SVC Society of Vacuum Coaters

TechCon 2021 Virtual

64th Annual Technical Conference Proceedings Virtual Event: May 3 – 7, 2021
 ISSN 0737-5921, ISBN 978-1-878068-41-5

One-Dimensional PIC/MCC Simulation of HiPIMS Discharges

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We demonstrate a self-consistent and complete description of discharge characteristics in high power impulse magnetron sputtering (HiPIMS) discharges via fully kinetic 1d3v particle-in-cell/Monte Carlo collision (PIC/MCC) electrostatic simulations. The interplay between the fundamental plasma parameters is analyzed through their spatiotemporal dynamics. Compared to conventional DC magnetron sputtering (DCMS), HiPIMS discharges require more physical processes to be considered in their simulations, such as Coulomb collisions between charged species, sputtering winds, i.e., gas rarefaction due to momentum exchange between the sputtered species and the background gas, metal ions ionized from the sputtered species, and secondary electron emission induced by these multiply charged metal ions. Considering all the above processes, this study provides the first detailed kinetic description of HiPIMS discharge in terms of discharge runaway, electron dynamics and sputtering wind. Some important conclusions previously obtained from global models are confirmed by this ab initio kinetic simulation. During the discharge runaway, i.e., the transition from the low-current DCMS regime to the high-current HiPIMS regime, metal ions gradually replace gas ions as the dominant ion, and the electron energization transitions from sheath energization to Ohmic heating in the ionization region. These results are beneficial for the design and optimization of HiPIMS discharge in practical applications.

www.svc.org **https://doi.org/10.14332/svc21.proc.0027**

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May 4, 2021

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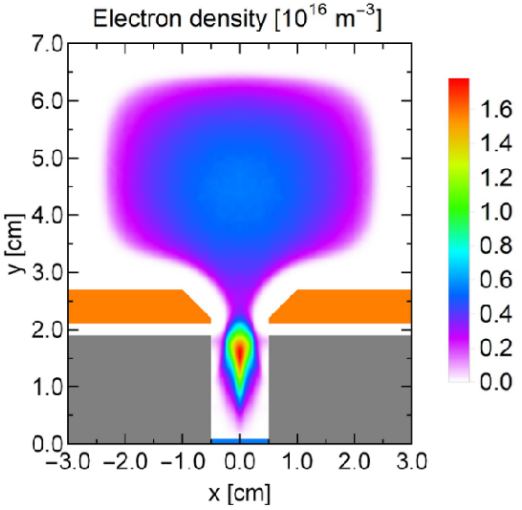
Outline

- Particle-In-Cell/Monte Carlo Collision (PIC/MCC)
- Particle simulation of magnetron discharges: 1D vs 2D
- HiPIMS discharge characteristics
  - Discharge characteristics
  - Electron kinetics
  - Gas rarefaction

PIC/MCC simulation

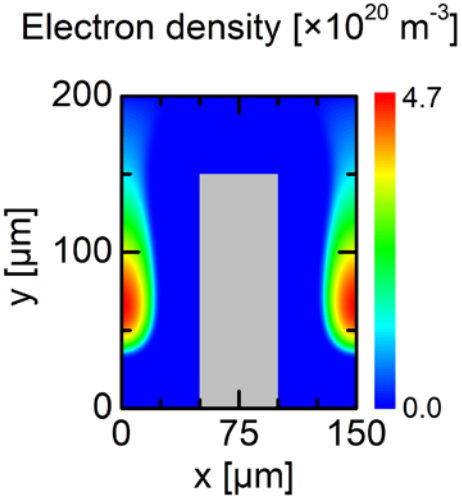
- Advantages
  - Self-consistent
  - Complete
- **ASTRA** Developed by ***Bocong Zheng***
  - Efficient PIC software
  - Applications in
    - Ion sources
    - Microplasmas
    - RF plasmas
    - Magnetized plasmas
    - etc.

Ion sources



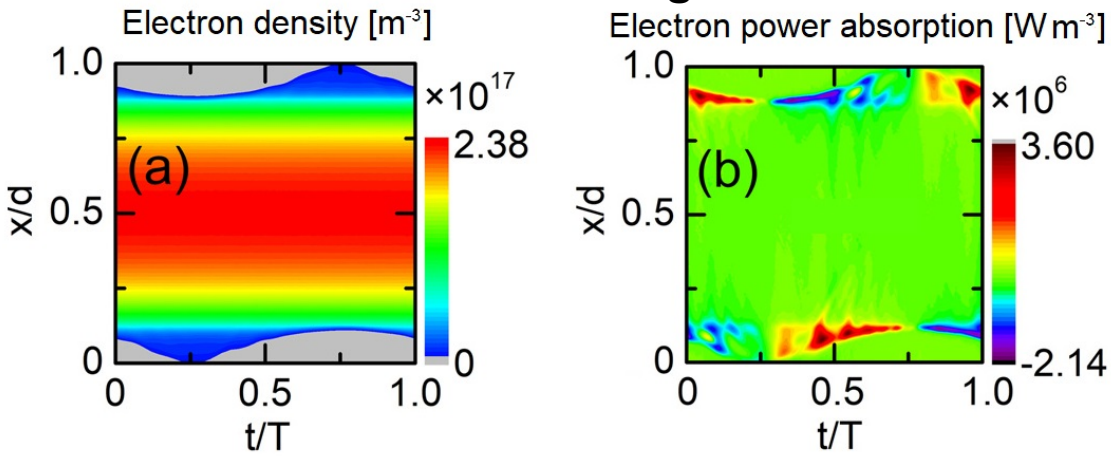
B. Zheng et al., In preparation

microhollow cathode discharges



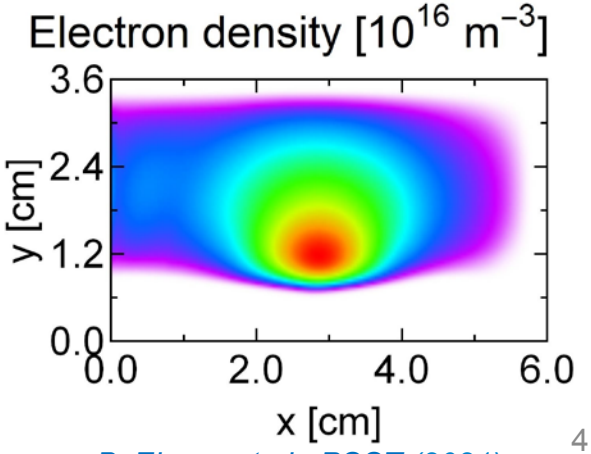
Y. Fu, B. Zheng et al., JAP 129, 023302 (2021)

CCP discharges



Y. Fu, B. Zheng et al., APL 117, 204101 (2020)

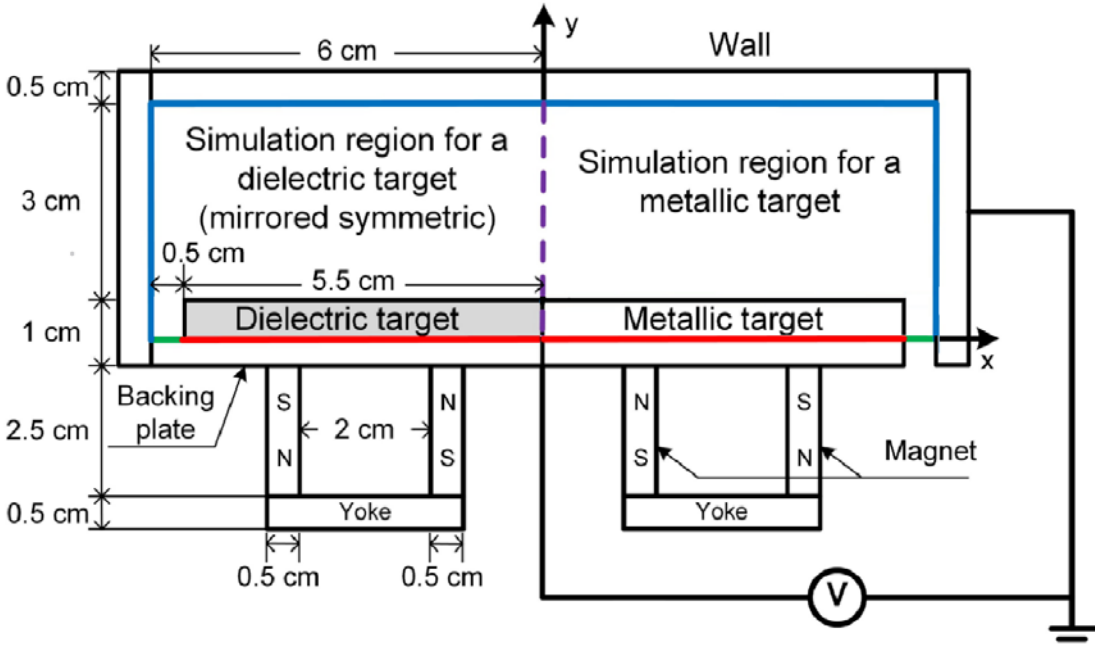
Magnetron discharges

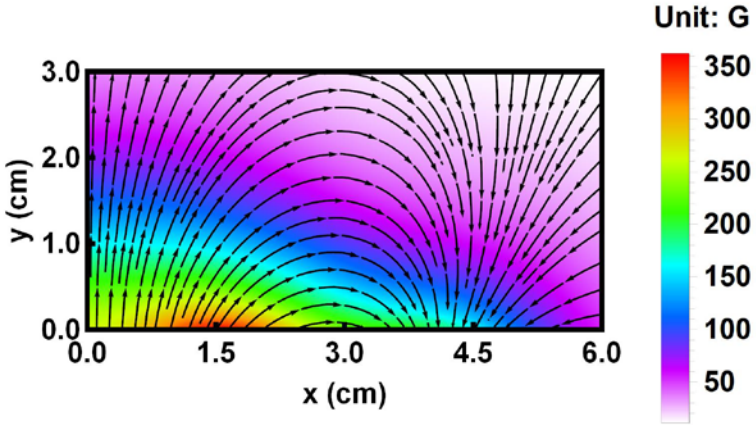


B. Zheng et al., PSST (2021) doi:10.1088/1361-6595/abe9f9

Magnetron sputtering discharges

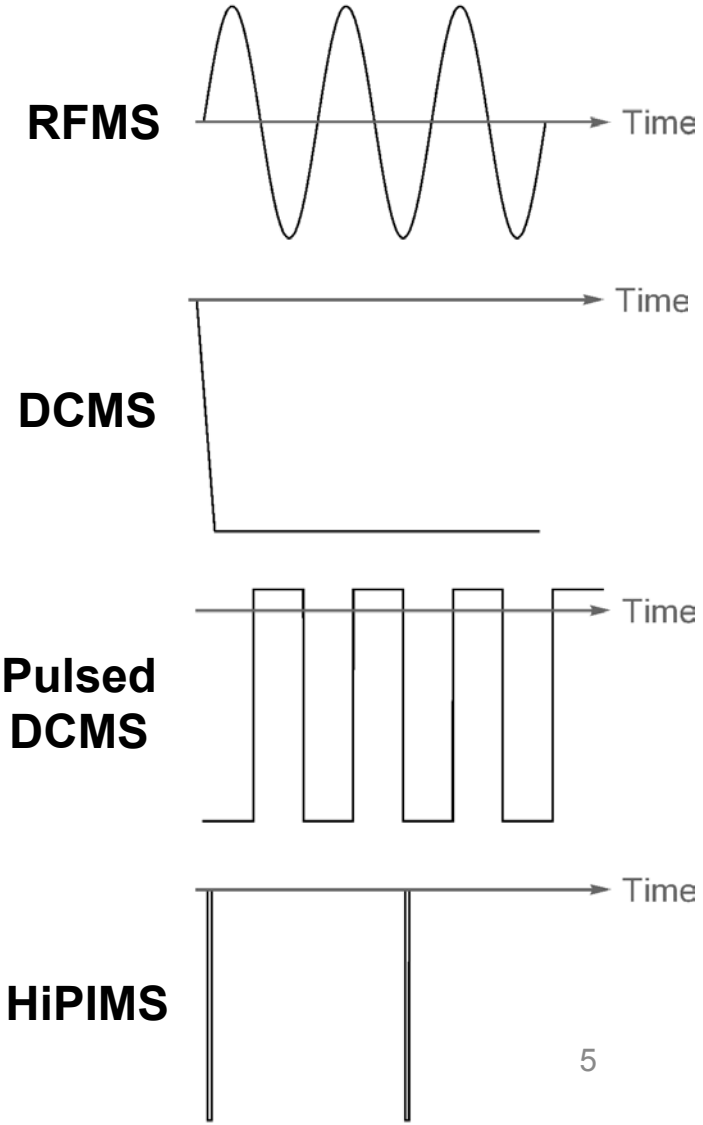
Schematic of a magnetron sputtering set-up



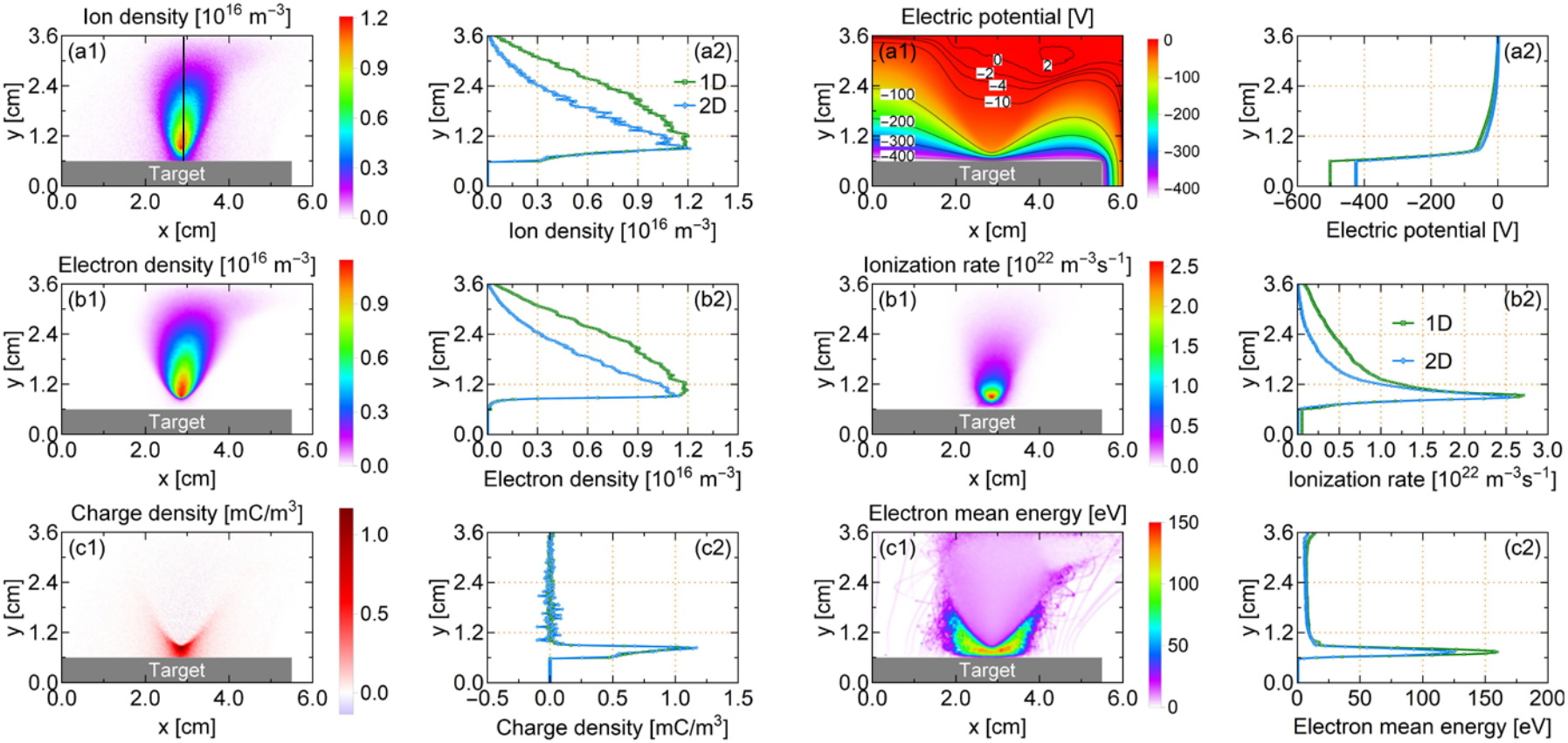


Magnetic field

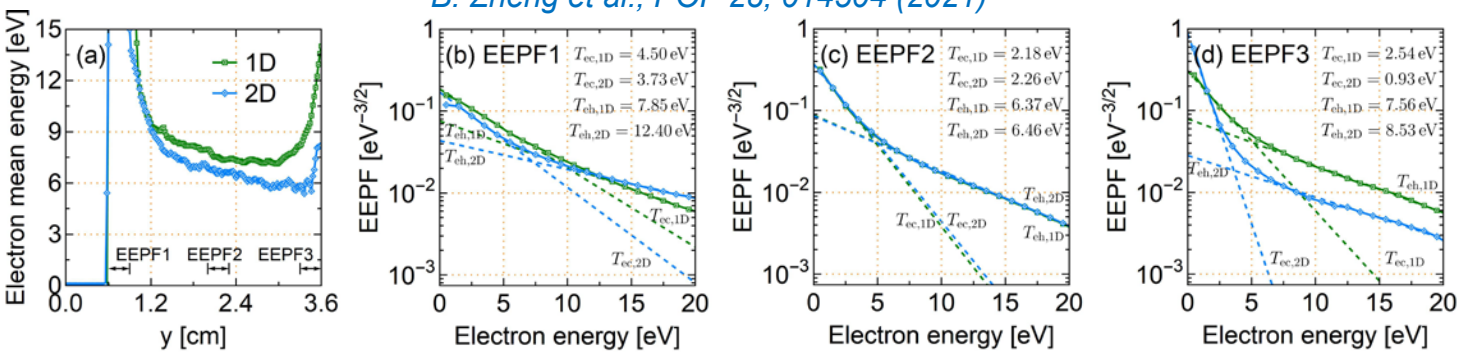
Voltage waveforms



PIC simulation of DC magnetron discharges: 1D vs 2D

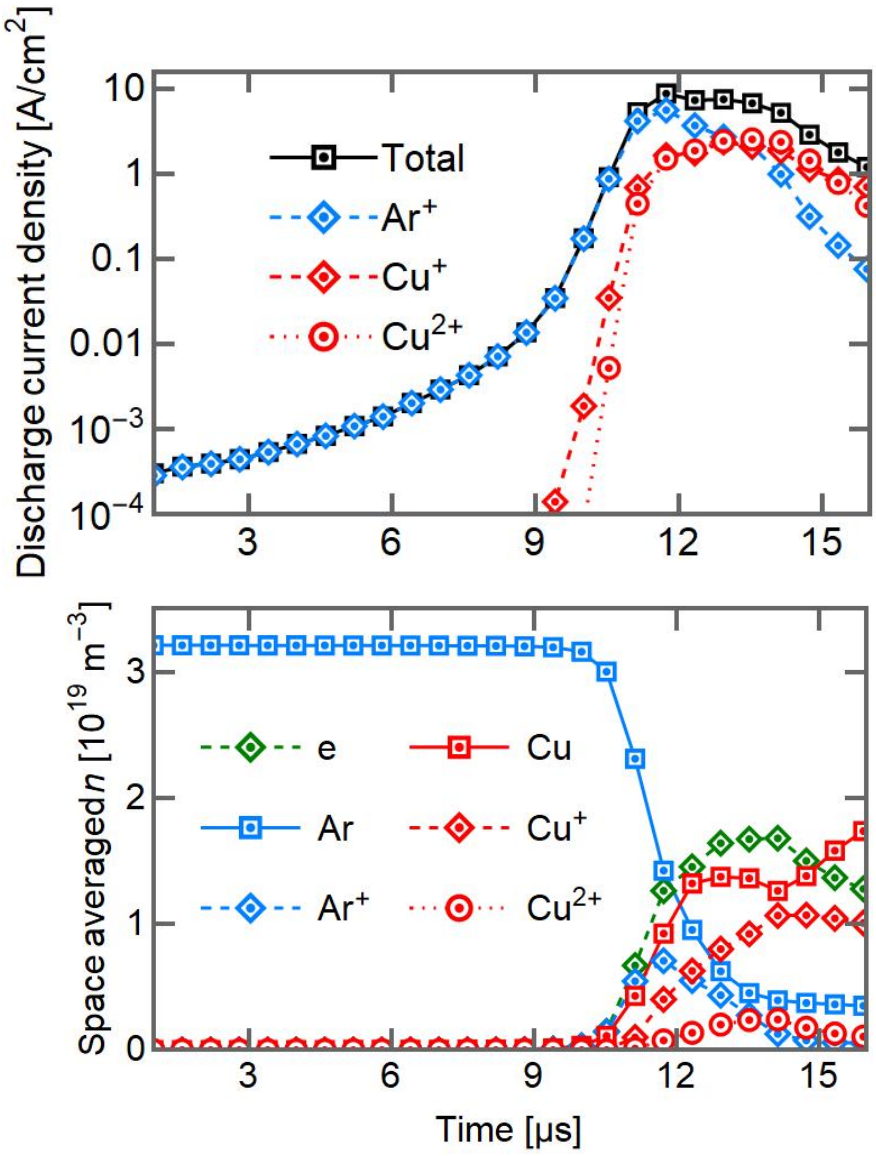


B. Zheng et al., POP 28, 014504 (2021)

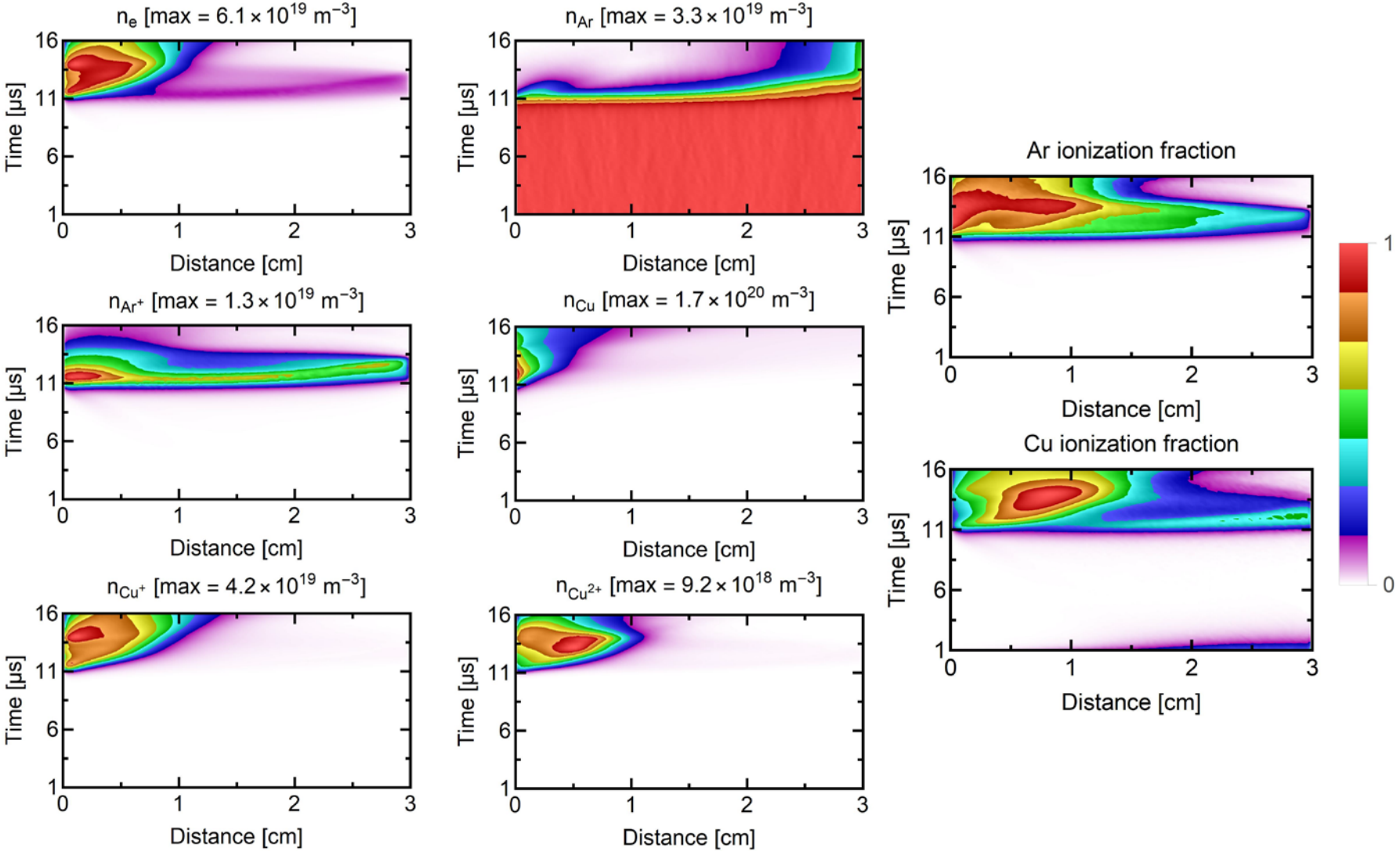


Discharge characteristics

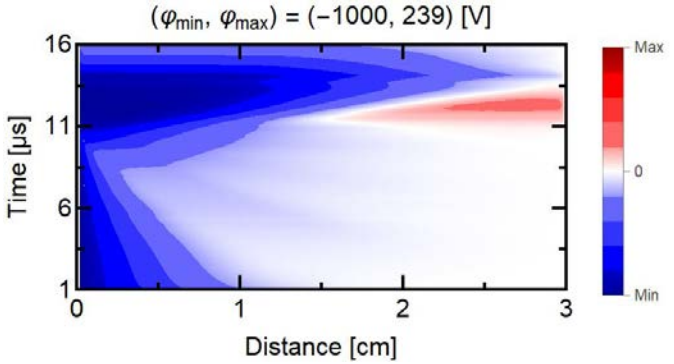
- Additional physical processes
  - Coulomb collisions
  - Sputtering wind
  - Metal ions
  - SEE induced by metal ions
- Discharge parameters
  - Voltage: -1 kV
  - Pressure: 1 mTorr
  - Gas: Ar
  - Target: Cu
  - Gap length: 3 cm

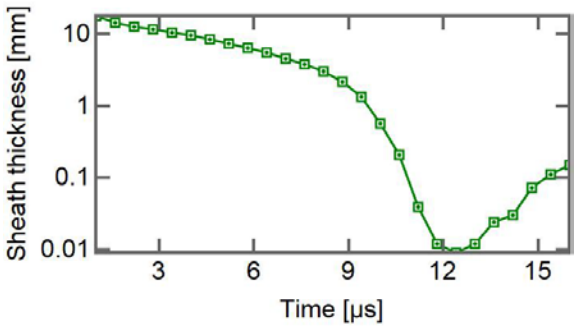


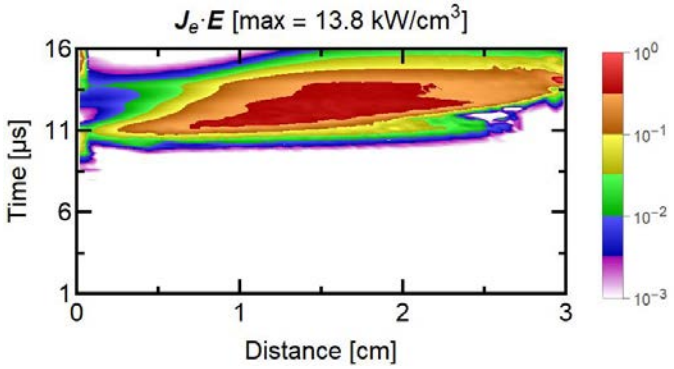
Spatiotemporal dynamics of species

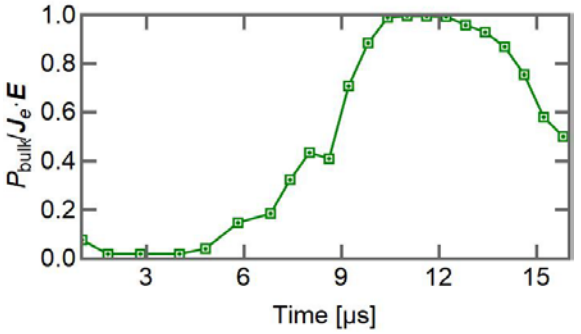


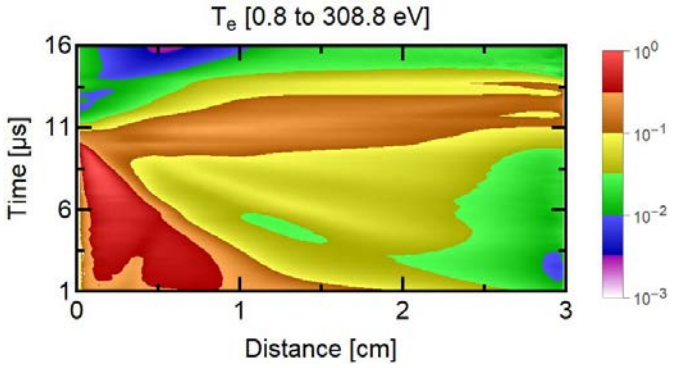
Electron kinetics

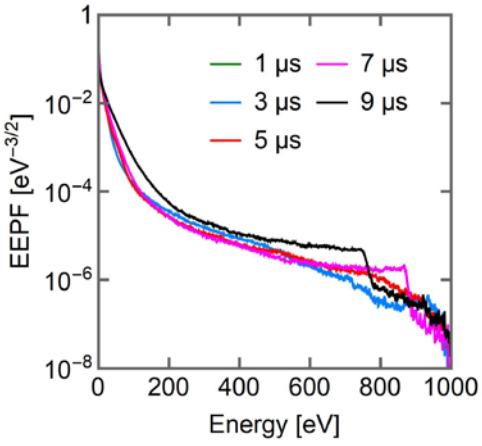


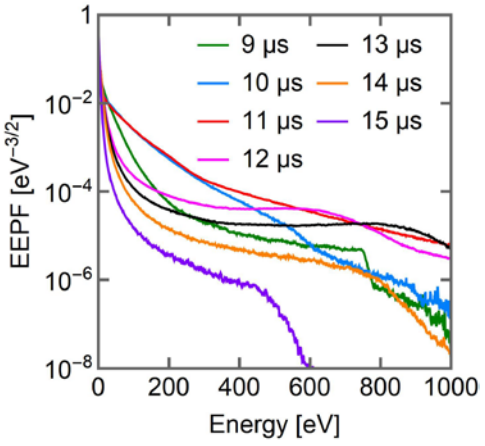






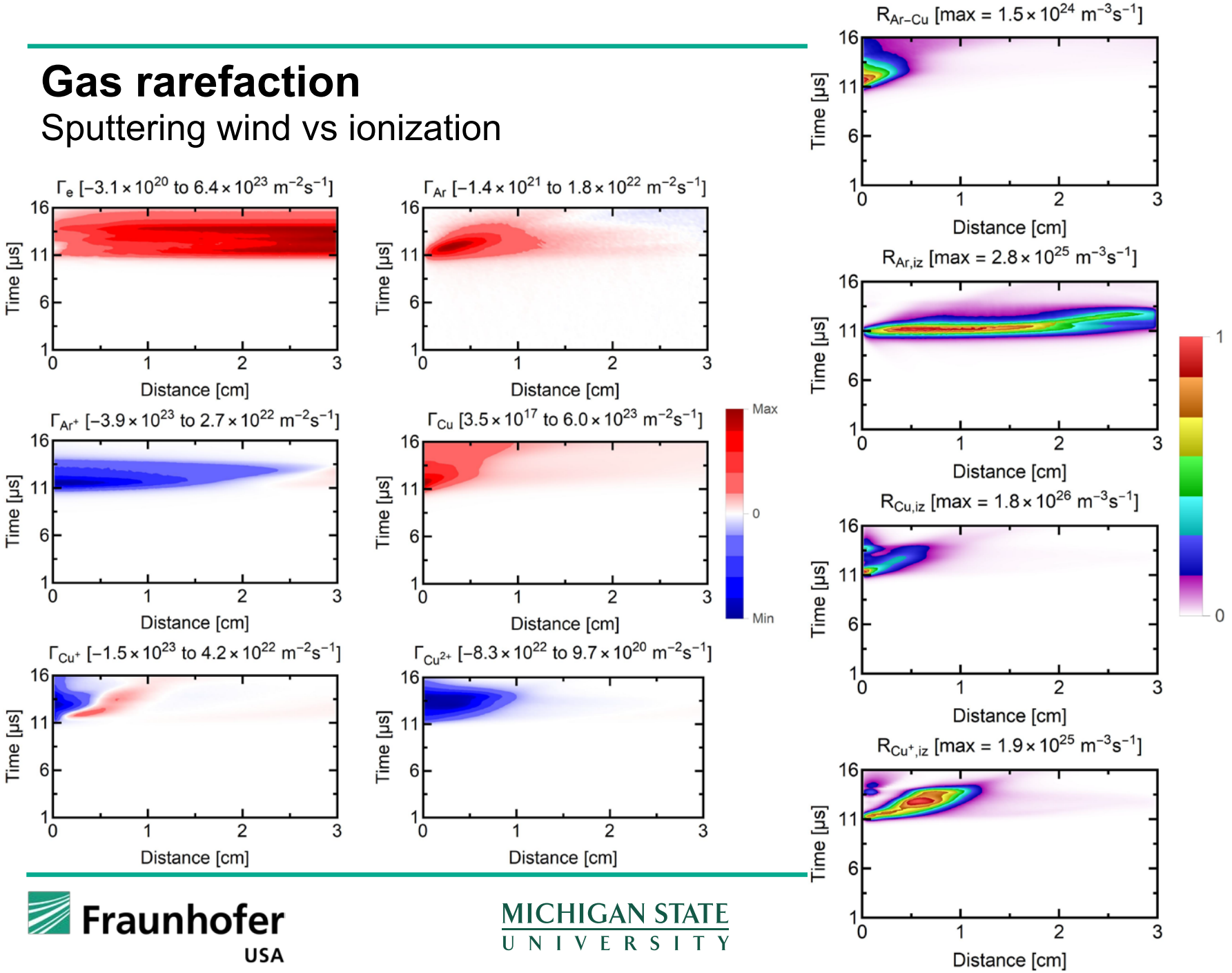






Gas rarefaction

Sputtering wind vs ionization



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Thank you

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