PLUME PLASMA SPACECRAFT INTERACTIONS

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EXECUTIVE SUMMARY

High-fidelity numerical plasma modeling has been a key aspect for predicting physics in plasma. Using Blue Waters, the researcher conducted a series of numerical studies on a variety of plasma-based flows such as space plasma–surface interactions including modeling spacecraft contamination from electric propulsion thrusters and anomalous spacecraft charging in low Earth orbit. These simulations are unique in that both electrons and ions are treated as computational particles. In order to do this, a GPU-based code, called CHAOS, was developed during the researcher's previous Blue Waters projects, and has demonstrated an 85% strong scaling. Given the immense range of length and timescales in plasma-based flows, a parallel computing architecture such as Blue Waters is necessary for their self-consistent numerical modeling.

RESEARCH CHALLENGE

Solar cell arrays provide onboard power for most spacecraft in orbits around Earth. These arrays have about a 1,000 V potential drop along their span, using wires to interconnect multiple dielectric photocells (Fig. 1). The positive potential of the interconnects attracts ambient electrons, creating an additional current loop that drains power generated by the solar panels. When the voltage across the interconnect is increased beyond a certain limit, the current dramatically shoots up, causing a large parasitic current. This phenomenon is known as "snap over." The major contribution of the collection current to the interconnect comes from the secondary electrons emitted by nearby dielectric surfaces. The objective of this work is to model plasma physics near solar panel interconnects using a kinetic particle-in-cell approach and to establish how plasma surface interactions affect parasitic current.

METHODS & CODES

The modeling was performed with the direct simulation Monte Carlo (DSMC) particle-in-cell (PIC) code, CHAOS (CUDA-based hybrid approach for octree simulations) that was developed to study neutral flows through porous media under a previous Blue Waters effort and was reported earlier. The approach utilizes the Morton Z-curve octree structure and a volume-of-fluids approach used to compute volume of cut-leaf nodes using ray-tracing, which is very efficient on GPUs [1]. The code has been used previously to model ion thruster plume contamination of spacecraft in the backflow region in a fully kinetic manner [2]. To model the snap-over phenomenon, the secondary electron emission process has been added to the code to model electron emission yields from magnesium fluoride, a typical dielectric, as a function of the incident ambient electron energy at the surface. It is assumed that every secondary electron that is emitted by the dielectric surface also leaves a positive charge on the surface. Emitted electrons are assumed to have an energy of 1 eV with velocities taken from a cosine distribution.

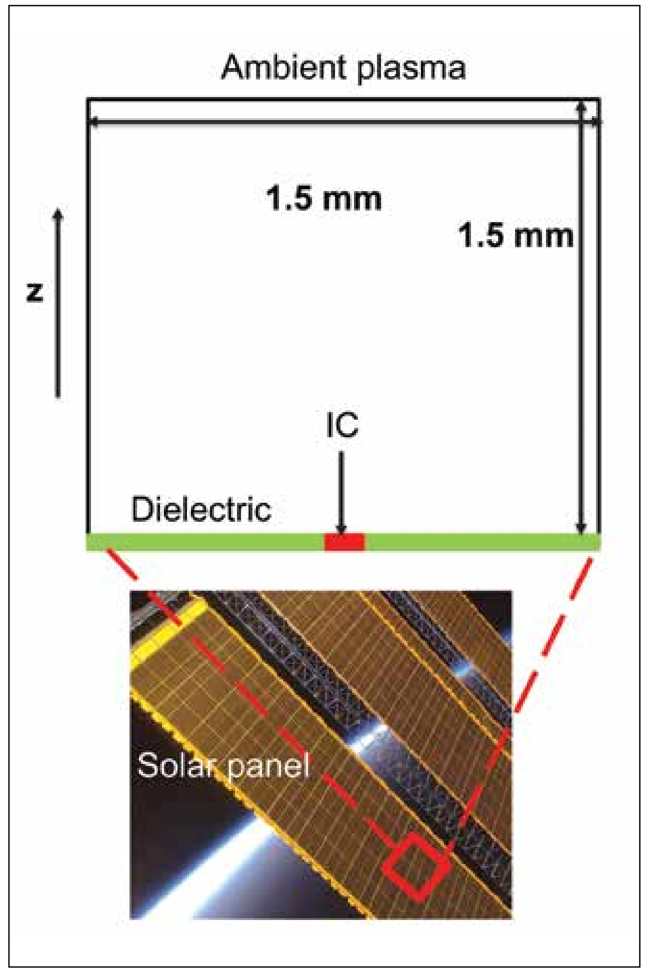

Figure 1: Computational domain of ambient plasma in front of solar cell array. Two dielectric elements are shown with the interconnect (IC) lying at 0.75 mm on the surface and their relationship to a typical solar cell array on a spacecraft.

Fig. 2 shows a key result from the research that was recently presented [3]. The left-hand side (LHS) chart shows the time variation of surface potential at three numerical probes that are approximately 0.075, 0.15, and 0.31 mm from the interconnect (IC), and the right-hand side (RHS) chart shows the accumulating surface charge on the dielectric photosensitive material as a function of time. When the secondary electron emission (SEE) is included, the dielectric discharges more slowly and to a higher potential, attracting more primary electrons from the ambient plasma. The surface charge on probes two and three for an emissive dielectric surface reaches a steady value at a higher charge than the charge for a nonemissive dielectric surface, as expected. However, at probe one, which lies very close to the IC, the charge collected on the surface keeps falling (RHS), even when the electric potential has reached a steady value (LHS). This shows that the region near probe 1 behaves as a conductor and collects an electron current similar to that of the IC.

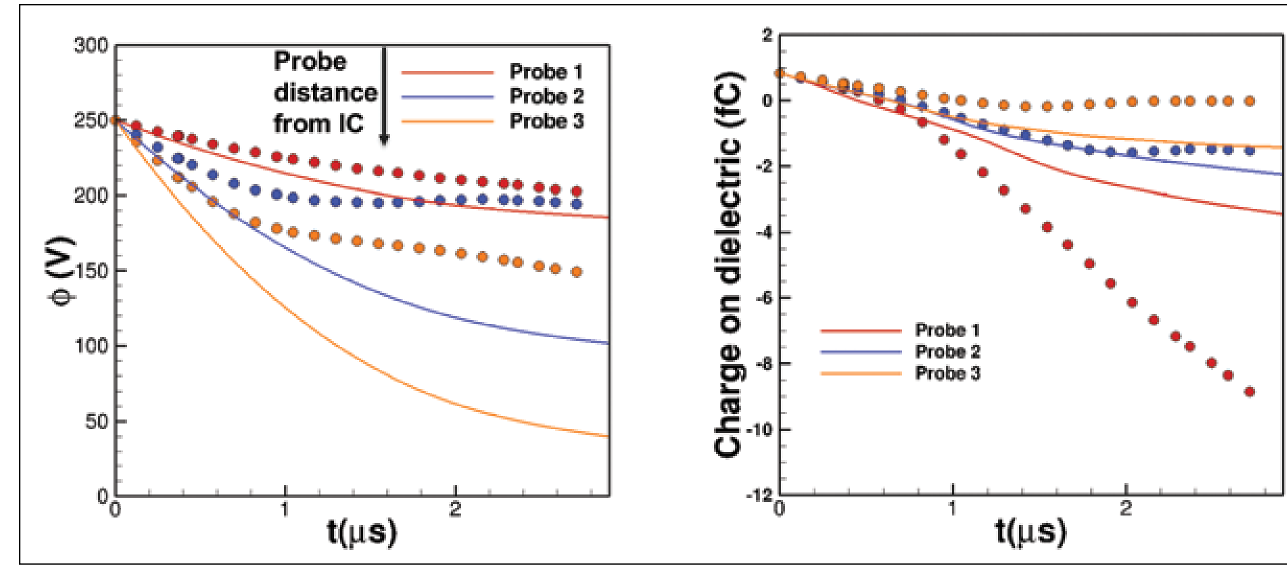

Figure 2: Electric potential and dielectric charging as a function of distance from the interconnect for simulations with and without secondary electron emission (SEE). Solid lines and closed circles indicate no SEE and with SEE, respectively.

These results have been obtained with a potential drop of 250 V across the IC. The effect of SEE is to cause electrons to gain kinetic energy of up to 250 eV initially when the surface is charged to a potential of 250 V at t = 0. This incident electron energy gives a yield of about 3.0 secondary electrons that charges the surface locally positively and emits two additional electrons near the dielectric. The more positive dielectric surface allows electrons in front of the dielectric with SEE to gain a higher z-velocity than without SEE, thereby increasing the total electron flux on the solar panel surface.

To understand the sensitivity of the results to the energy at which electrons are emitted from the dielectric material, additional simulations were performed wherein the emitted energy was reduced from 1 to 0.1 eV. The PI found that electrons have a higher density near the dielectric surface for the higher emitted energy case because the electrons emitted from the dielectric surface are attracted toward the same positively charged dielectric surface, and the ones that are emitted with the lower kinetic energy are more likely to be reincident on the dielectric surface, effectively negating the positive charge on the surface caused by the secondary electron emission. This was also evident in the time discharging of the surface electric potential where the time variation of surface potential on probes two and three for the lower emitted energy case was closer to the case without SEE than the higher energy emitted case. Since a major fraction of emitted secondary electrons is reincident on the dielectric surface for the lower energy emitted case, they do not reach the interconnect, causing a 25% decrease in the IC current for the lower energy emitted case.

WHY BLUE WATERS

As efficient as the algorithms are in the CHAOS code, the kinetic modeling of electrons in the presence of heavy ion masses such as positive atomic oxygen or xenon is rare because such simulations are computationally challenging. The ability to perform heterogeneous computing on a large number of combined CPU/GPU nodes is unique to the Blue Waters architecture. This hardware has enabled the PI to demonstrate the first ever such simulations of plasma-based flows.