Simulation of Using Background Plasma to Neutralize for Charged Particle Thrusters on Nanospacecraft

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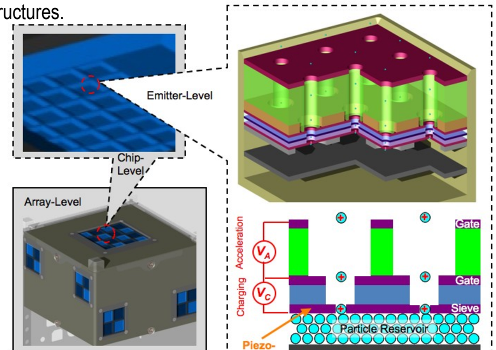
Motivation

- The Nanoparticle Field Extraction Thruster (NanoFET) is an electric propulsion device that charges and accelerates nanoparticles using electrostatic fields and MEMS structures.

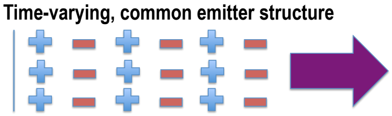


Conceptual Nanospaceraft with NanoFET

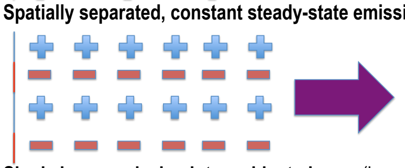
- Can NanoFET and other particle thrusters, e.g. colloidal thrusters, neutralize both the emitted beam and spacecraft while maintaining performance without an electron source?
  - **Through emission of positive and negatively charged particles**
  - **Through neutralization from background plasma**

Three Possible Neutralization Methods

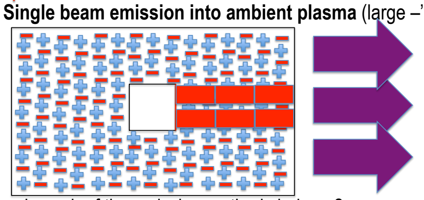
- Three possible neutralization methods
  - **Time-varying, common emitter structure**



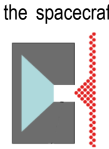
  - **Spatially separated, constant steady-state emission**



  - **Single beam emission into ambient plasma** (large –'s are particles)



- How do each of the emission methods behave?
- Will thrust performance be degraded?
- Why is neutralization needed?
  - Without neutralization in an electric propulsion system, the spacecraft will charge up creating a virtual cathode situation.
  - Other options are hollow cathode neutralizers and field emitter array cathodes.
    - Hollow cathodes increase complexity of the system as well as decrease efficiency by up to 20%.

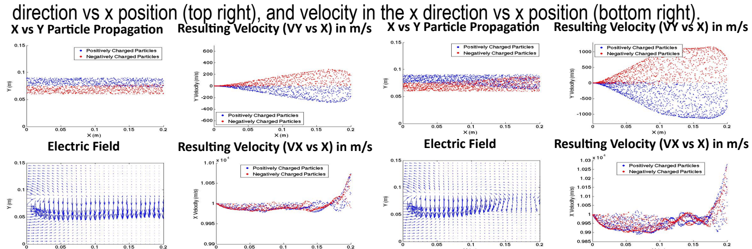


Evaluation Methodology

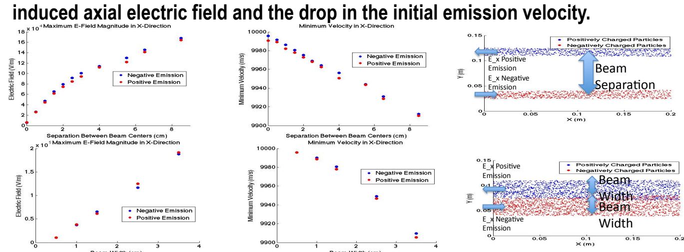
- Simulations are done in OOPIC PRO^{TM}, a 2.5 dimensional object-oriented particle-in-cell simulator based on XOOPIC Physics Package developed at UC-Berkeley.
- Parameters to control are: time step, coordinate system, simulation space, mesh, electrostatic model, particle characteristics, emitter characteristics, plasma density and composition, thermal temperature, drift velocity, and boundary characteristics
- We chose the following parameters:
  - 200 nm polystyrene particles->4.4*10^{-18} kg and 7.32*10^{-16} C->specific charge of ~**100 C/kg** compared to 50 nm hollow polystyrene particles->4.45*10^{-20} kg and 4.46*10^{-17} C->specific charge of ~**1000 C/kg**
  - Plasma density of **6.7*10^3 cm^{-3}** (electrons and atomic oxygen ions) and temperature of 0.1 eV
  - Current density of **1 A/m^2** in spatial-varying case or **1.6 uA/m^2** into ambient plasma
  - Particle exhaust velocity of **10^4 m/s ->1000 s** Isp, plasma drift velocity of **7500 m/s**
  - Time step of **5*10^{-8} s**, Cartesian coordinates, electrostatic model
  - Equipotentials on spacecraft walls, charge-bleeding dielectrics on simulations walls

Results to Date

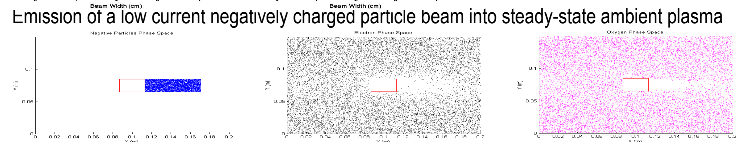
- Emitted **net neutral beam** with beam propagating left to right shown when the beam gets to the edge of the simulation space for 200 nm solid polystyrene particles with a specific charge of 100 C/kg (left) and 50 nm hollow polystyrene particles with a specific charge of 1000 C/kg. Diagnostics shown: Particle propagation (top left), electric field (bottom left), velocity in the y direction vs x position (top right), and velocity in the x direction vs x position (bottom right).



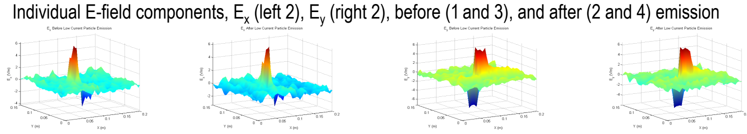
- As particles propagate, the image charge induced axial electric field local to the emitter causes decrease in velocity, with **maximum velocity drop of 0.22%** relative to the initial emission velocity for the 200 nm solid polystyrene particle.
- Radial electric field between beams only **slowly draws beams together** over 0.2 m of simulation space.
  - This indicates that the **heavy, equally massed** particles are slow to move.
- Emitting particles with a **higher specific charge will result in a larger drop in velocity** due to the image charge induced axial electric field; however, the beams converge more readily, making the **resulting beam more neutral**.
- **Reducing beam separation and beam width will result in reducing the image charge induced axial electric field and the drop in the initial emission velocity.**



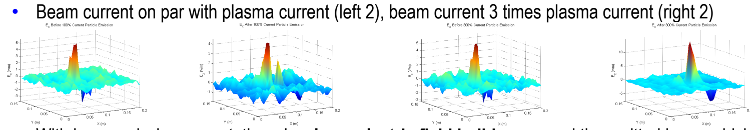
- Emission of a low current negatively charged particle beam into steady-state ambient plasma



- Wake effect to the right as plasma & particles are flowed to the right w/o perturbation of plasma
- Individual E-field components, E_x (left 2), E_y (right 2), before (1 and 3), and after (2 and 4) emission



- No significant change in E-field except E_x to the right of the spacecraft due to the emission of negatively charged particles: **E_x drop of 21%**
- Emission of a high current negatively charged particle beam into steady-state ambient plasma
  - Beam current on par with plasma current (left 2), beam current 3 times plasma current (right 2)



- With large emission current, there is a **large electric field build up** around the emitted beam which continues to grow as the current grows, eventually becoming **very significant**.

Conclusions

- Care must be taken in using self-neutralization of charged particle thruster, e.g. colloidal thrusters.
  - Neutralization possible through beams with narrow width and close separation.
  - Velocity degradation at high thrust/current density levels.
  - High electric field can be created external to thruster between positive & negative particle populations.
- For nanosatellite applications, may have negligible effects due to low current density levels.
- NanoFET must emit at low current levels to match plasma number density
- Nanospacecraft charges slightly negatively due to the ambient plasma (floating potential)
  - Helps to mitigate the image charge effects and accelerate negative particles away
- Higher plasma current density should draw ions to help neutralize emitted beam