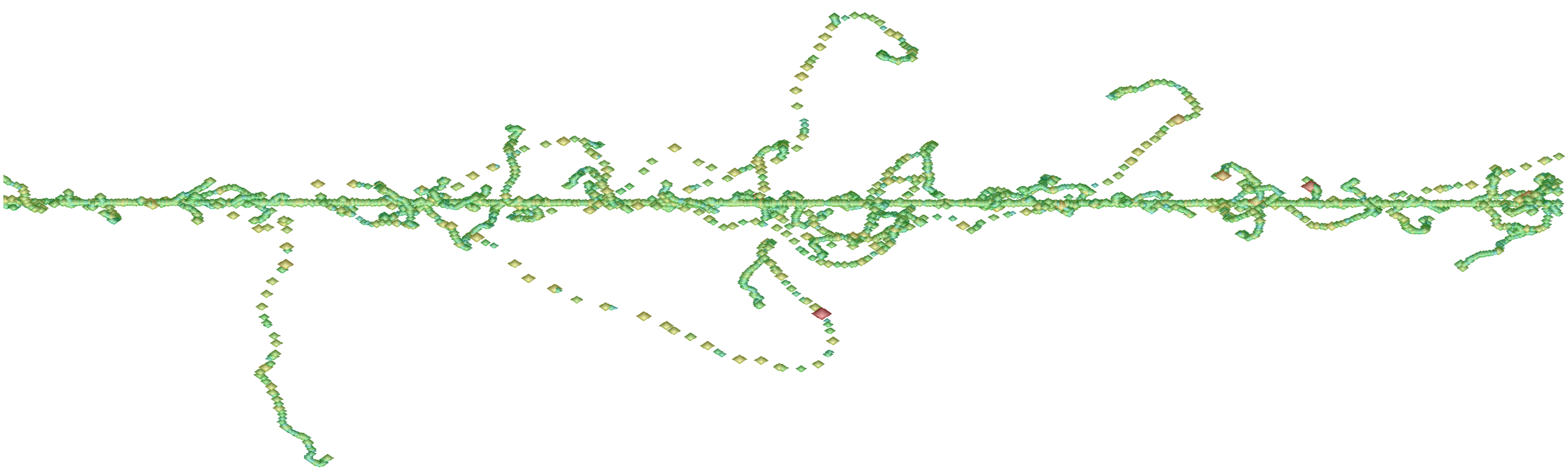
Monte Carlo Transport of Low Energy Electrons

R. A. Reed, R. A. Weller, R. D. Schrimpf,
J. Fang, M. Reaz, S. T. Pantelides,
Vanderbilt University

Makoto Asai
SLAC

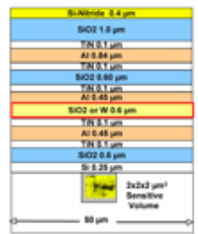
S. L. Weeden-Wright
Lipscomb University

M. V. Fischetti
UT-Dallas



MRED + TCAD and/or Calorimetry

Device/Circuit/System Virtualization



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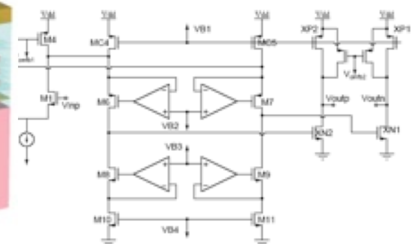
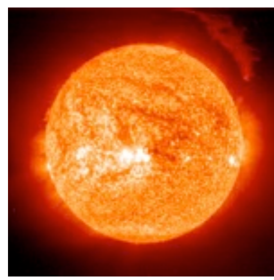
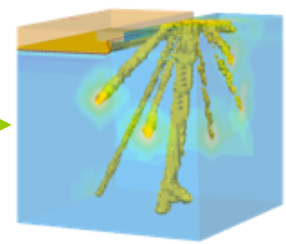


Radiation Event Generation





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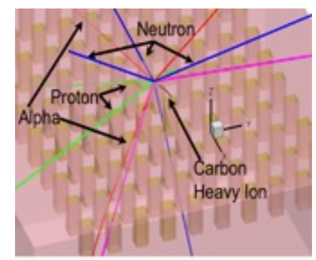
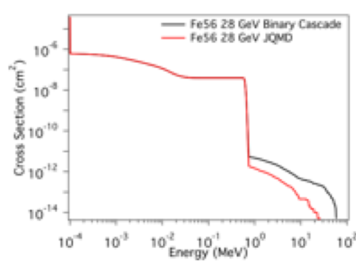
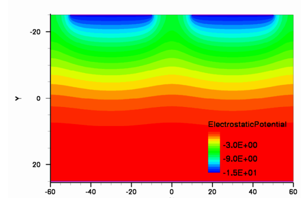
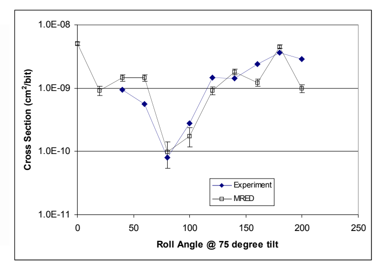


Response Prediction





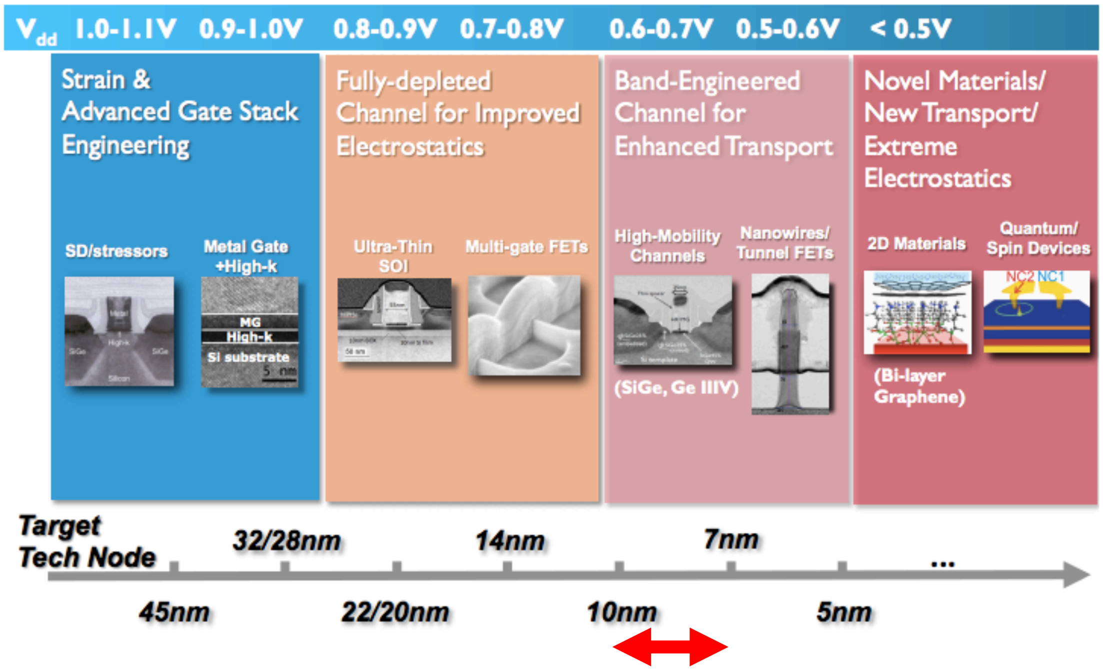


Calorimetry

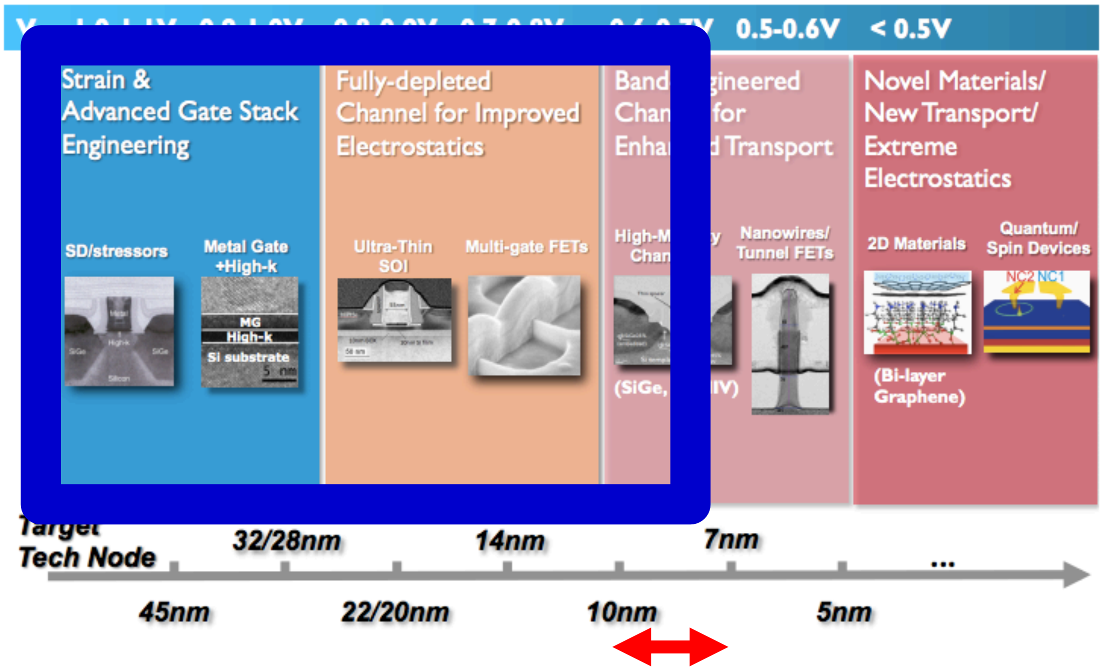
TCAD

Other…

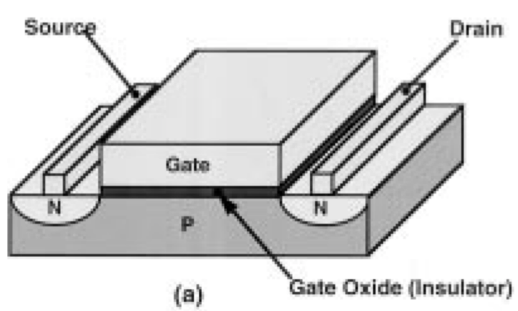
Semiconductor Technology Trends



Semiconductor Technology Trends

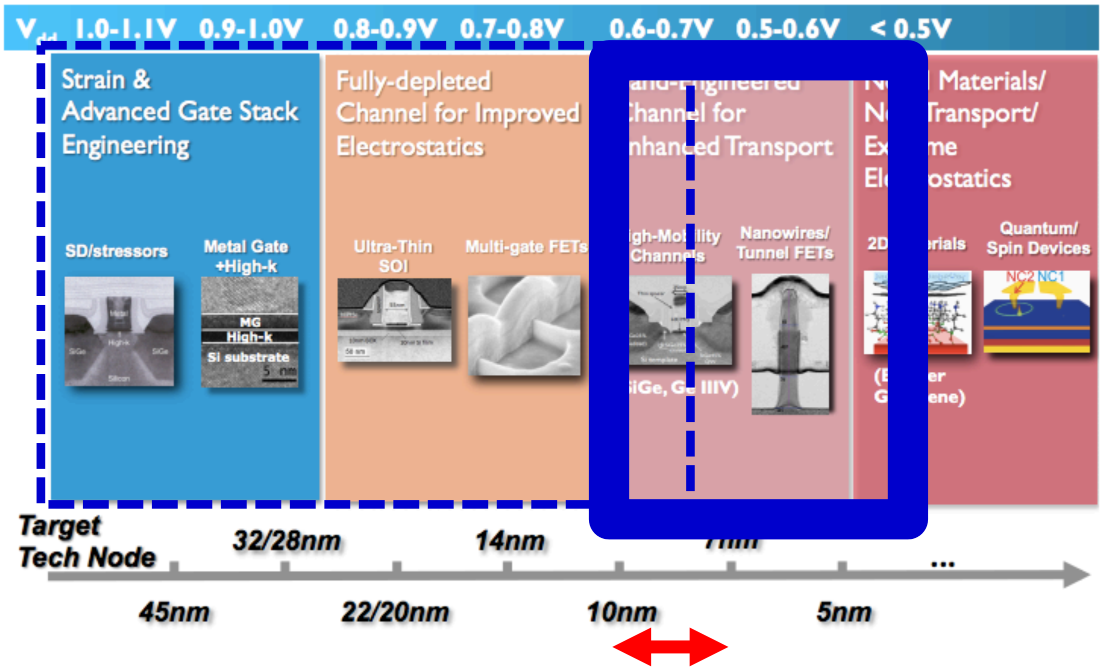


MRED



Goldhaber-Gordon, Proc. of IEEE, 85(4):521, May 1997

Semiconductor Technology Trends



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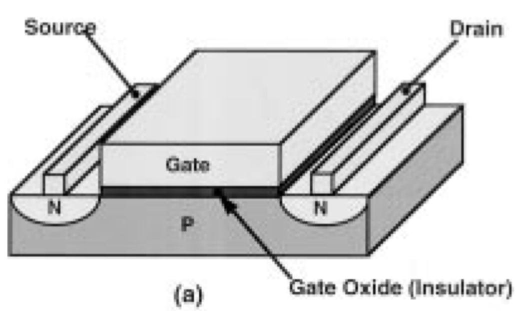

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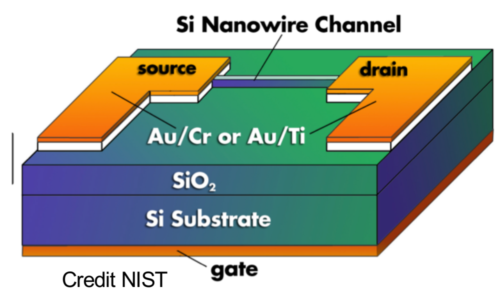
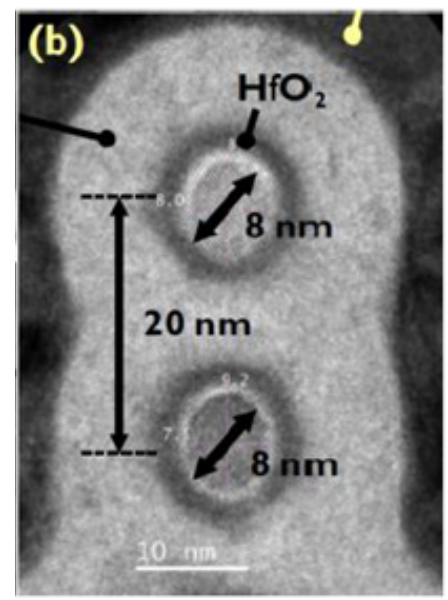
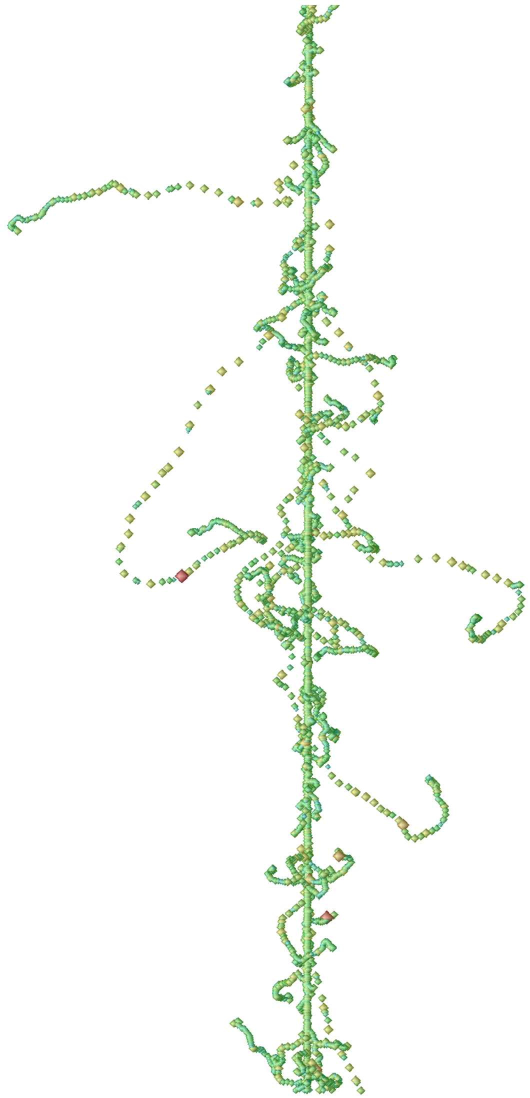


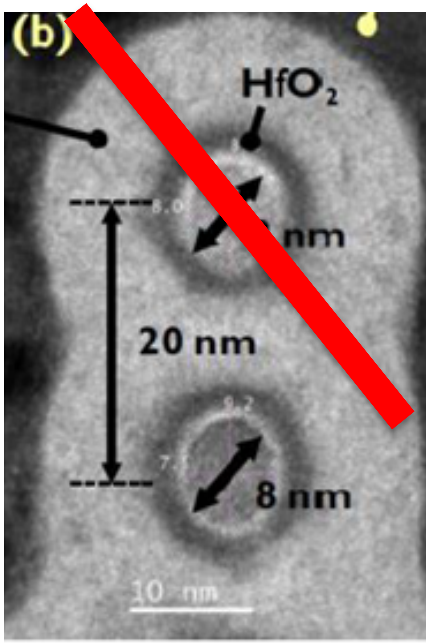
Credit NIST



MRED Simulation of Ion Transport



δ-rays



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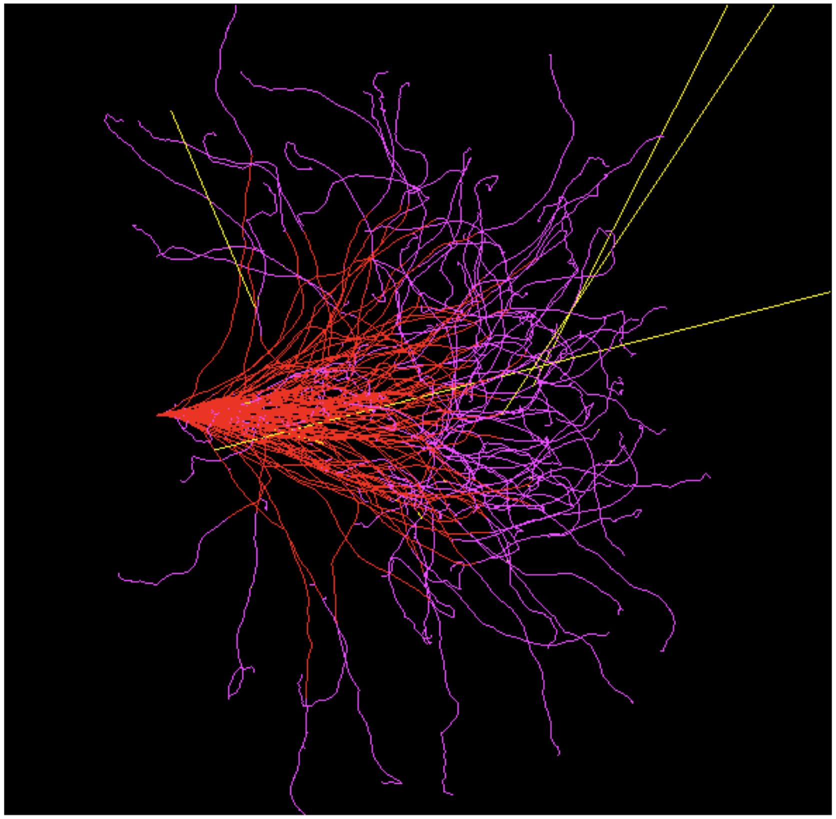
Production and Transport of Electrons

- G4 Standard E-M >~1 keV
- PENELOPE 2008 >~100 eV



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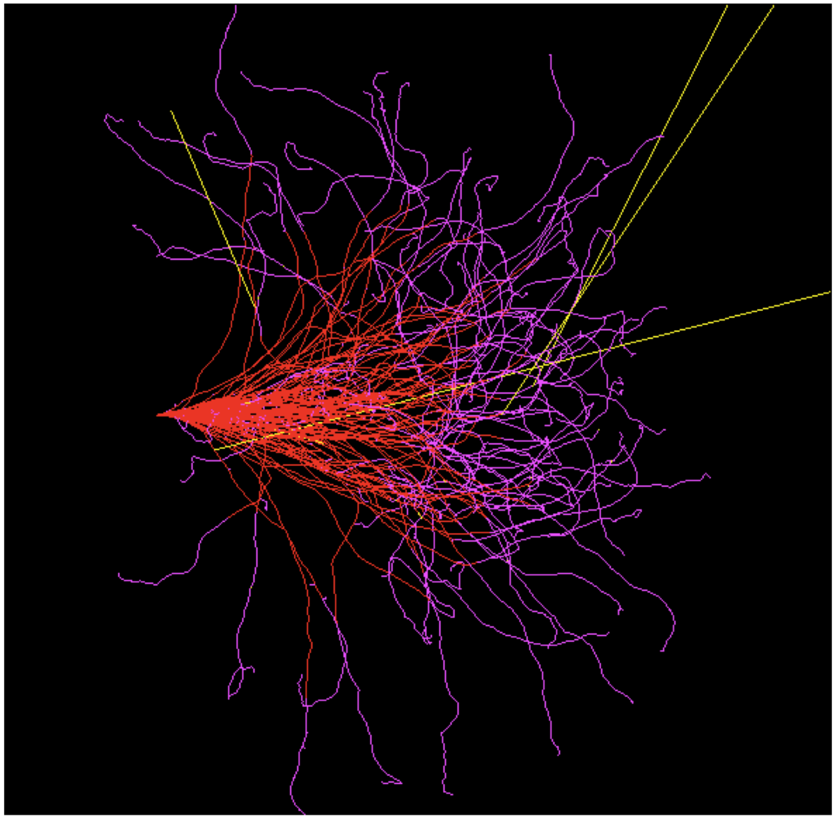
Key question:

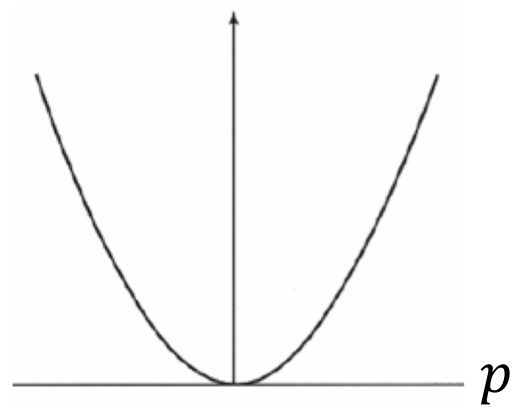
Is it possible to model electron transport and associated charge generation in nanoscale volumes?



Crystal Structure and Energy Bands

- Free particle E(p) is parabolic

$$E = \frac{p^2}{2\,m}$$



Crystal Structure and Energy Bands

- Free particle E(p) is parabolic
- Crystal structure imposes a periodic force on “low” energy electrons
- The quantum nature of electrons and the periodic crystal potential cause the electron’s to be in well defined energy states (density of states)

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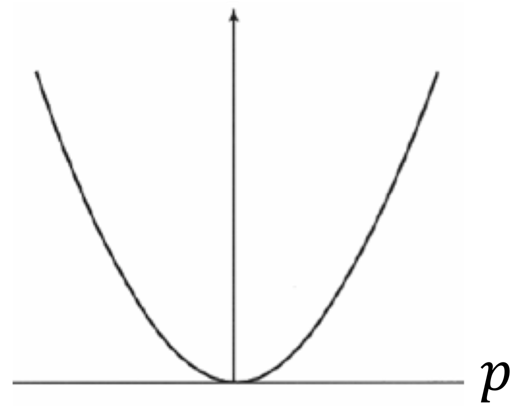

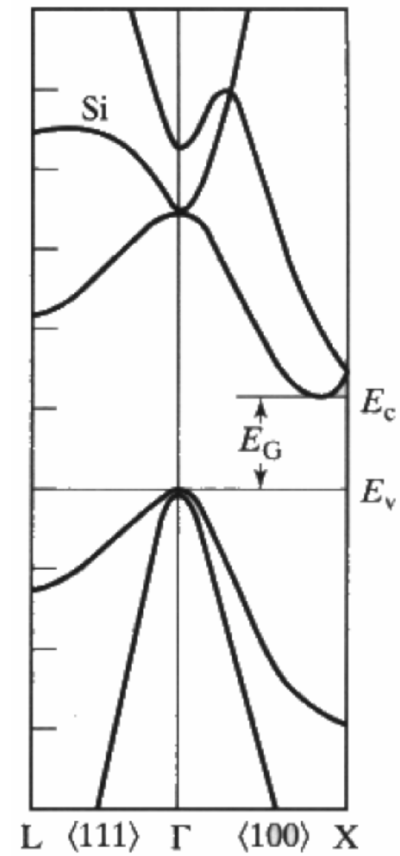

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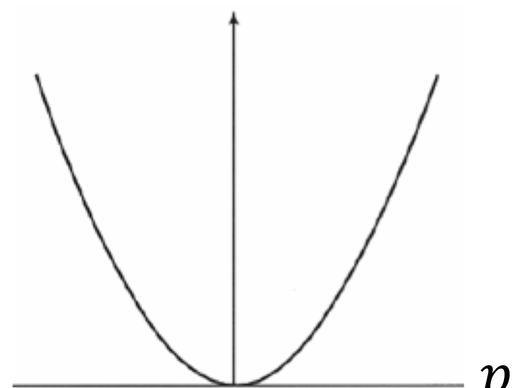
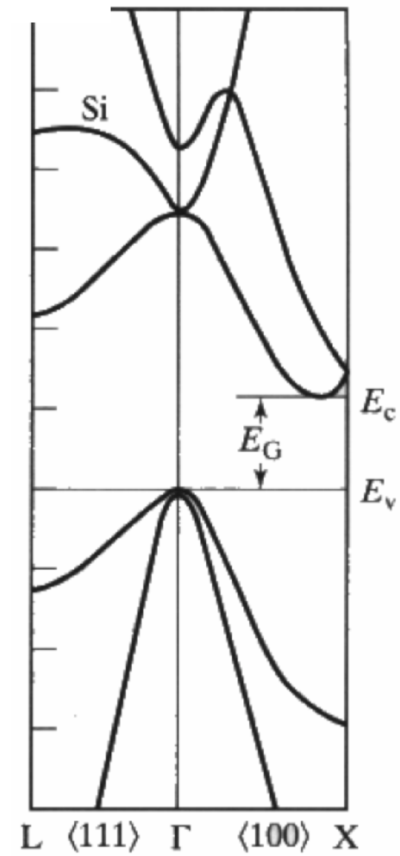
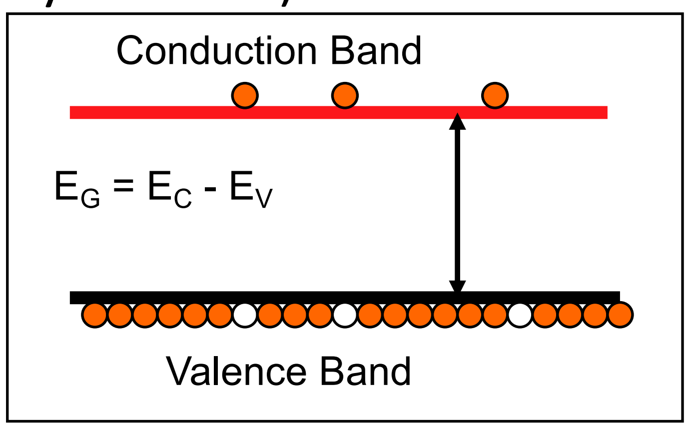




TCAD

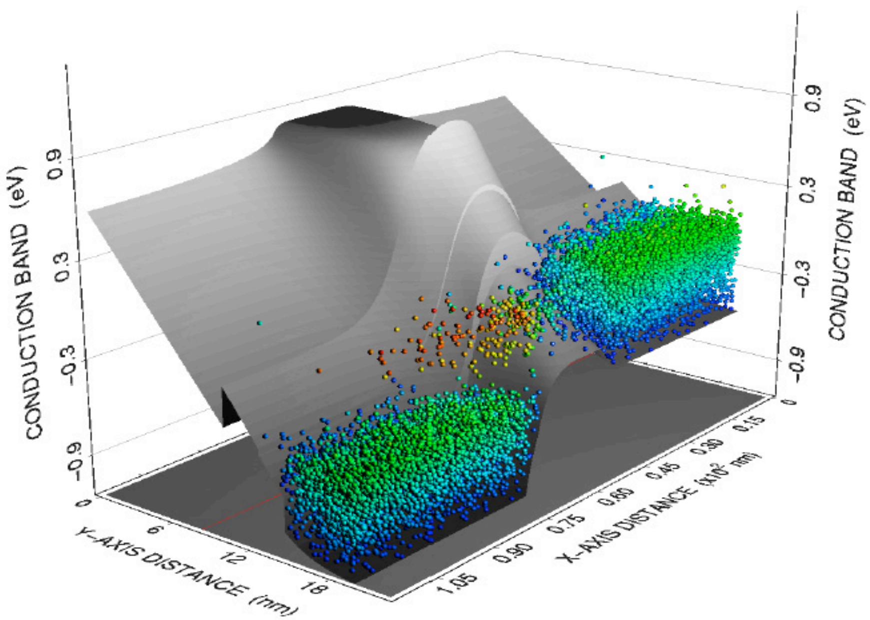
?



Anduril: Monte Carlo Simulation of e-h Transport

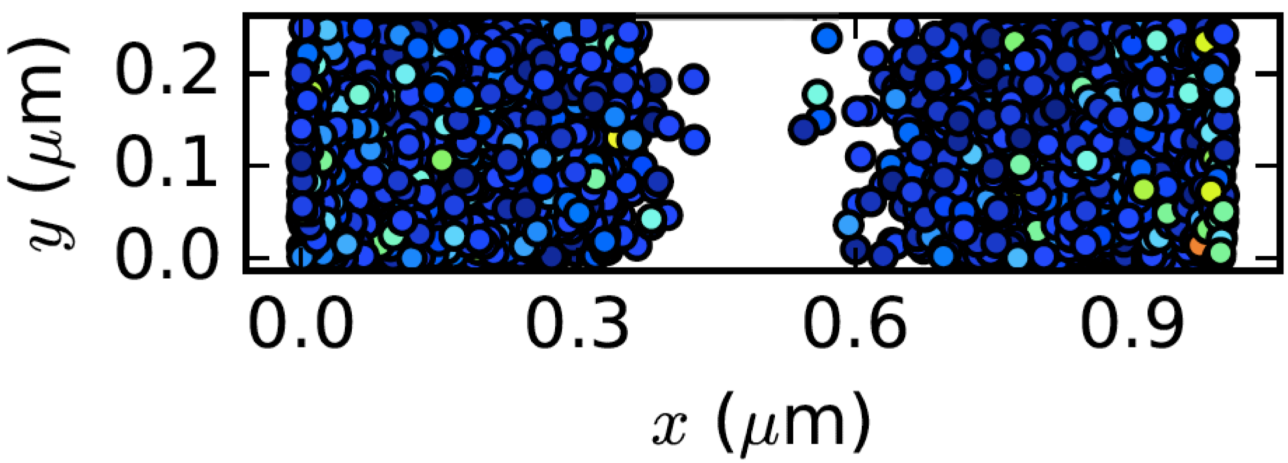
Courtesy of Massimo Fischetti

- **Full 3D band structure and density of states (<10 eV for Si)**
- **Coupled solution of Boltzmann transport equation and Poisson equation**
- **Includes carrier-carrier, impurity, phonon-electron, interface trap, plasmonic scattering**
- **Impact ionization, tunneling, and quantization**



15nm III-V MOSFET showing the spatial and energetic distributions of electrons within the device

Anduril Simulation of a Reversed Biased p-n Junction



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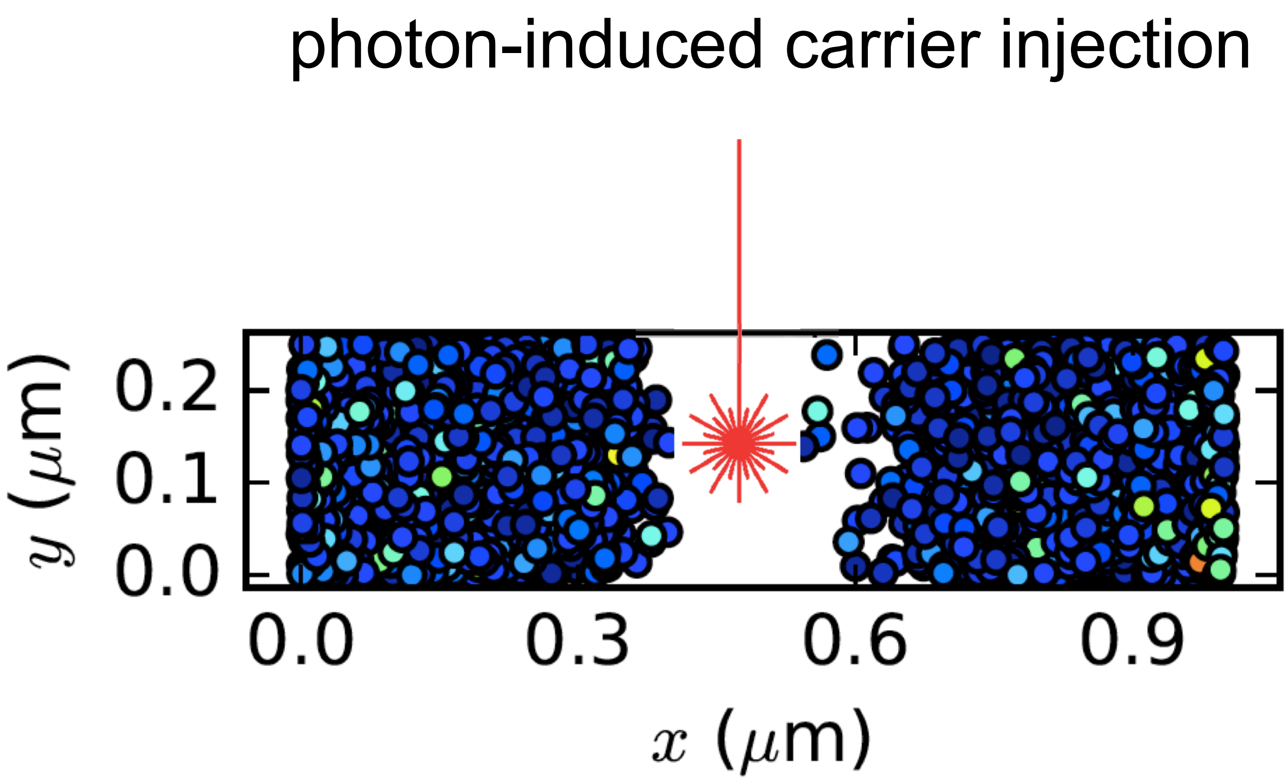
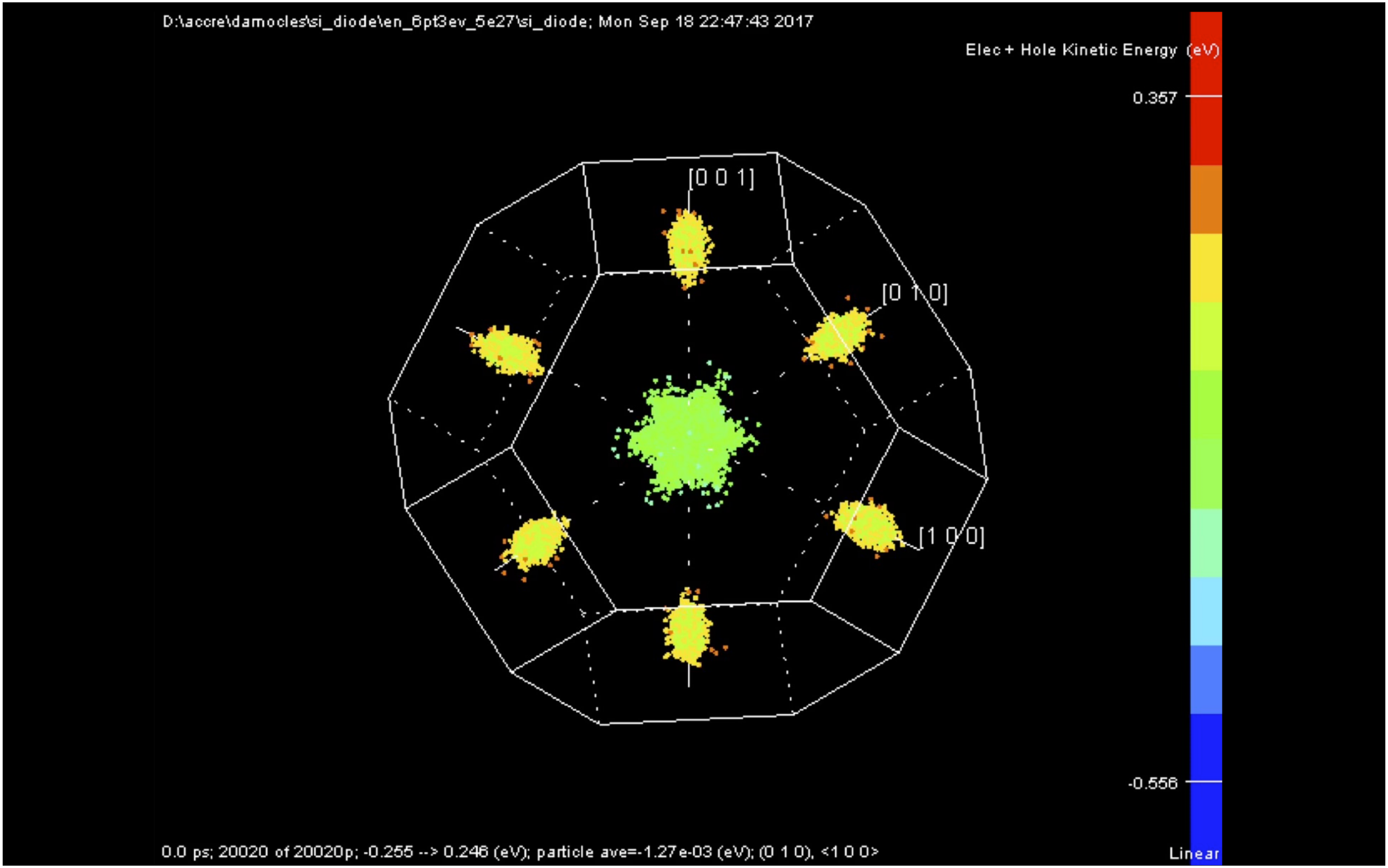
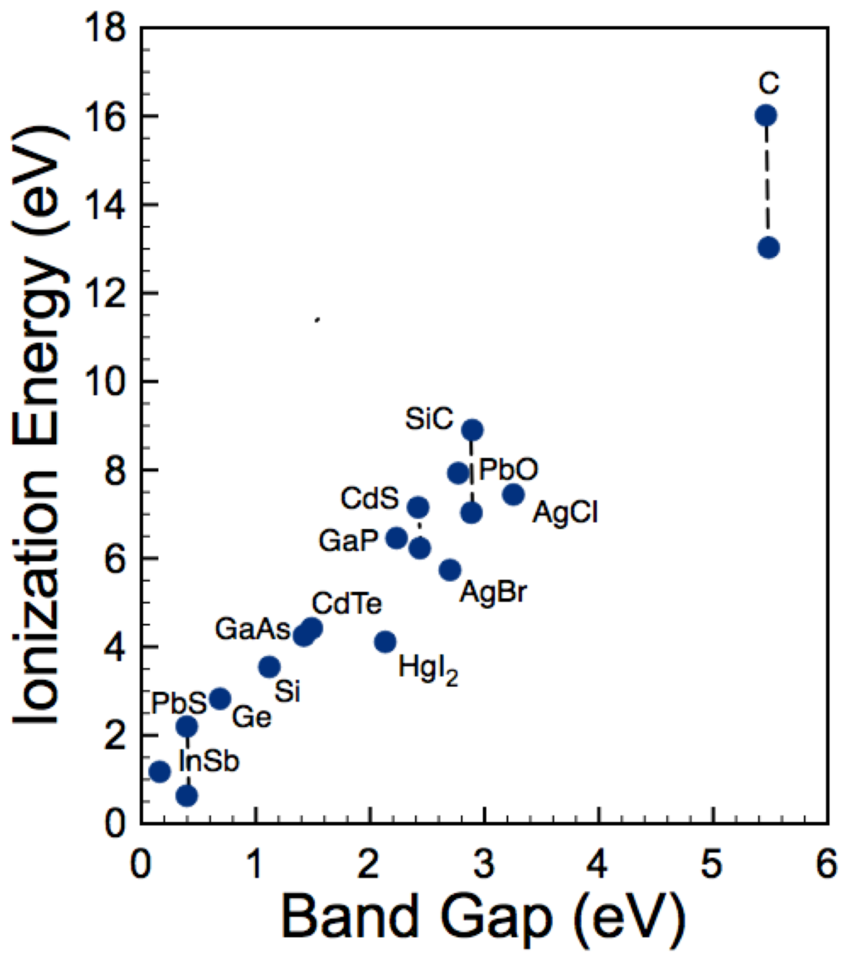



D:\accre\damocles\si_diode\en_6pt3ev_5e27\si_diode; Mon Sep 18 22:47:43 2017
Elec + Hole Kinetic Energy (eV)
0.357
-0.556
Linear
[0 0 1]
[0 1 0]
[1 0 0]
0.0 ps; 20020 of 20020p; -0.255 --> 0.246 (eV); particle ave=-1.27e-03 (eV); (0 1 0), <1 0 0>

An Aside: Average Energy to Create an e-h Pair



For Si: 3.6 eV/e-h

C. A. Klein, "Bandgap Dependence and Related Features of Radiation Ionization Energies in Semiconductors", *J. Appl. Phys.*, Vol 39, No. 4, 1968, pp. 2029-38

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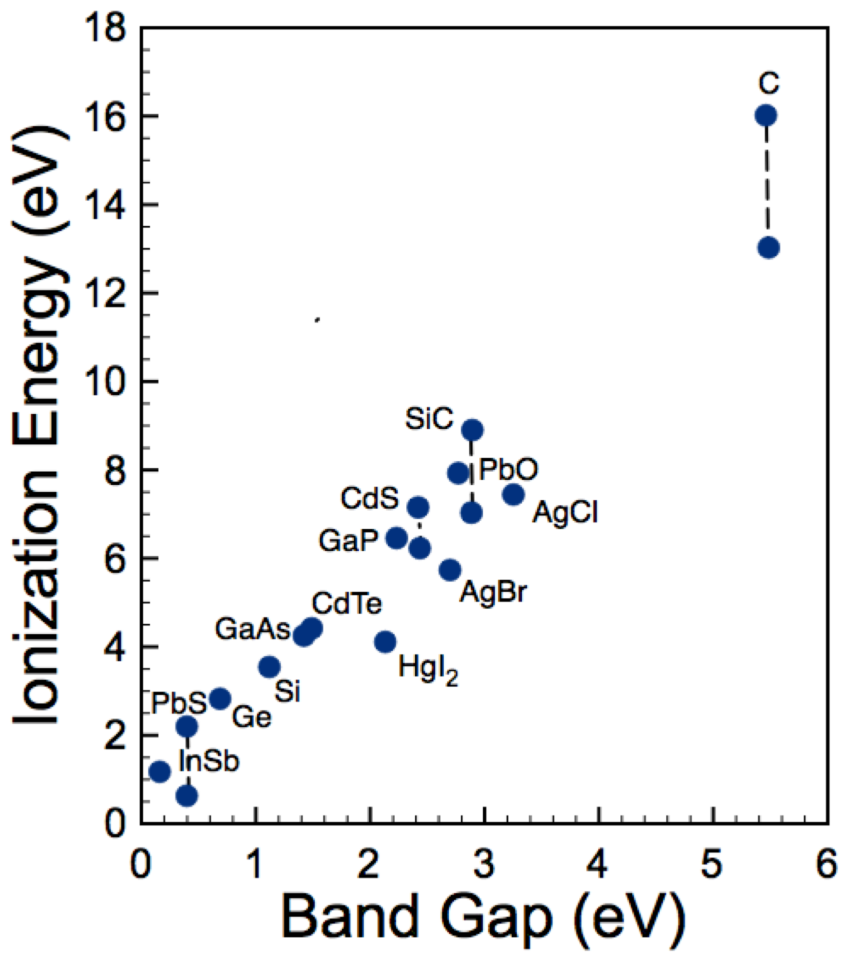

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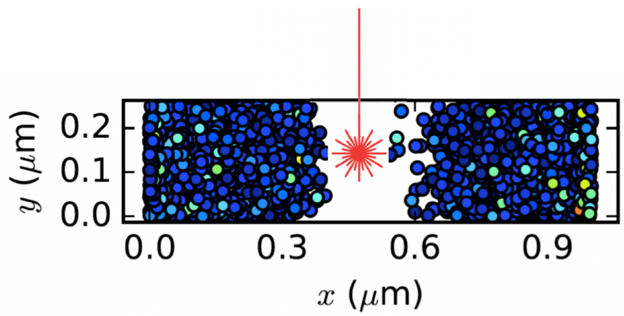
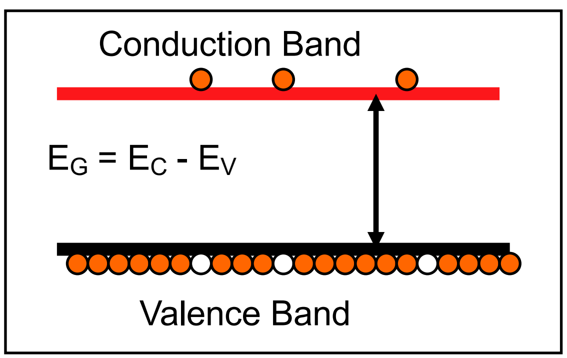
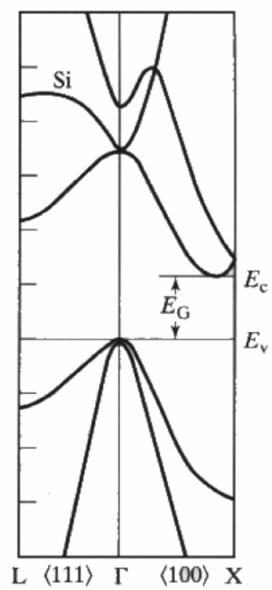
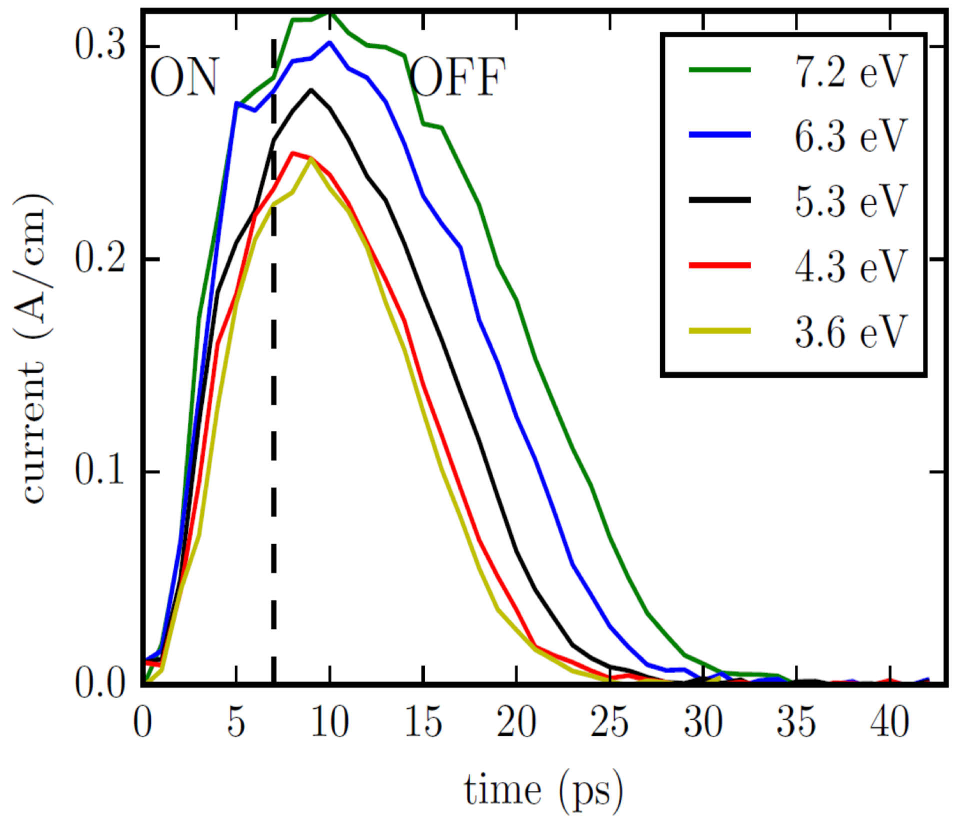
Current on Contact for Different Photon Energies

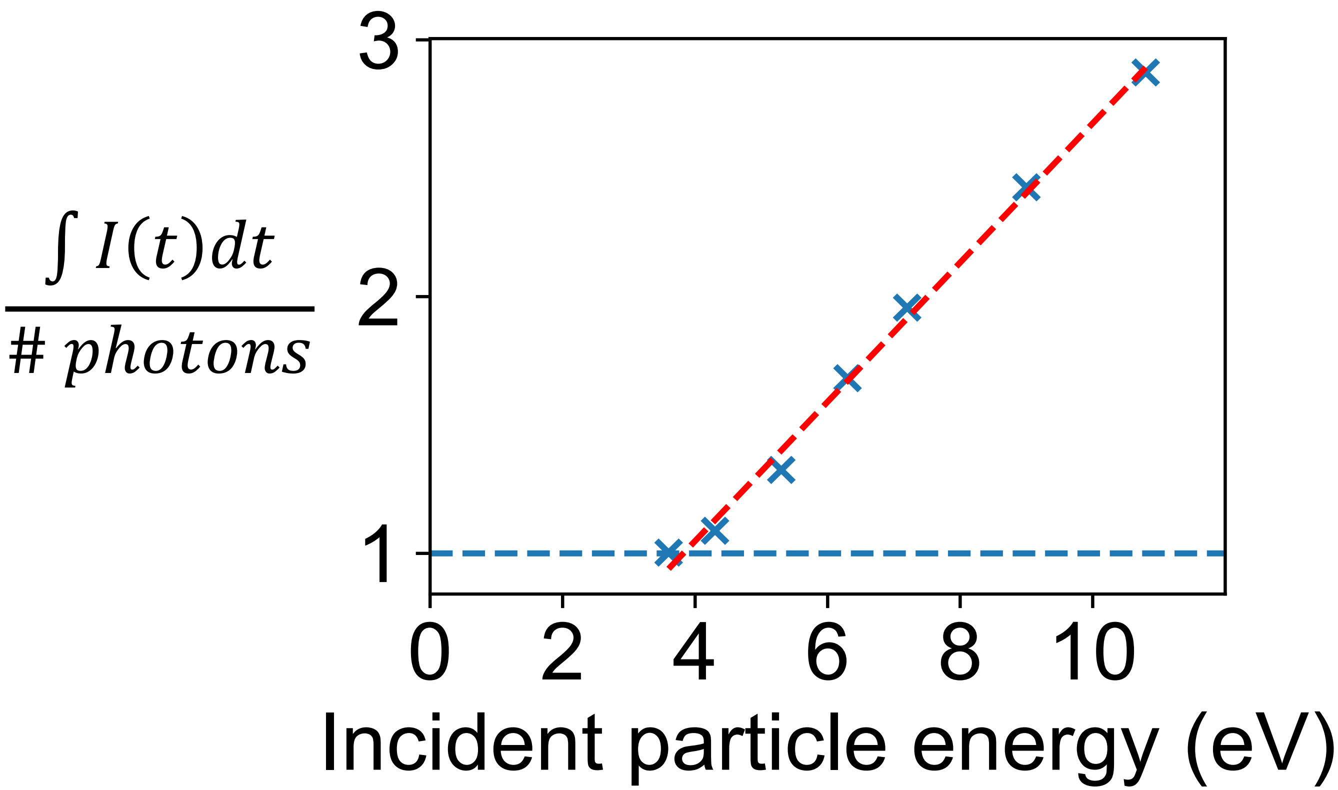








Average # e-h Pairs/Photon vs Photon Energy



1/slope = 3.6 eV/e-h pair !

Bridging the 100 eV and 10 eV gap?