



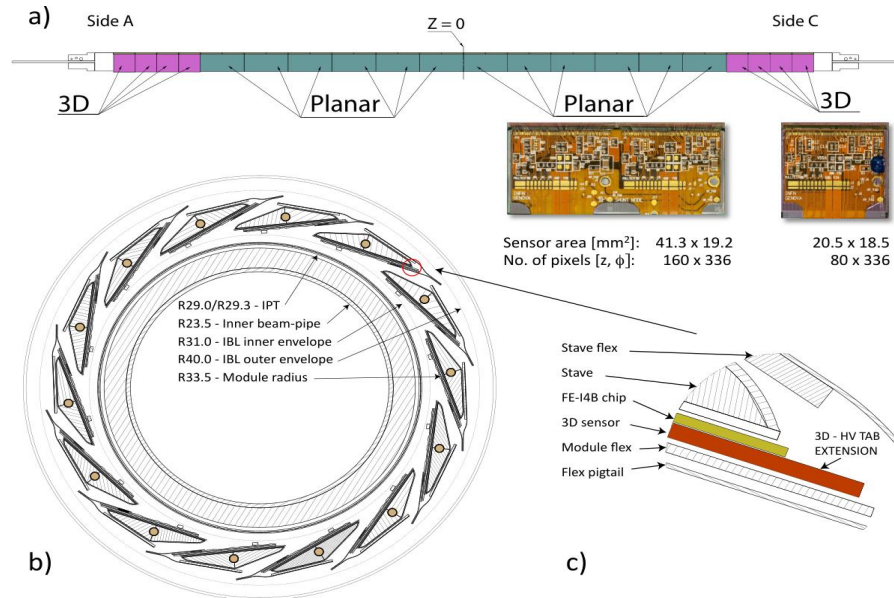
Design and fabrication of a Novel 3D Trench Columnar Electrodes Silicon Sensor

Huimin Ji, Manwen Liu, Zhihua Li, Jun Luo, Peng Xu

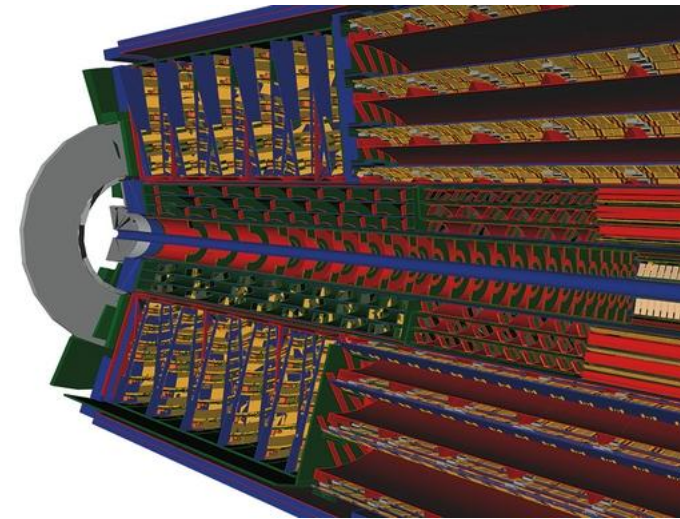
Institute of Microelectronics, Chinese Academy of Sciences (IMECAS)



- The continuous upgrading and replacement of major scientific facilities have put forward higher requirements for the performance of sensors.



Schematics of the IBL with the placement of the 3D modules at the ends of the staves: (a) Stave layout with the organization of planar and 3D sensor modules. (b) Layout of the IBL detector with the 14 staves around the IBL positioning tube (IPT) and (c) zoom of one stave side where a 3D sensor module is visible.
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<https://doi.org/10.1088/1748-0221/10/05/C05001>

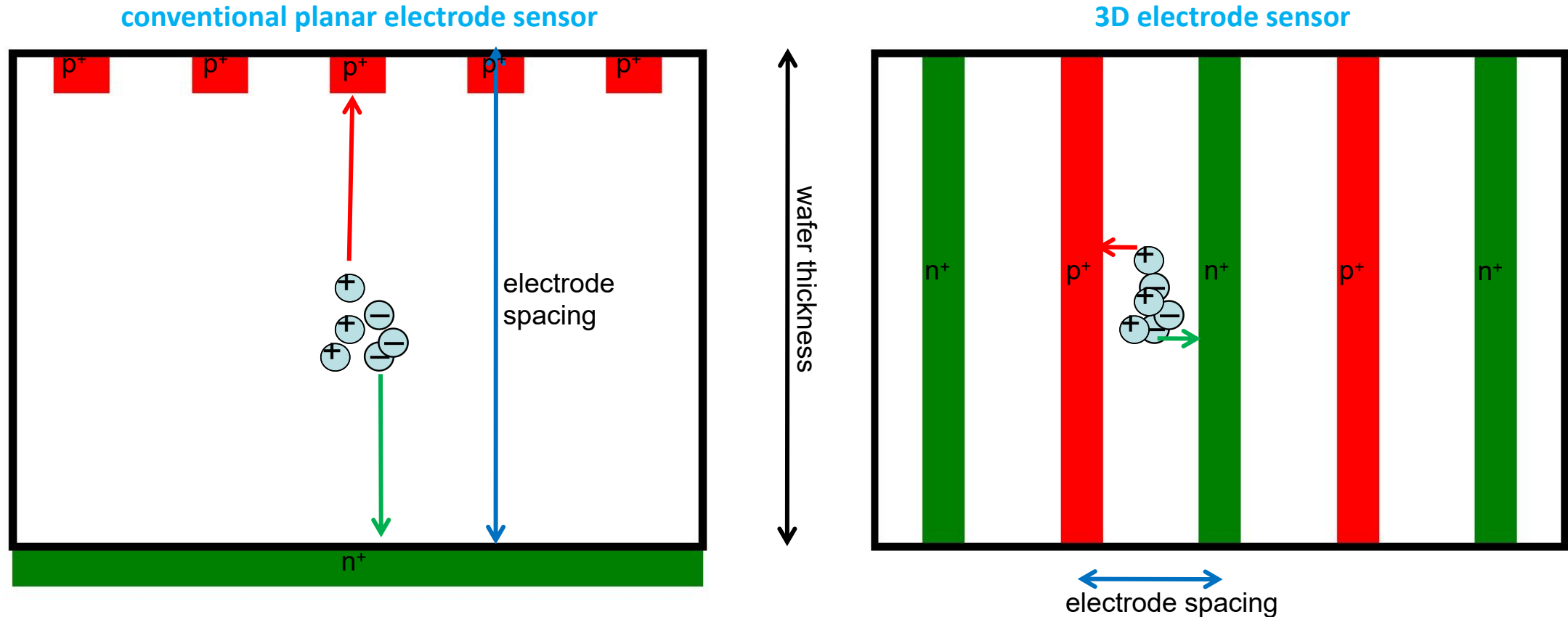


The ATLAS ITk, comprising strip (outer layers) and pixel (inner layers) detectors with more than five billion readout channels. (Image: ATLAS Collaboration/CERN)

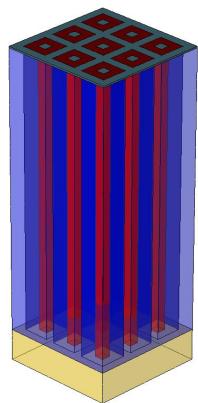
- The Large Hadron Collider (LHC) and Future Circular Collider (FCC) at CERN
- Beijing Electron-positron Collider, Shanghai Synchrotron Radiation Facility
- Large Circular Electron-Positron Collider (CEPC), X-ray free Electron Laser

>>> Background

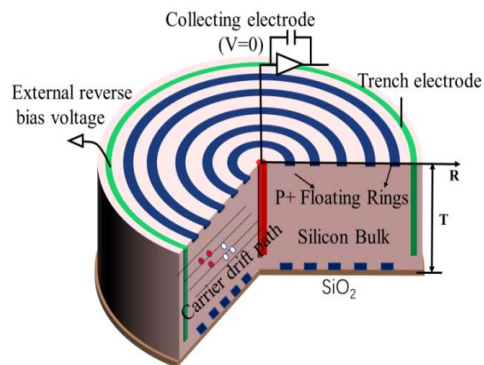
- Compared with planar sensors, 3D detectors have the following advantages: fast response, radiation hardness, low power consumption and low noise.



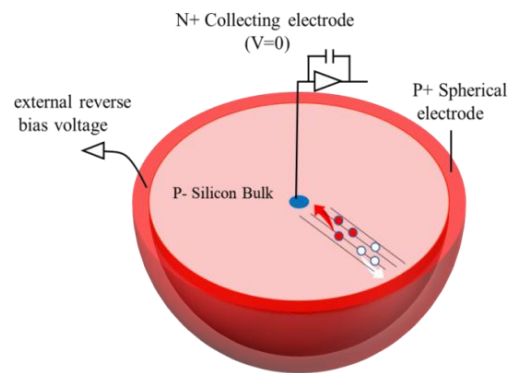
- In the early stage, multiple theoretical models of 3D trench electrode sensors were proposed and verified through TCAD simulation.



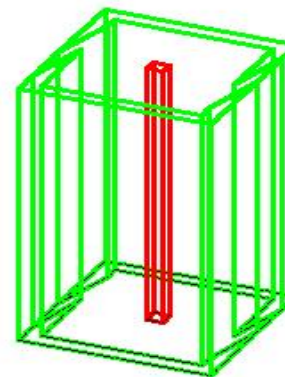
Ultra-fast,
radiation-resistant



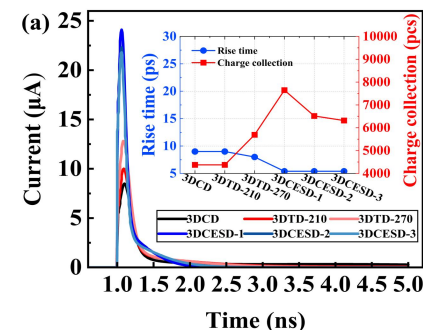
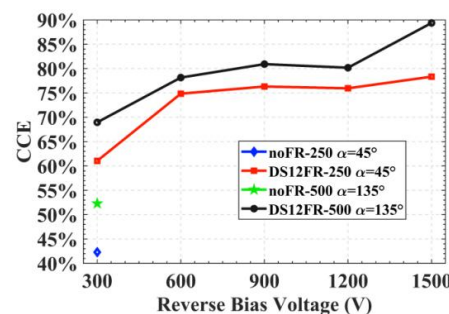
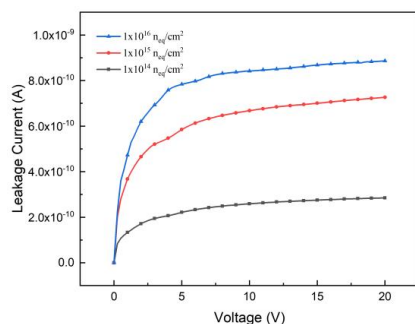
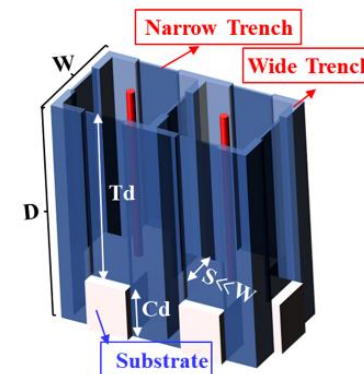
Large area,
small proportion of dead zones



Low capacitance, uniform
electric field distribution

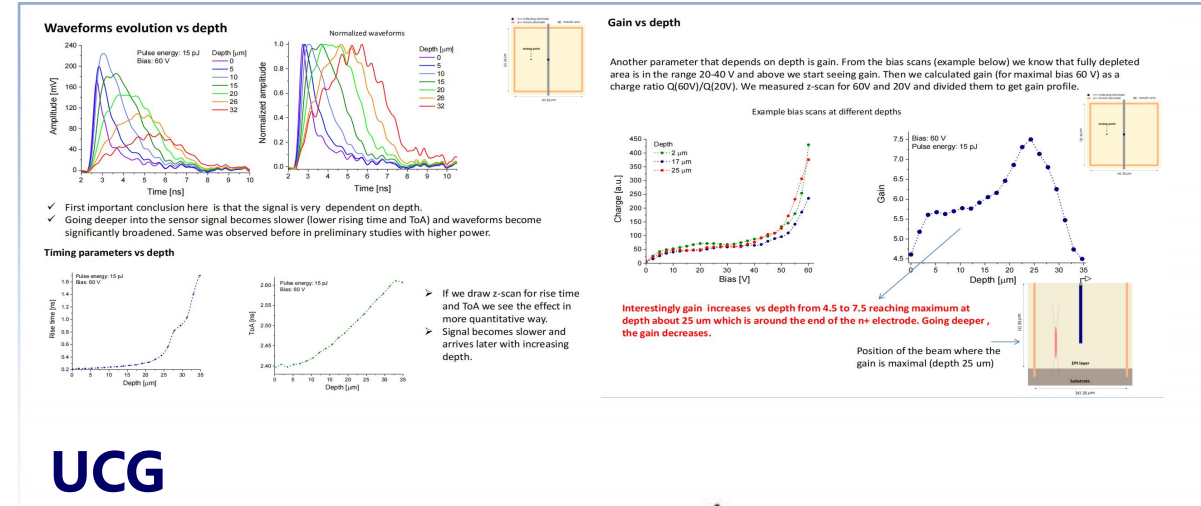
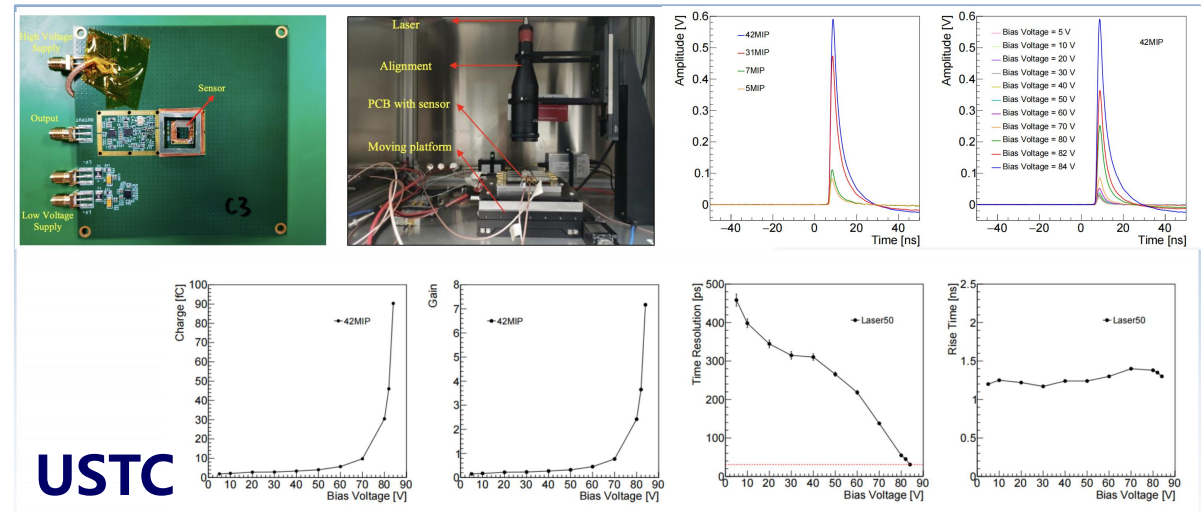
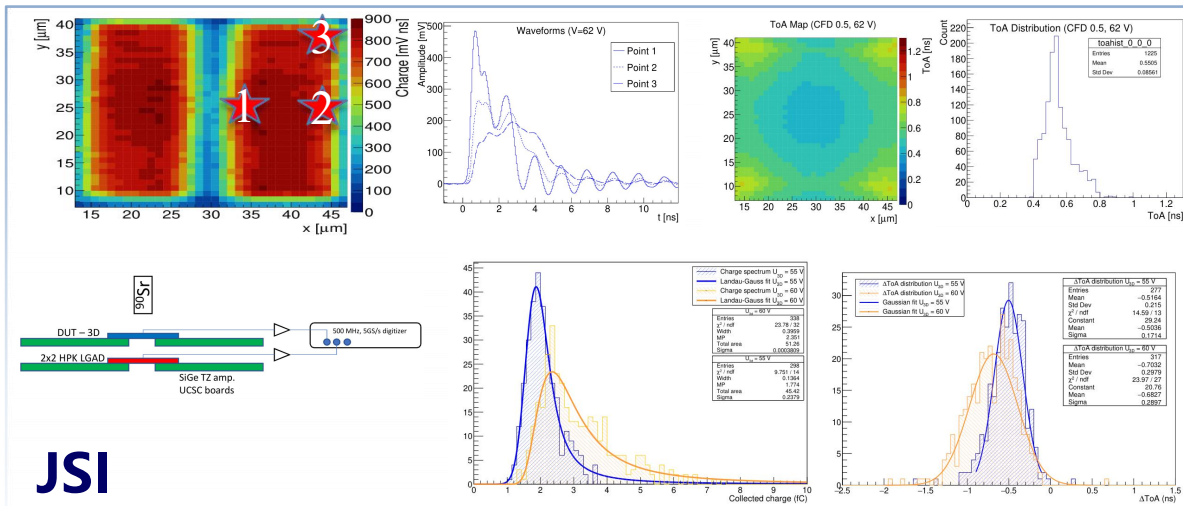
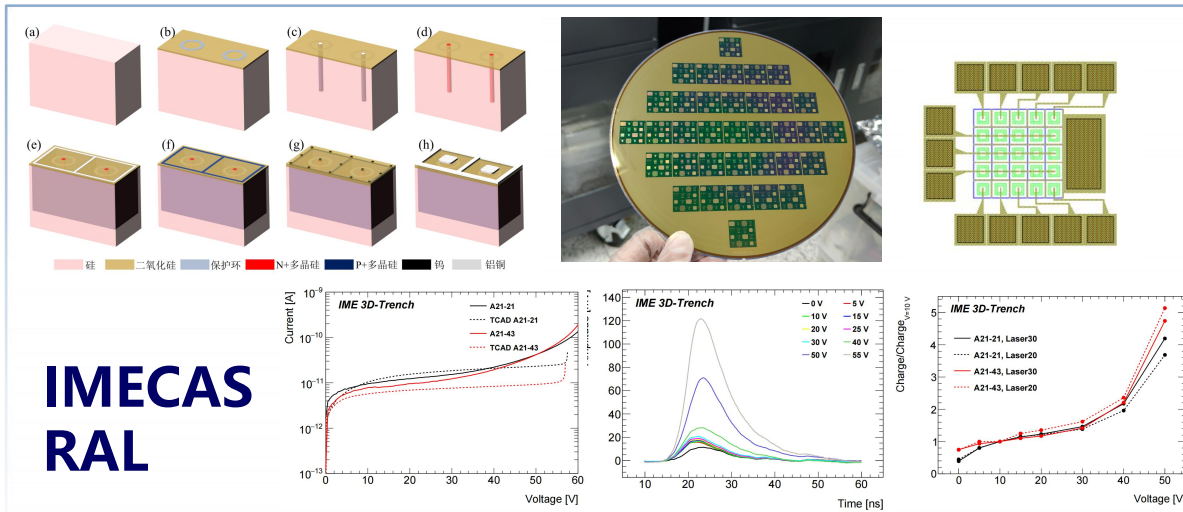


small proportion of dead zones,
Through-etching

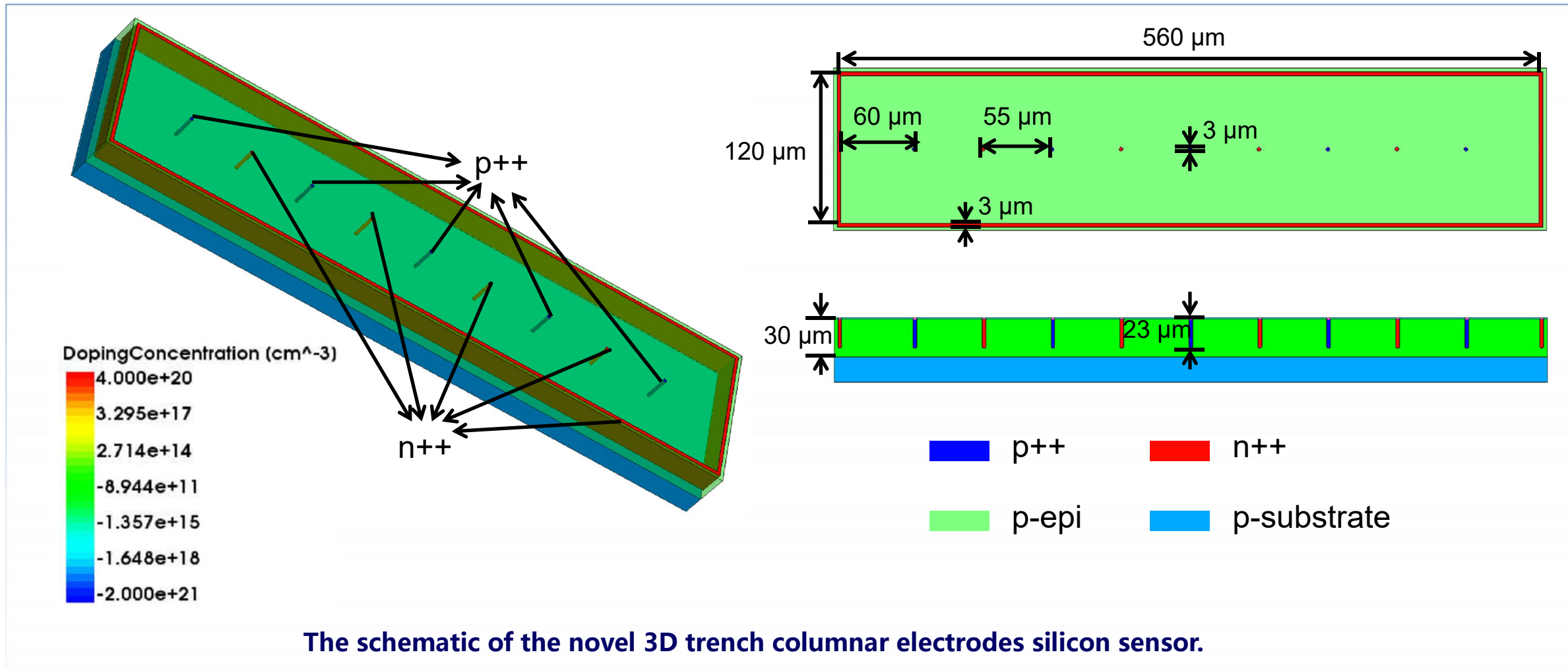


TCAD simulation verified its strong radiation resistance, high charge collection, and ultrafast time characteristics

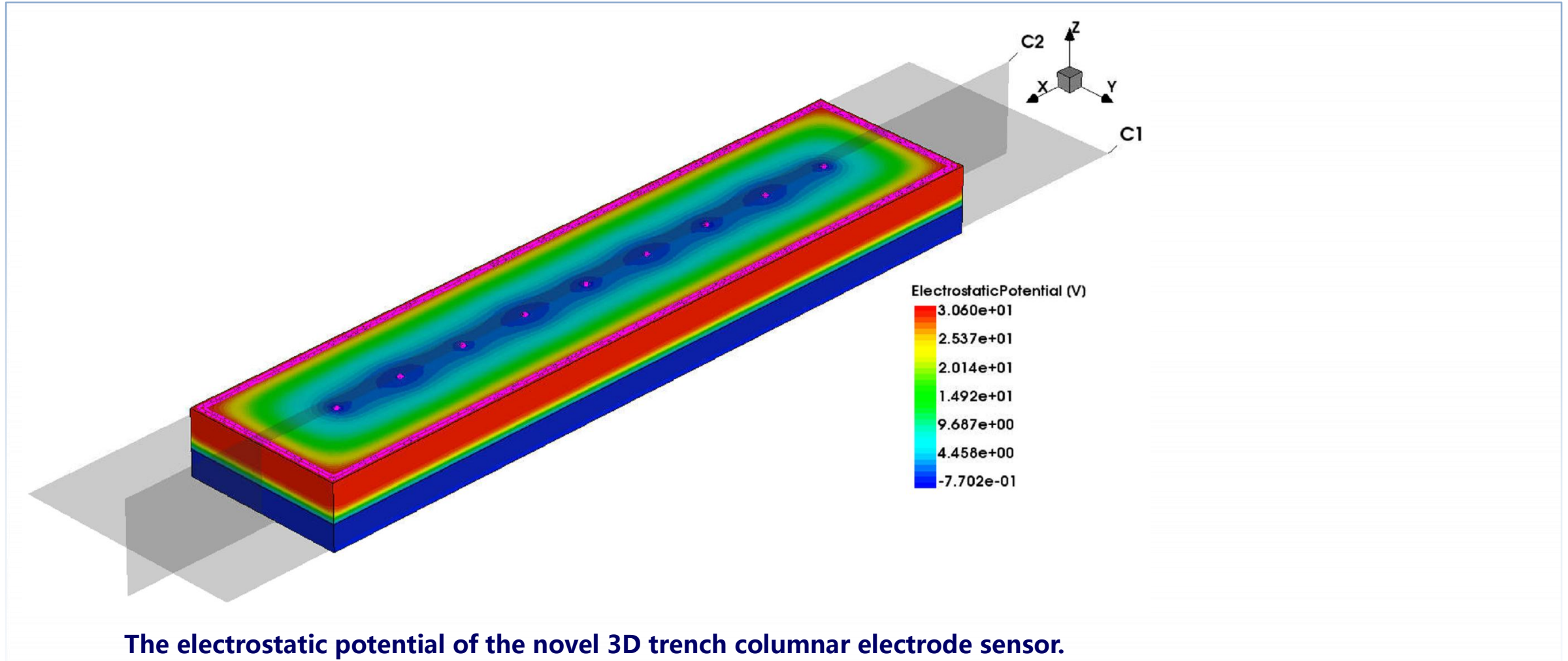
➤ IMECAS 3D Column-Trench silicon sensor with internal gain.



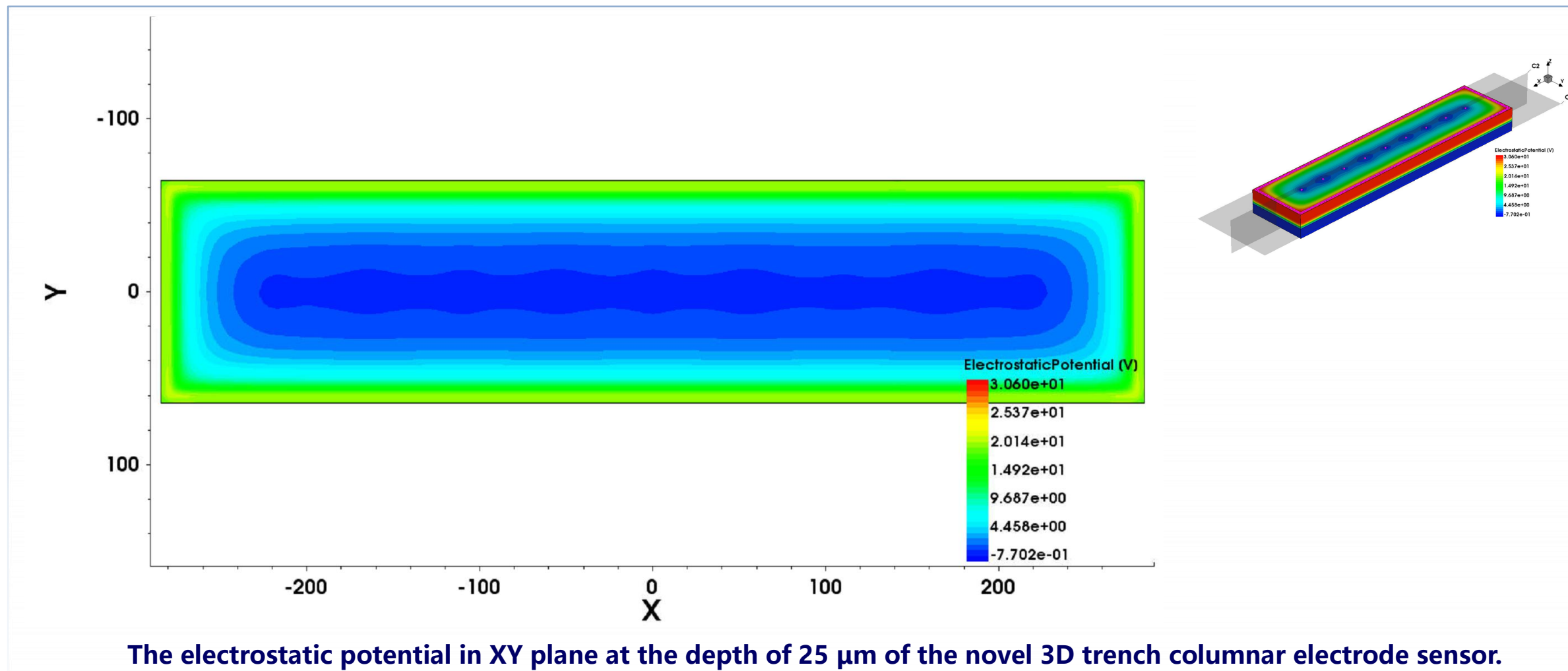
➤ The novel 3D trench columnar electrodes silicon sensor has been proposed.



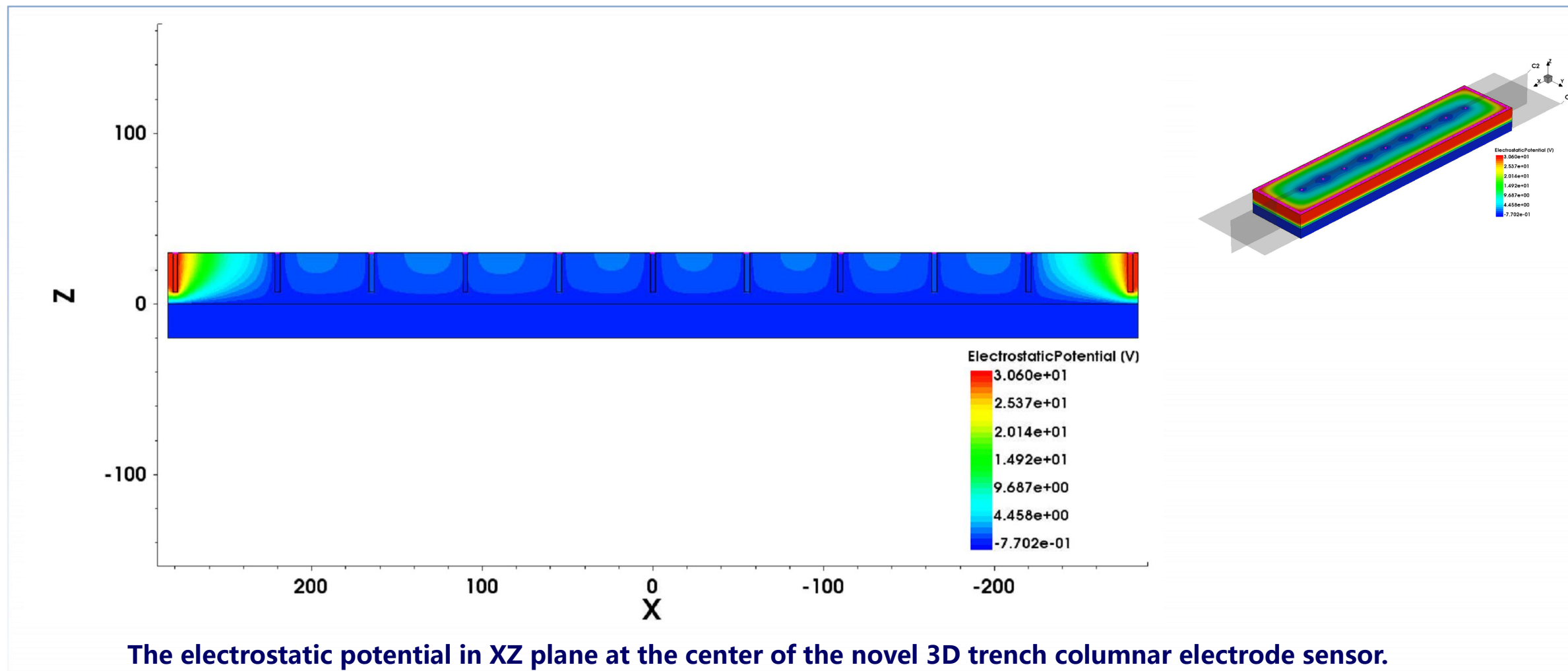
➤ 30 V is applied to the n-trench, 0 V is applied to the n-columns.



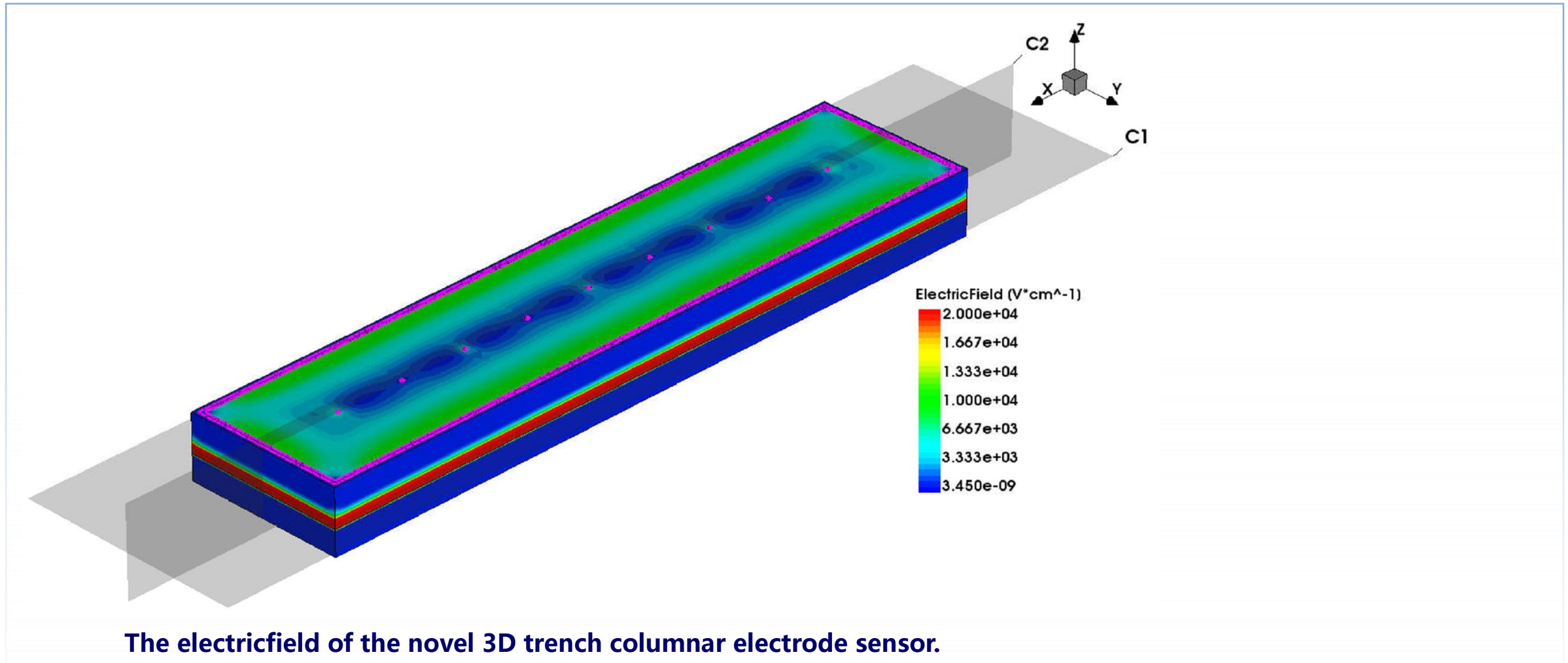
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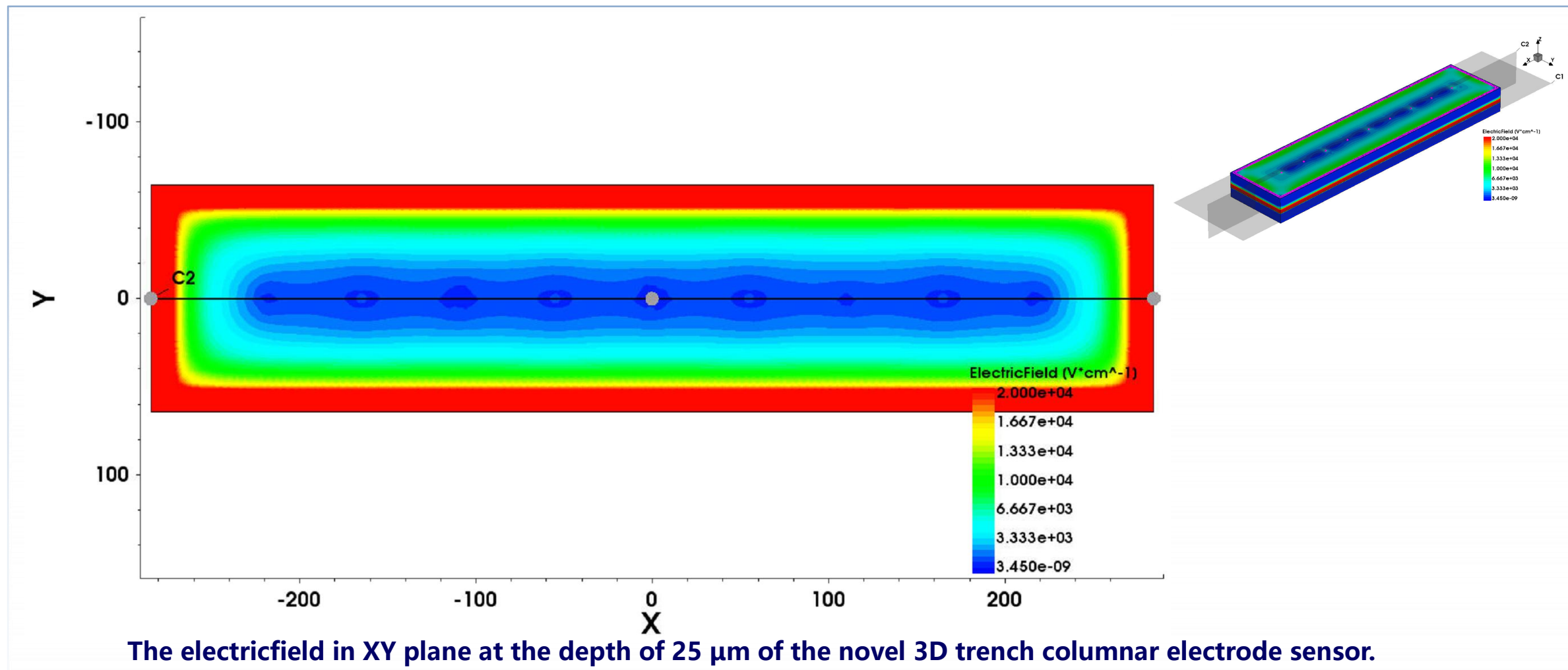
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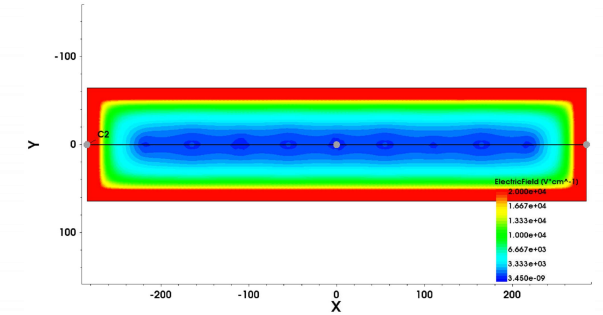
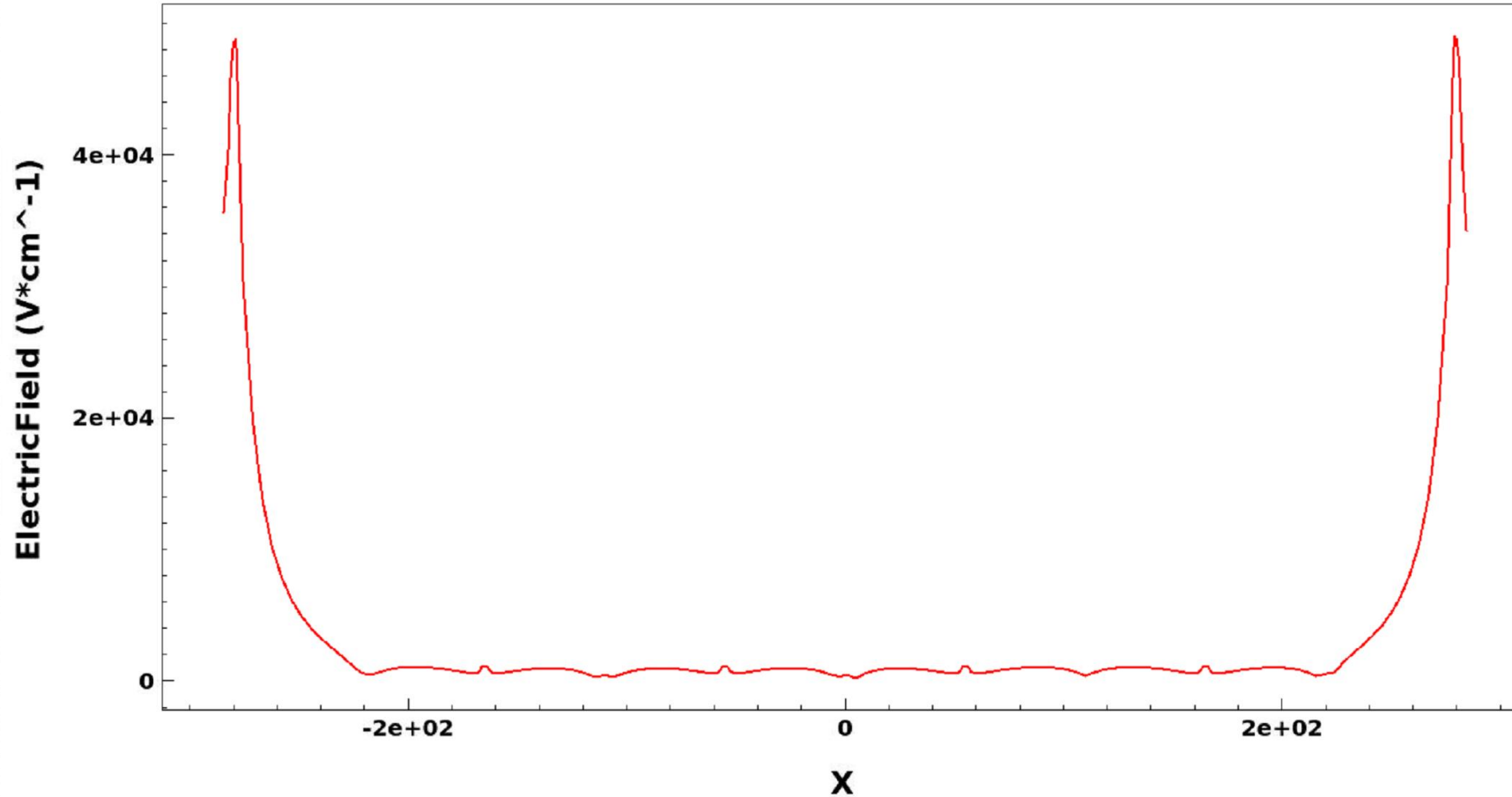
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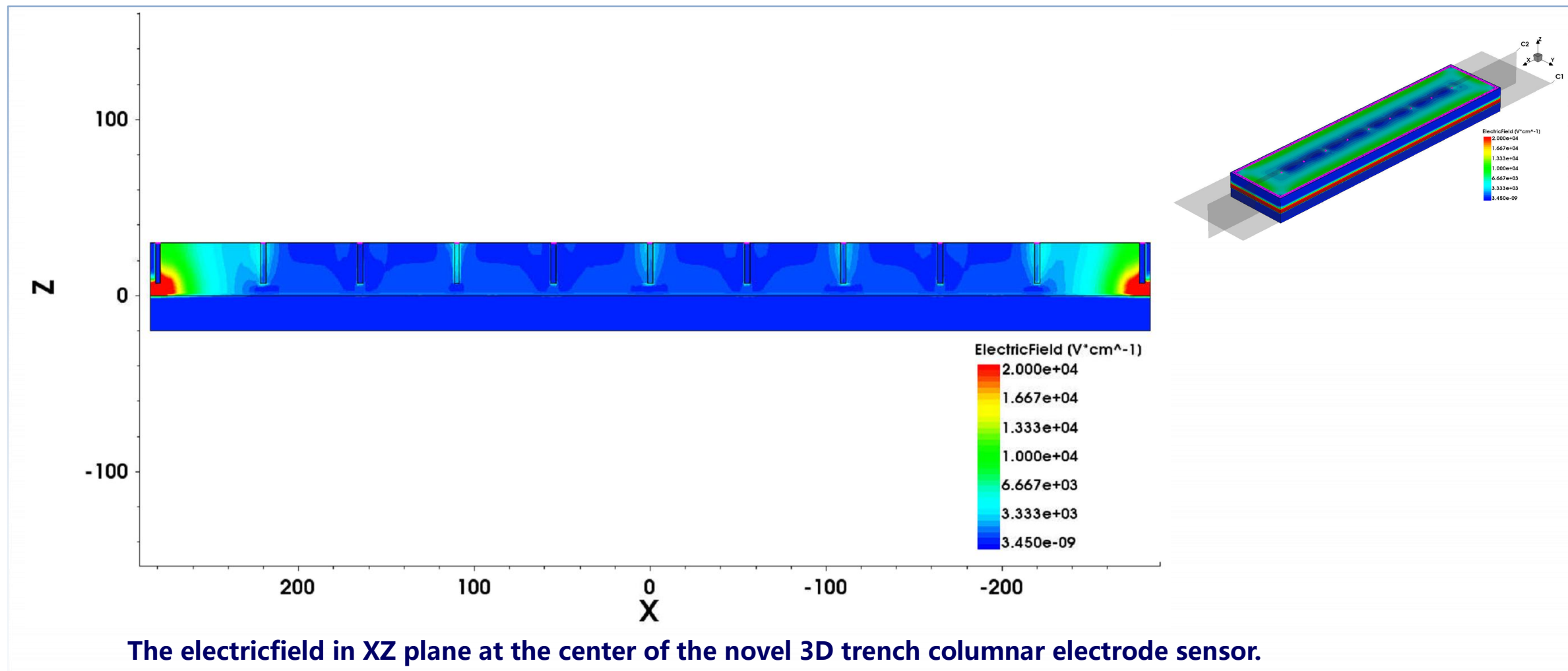


➤ 30 V is applied to the n-trench, 0 V is applied to the n-columns.

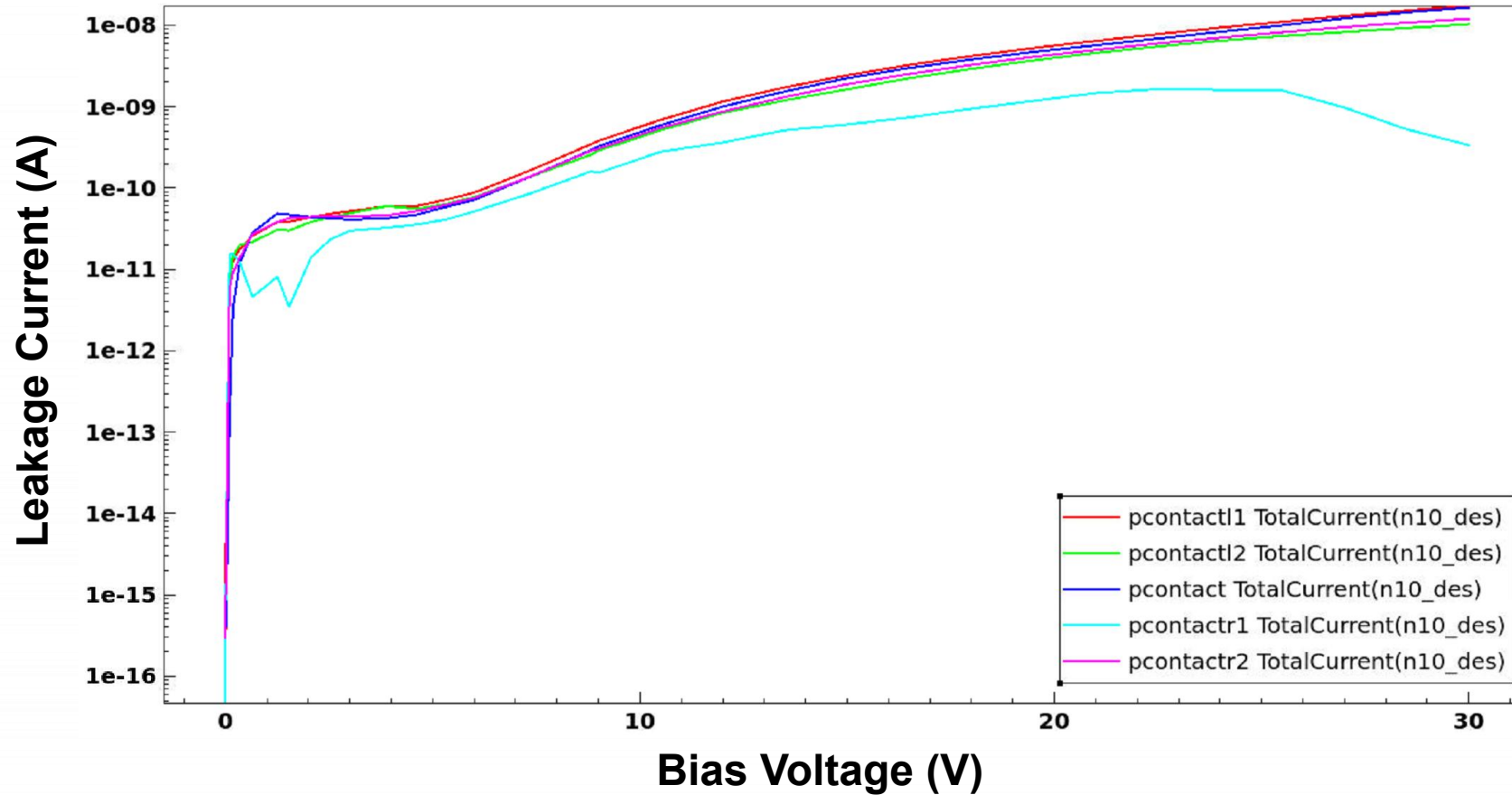


The electricfield along the x-axis at the depth of 25 μm of the novel 3D trench columnar electrode sensor.

➤ 30 V is applied to the n-trench, 0 V is applied to the n-columns.

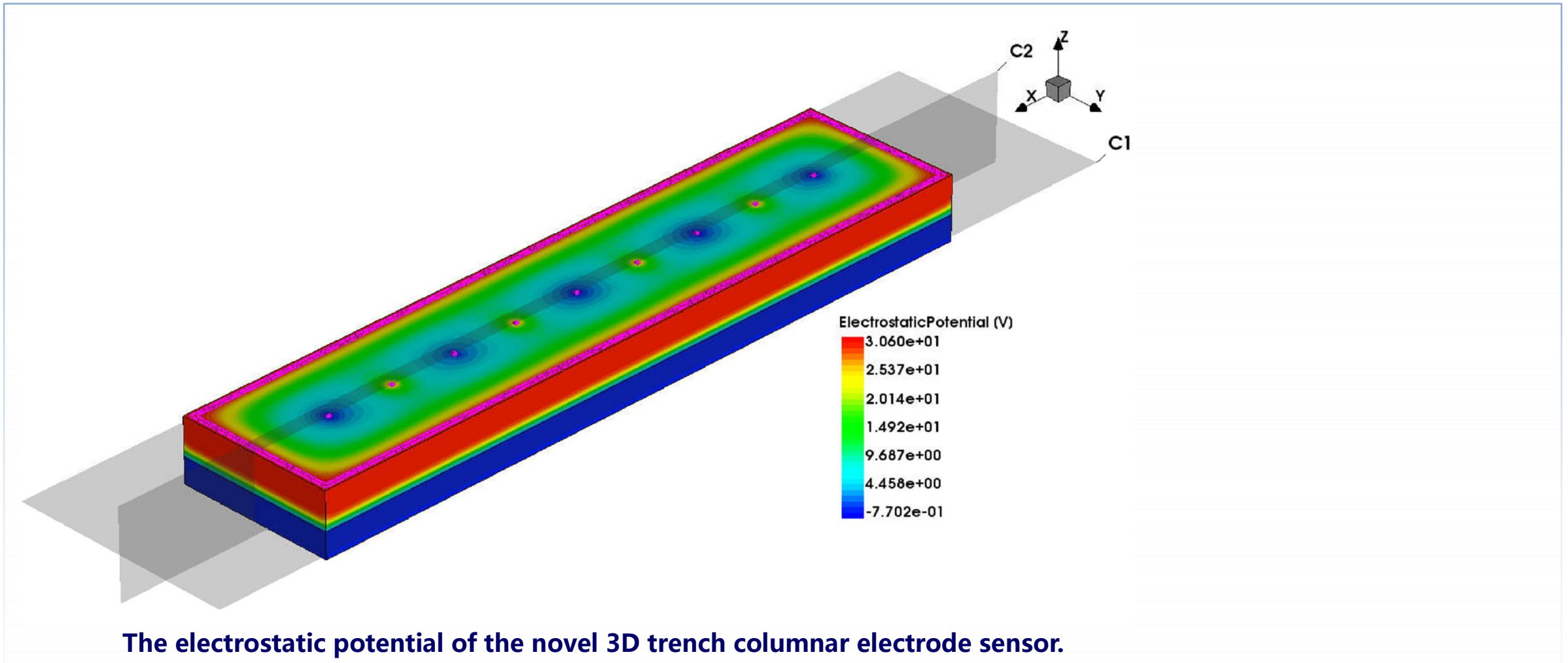


➤ 30 V is applied to the n-trench, 0 V is applied to the n-columns.

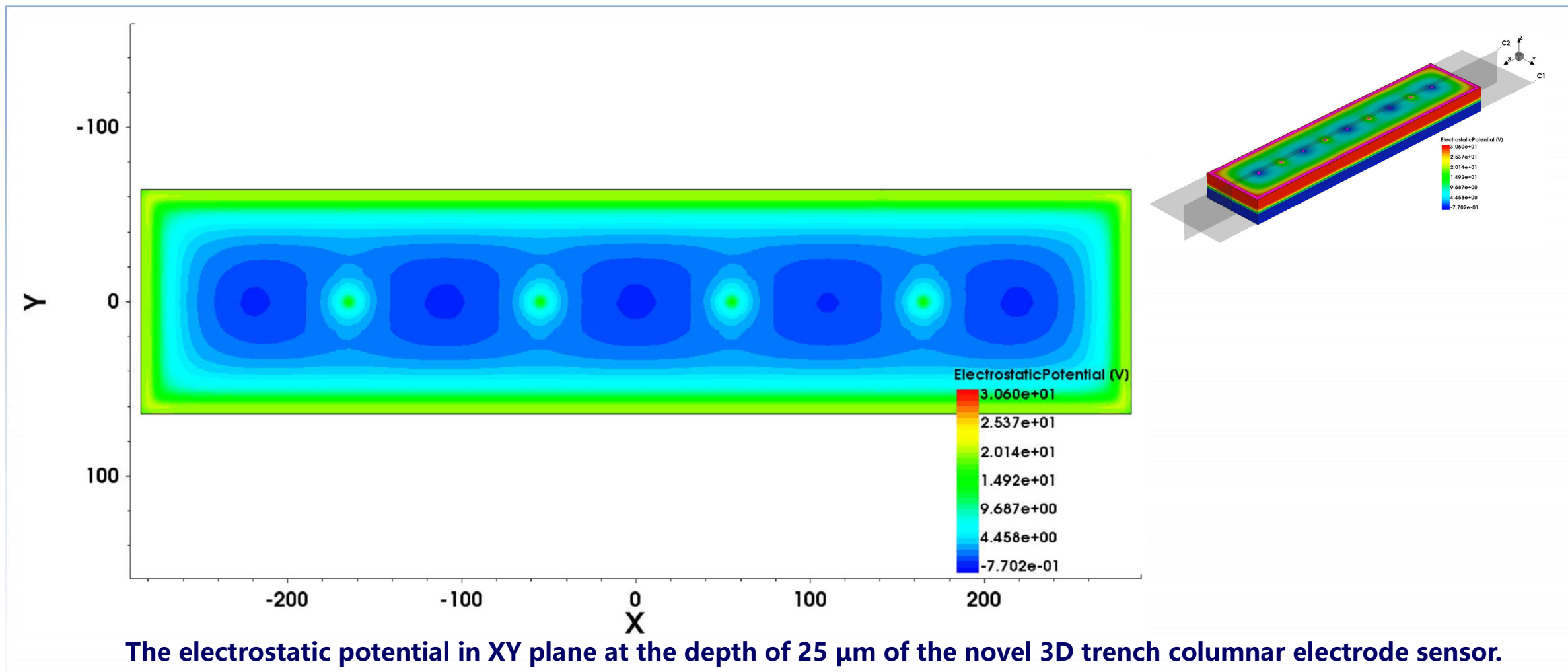


I-V curve of the novel 3D trench columnar electrode sensor.

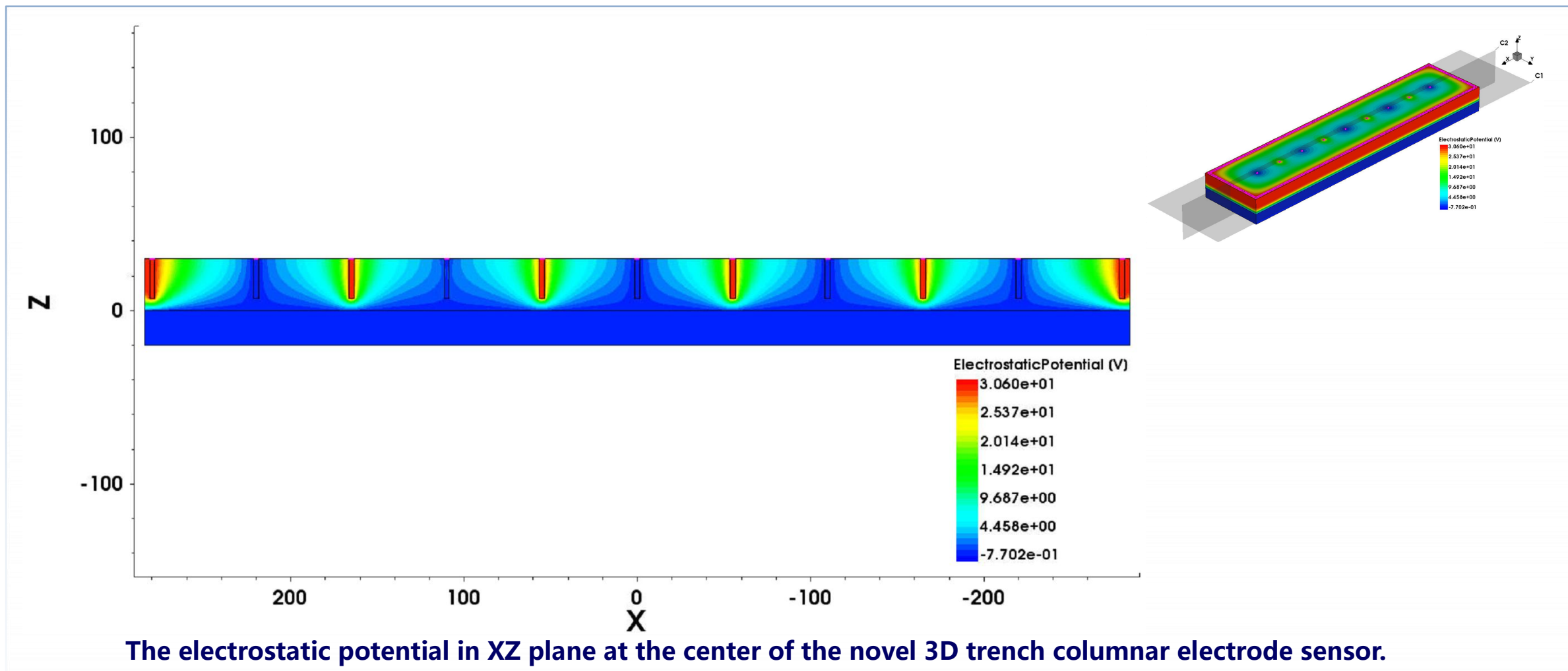
- 30 V is applied to the n-trench and n-columns.



- 30 V is applied to the n-trench and n-columns.

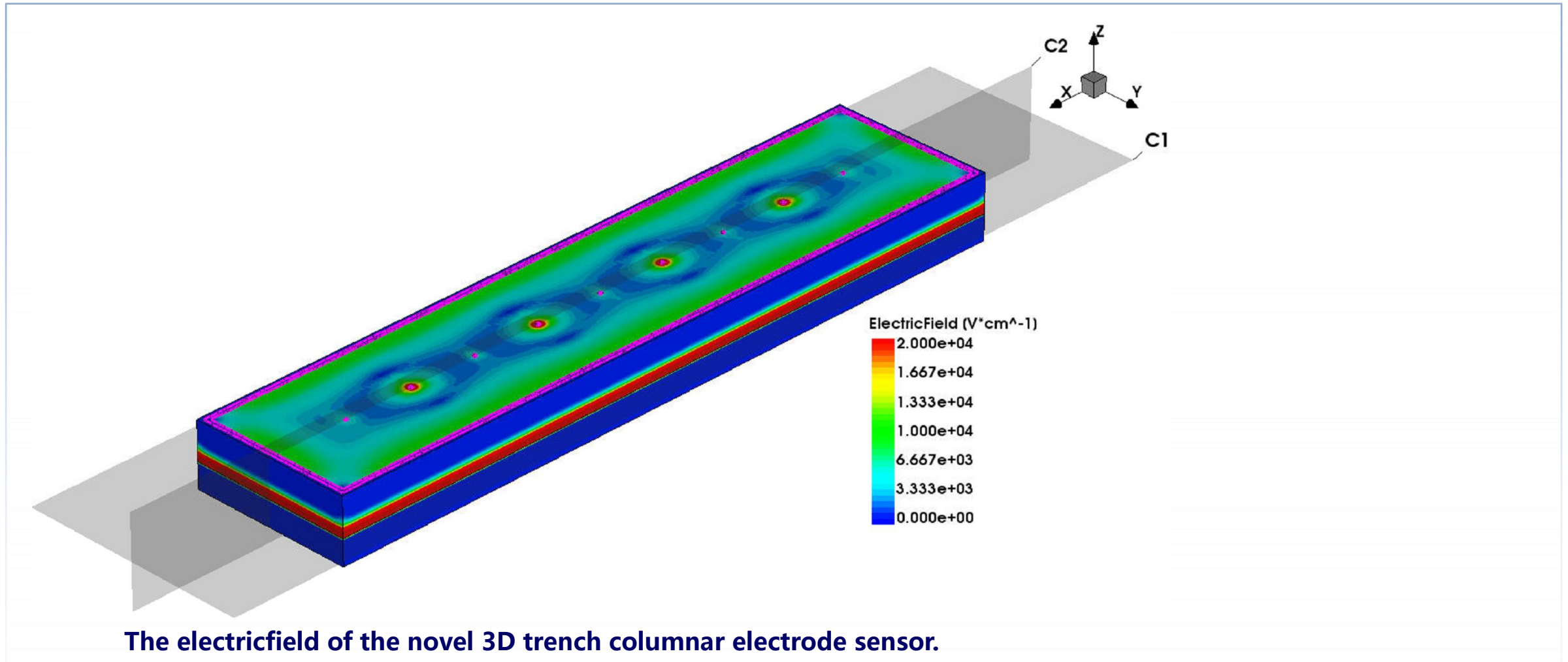


➤ 30 V is applied to the n-trench and n-columns.



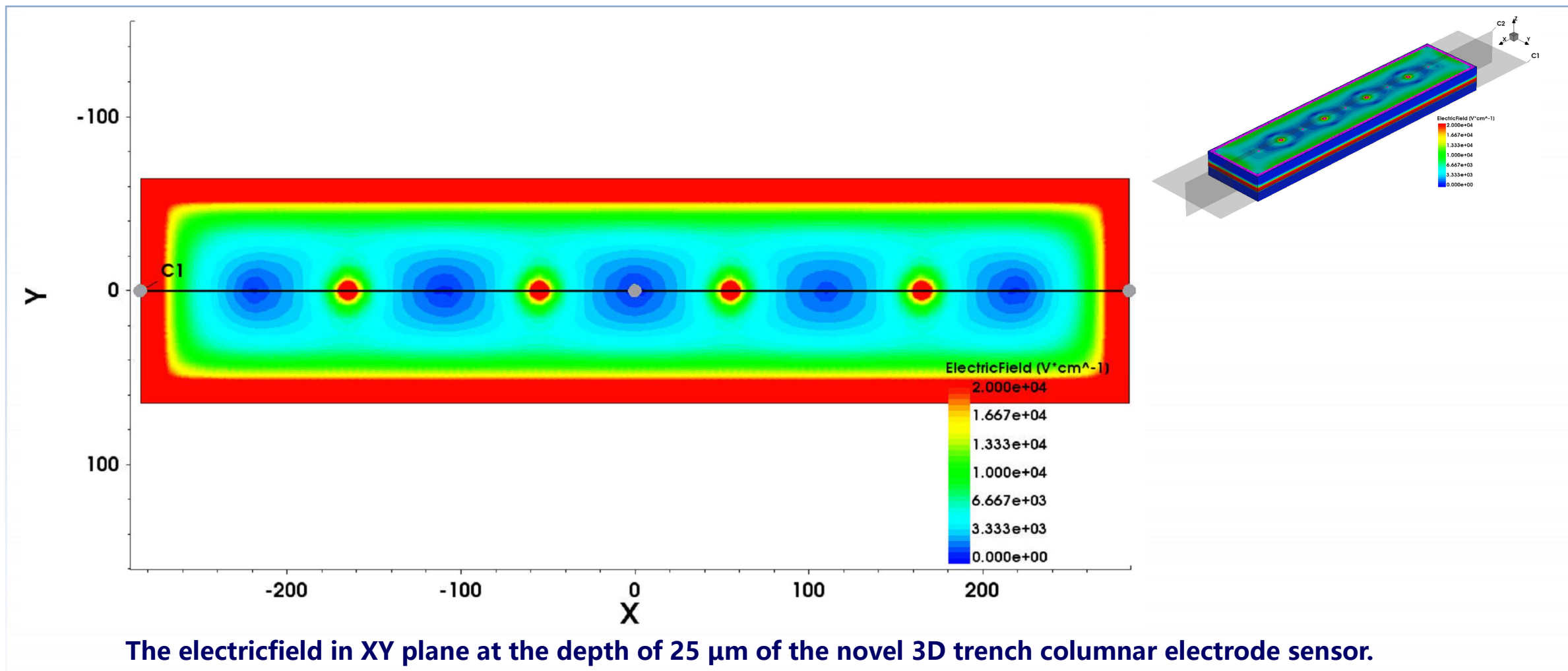
3D Simulation

- 30 V is applied to the n-trench and n-columns.

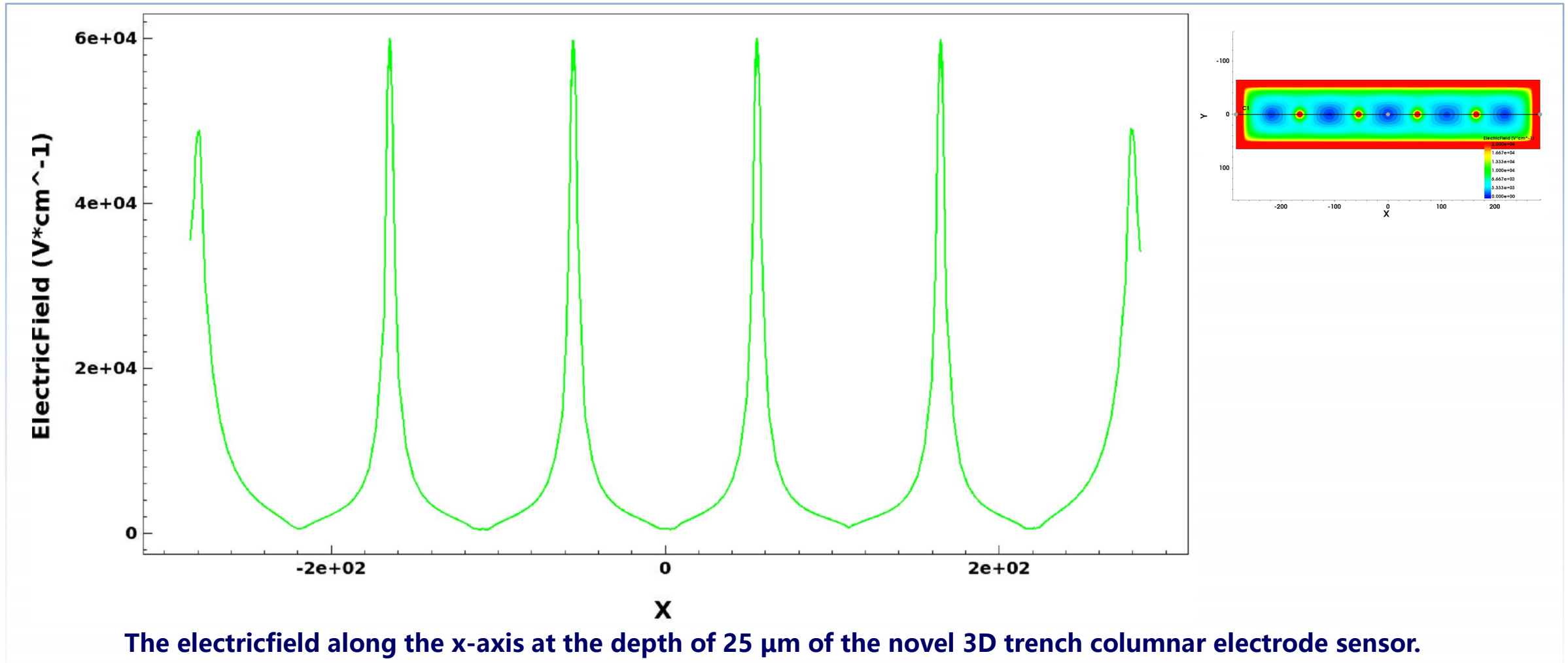


>>> 3D Simulation

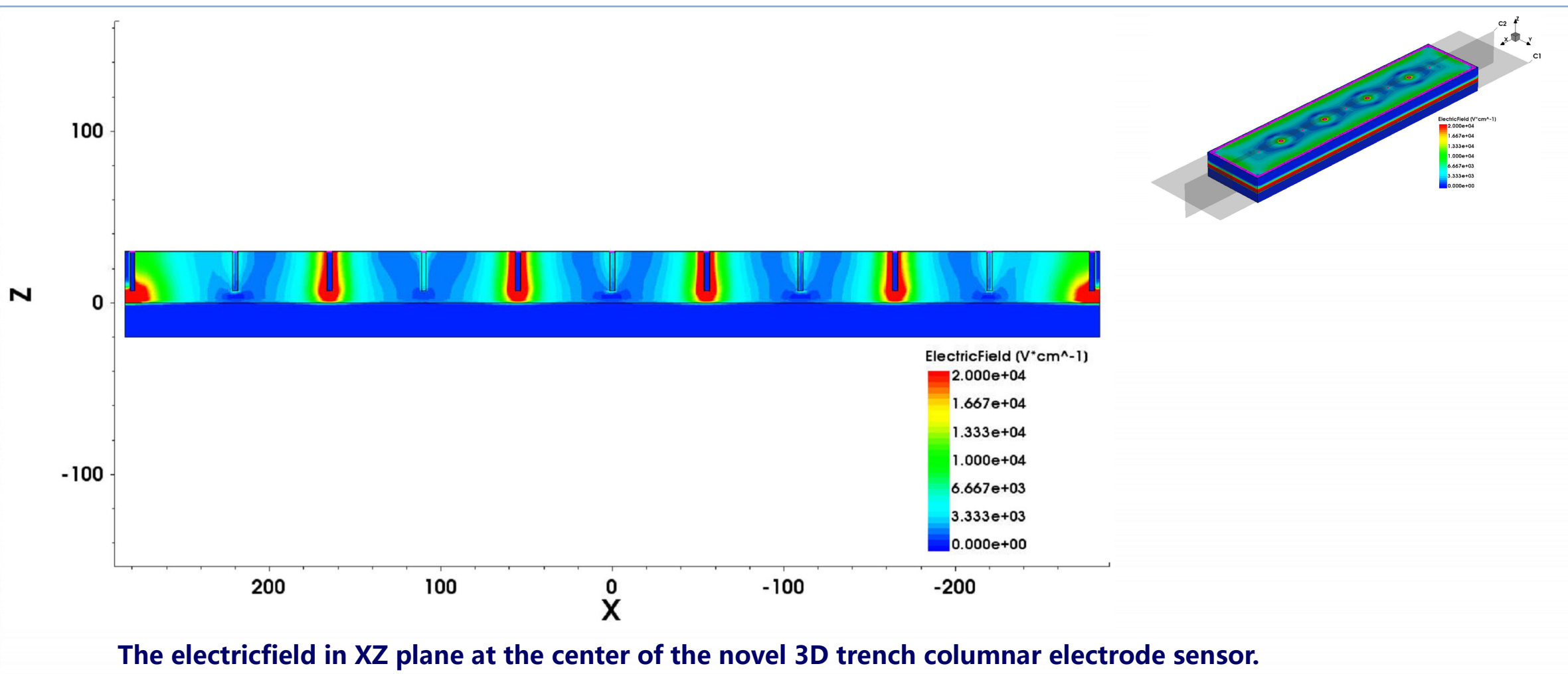
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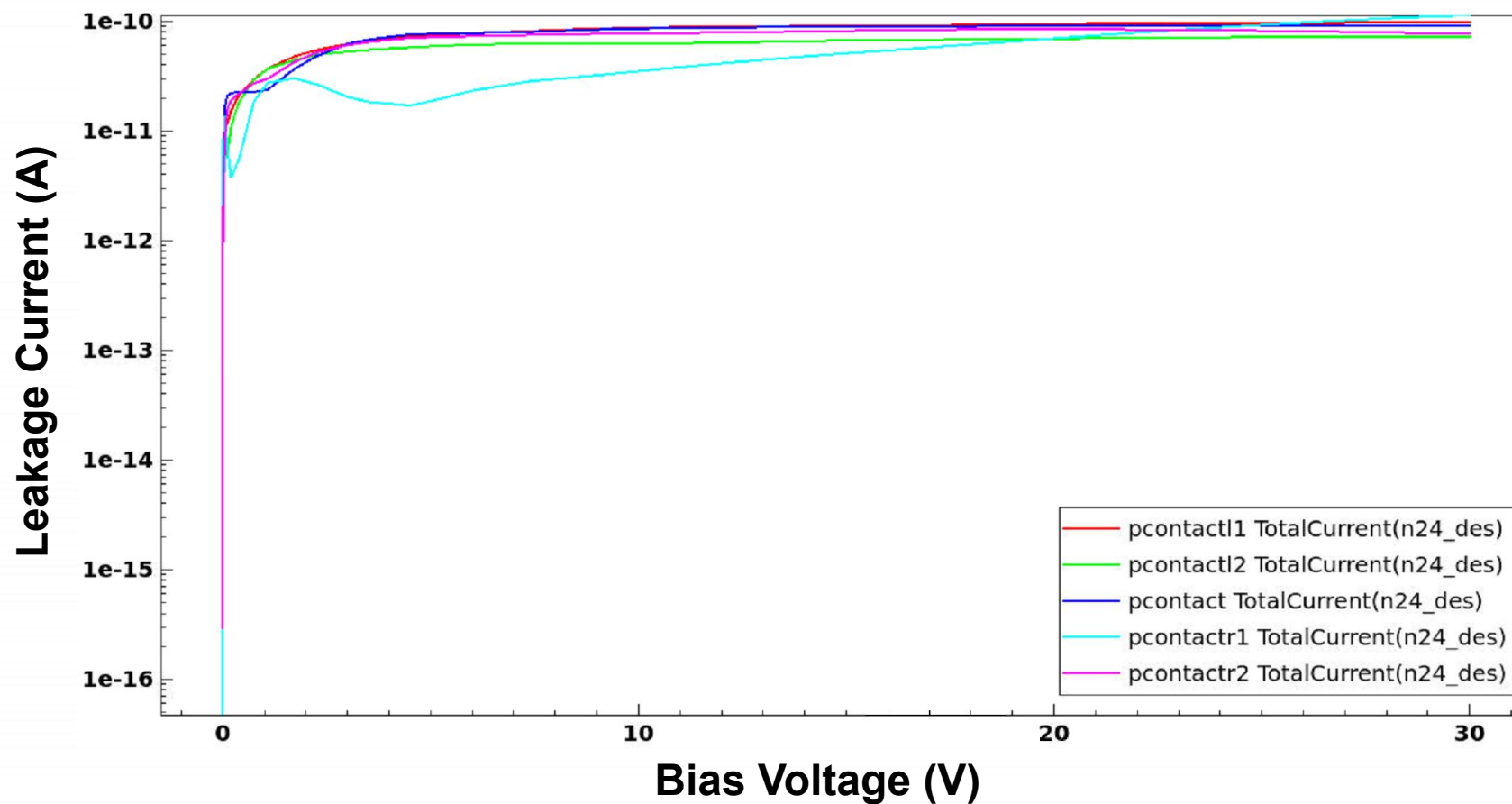
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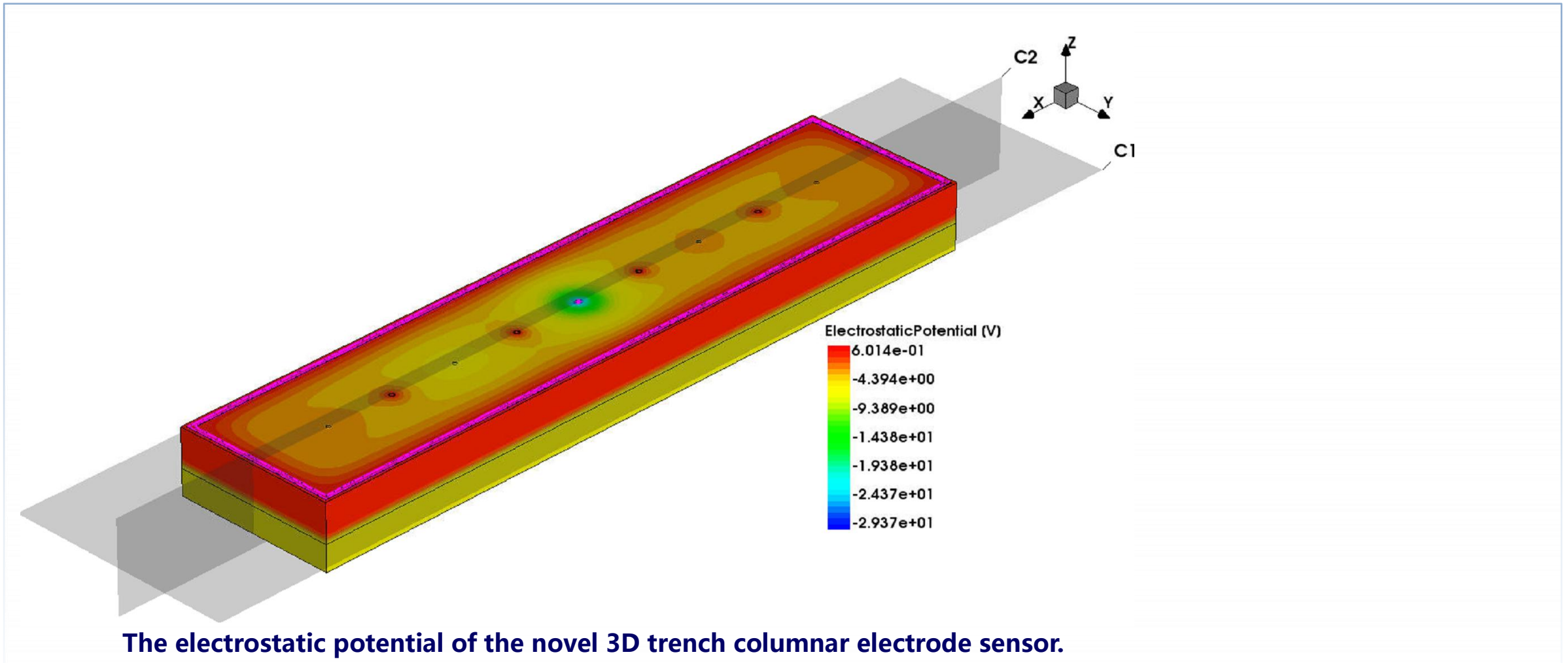


➤ 30 V is applied to the n-trench and n-columns.

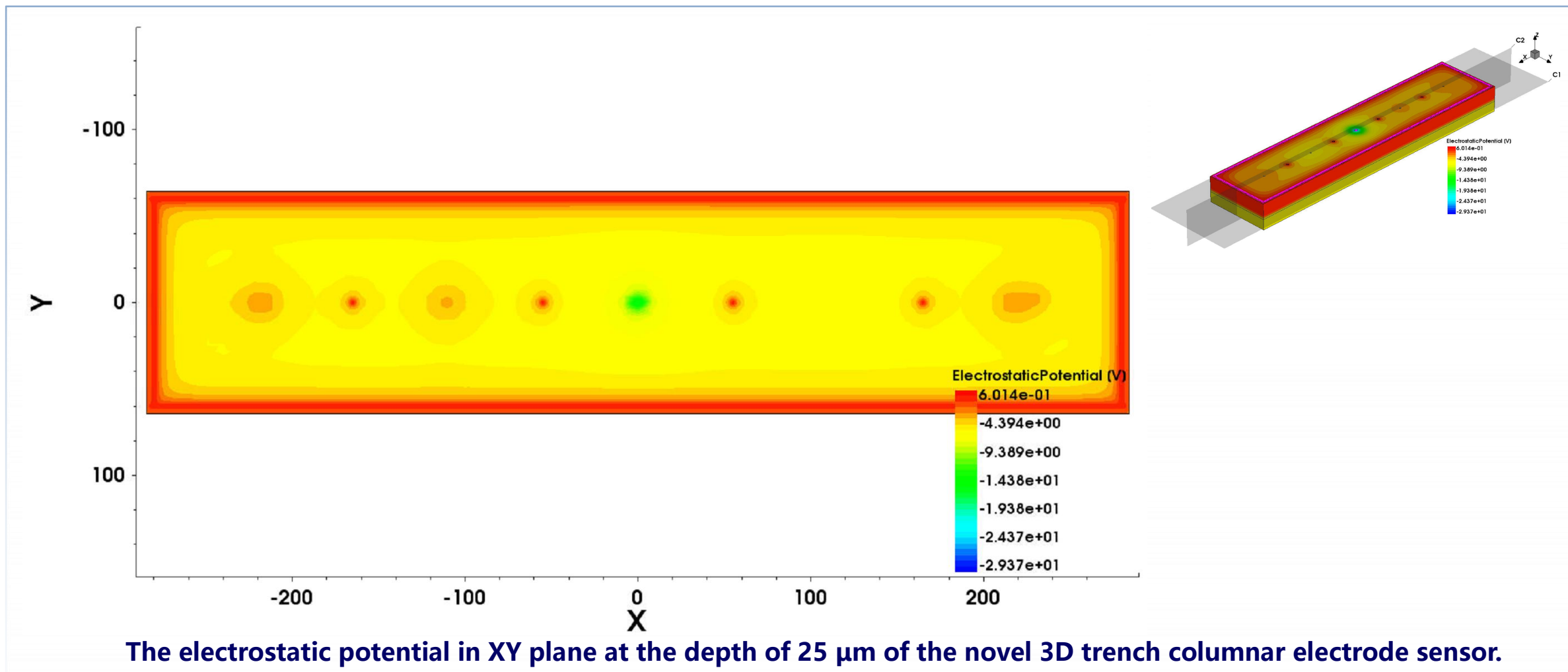


I-V curve of the novel 3D trench columnar electrode sensor.

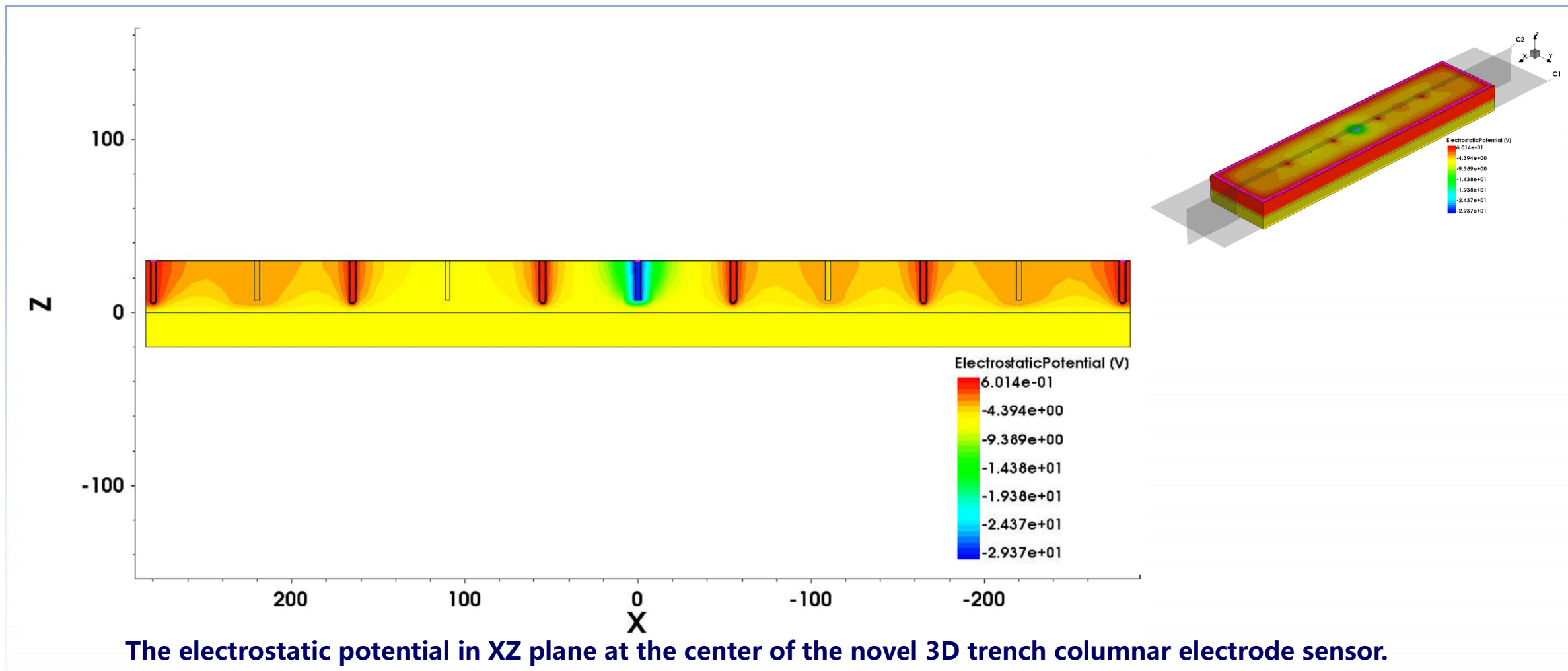
➤ -30 V is applied to the p-column.



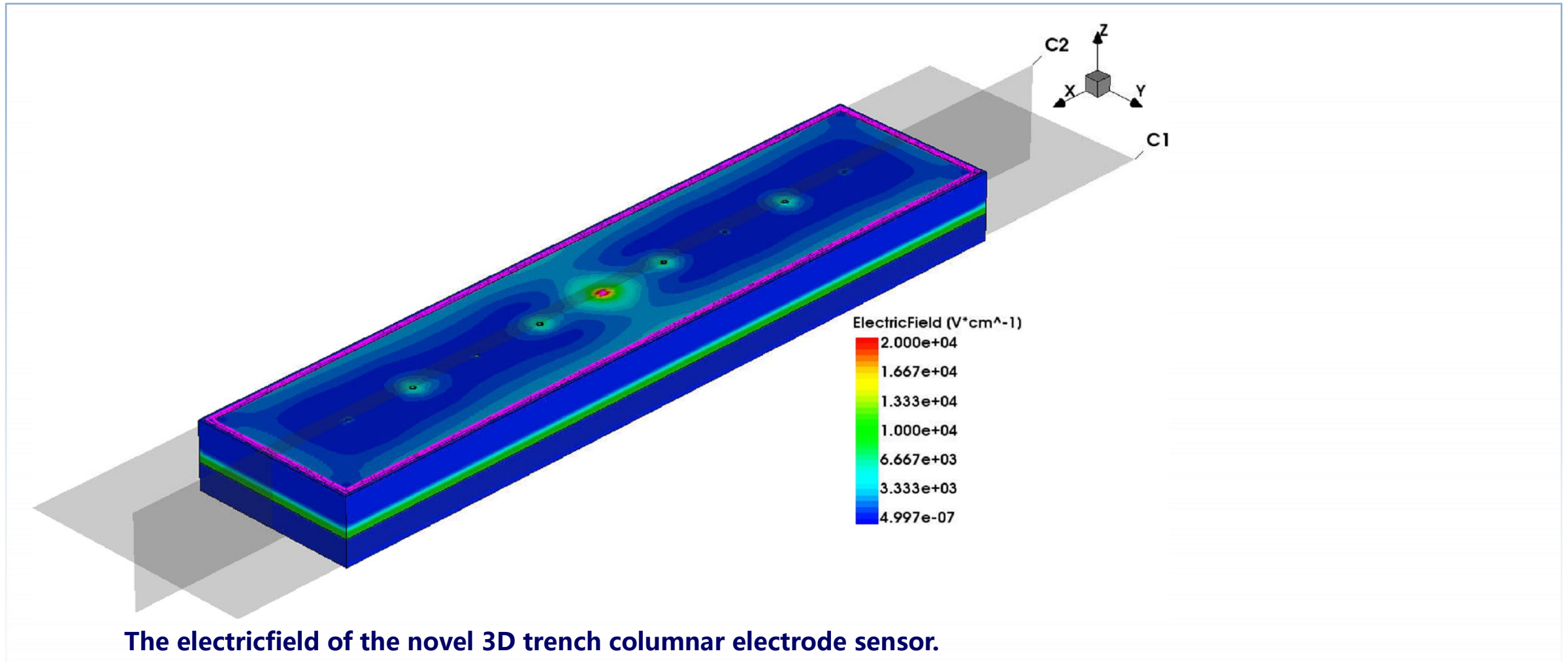
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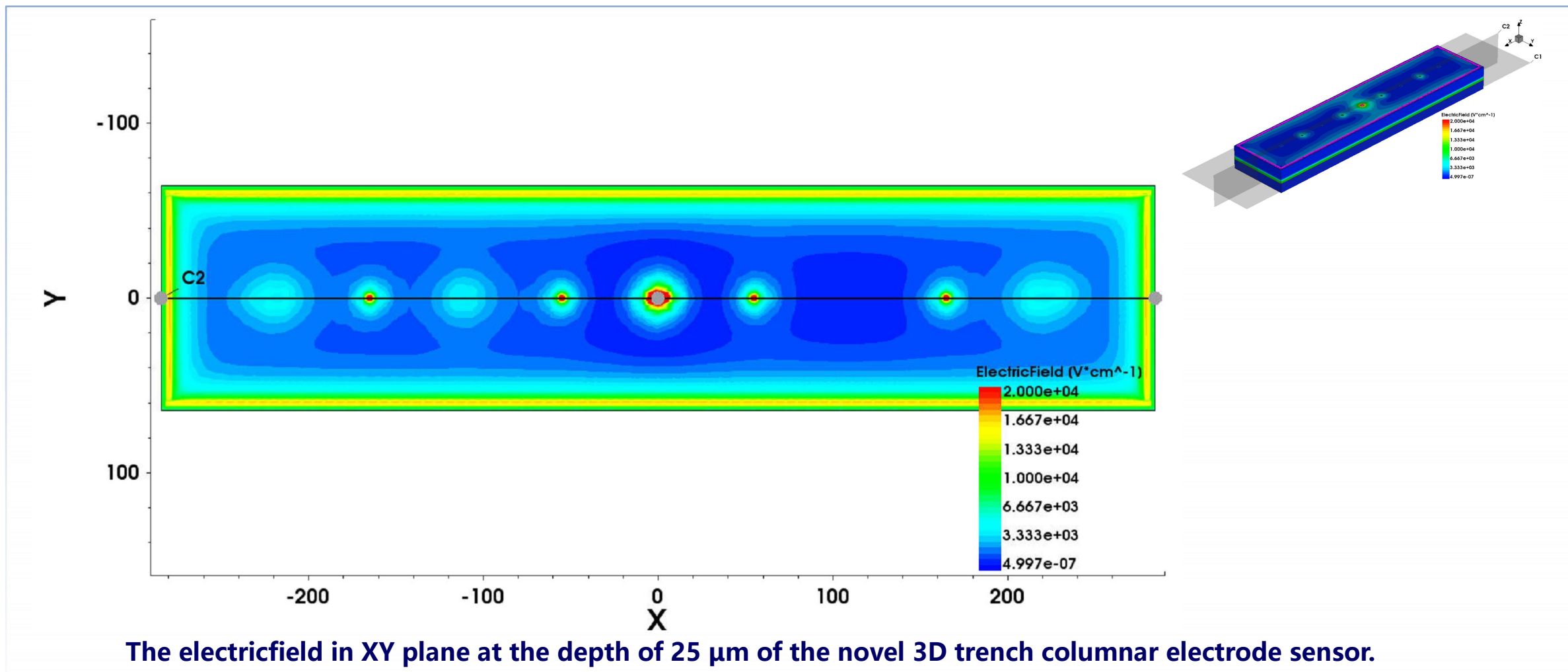


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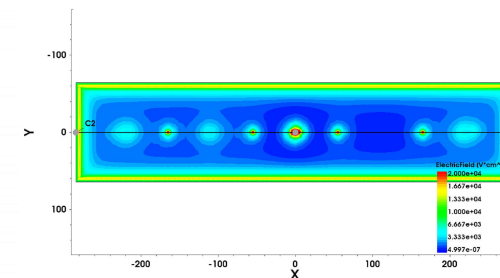
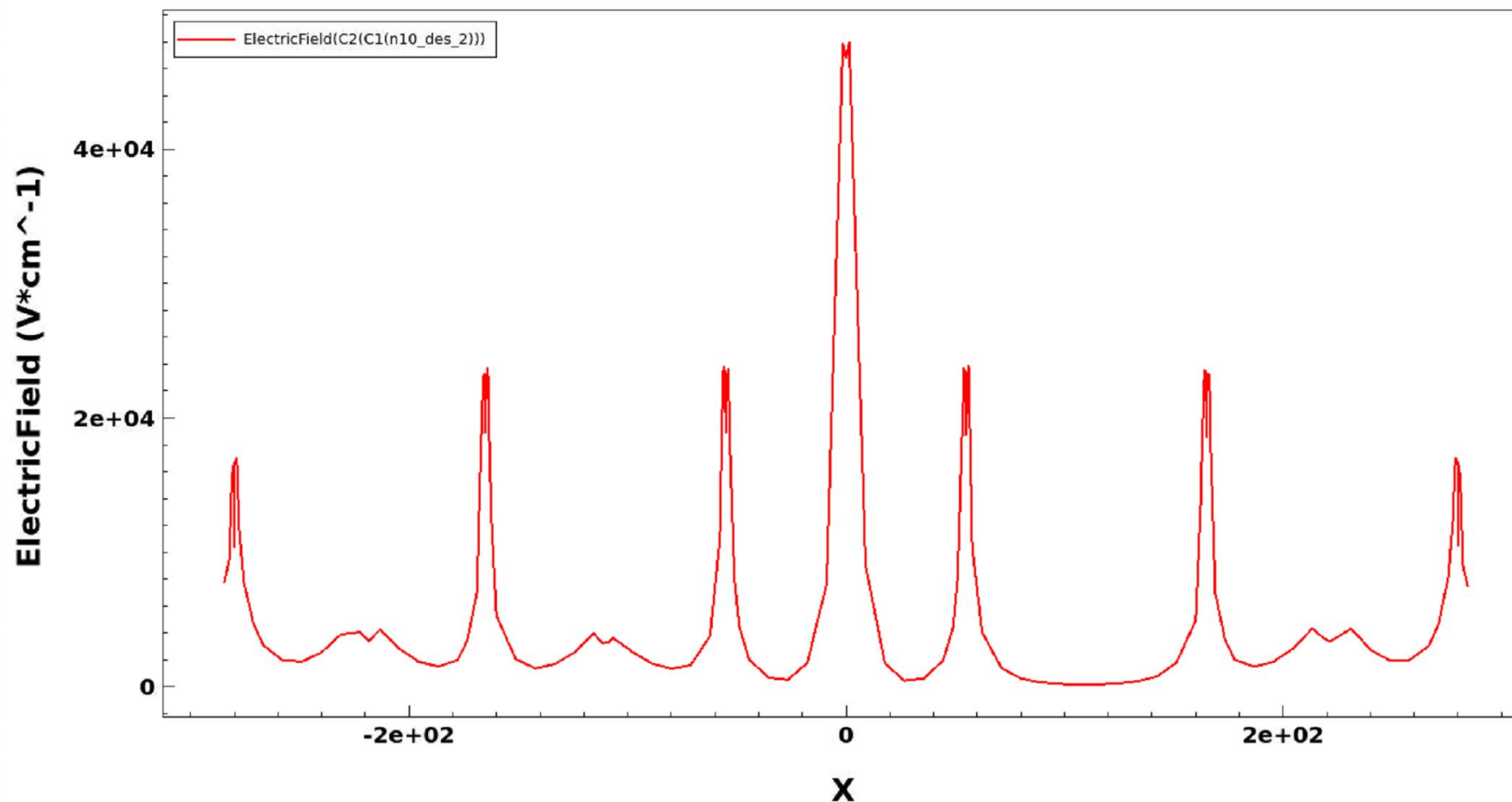


>>> 3D Simulation

➤ -30 V is applied to the p-column.

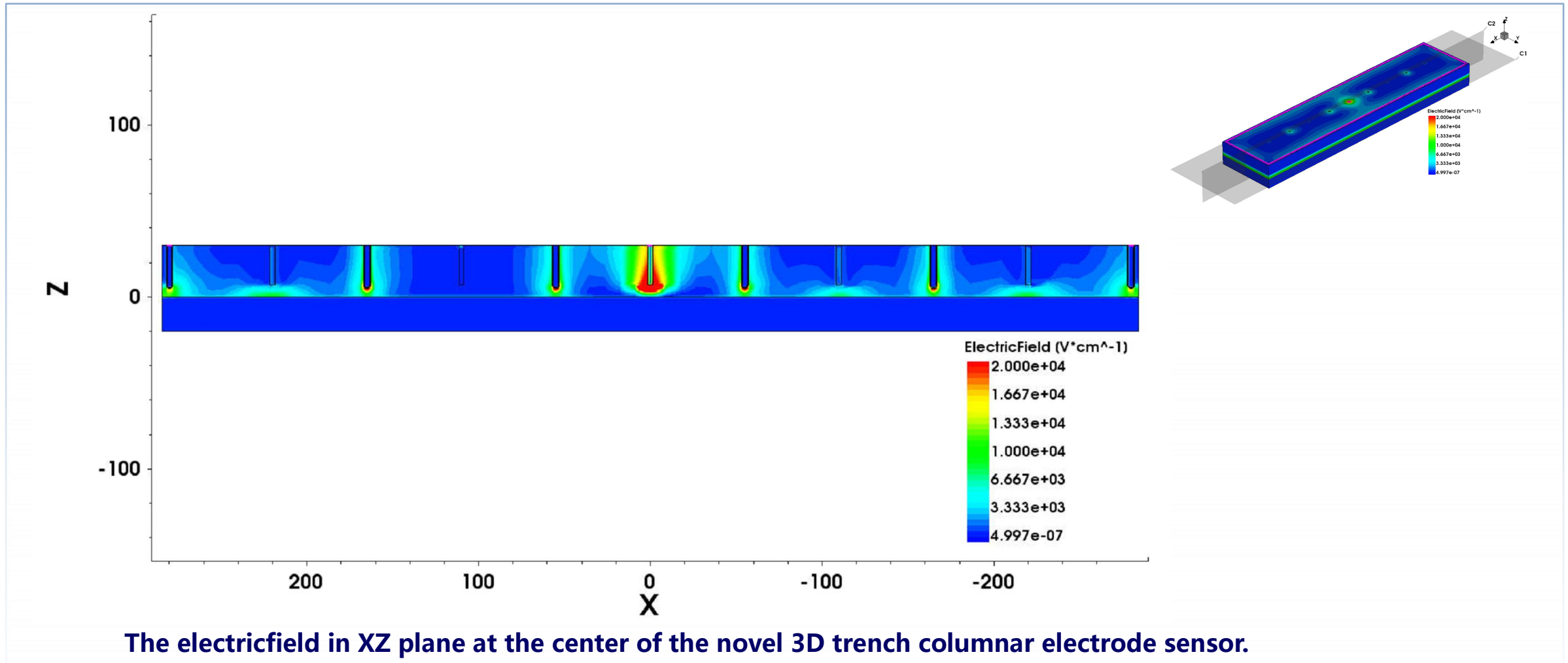


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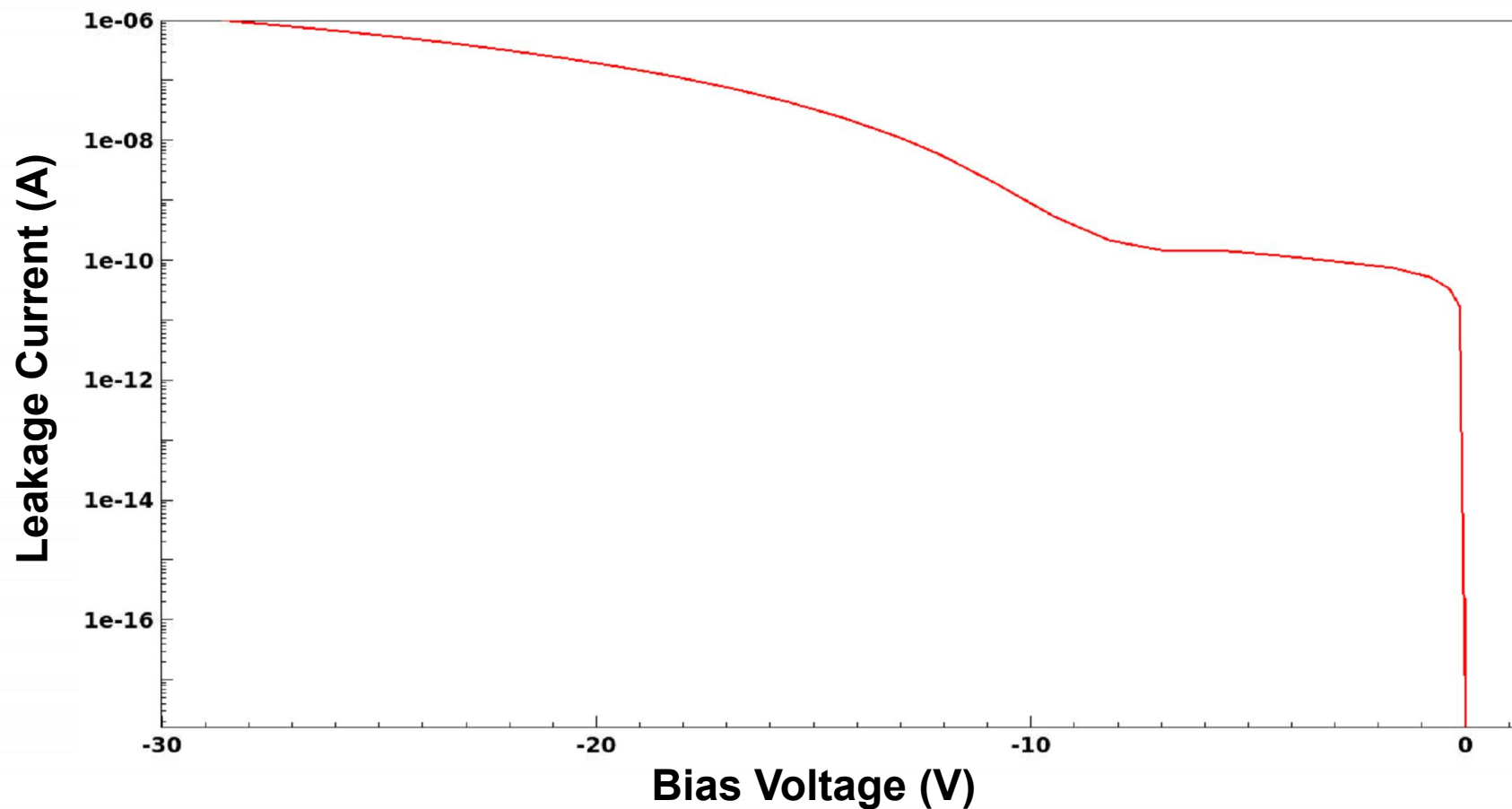


The electricfield along the x-axis at the depth of 25 μm of the novel 3D trench columnar electrode sensor.

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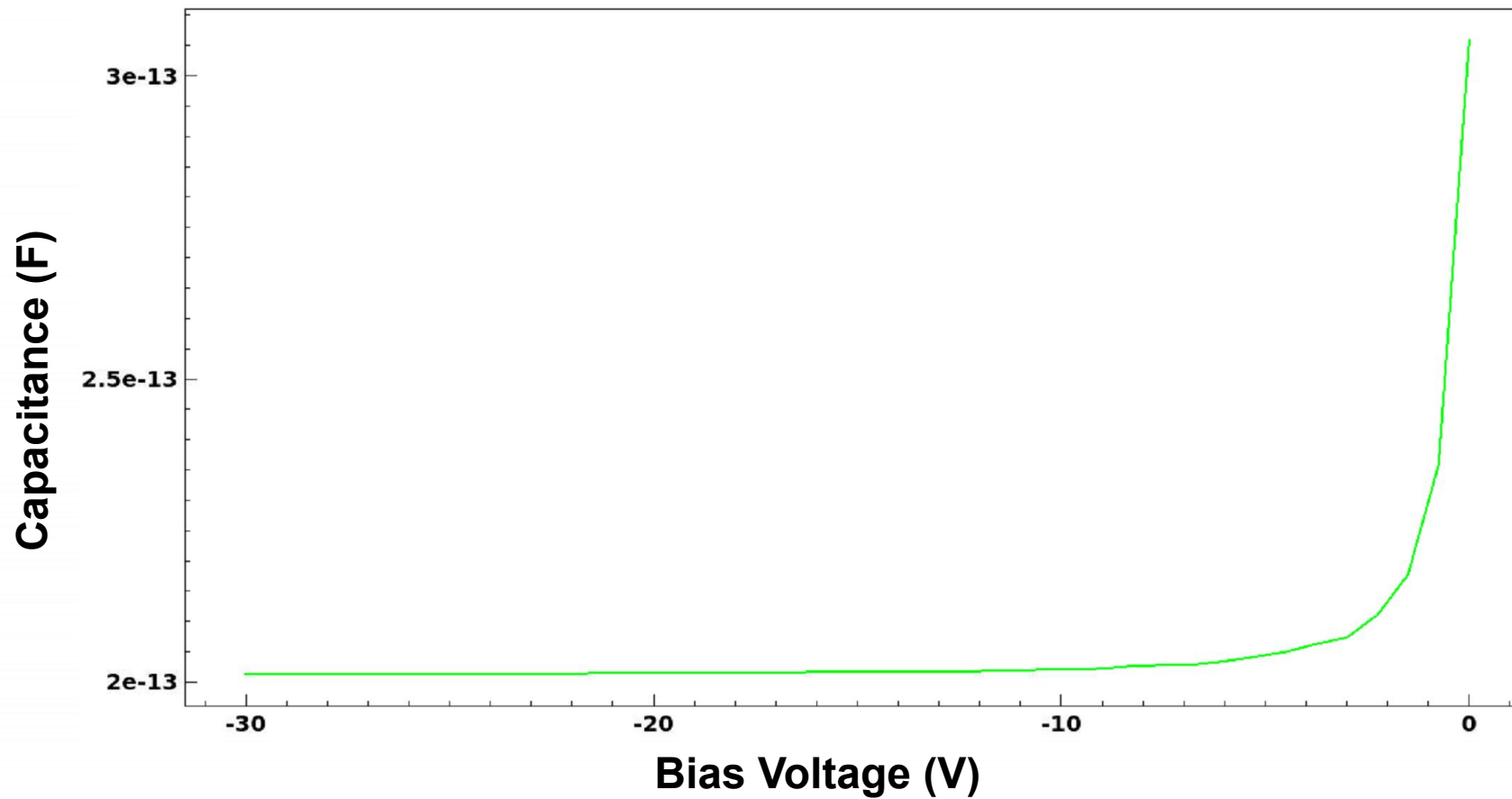


➤ -30 V is applied to the p-column.



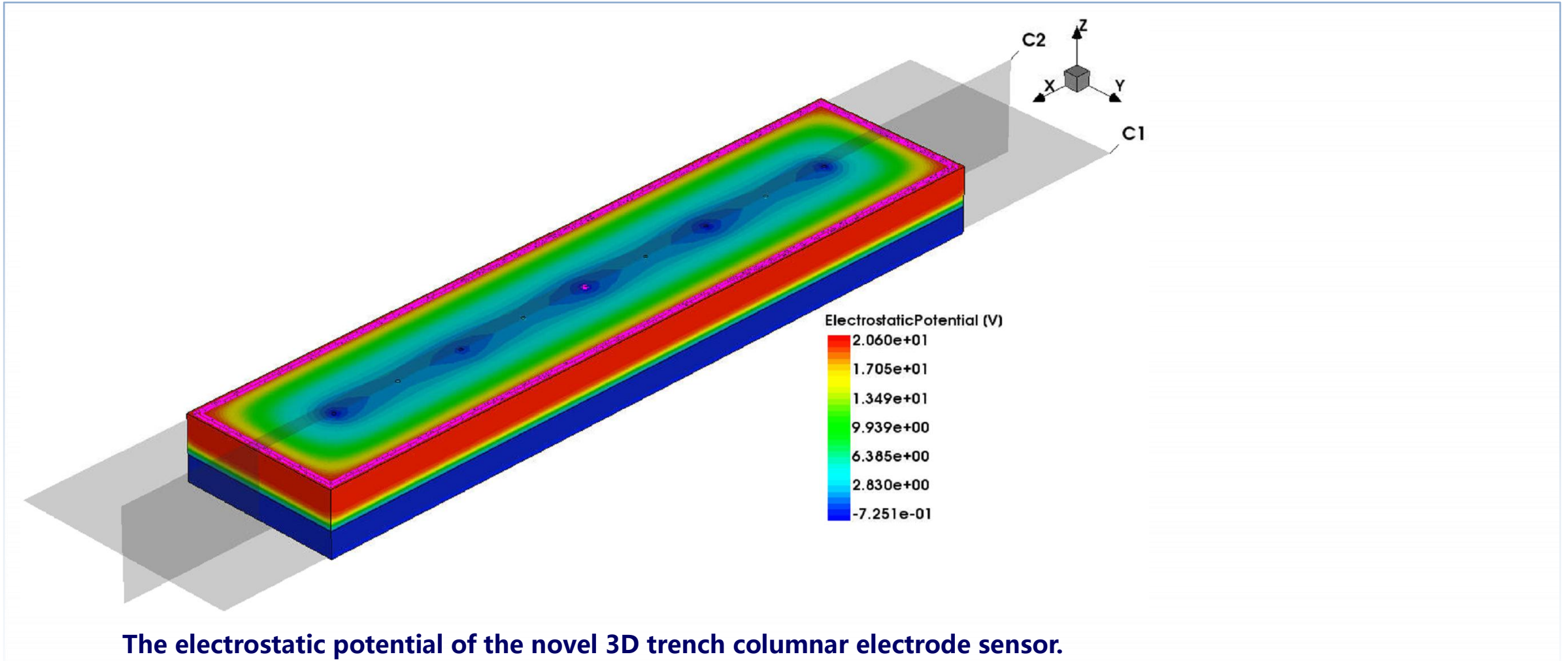
I-V curve of the novel 3D trench columnar electrode sensor.

➤ -30 V is applied to the p-column.

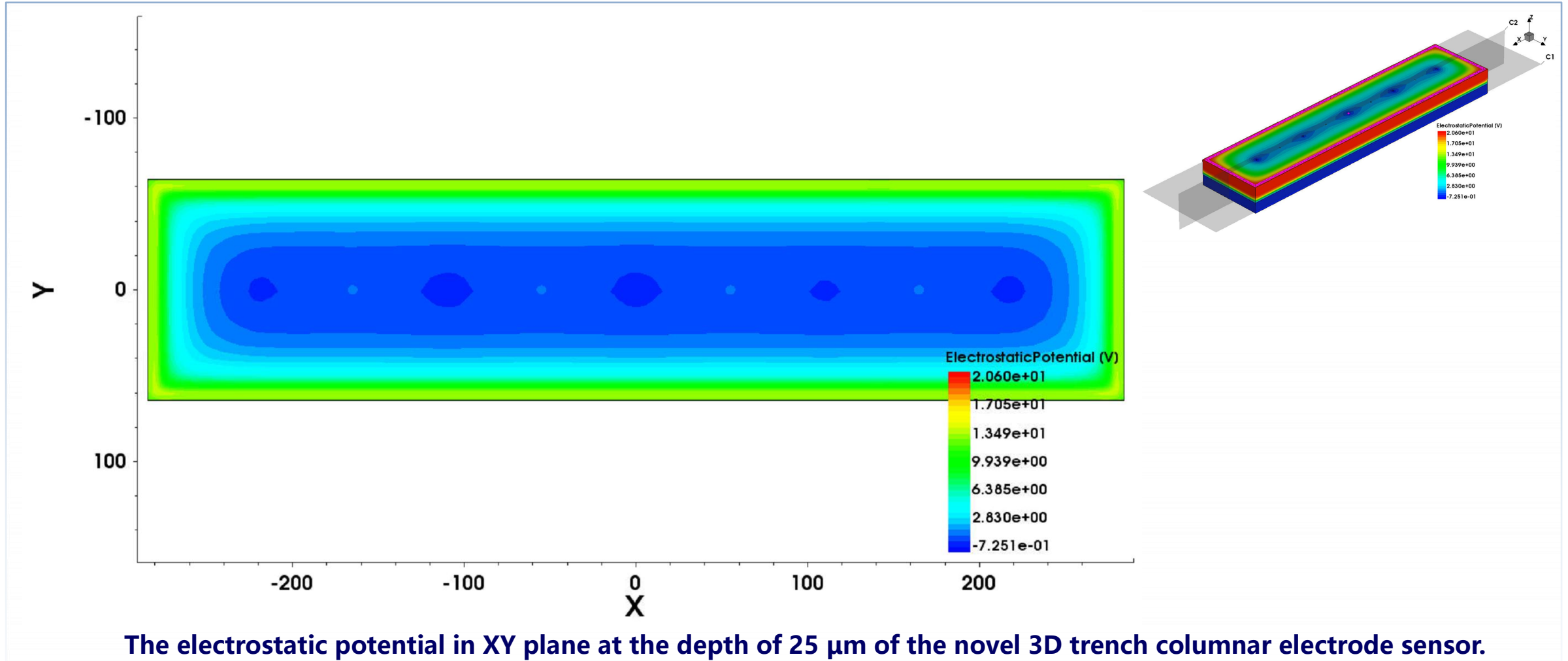


C-V curve of the novel 3D trench columnar electrode sensor.

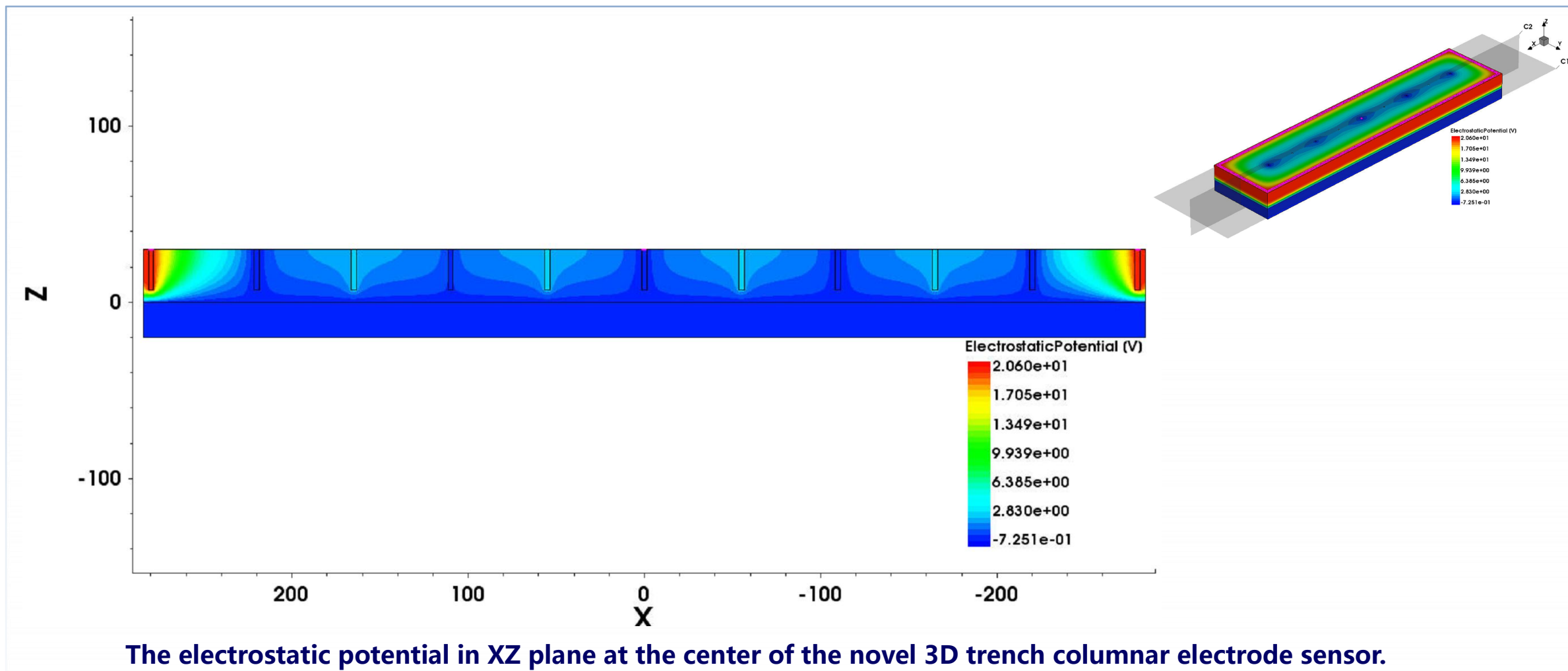
➤ 20 V is applied to the n-trench.



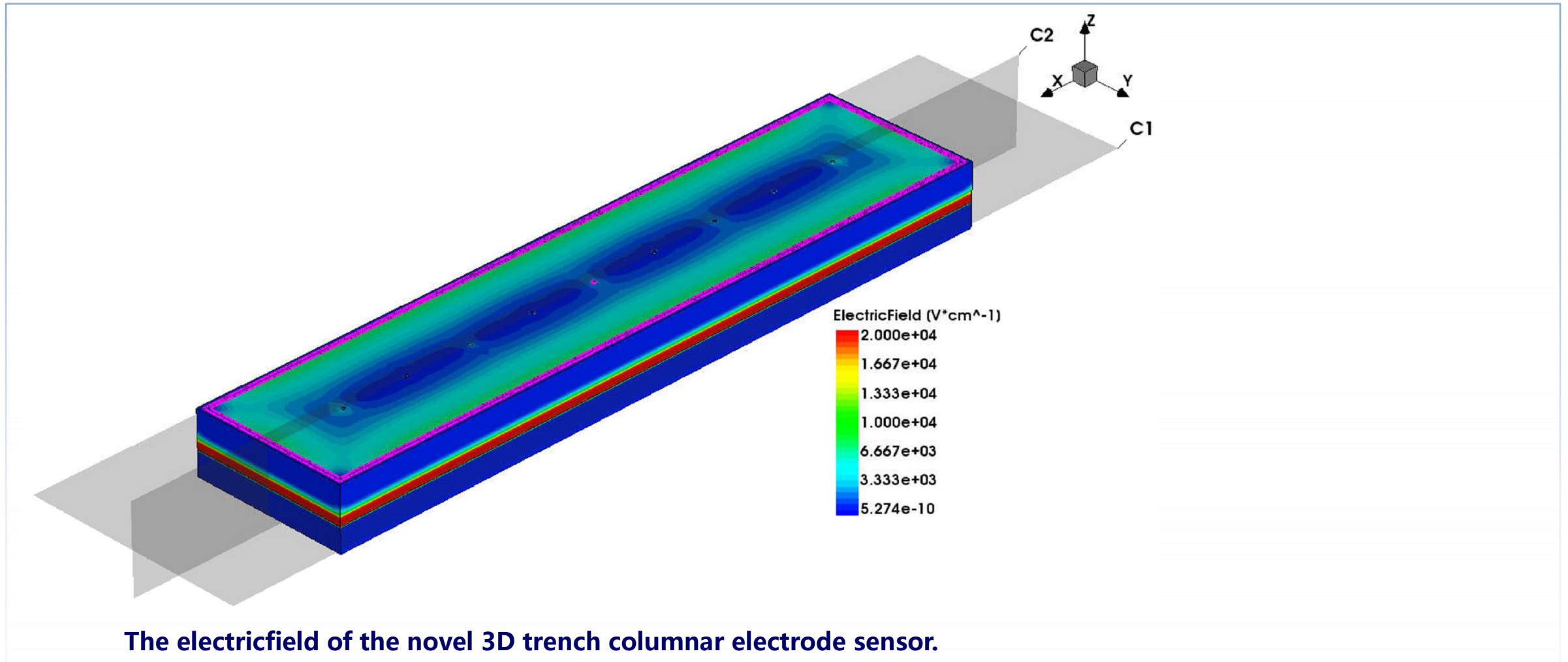
➤ 20 V is applied to the n-trench.



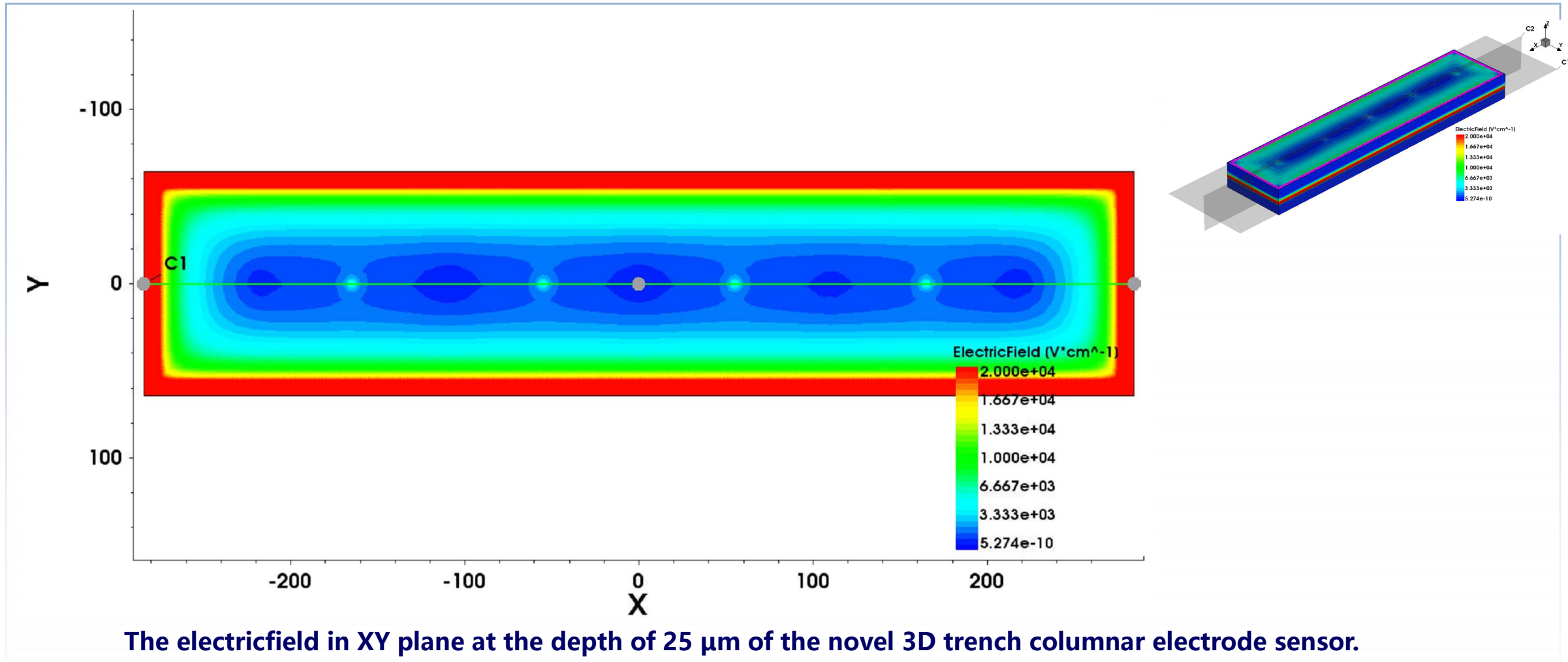
➤ 20 V is applied to the n-trench.



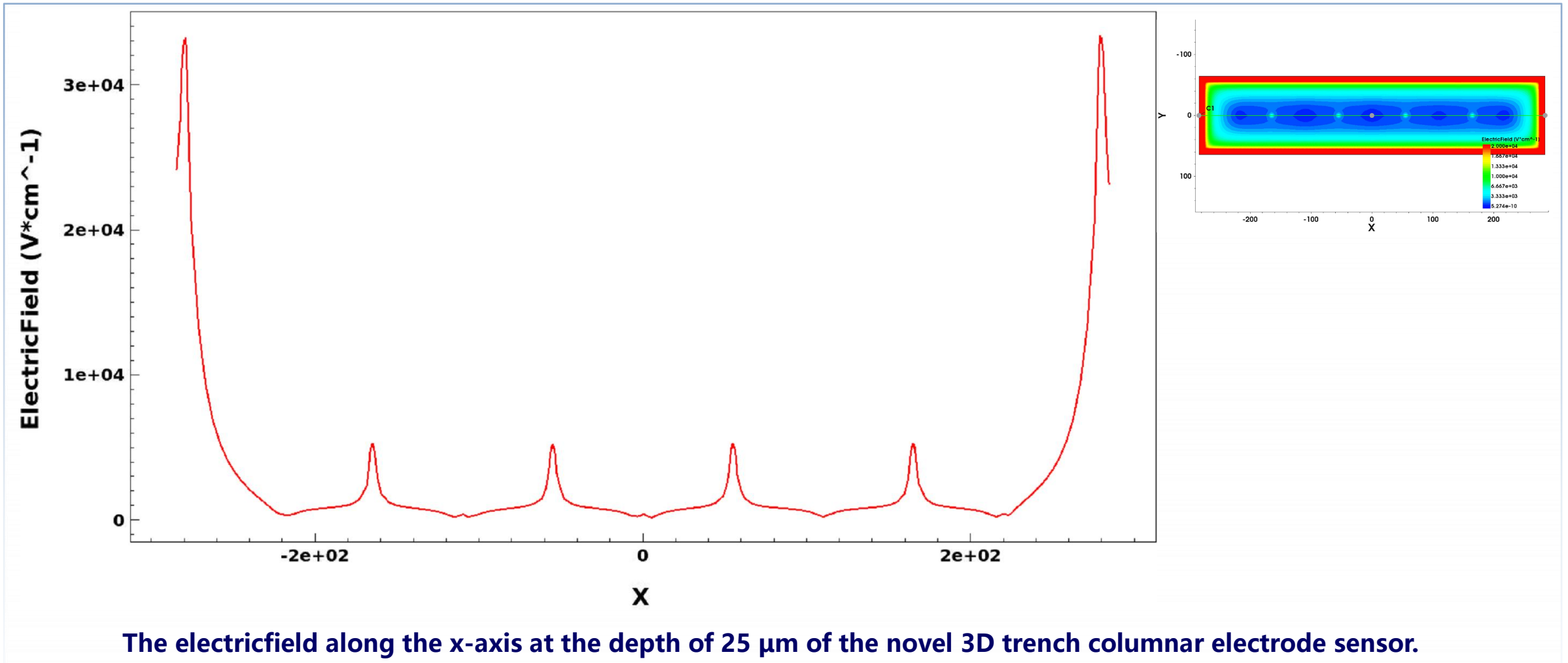
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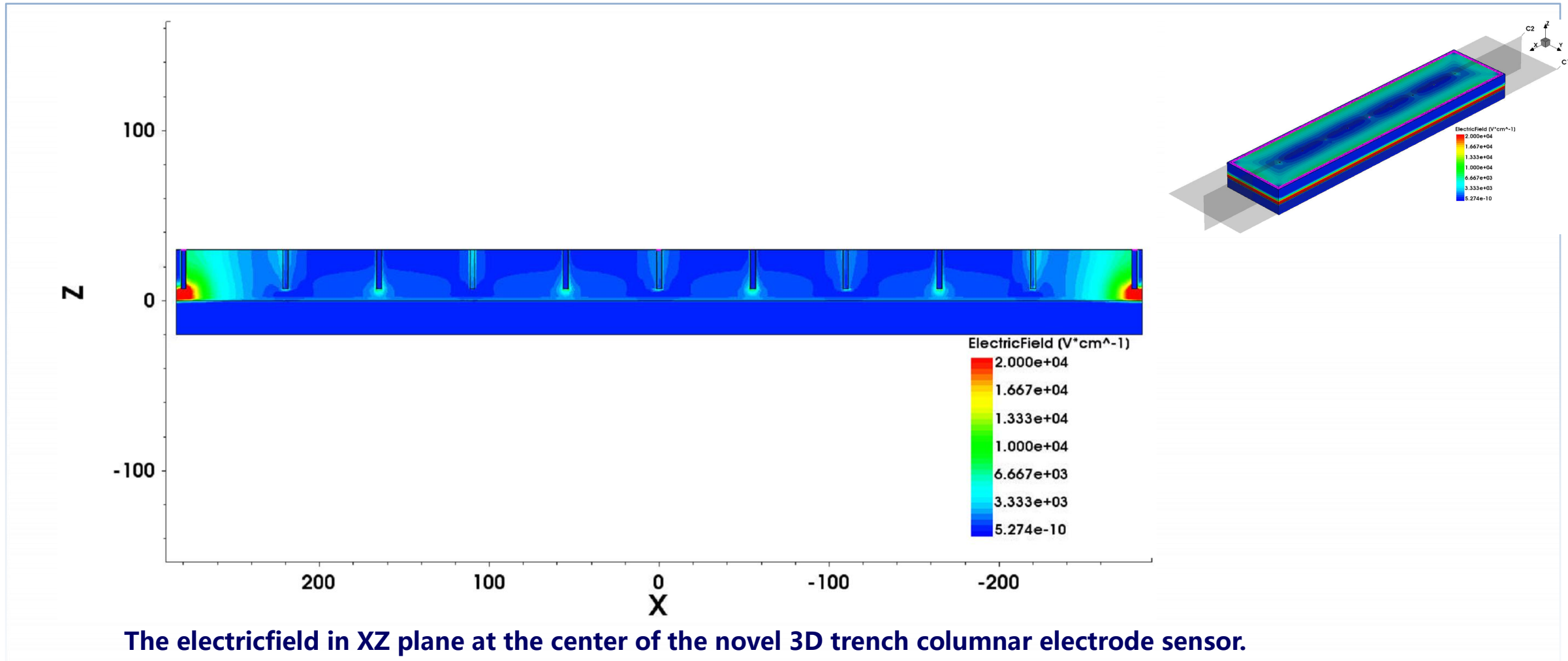


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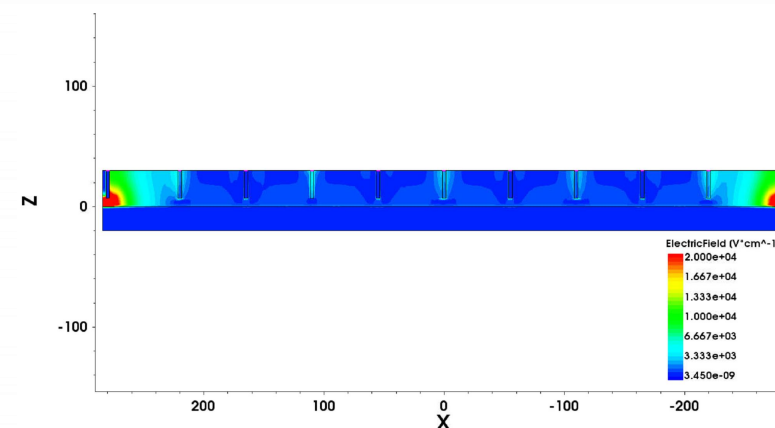
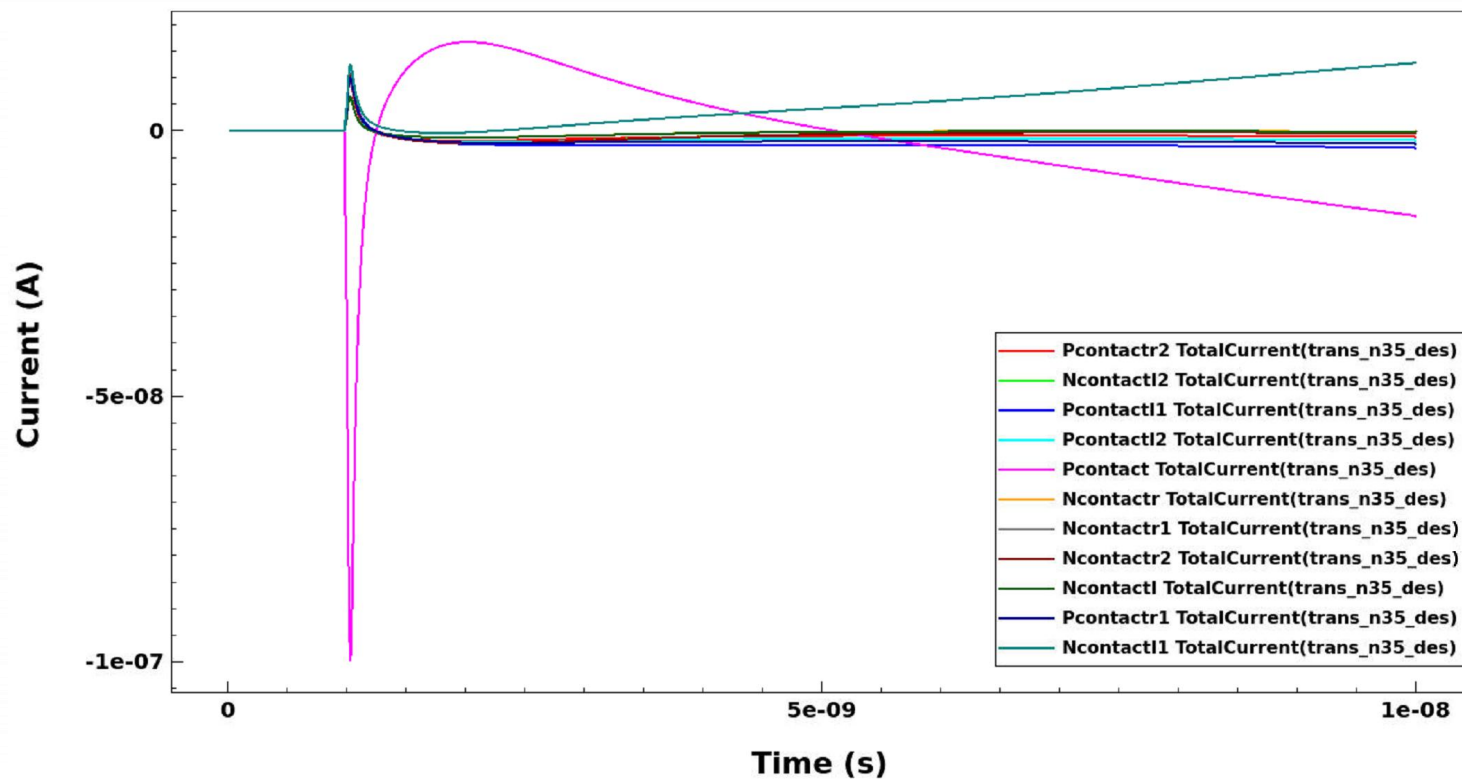


The electricfield along the x-axis at the depth of 25 μm of the novel 3D trench columnar electrode sensor.

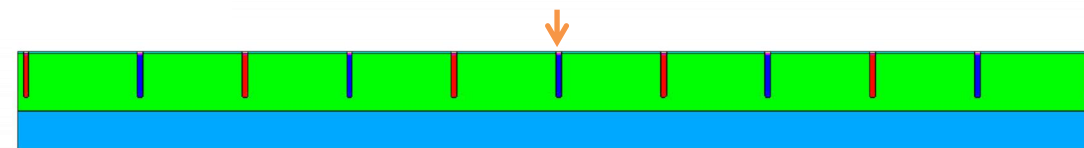
➤ 20 V is applied to the n-trench.



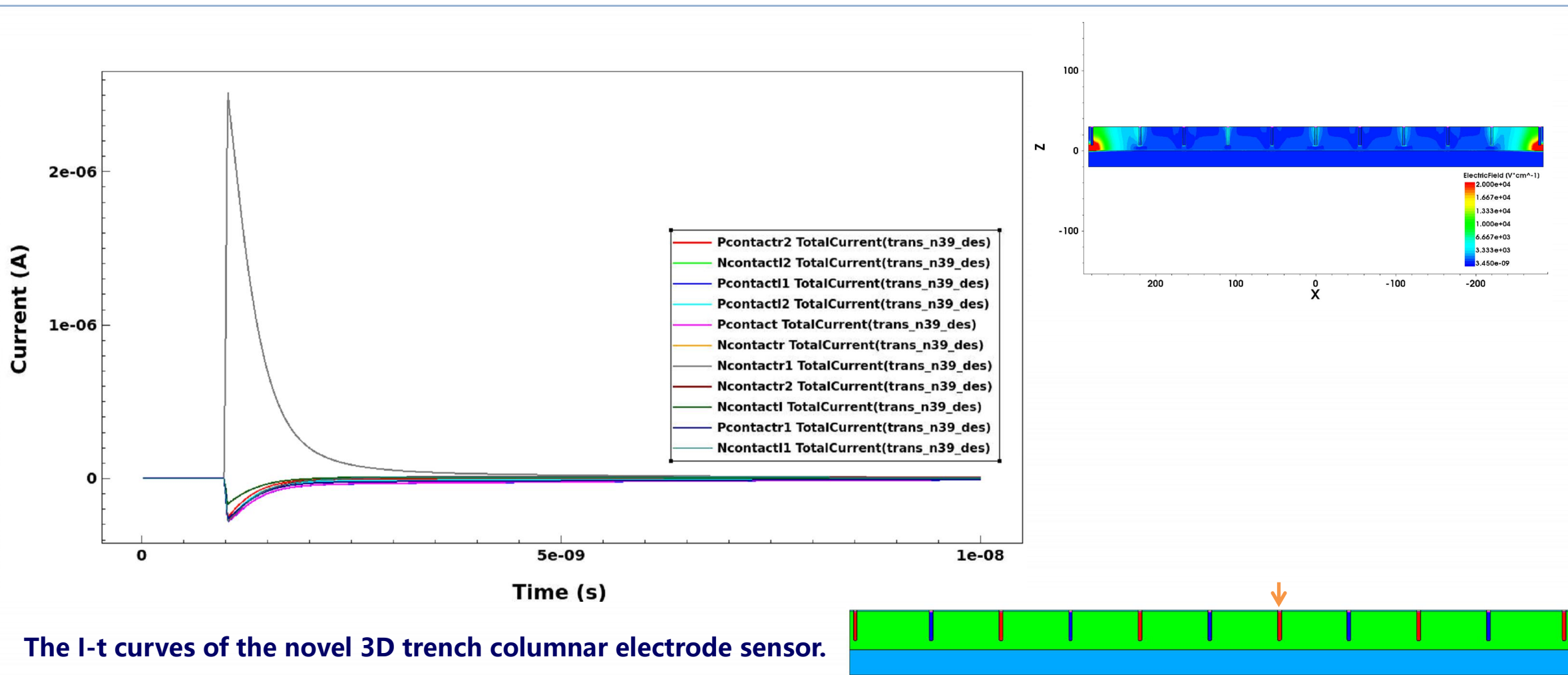
➤ 30 V is applied to the n-trench, 0 V is applied to the n-columns.



The I-t curves of the novel 3D trench columnar electrode sensor.



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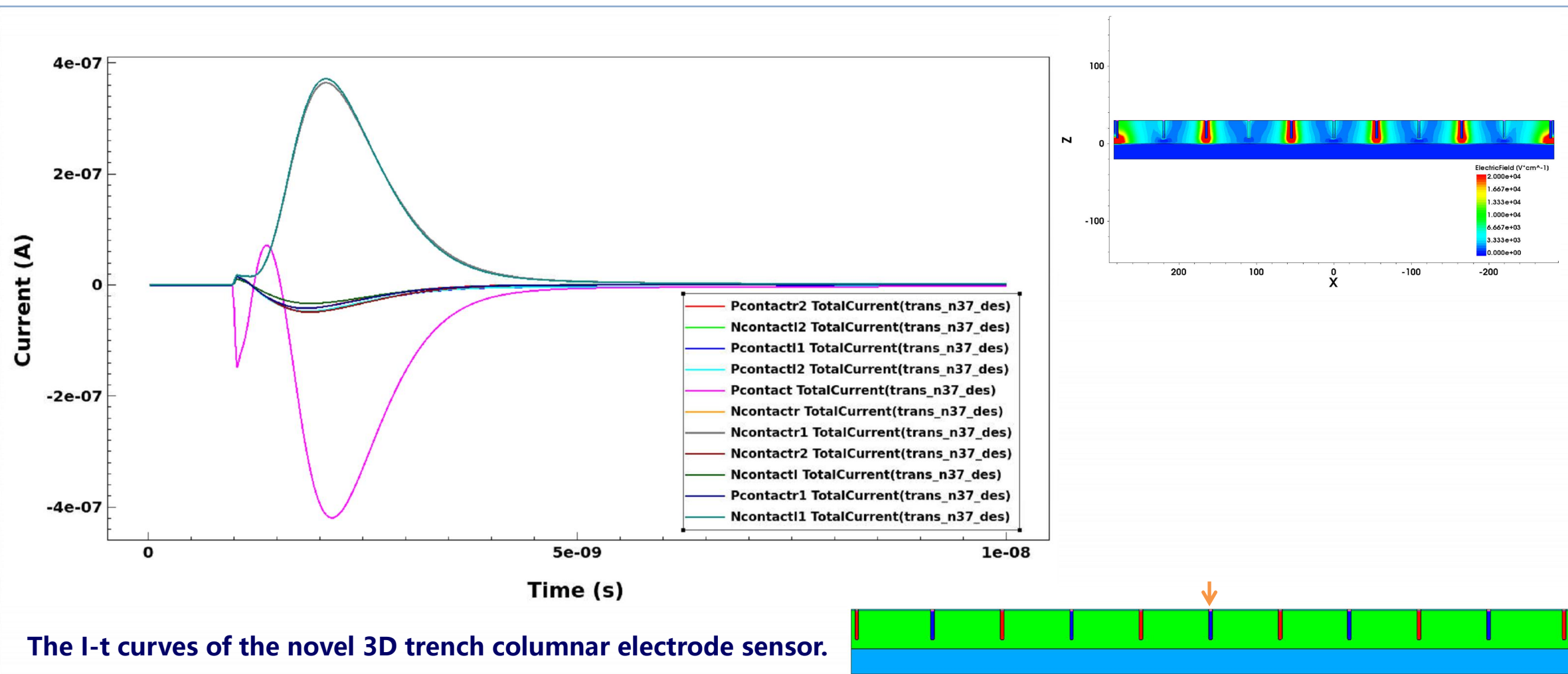


The I-t curves of the novel 3D trench columnar electrode sensor.

>>> 2D Simulation

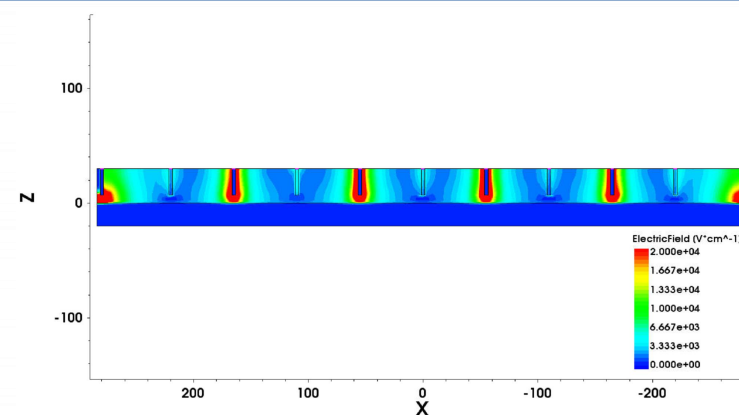
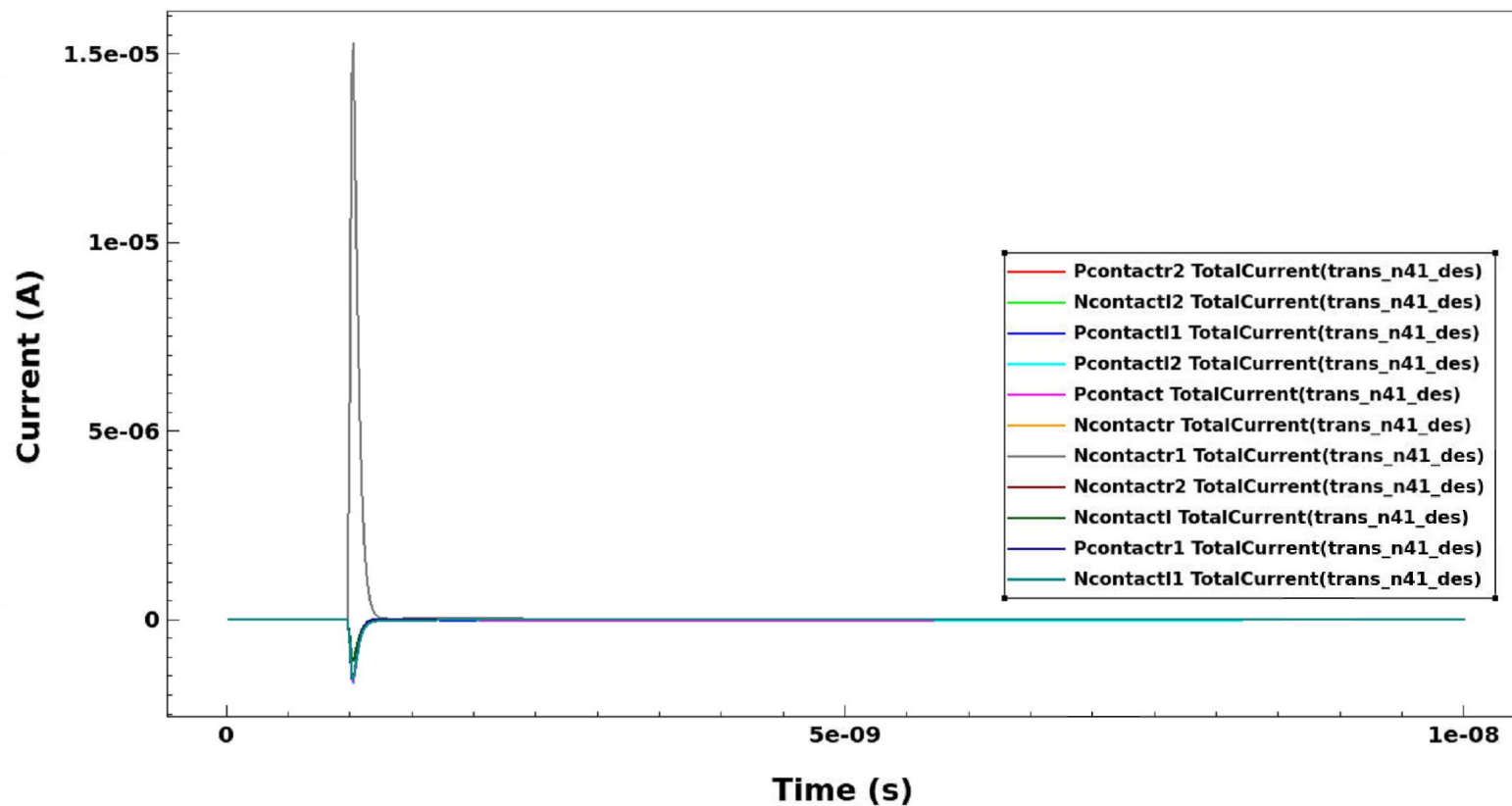


➤ 30 V is applied to the n-trench and the n-columns.

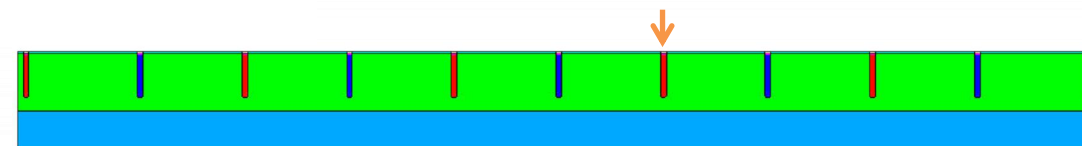


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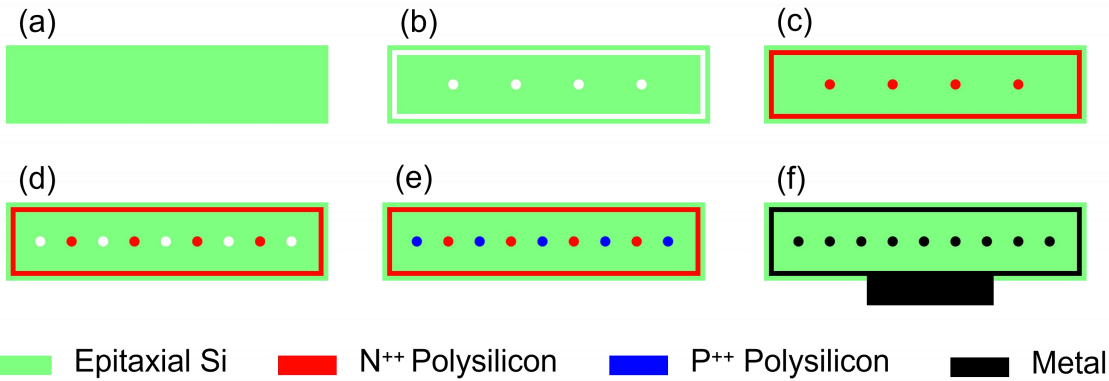
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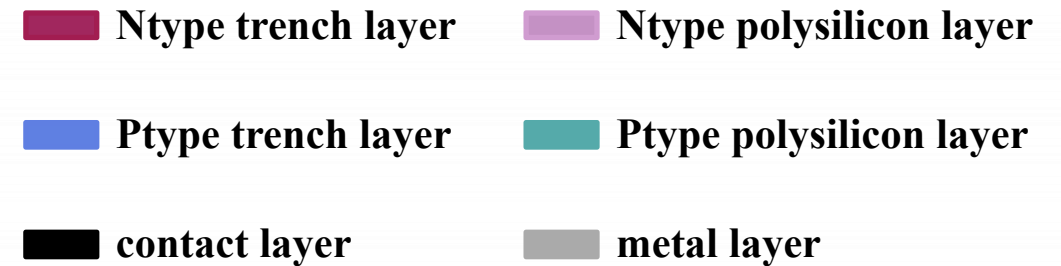
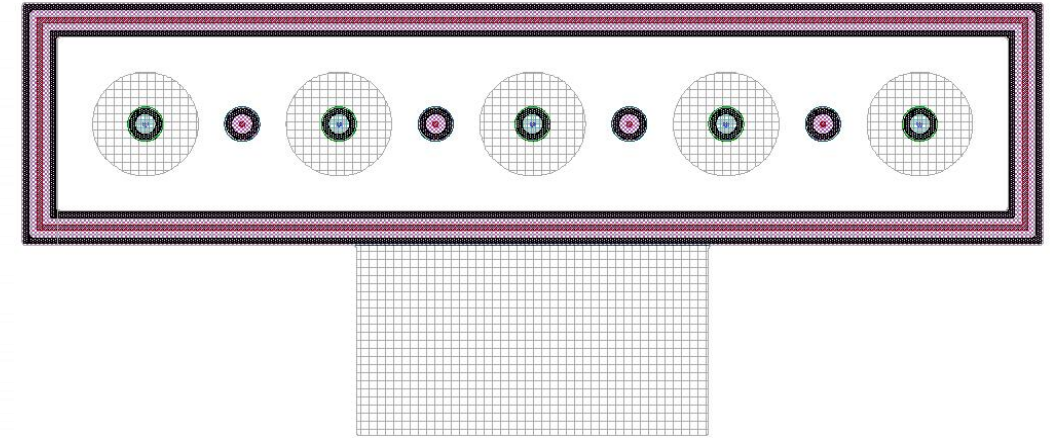
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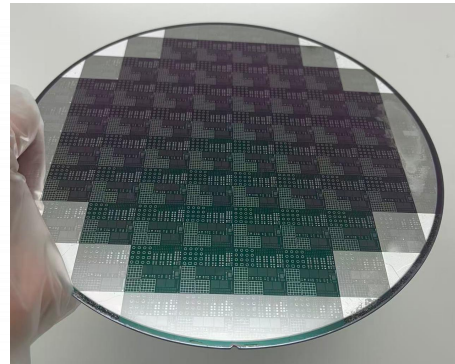
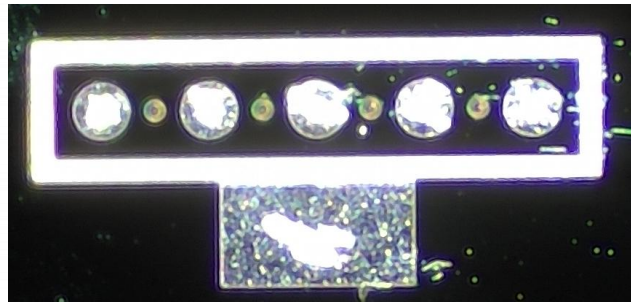
➤ Fabrication process, layout, microscope image and the completed wafer



The simplified fabrication process flow of the novel 3D trench columnar electrode sensor.

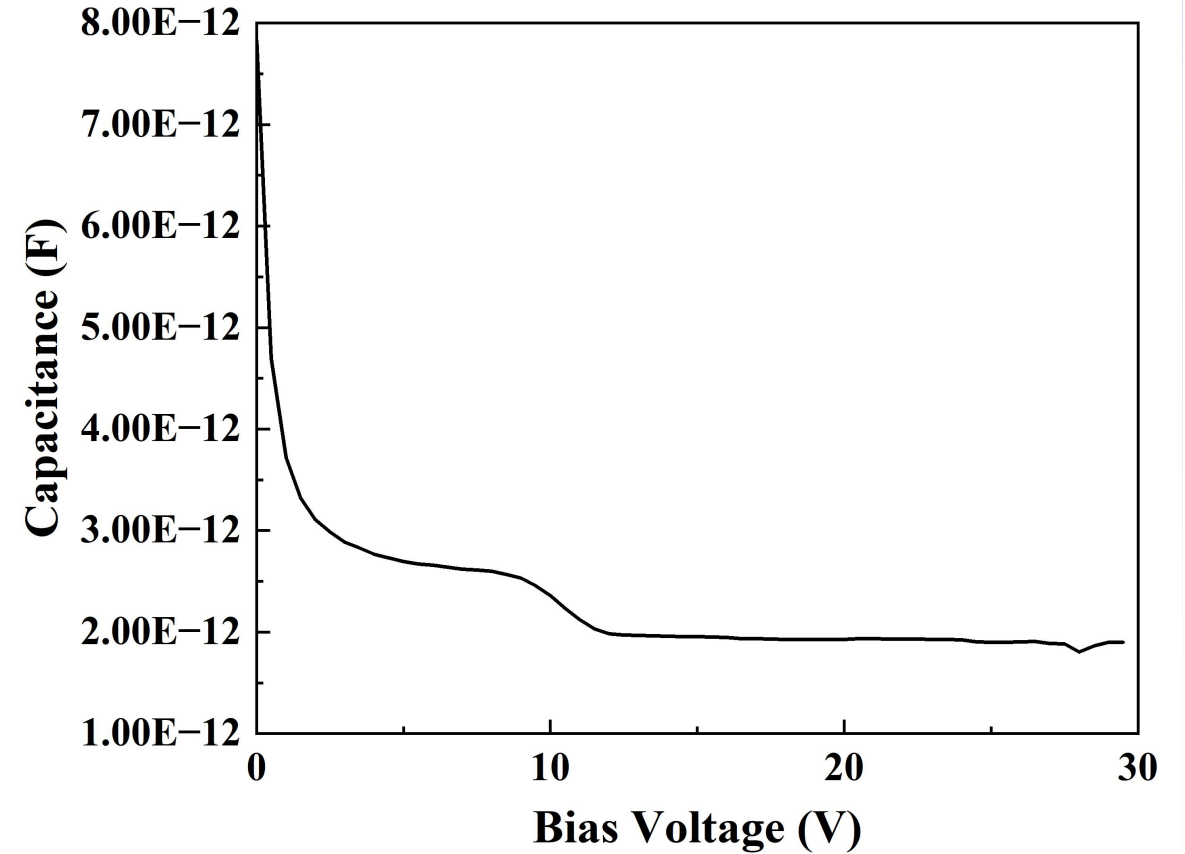
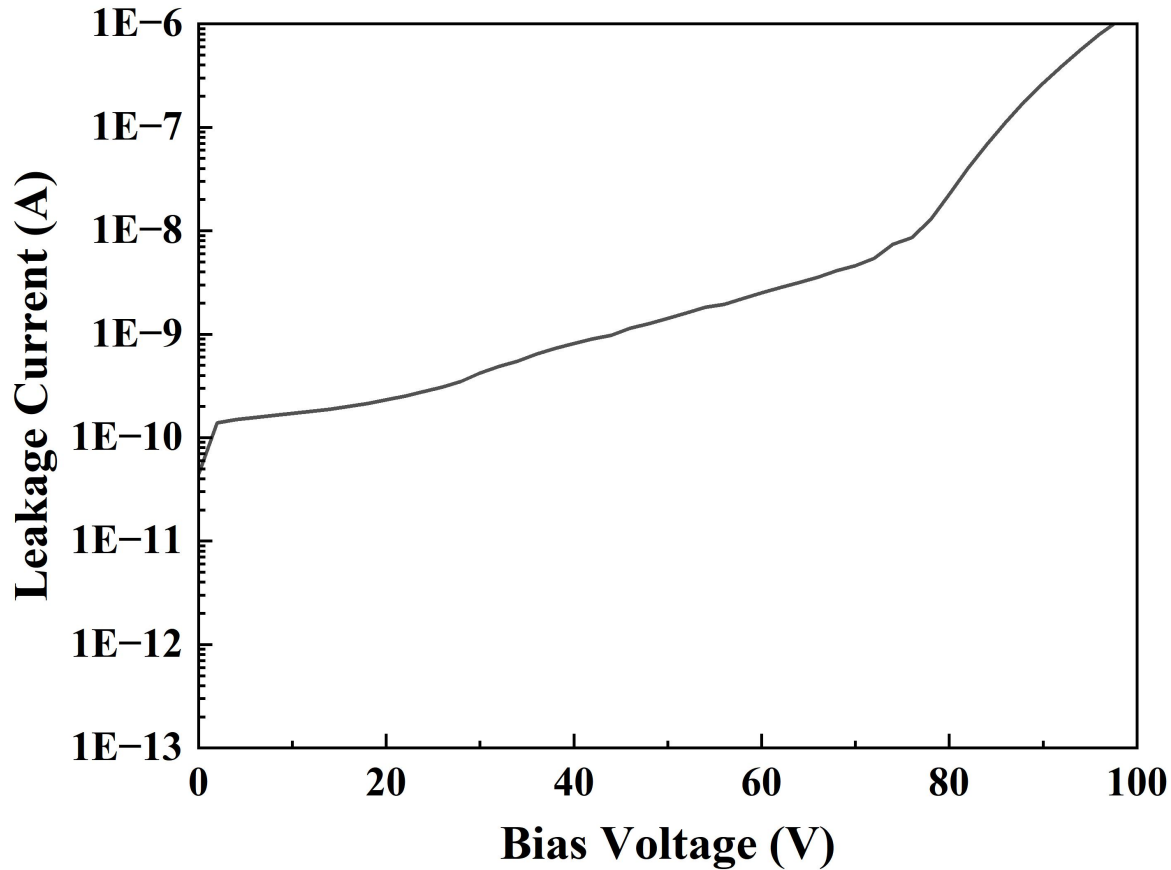


The layout of the novel 3D trench columnar electrode sensor.



The microscope image and the completed wafer of the novel 3D trench columnar electrode sensor.

➤ Electrical characteristics of the novel 3D trench columnar electrode sensor.



The I-V,C-V curves of the novel 3D trench columnar electrode sensor.

- A novel 3D trench columnar electrode sensor consisting of two types of vertical cylindrical electrodes and an outer surrounding trench electrode has been designed and successfully fabricated at the 8 inch CMOS pilot line at the Institute of Microelectronics of the Chinese Academy of Sciences (IMECAS).
- Five p-type and four n-type column electrodes are alternately arranged in a one-dimensional interleaved pattern to form periodic signal-isolation electrode pairs, with a closed-loop n-type rectangular trench electrode surrounding all inner columns to provide a uniform boundary electric field.
- TCAD simulations are performed to analyze the electrostatic potential and electric field distribution, IV, CV characteristics, and transient I-t response.
- Experimental results show pF-scale device capacitance and nA-level dark current under depletion bias. The preliminary results shown in this paper demonstrate that the devices are successfully working.
- Further tests are planned to investigate their characteristics in more detail. Future devices, incorporating lessons learned from the current batch, are currently being designed.



Thank you!

