Modeling of space-charge effects in thermionic devices

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Introduction: the formation of space charge cloud in (photon enhanced) thermionic emitters is a known issue that may dramatically limits the performance of devices like the recently proposed Photon Enhanced Termionic solar cells [1].
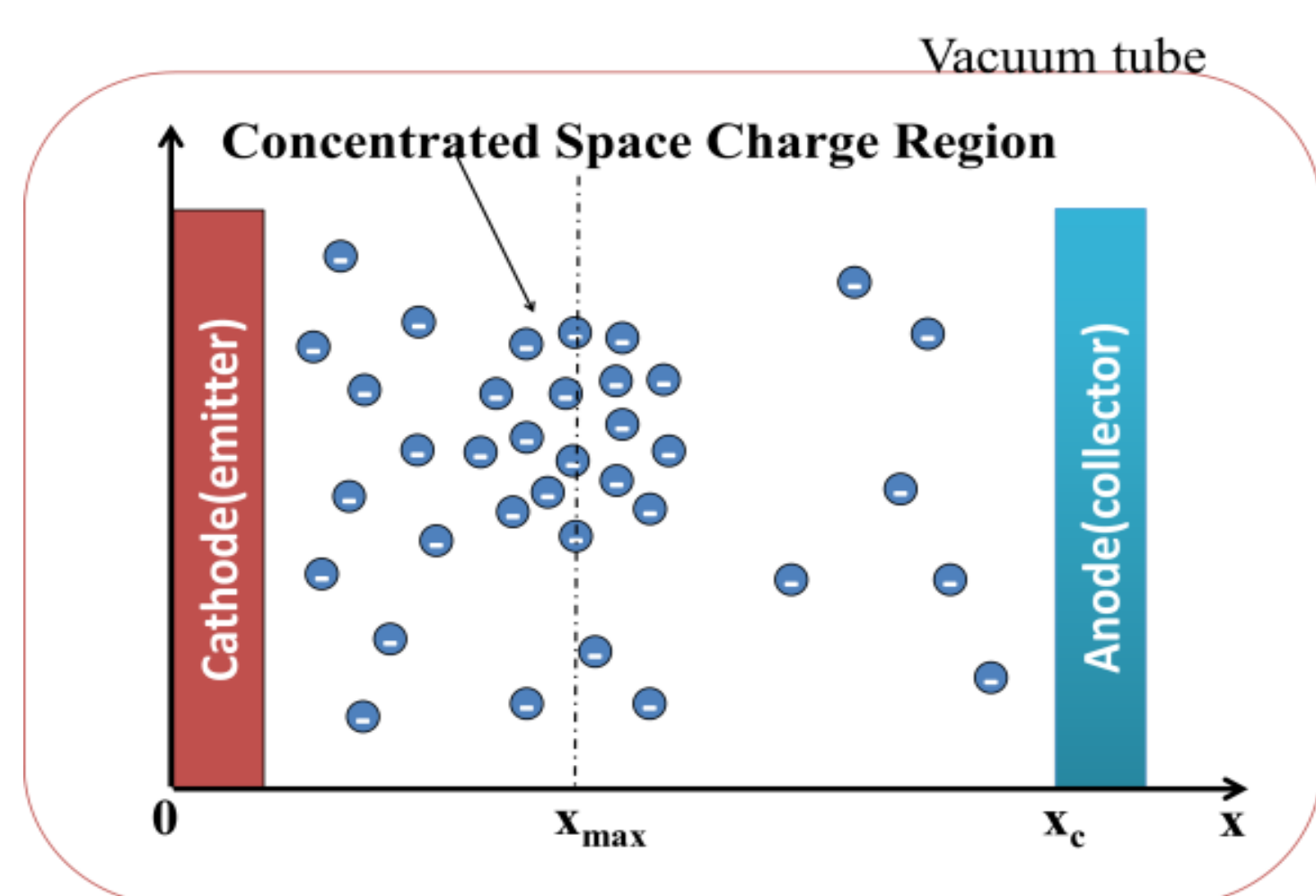

Figure 1. Scheme of the space charge cloud formation

Aim: Properly modeling space charge limited electron emission in 3D architectures

Computational Methods:

Starting from the Electron beam divergence model in COMSOL Library, we implemented a <u>Successive over relaxation</u> (SOR) algorithm [2]:

Initial conditions: $V(z) = 0$, $\rho'_{-1} = \rho' = \rho = 0$
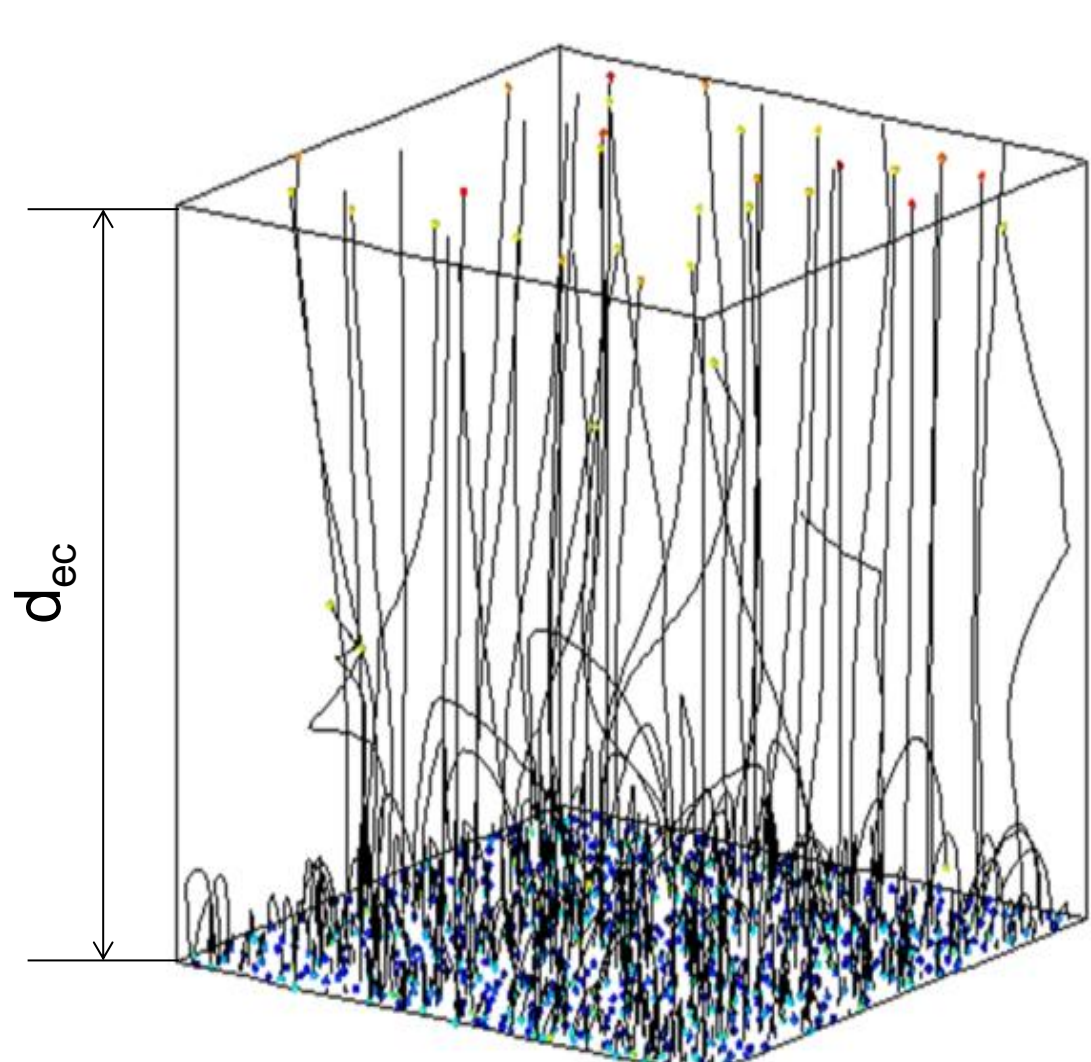
ρ : space charge at present iteration

ρ_{-1}: space charge at previous iteration,

$V(z)$: self potential

1. Step 1: **Particle Tracing**: calculation of ρ from electron trajectories

2. Step 2: **Electrostatic 1**: calculation of V from $\rho' = \rho*\omega + (1- \omega)* \rho'_{-1}$, ω : relaxation parameter

3. Step 3: Ausiliary **Electrostatic 2**: $\rho'_{-1} = \rho' = \varepsilon*div(\mathbf{E_1})$

- "bounce" boundary conditions at sides
- Inlet BC for emission, featuring Maxwell-Boltzmann velocity statistics, random angular emission and emission position
- N=1000 particles simulated

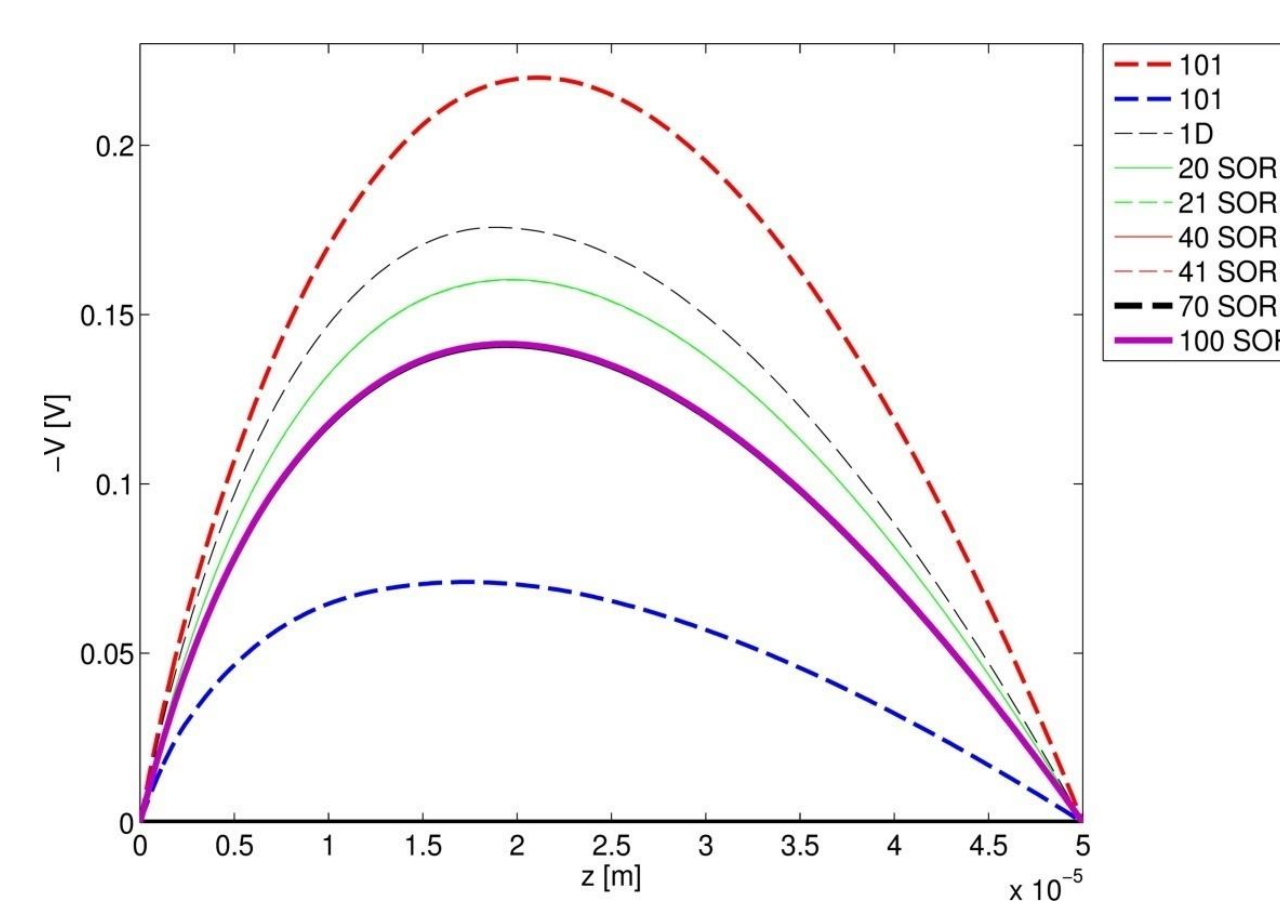**Figure 2**. Simulation box and Calculated electron trajectories

Results:

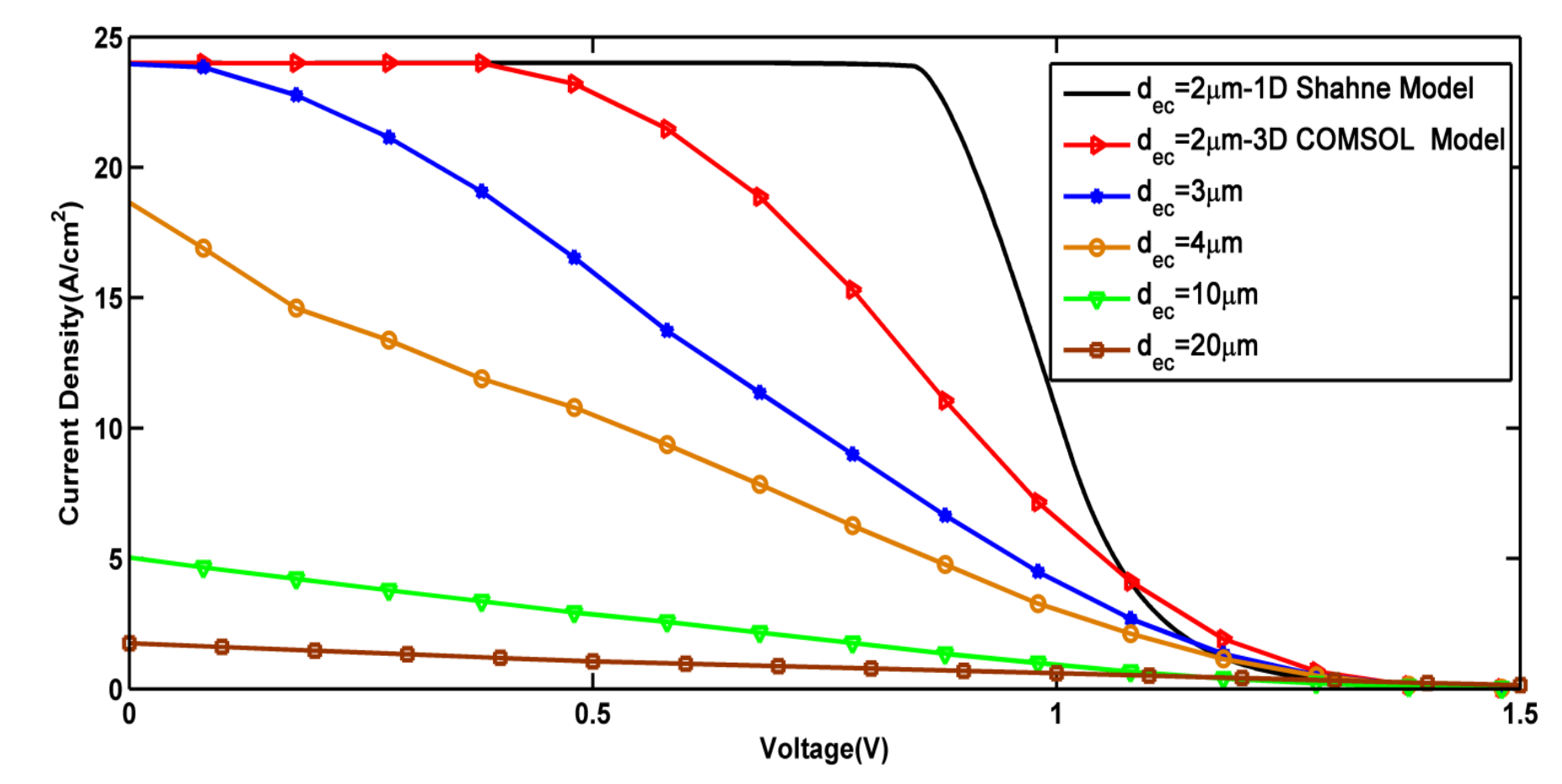**Figure 3**. Space-charge self potential

Figure 4. Calculated J-V curves for a PETE solar cell for different anode-cathode distances

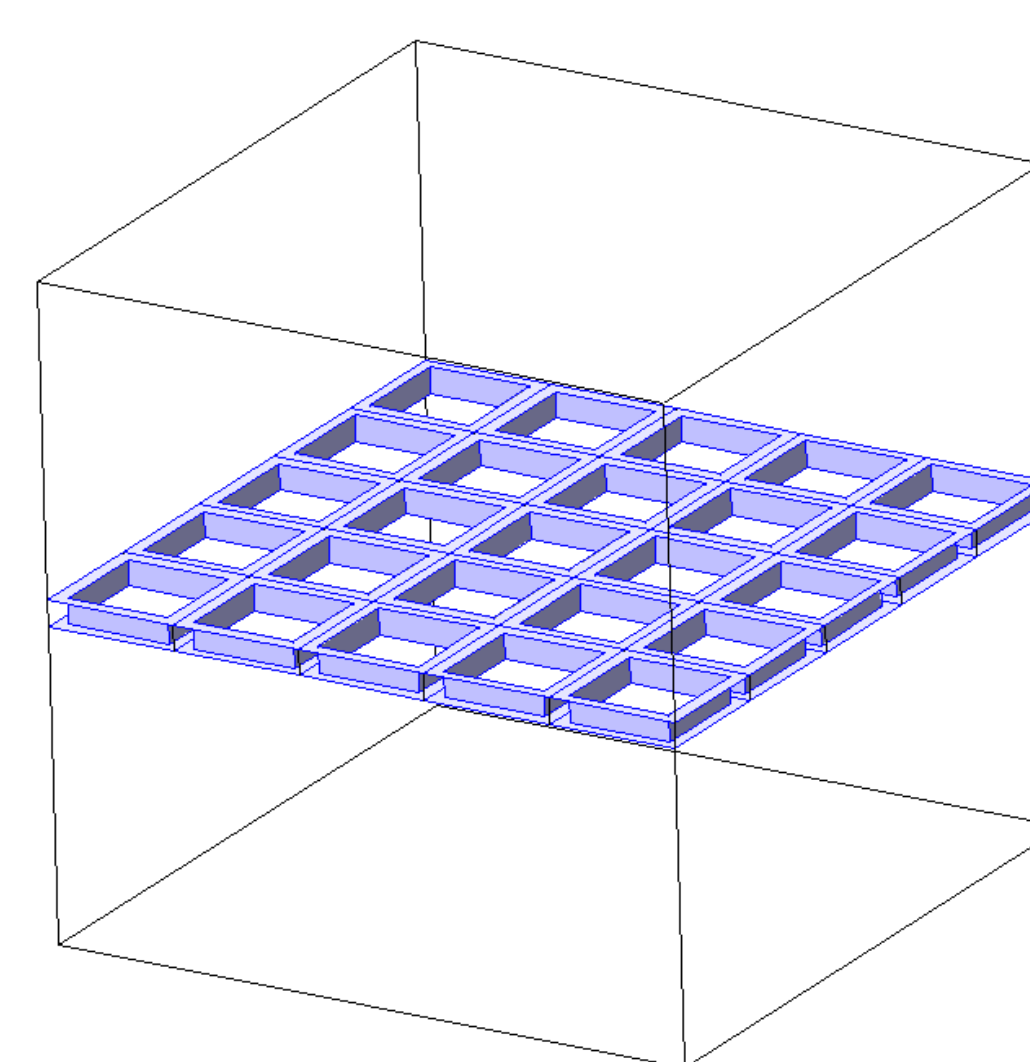The introduced SOR algorithm allows to reach convergence of the iterative computation.

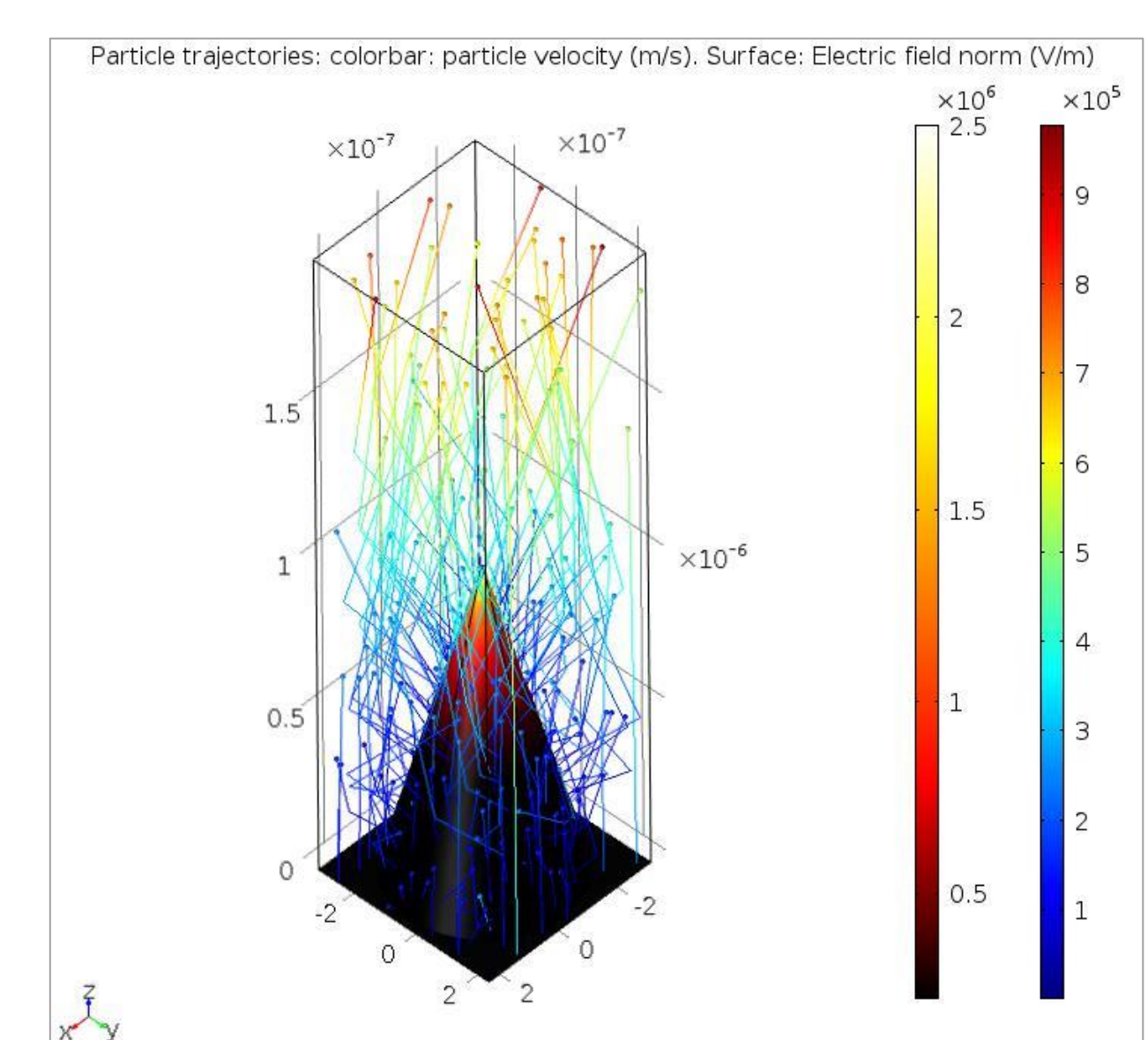**Figure 5**. gate electrode insertion in anode-cathode

Figure 6. Nanostructured cathode surface

The model now is being exploited to investigate 3D architectures to mitigate the space charge cloud effect.
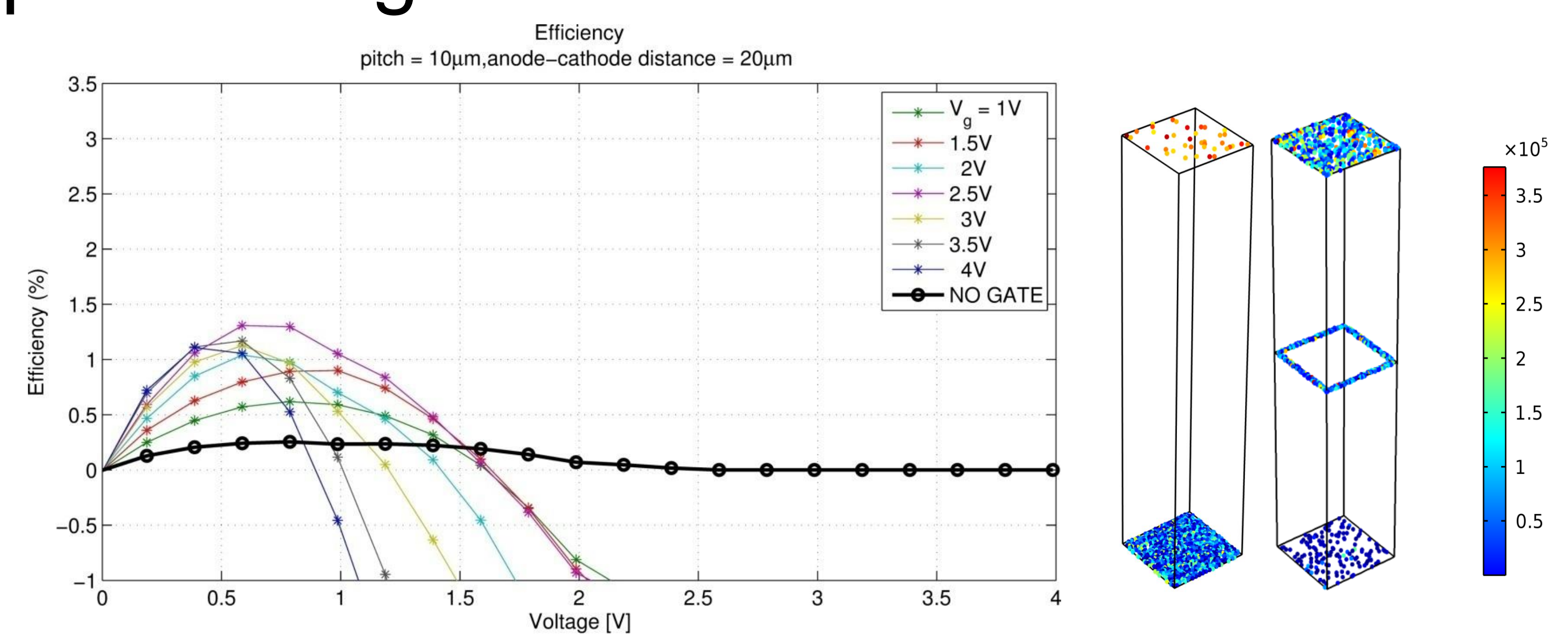

Figure 7. Efficiency of PETE solar cell with 20µm anode-cathode distance with additional gate electrode insertion. Final particle positions without and with gate.

Conclusions: We developed a tool for analyzing space charge limited electron emissions in complex 3D architectures

References:
[1] J.W. Schwede, et a., Nat. Commun. 4 1576 (2013).
[2] A. R. Knox, Solid State Electronics 45, 841 (2001)