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Simulation of a laser triggered vacuum switch

Andrew Fierro, Chris Moore, Weng Chow, Laura Biedermann, Matthew Hopkins

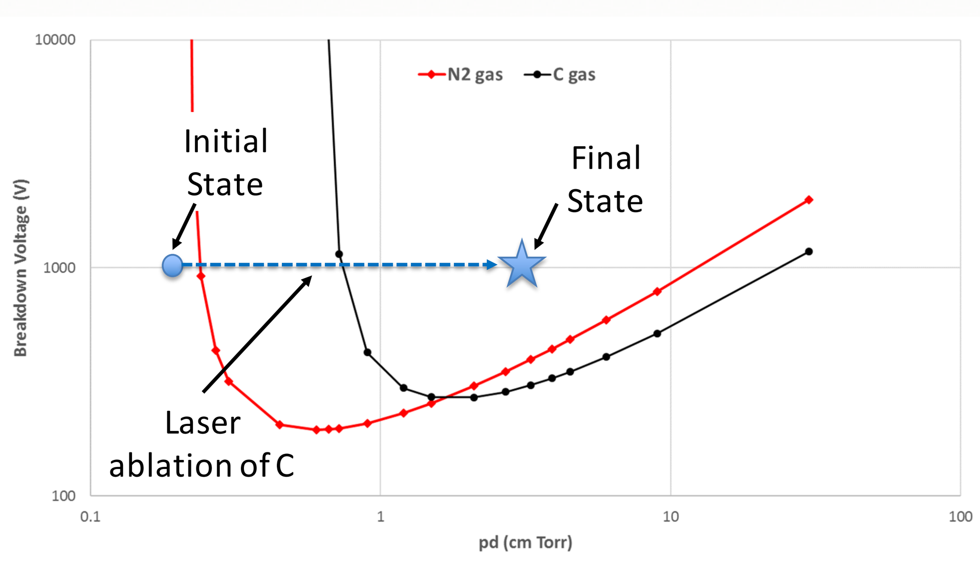
Sandia National Laboratories, Albuquerque, New Mexico, United States

Introduction

Laser triggered vacuum switches (LTVS) use input laser energy to inject electrons, ions, and neutral material from a trigger target into an electrically stressed vacuum gap. The reliability, power, and high output power of lasers make the LTVS an appealing approach for low-jitter, high voltage switching applications. Modeling of a LTVS allows for optimization of both laser and trigger material parameters for efficient operation. Essential to the laser triggering process is the injection of charged and neutral species at the trigger material surface. As such, a material supply model has been developed and is a function of the input laser intensity, wavelength, and pulse shape. This material model serves as an input infux boundary condition for into a particle-in-cell (PIC), direct simulation Monte Carlo (DSMC) code which simulates plasma growth and gap closure. Two hemispherical electrodes with a gap distance of 3 mm are simulated with the laser propagating axially towards the cathode through a small hole in the anode. An applied potential of several kV establishes an electrostatic potential.

Theory of operation

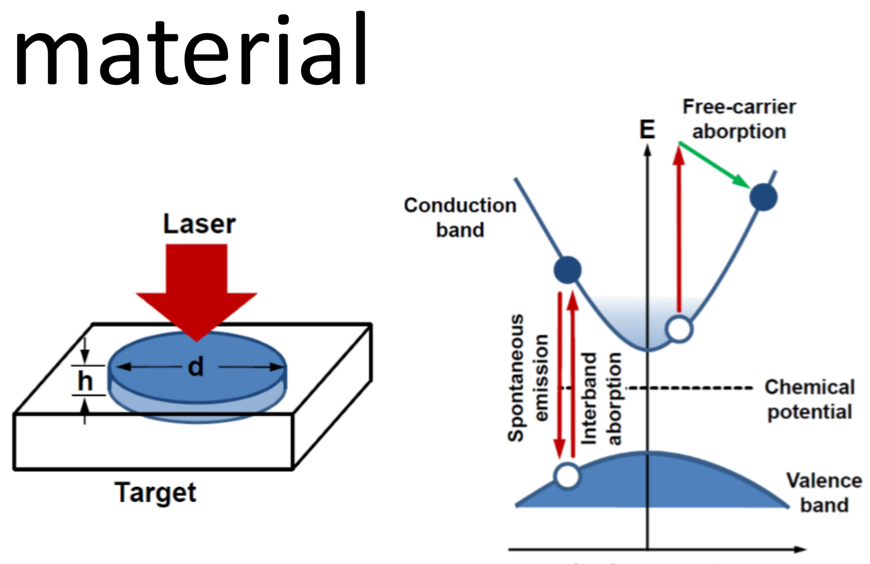
- At low *pd* (pressure times gap distance), the Paschen curve predicts a a large breakdown voltage far above the minimum.
- The LTVS is operated in this region initially, low pressure (0.5 torr) with a fixed gap distance, *d* (3 mm). *pd* = 0.15 torr cm
- An axially propagating laser pulse onto a carbon-coated electrode results in the injection of neutral carbon into the gas.



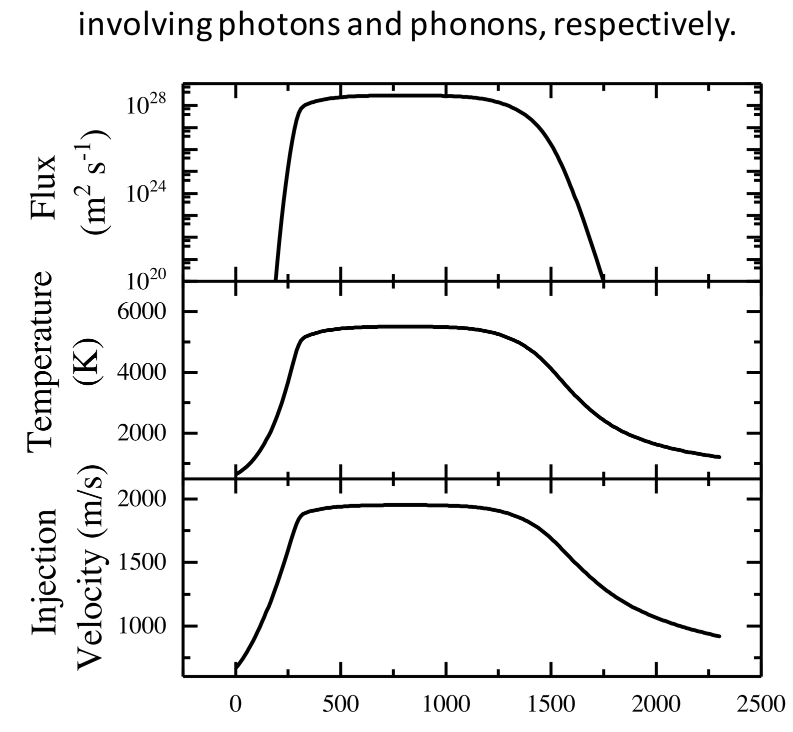
Simulated pure nitrogen and carbon Paschen curves

Injection of neutral material

- Use commercial laser diode bar from DILAS Diode Laser INC
  - λ = 980 nm
  - Peak Power = 330 W
  - Pulse Duration = 1 µs
  - 100 µm spot size on target
- Model the material ablation due to laser heating of the solid by tracking dynamics of electron and hole populations in momentum resolved conduction- and valence-band states.
  - Include optical transitions: absorption, emission, and free-carrier absorption
  - Include carrier-carrier and carrier-phonon scattering
  - Scattering results in lattice heating and target material ablation
  - For details see [1]
- Results for the neutral carbon flux during the laser pulse shown on the right



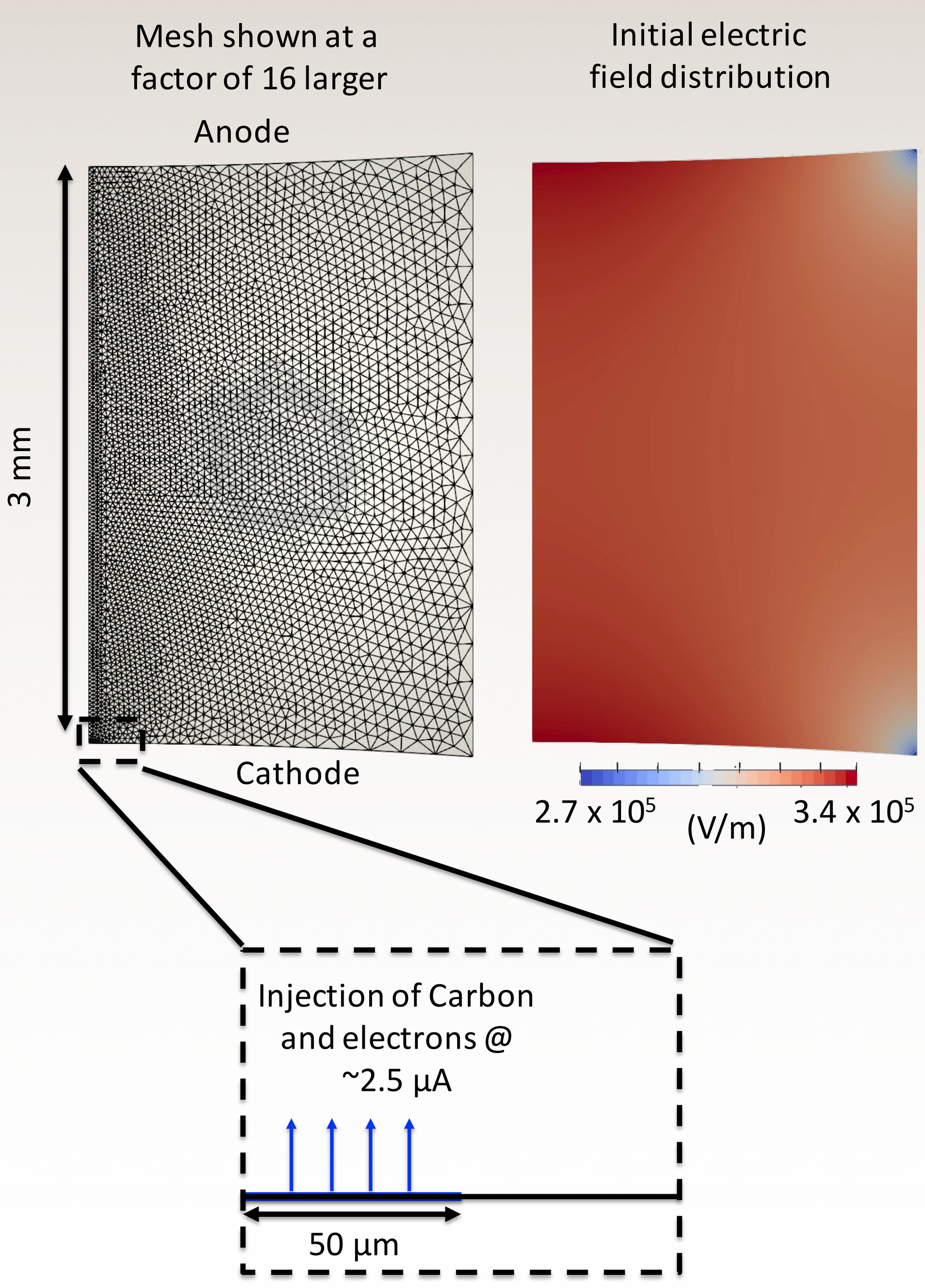
(left) Schematic of laser interaction region (right) Basic crystal band structure, showing relationship of carrier energy and momentum. The red and green arrows indicate transitions involving photons and phonons, respectively.



Output flux, temperature, and injection velocities for the carbon neutral material derived from the material supply injection model.

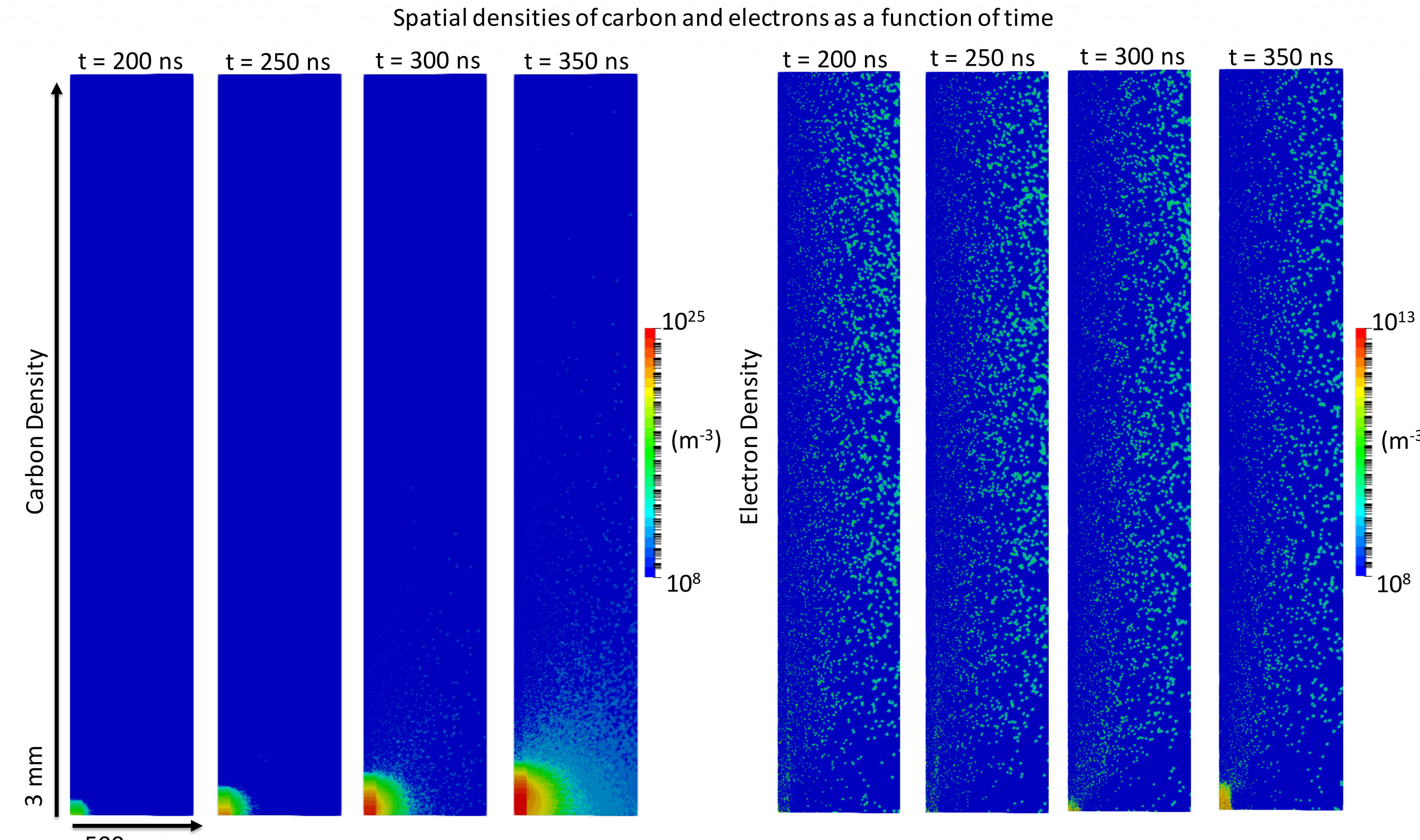
Simulation setup

- Simulated using a particle-in-cell (PIC) method with Direct Simulation Monte Carlo (DSMC) method for collisions. Use a 2D model of two hemispherical electrodes separated by a gap distance of 3 mm.
- Included are electron-neutral impact cross sections for molecular and atomic nitrogen as well as carbon species. Heavy body interactions between carbon and molecular nitrogen are also included.
- The laser is assumed to interact with a 50 µm radius region of carbon near the symmetry boundary. Laser-plasma interactions are currently neglected.
- Approximately 2.5 µA of trickle current is constantly sourced through the cathode.

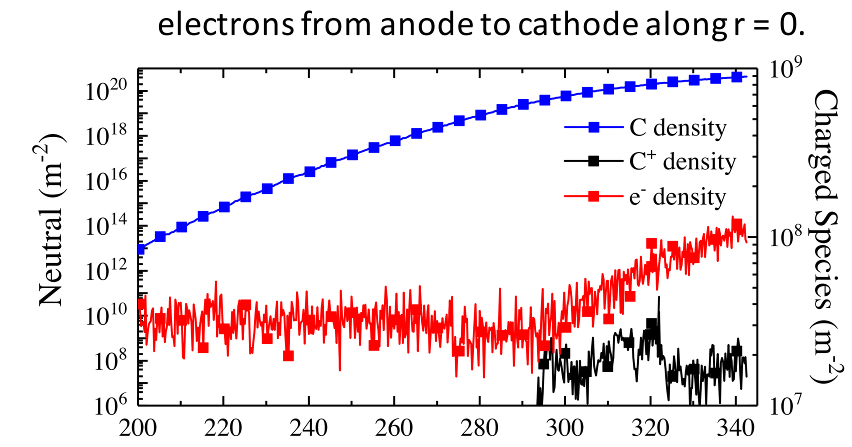


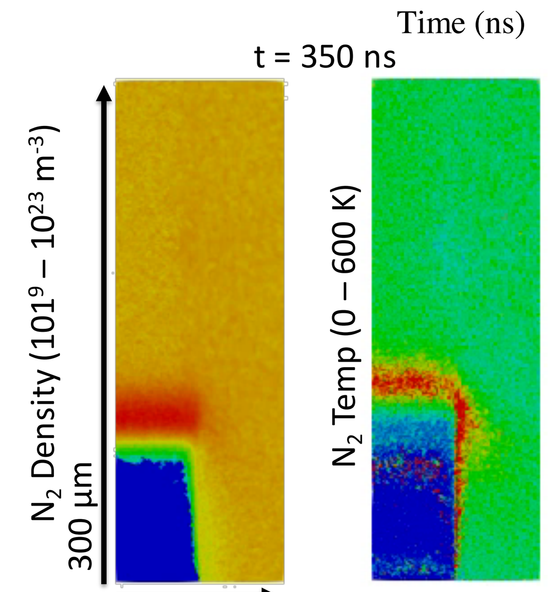
Simulation Results

Spatial densities of carbon and electrons as a function of time



Integrated density of carbon species and electrons from anode to cathode along r = 0.





Shock generated from the injection of neutral carbon interacting with the background molecular nitrogen.

- At t = 200 ns, the beginning of carbon injection occurs and results in a density of approximately 10^{16} m^{-3}. Electrons up to 250 ns interact little with the inject carbon neutrals.
- It is observed, starting with at approximately 300 ns that the density of carbon has reached 10^{25} m^{-3} and electrons begin to multiply in this region due to electron impact ionization.
- The injection of large amounts of neutral carbon leads to a shock that occurs in the background nitrogen gas.

References

1. W. Chow, C. Moore, L. Biedermann, M. Hopkins, D. Dagel, and K. Cartwright, “Carrier Dynamics Model for Laser-Solid Interactions”, Sandia SAND report, SAND2017-9029, 2017.

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