Understanding the Humidity Sensitivity of Sensors with TCAD Simulations

I-S. Ninca[a,*], I. Bloch[a], B. Brüers[a], V. Fadeyev[b], J. Fernandez-Tejero[c], C. Jessiman[d], J. Keller[d], C. T. Klein[d], T. Koffas[d], H. M. Lacker[e], P. Li[e], C. Scharf[e], E. Staats[d], M. Ullan[f], Y. Unno[g]

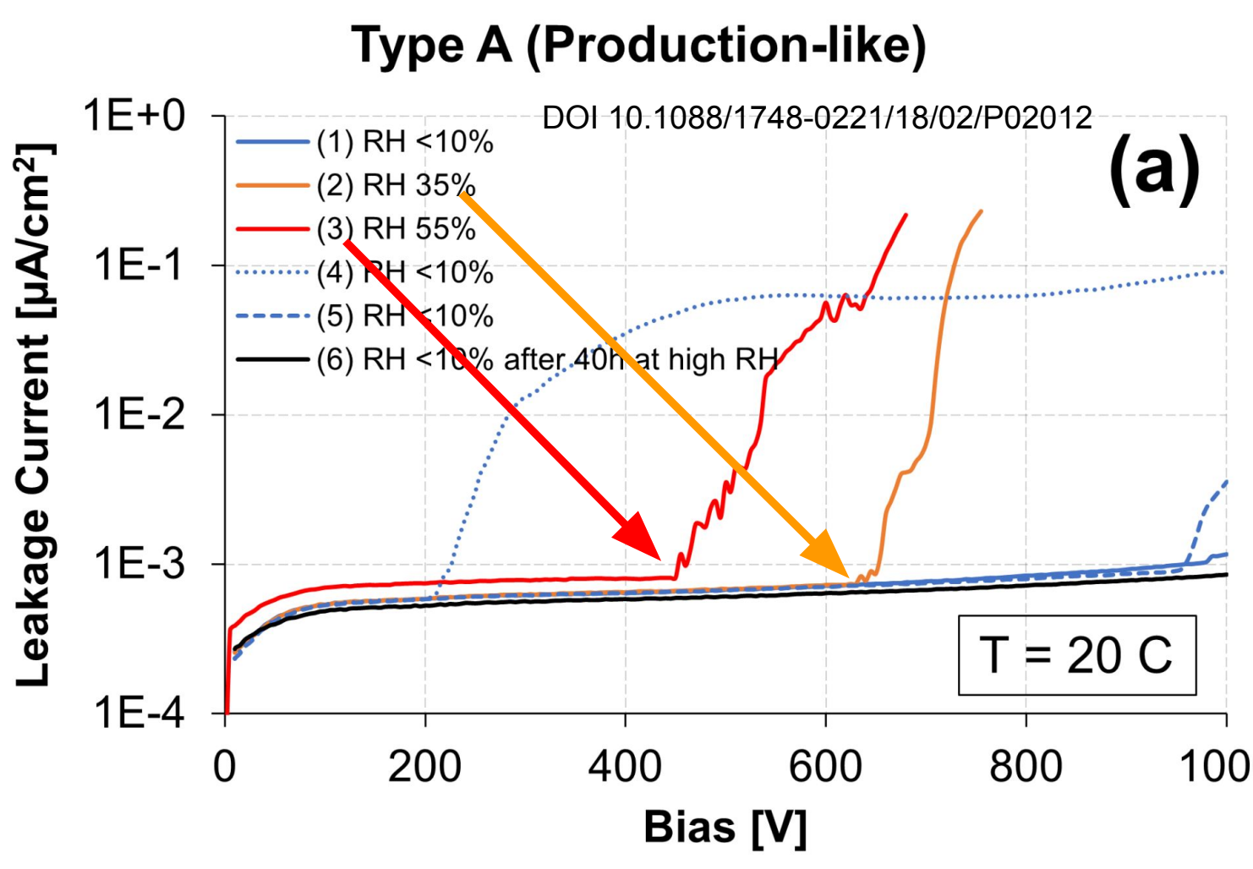
[*] Corresponding Author (ilona.ninca@desy.de)

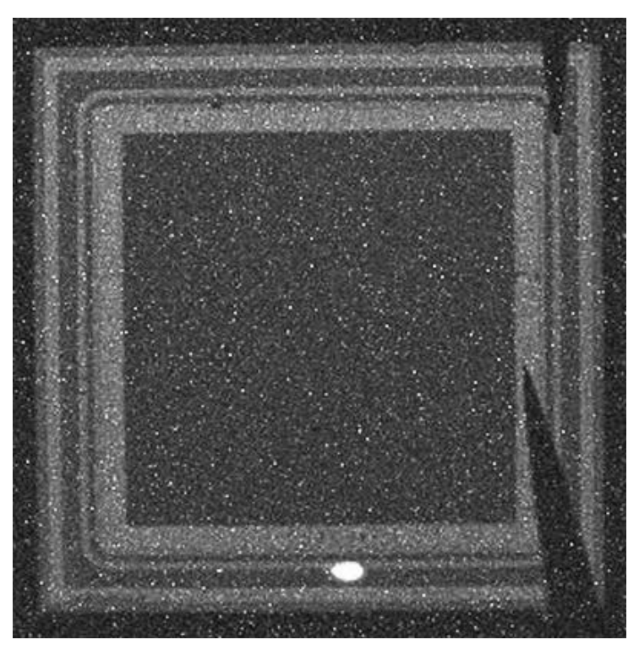
[a] DESY Zeuthen, Platanenallee 6, 15738 Zeuthen, Germany
[b] Santa Cruz Institute for Particle Physics (SCIPP), University of California, Santa Cruz, CA 95064, USA
[c] Department of Physics, Simon Fraser University, 8888 University Drive, Burnaby, B.C. V5A 1S6, Canada
[d] Physics Department, Carleton University, 1125 Colonel By Drive, Ottawa, Ontario, K1S 5B6, Canada
[e] Institut für Physik, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin, Germany
[f] Instituto de Microelectrónica de Barcelona (IMB-CNM), CSIC, Campus UAB-Bellaterra, 08193 Barcelona, Spain
[g] Institute of Particle and Nuclear Study, High Energy Accelerator Research Organization (KEK), 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

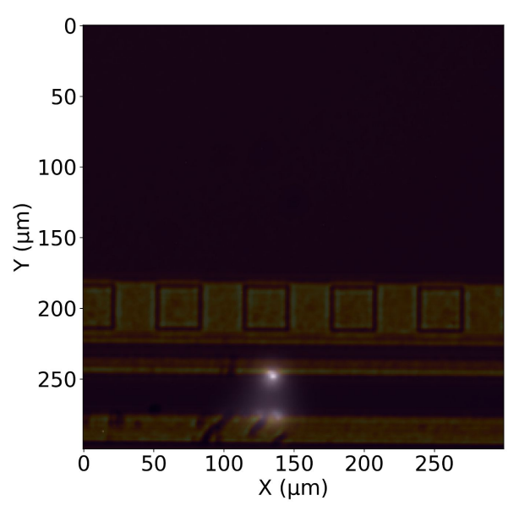
Sensor Humidity Dependence

★ Silicon sensors showed electrical breakdown at lower bias voltages in high humidity [https://doi.org/10.1016/j.nima.2020.164406]

★ Prevention method: dry storage and testing







★ Hot-electron emission microscopy with a <1 k€ CMOS camera was used to make the region where breakdown happens visible as bright spots

Measurement plan

★ Investigate how relative humidity (RH) affects charge transport in the guard ring region of sensors by generating localized free charge carriers near the surface with picosecond pulses of laser light: Top Transient Current Technique (TCT)

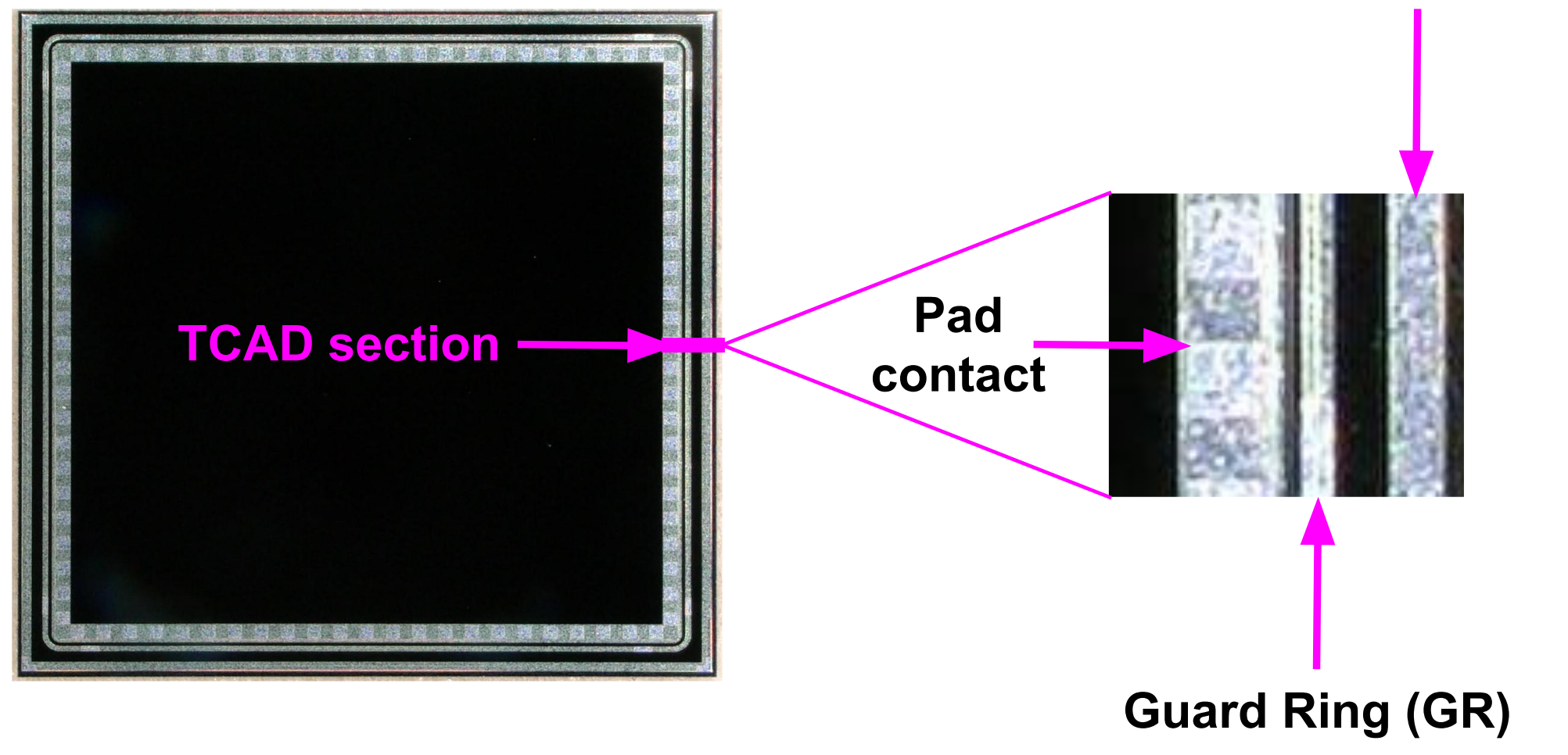
★ Simulate the electrical behavior of test structures using Sentaurus Technology Computer Aided Design (TCAD)

★ Test structure used: 8 mm x 8 mm n+/p/p+ (n-in-p) diodes (MD8 diodes)

★ An active thickness of ~ 295 µm was calculated based on capacitance-voltage measurements

★ Bulk doping: p-type concentration ~ 4.2 × 10^{12} cm^{-3}

★ $V_{depletion}$ ≈ - 280 V



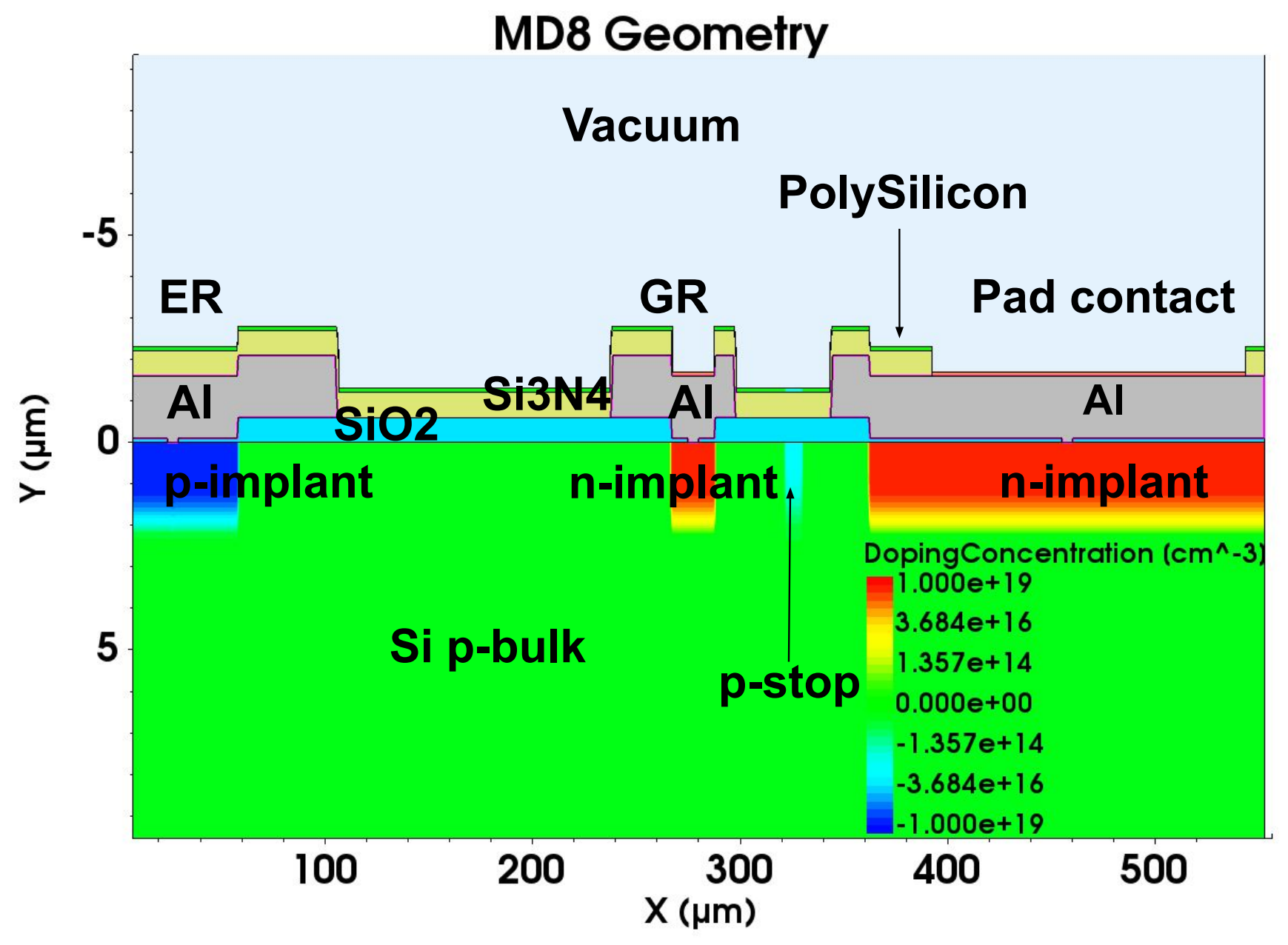
TCAD Geometry Implementation

★ Silicon active thickness = 295 µm

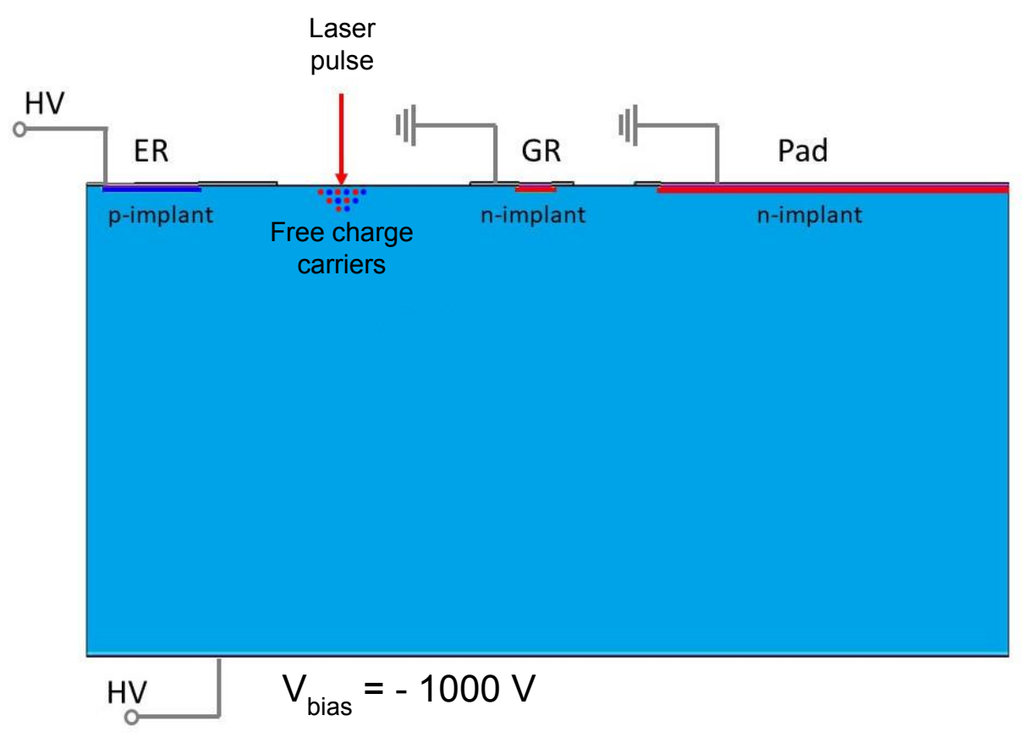
★ Passivation on top of the diode is made out of ~ 0.6 µm Si3N4 and ~ 0.6 µm SiO2

★ Fixed oxide charges concentration at the interface between SiO2 and Silicon = 10^{11} cm^{-2}

★ To implement humidity in TCAD, a 0.1 µm thick PolySilicon layer is generated on top of the passivation. The sheet resistance is modified based on laboratory measurements [DOI: 10.1109/NSSMIC.2014.7431261]. The PolySilicon is directly connected to the GR and pad, but it is not connected to the ER.



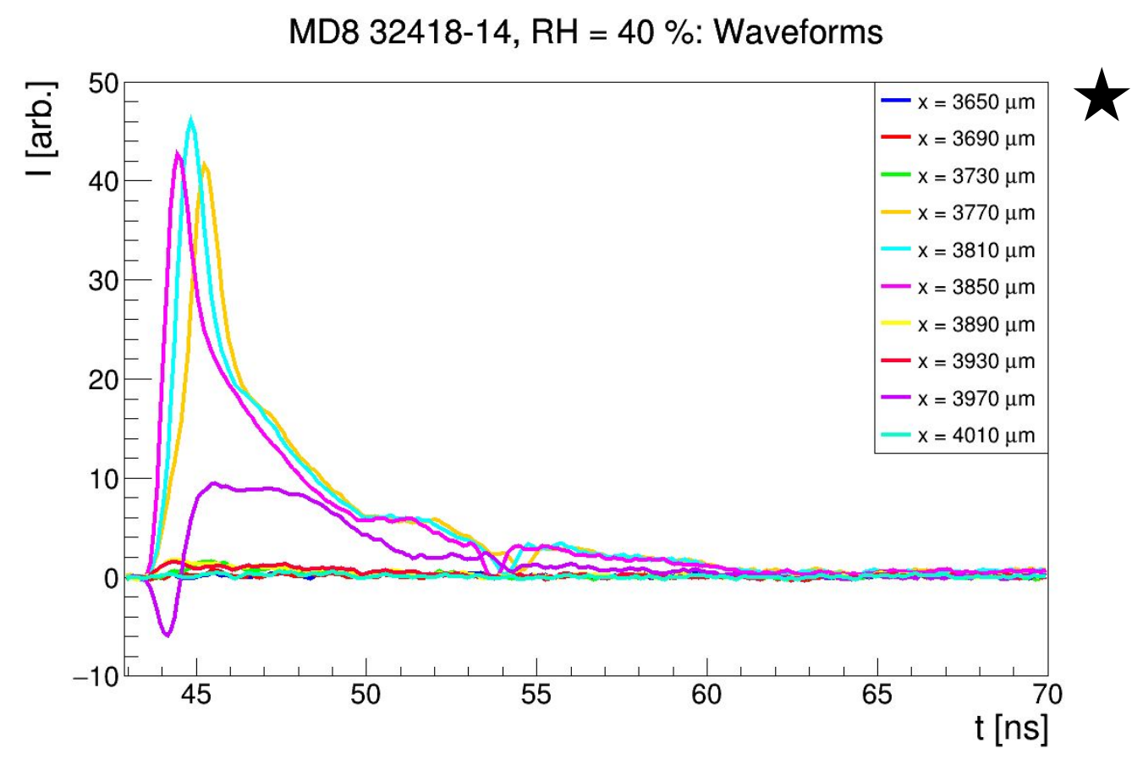
Top-Transient Current Technique (TCT)



★ Method: use a red laser (λ = 660 nm) to illuminate region between ER and pad

★ Measure: transient current generated by the electron-hole pairs drift

$$I(t)=e_0 N_{e,h}(t)\mu_{e,h}(E(r(t)))E(r(t))E_w(r(t))$$

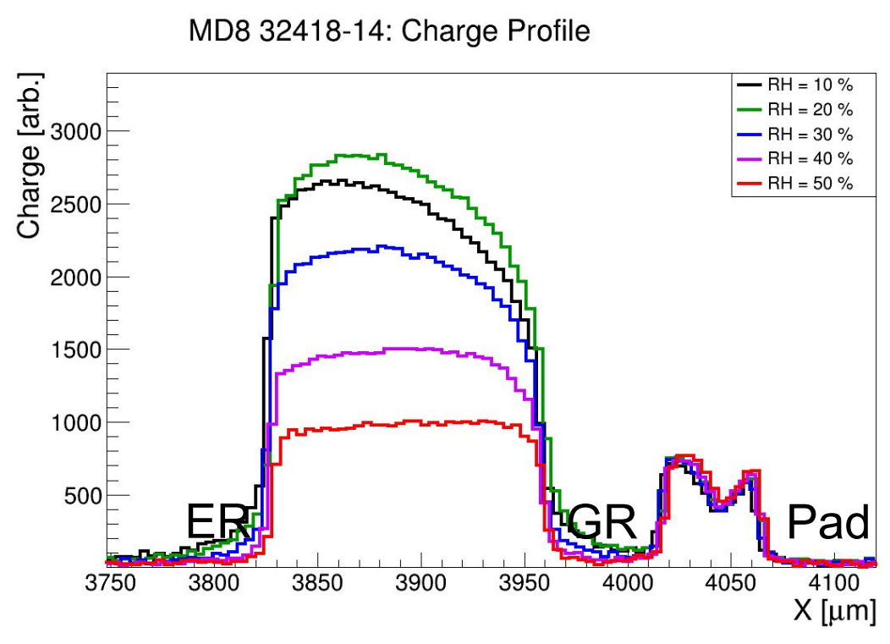


★ The charge profiles were extracted by integrating the transient current(s) for t = [43; 80] ns to prevent charge losses

★ The prompt currents were extracted by integrating the transient current(s) for t = [43,5; 43,9] ns

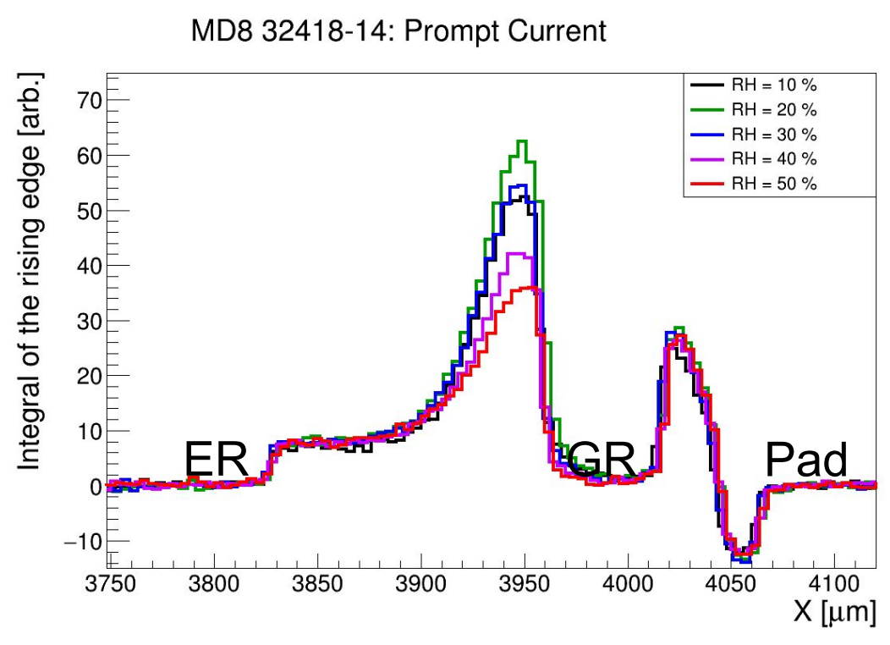
Discussion of Top-TCT Results

★ Between the ER and GR, the collected charge decreases with the increase in RH

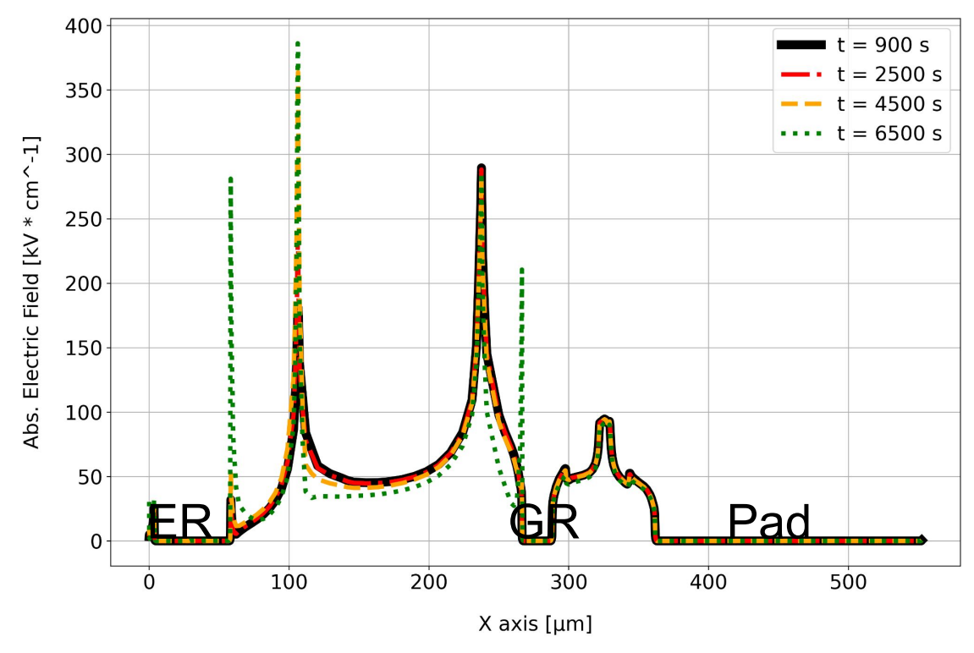


★ The maximum of the prompt current is near the outer edge of the GR

★ The prompt current decreases as the laser moves towards the ER



★ TCAD absolute electric field cut line along x for y = 100 nm shows two high field regions, near the ER and near the GR

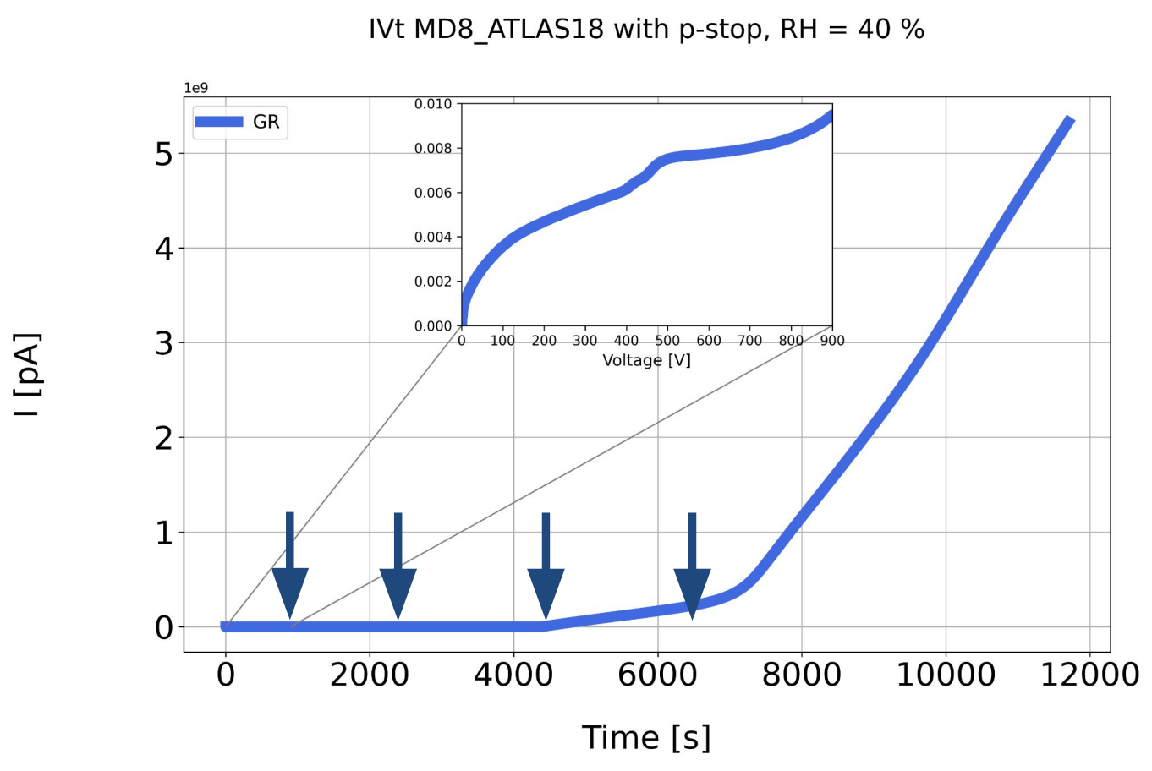


TCAD Simulation

★ The bias voltage is ramped from 0 V in steps of 10 V/10 s

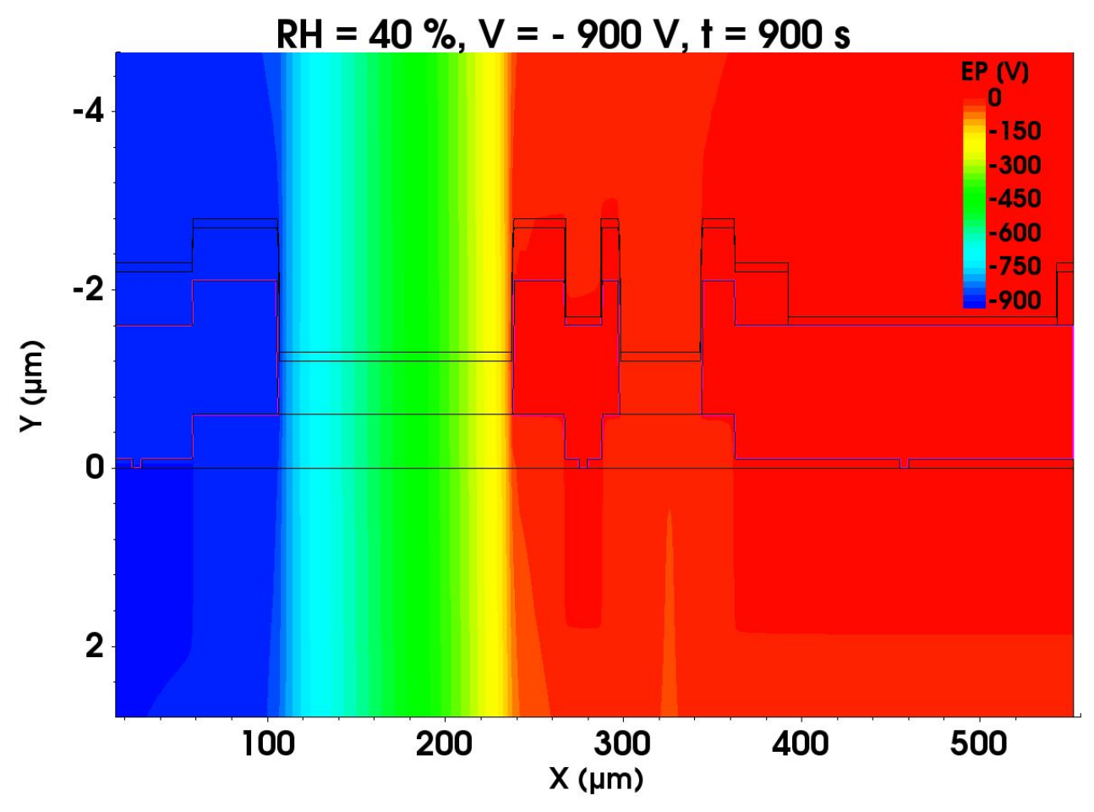
★ After 900 s, the bias voltage is constant at - 900 V

★ Soft breakdown starts at time = 4372 s - the arrows below point the timestamps for the TCAD results shown

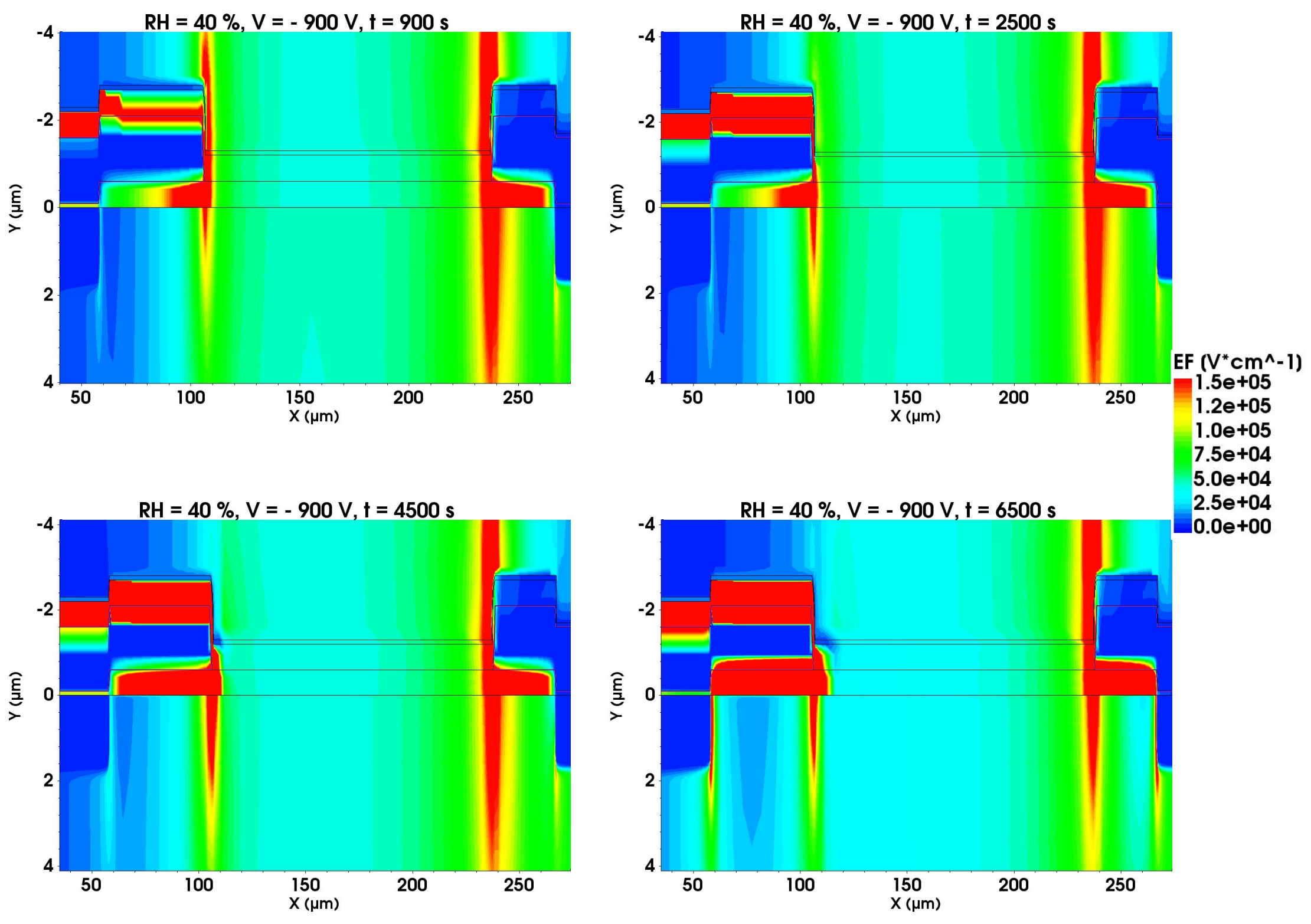


★ - 900 V applied on the **ER** and **backside**

★ **GR** and **pad** set at 0 V



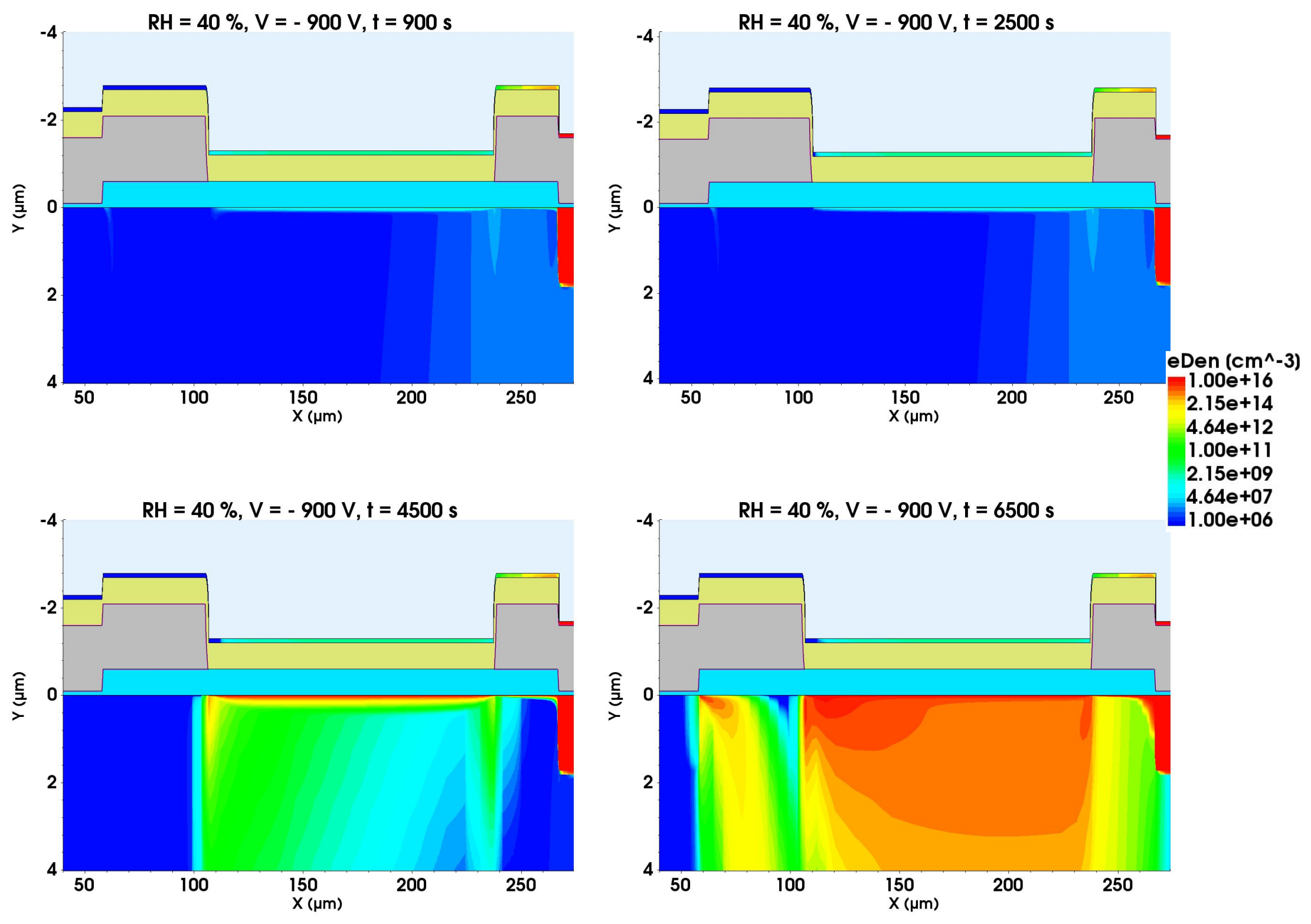
TCAD Results: Electric Field



★ After ramping (t = 900 s), two high field regions are already formed near the ER and near the GR

★ At t = 6500 s new high field region appear near the ER implant and near the GR implant

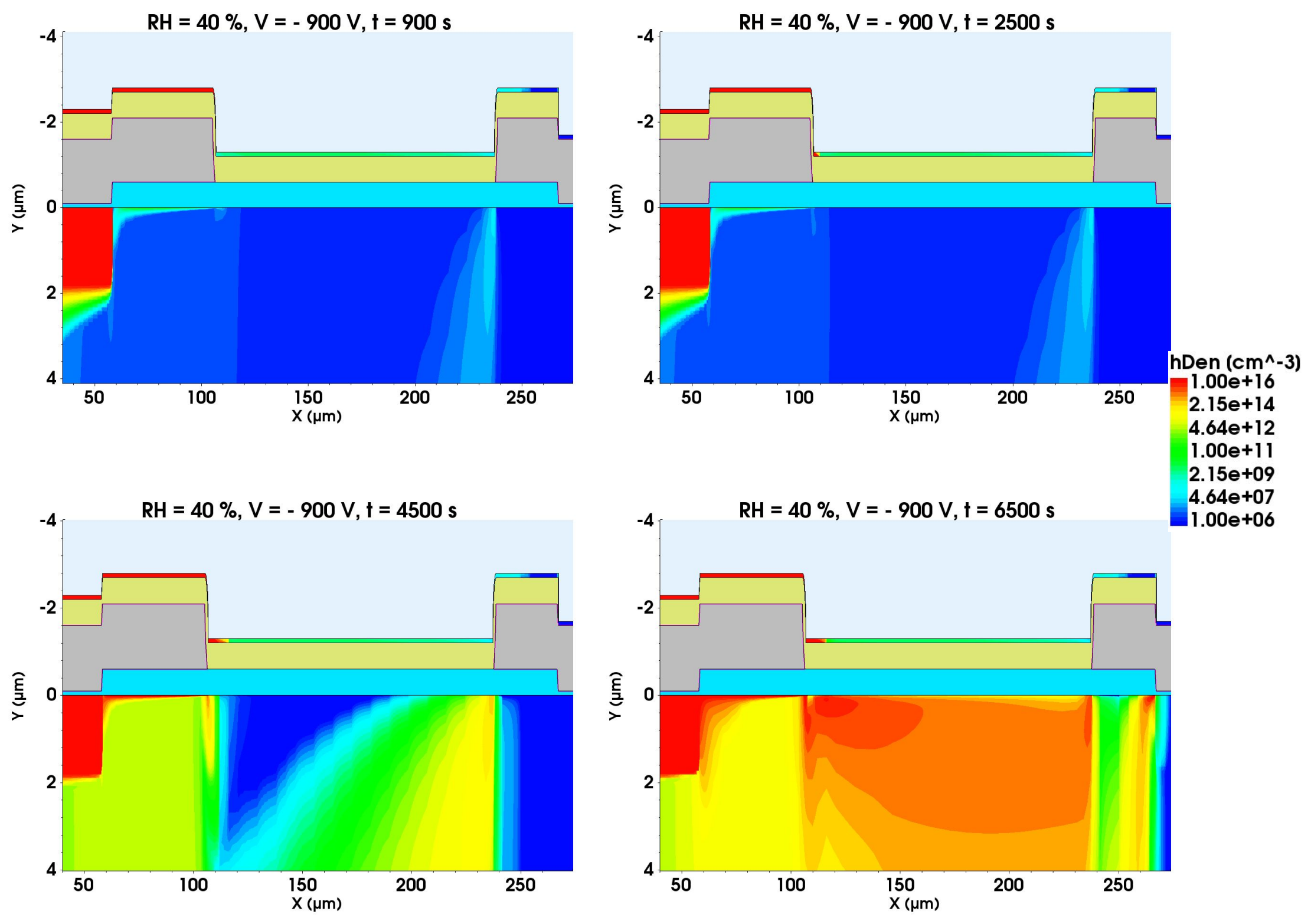
TCAD Results: Electron Density



★ After ramping (t = 900 s), there is a low density electron channel in between the ER and GR due to the positive fixed oxide charges at the interface between SiO2 and Silicon

★ The electron density at the interface increases when the current starts rising

TCAD Results: Hole Density



★ A high density of holes are present in the PolySilicon layer on top of the ER

★ Over time, a high concentration of holes in the PolySilicon layer moves laterally towards the GR

★ The hole density below the inversion layer grows with time

Summary

★ Top-TCT measurements and TCAD simulations of silicon sensors have been performed as a function of relative humidity with a focus on the guard ring region to study humidity-related electrical breakdown.

★ The collected charge between the guard ring and the edge decreases with rising relative humidity in laboratory measurements. The maximum prompt current observed in the measurement coincides with an electric field peak in the simulation which would induce charge multiplication of drifting electrons.

★ Electrical breakdown is observed in the TCAD simulation at high humidity after waiting some time at a constant bias voltage.

★ Next up are further simulations and measurements in breakdown conditions and further studies on the parameters which drive breakdown in the simulation, such as the coupling of the resistive layer on the surface and the fixed oxide charge density.