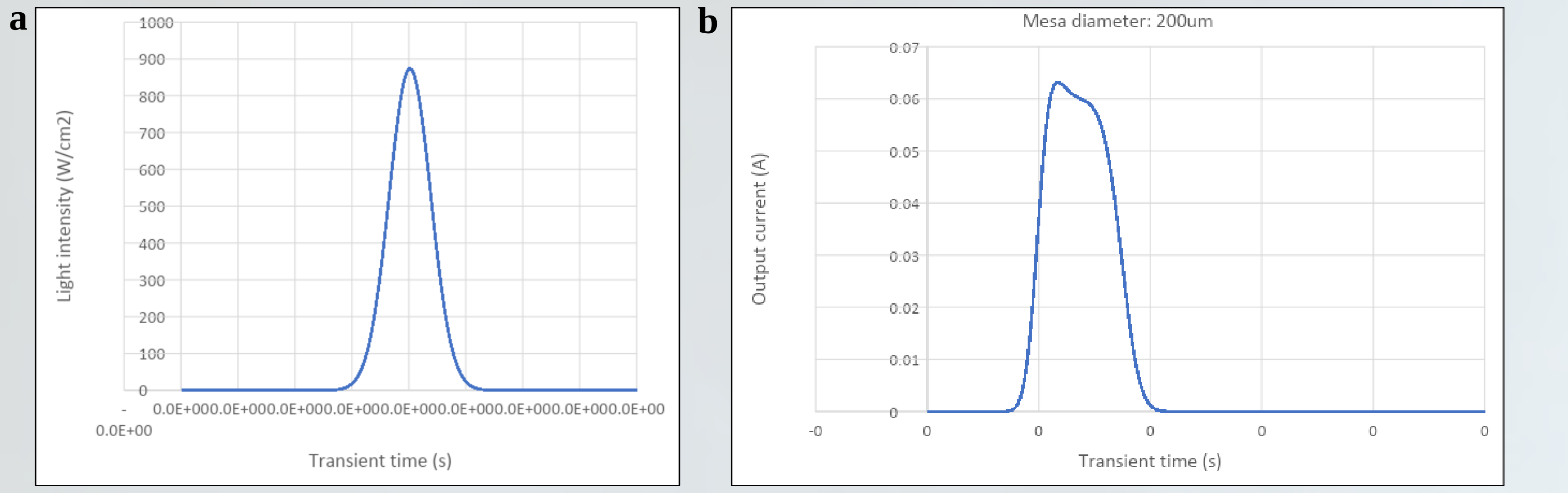

Figure 7. Simulated diode transient response with Silvaco. **(a)** 1024 nm infrared laser intensity striking diode as a function of time. **(b)** Diode response current as function of time. Simulation results will be used to compare with laboratory results, which will consist of measuring response current from germanium photodiode from laser with the same wavelength. This measurement is of central importance to final camera design.

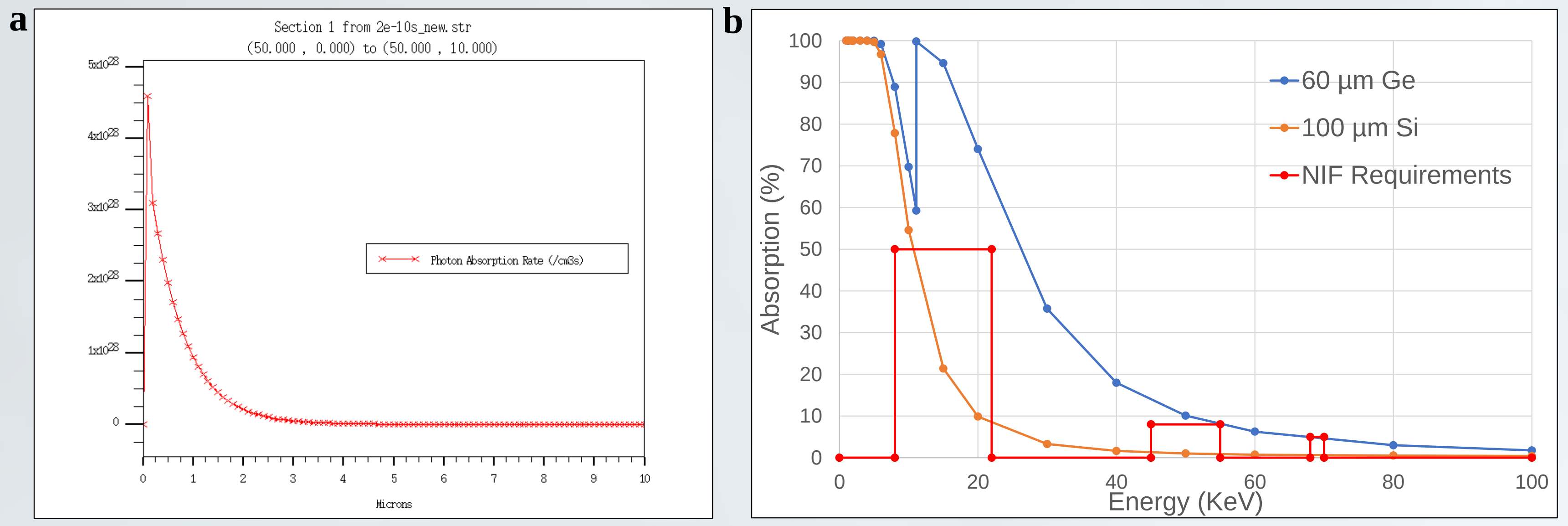

Figure 8. Simulated diode absorption vs diode thickness. **(a)** Simulated diode penetration depth of monochromatic light. **(b)** Beer's law prediction of diodes with desired frequency and temporal response with data from [2]. Simulation results will be used to compare with laboratory results, which will consist of measuring response current from germanium photodiode from Manson characteristic x-ray source. This measurement is of central importance to final camera design.

References

1. Ping, Y. et al. Enhanced energy coupling for indirectly driven inertial confinement fusion. *Nature Phys.* **15**, 138–141 (2019)
2. Hubbell, J.H. and Seltzer, S.M. (2004), Tables of X-Ray Mass Attenuation Coefficients and Mass Energy-Absorption Coefficients (version 1.4). http://physics.nist.gov/xaamdi (2019, July 29). National Institute of Standards and Technology, Gaithersburg, MD.

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