Humidity Studies on Silicon Sensors

Ilona-Stefana Ninca[1]
[1]Deutsches Elektronen-Synchrotron (DESY)

SiDet R&D Meeting

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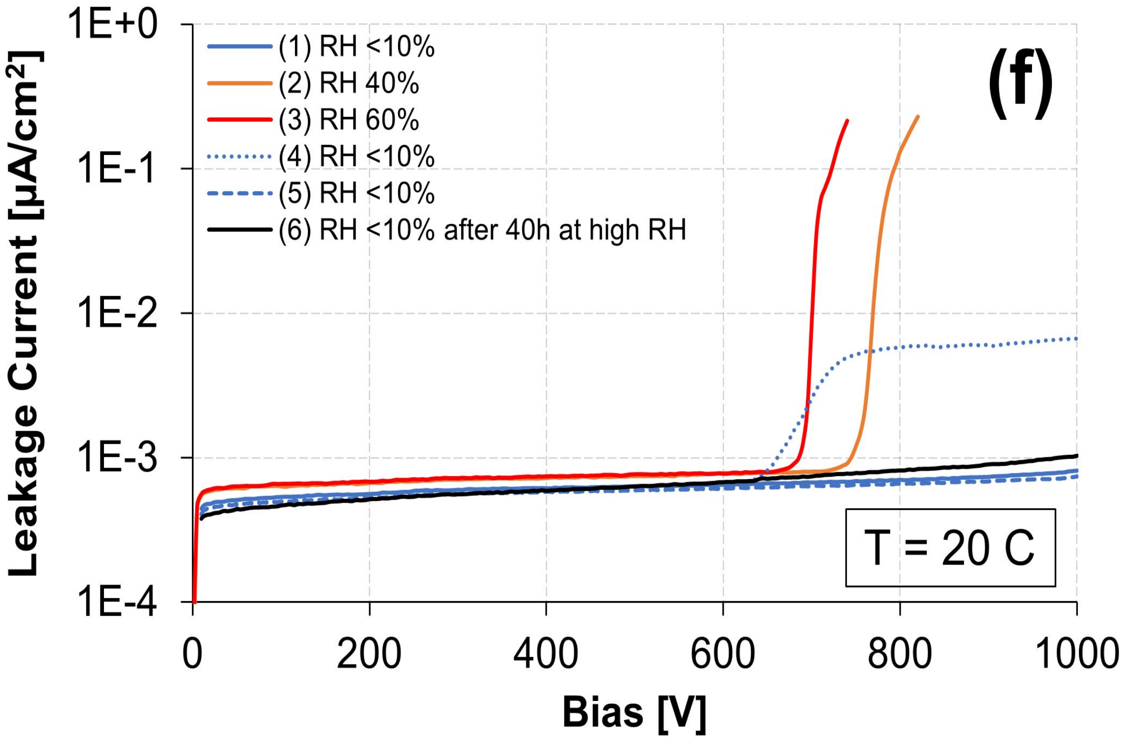
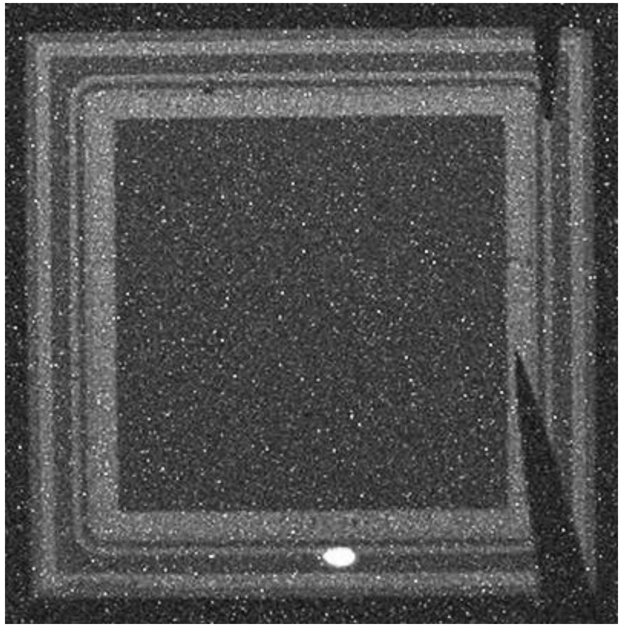
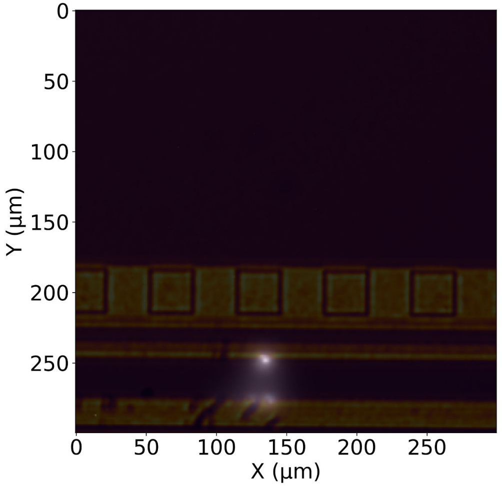
Humidity Studies Motivation



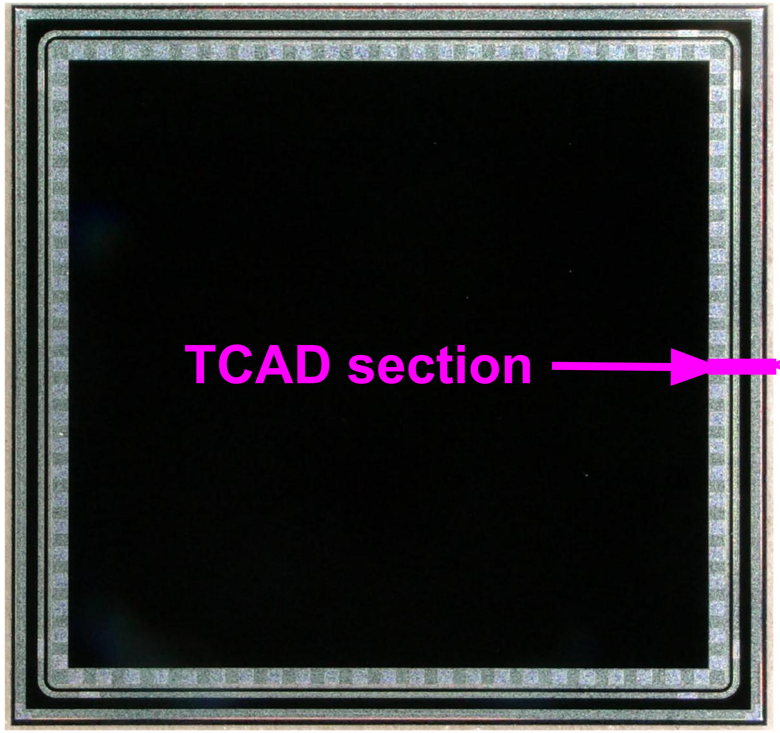




https://doi.org/10.1016/j.nima.2020.164406

- ★ Large area sensors in ATLAS ITk showed humidity sensitivity early breakdown
- ★ Reverse-bias blocks current flow
  - ○ small amount of current, called leakage current, can still flow through the sensor
- ★ Region where breakdown happens: visible as bright spots in the sensor edge proximity

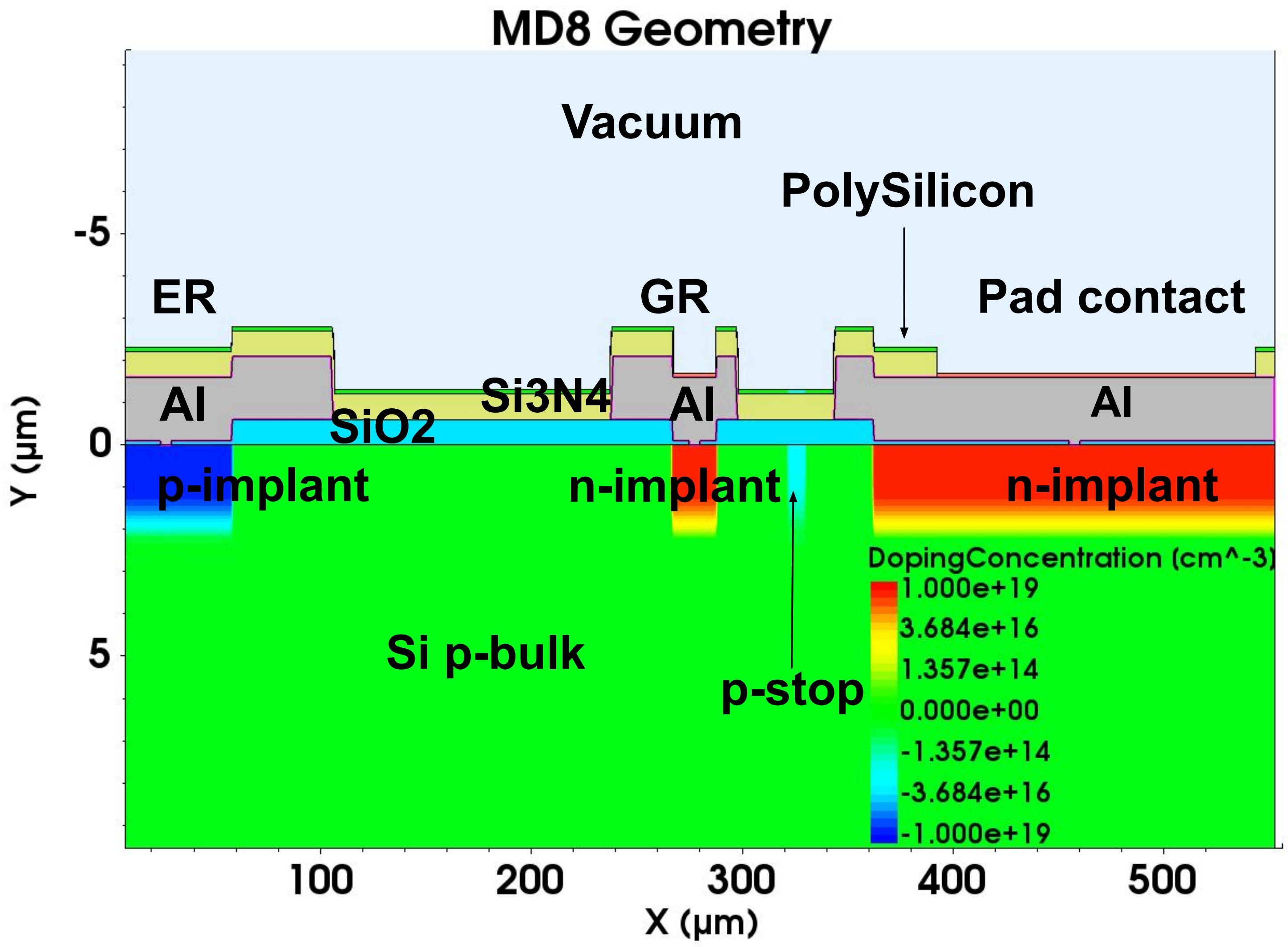
ATLAS18 Test Structures



- ★ 8 mm x 8 mm n^+pp^+ (n-in-p) diodes (**MD8 diodes**)
- ★ Active thickness ~ 295 µm
- ★ Bulk doping: p-type concentration ~ 4.2×10^{12} cm^{-3}
- ★ V_{FD} = ~ - 274 V

- ★ 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)

Technology Computer Aided Design (TCAD) Simulations



- ★ 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 [DOI: 10.1016/j.nima.2016.06.032]. 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 (Top-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

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

★ e_0 = elementary charge

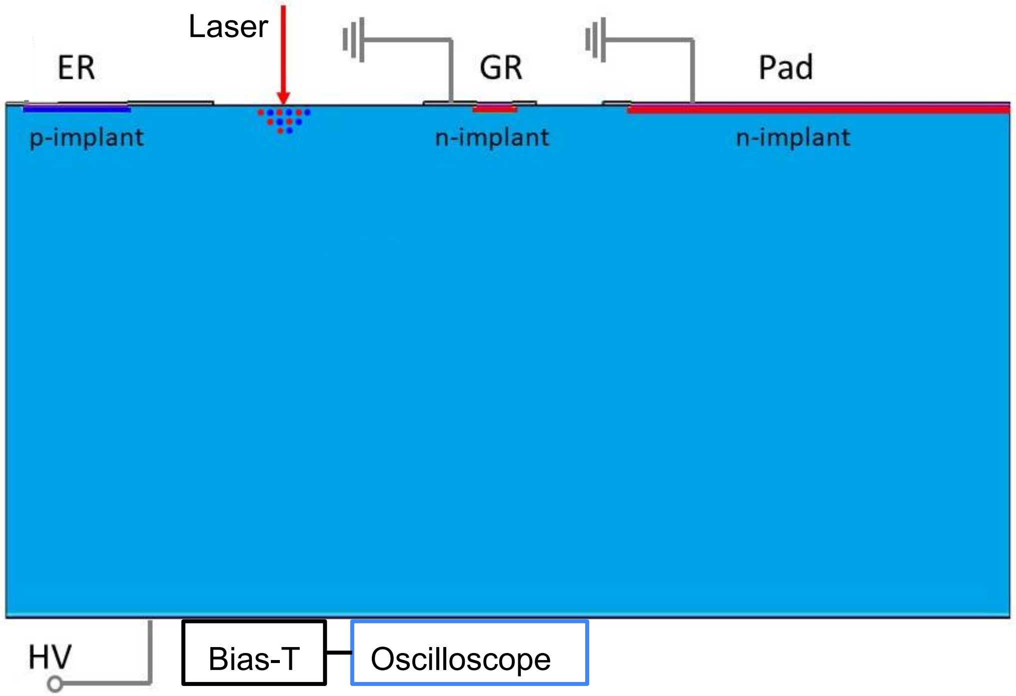
★ $N_{e,h}$ = number of created e-h pairs

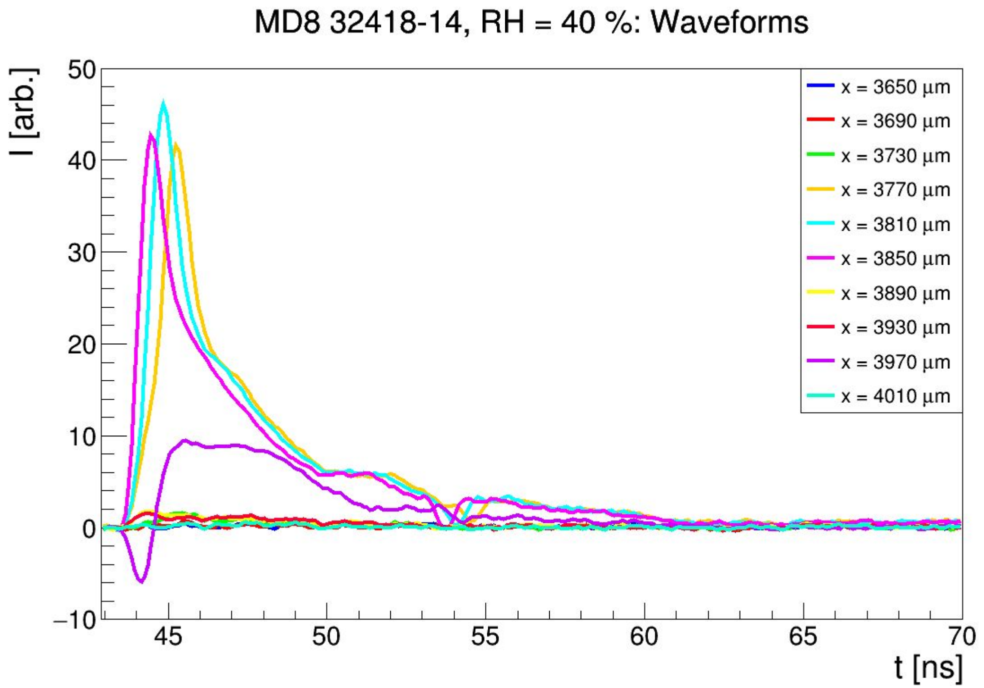
★ $\mu_{e,h}$ = mobility

★ $E_w(y)$ = weighting field

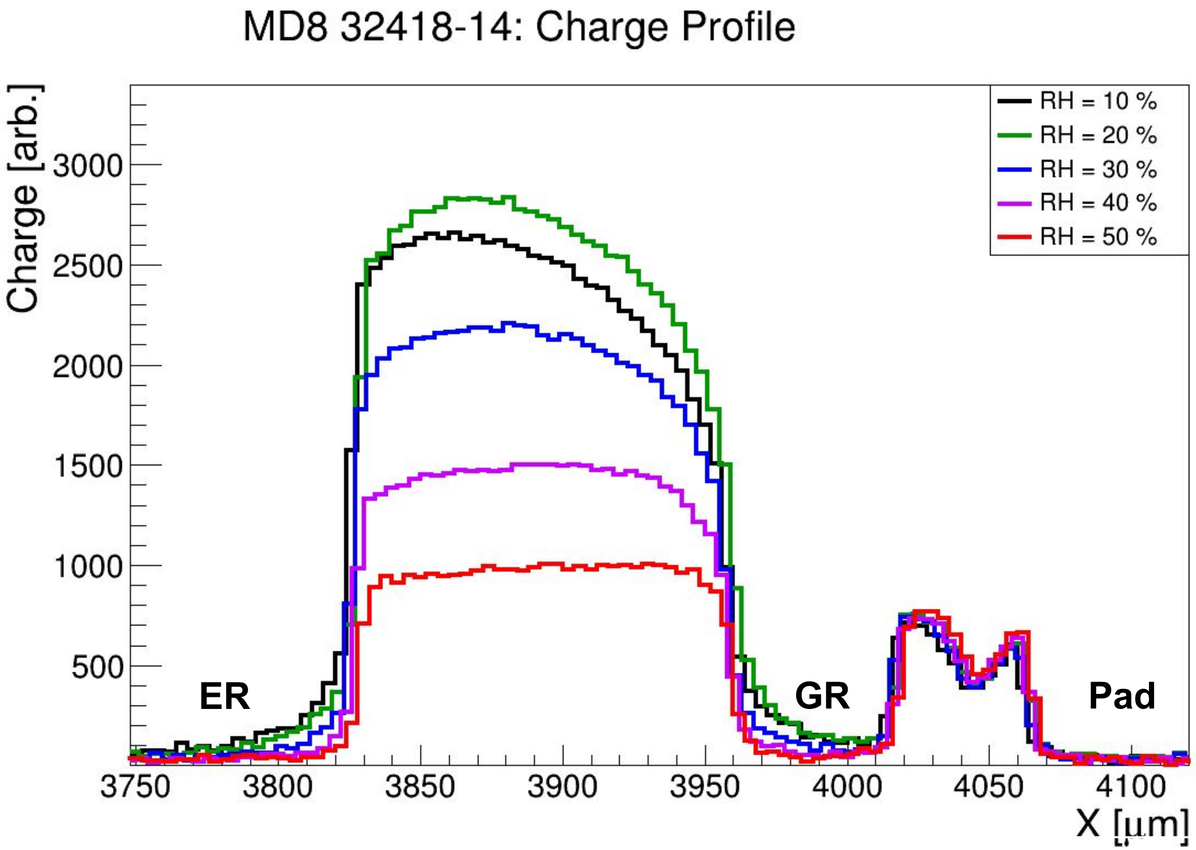
★ The charge profiles were extracted by integrating the transient current(s) for t = [43; 80] ns to prevent charge losses

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

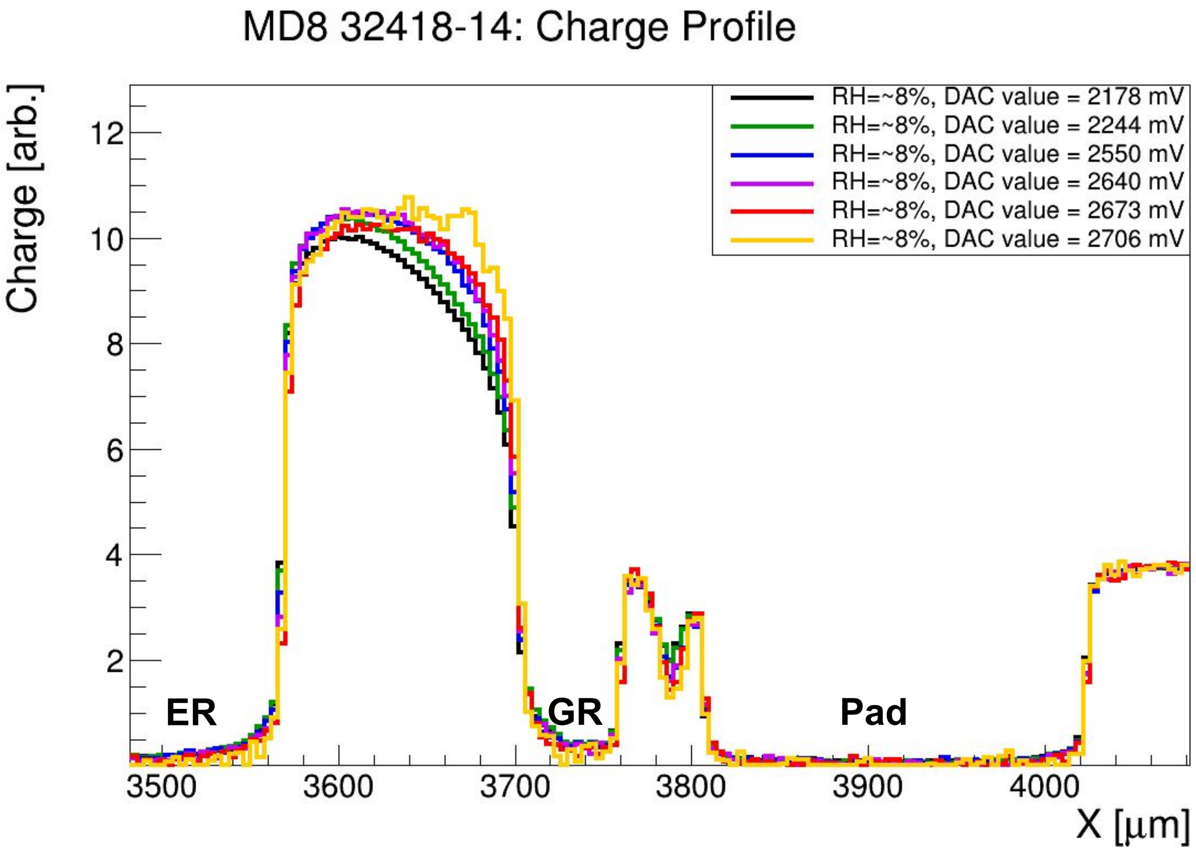




Charge Profiles

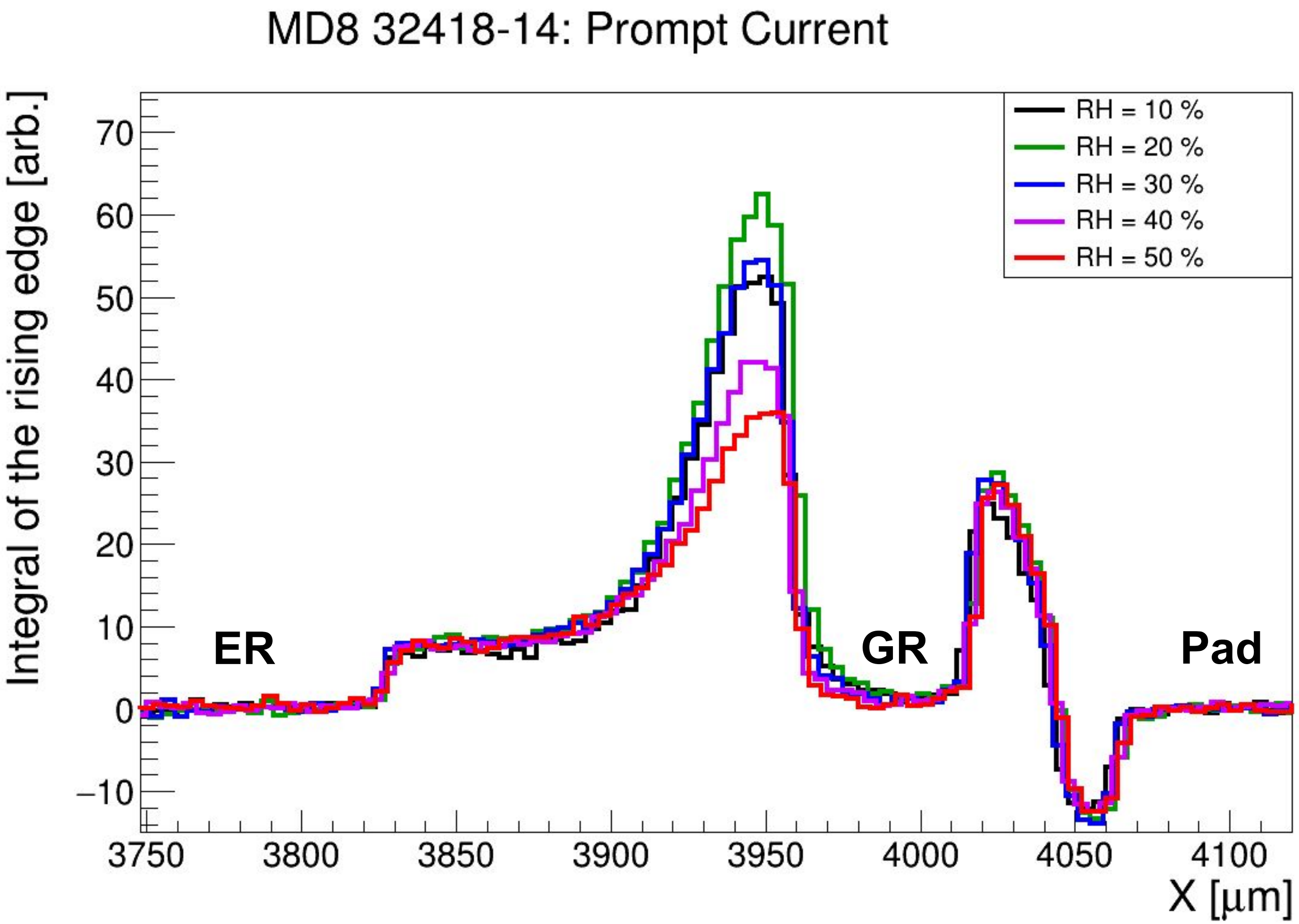


Charge profiles between the ER and pad metalization for different values of RH and V_{bias} = −1000 V. Bias was not applied until the desired RH value was reached. Between the ER and GR, the collected charge decreases with the increase in RH.



Normalized collected charge between the ER and pad window at RH = 8 %, V_{bias} = −1000 V and different laser intensities (a larger DAC value corresponds to a lower intensity). The collected charge was normalized to the charge collected in the pad window, which starts at X = 4010 μm, for each laser intensity.

Prompt Current

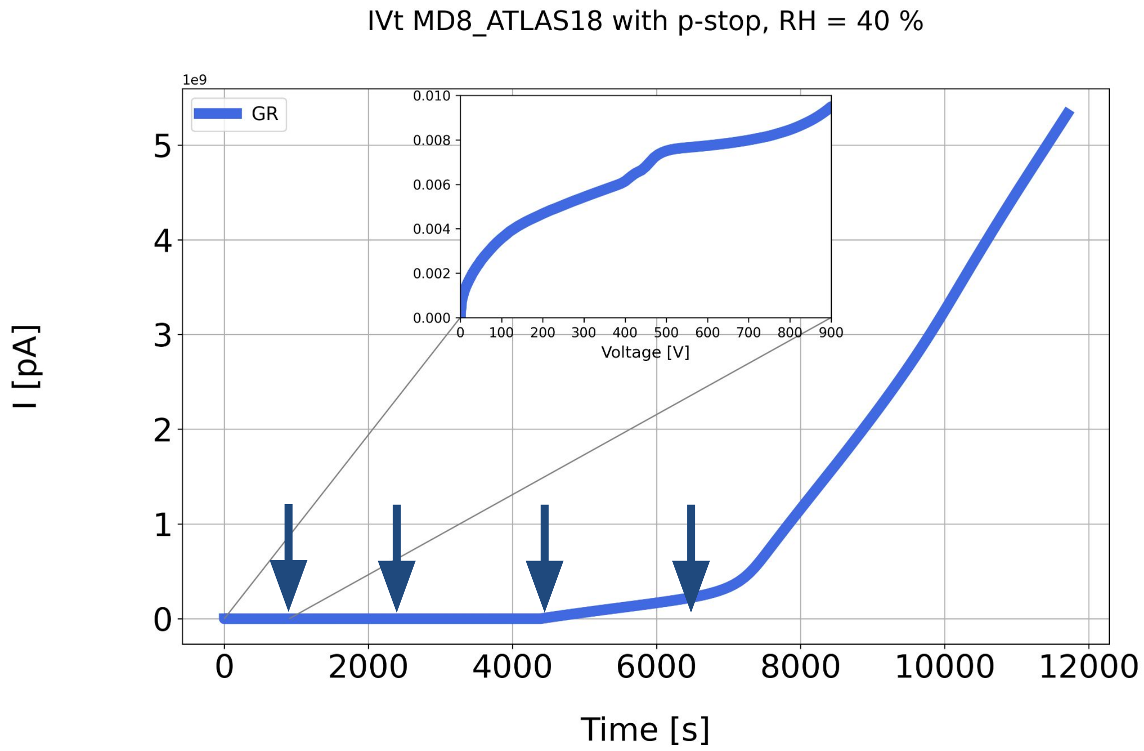


Prompt currents between the ER and pad metalization for different RH and V_{bias} = −1000V.

- ★ 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 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



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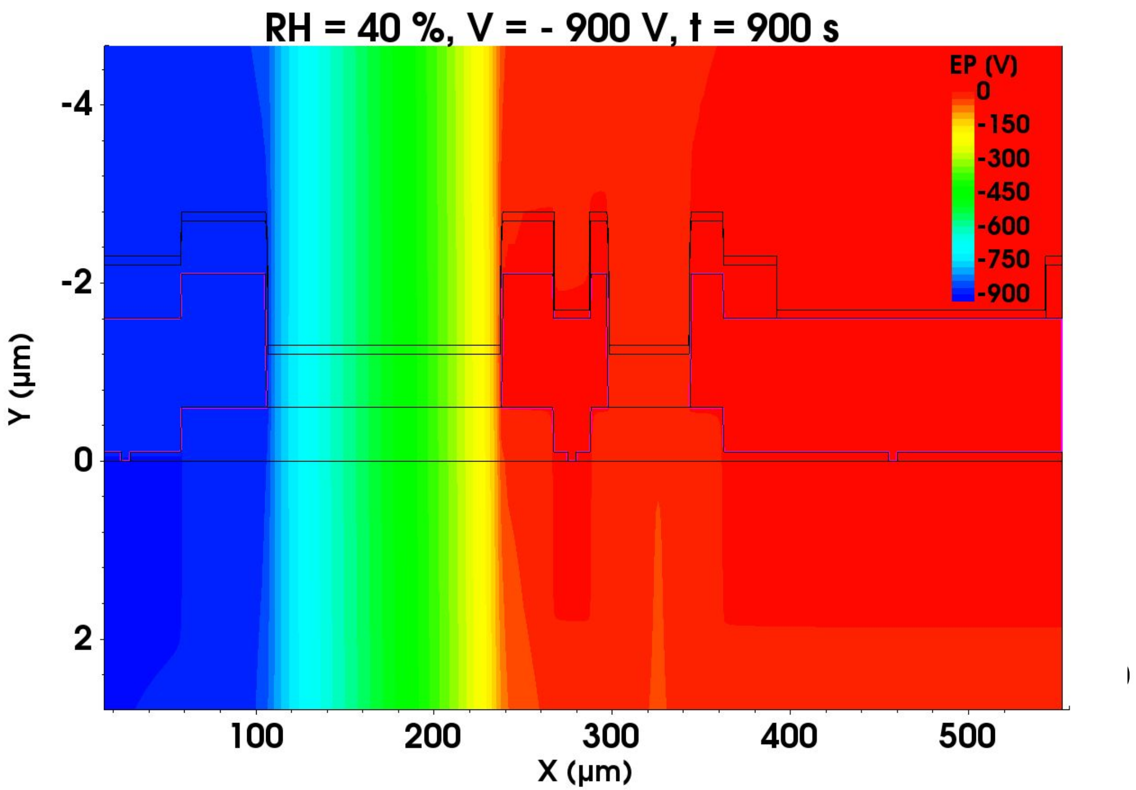
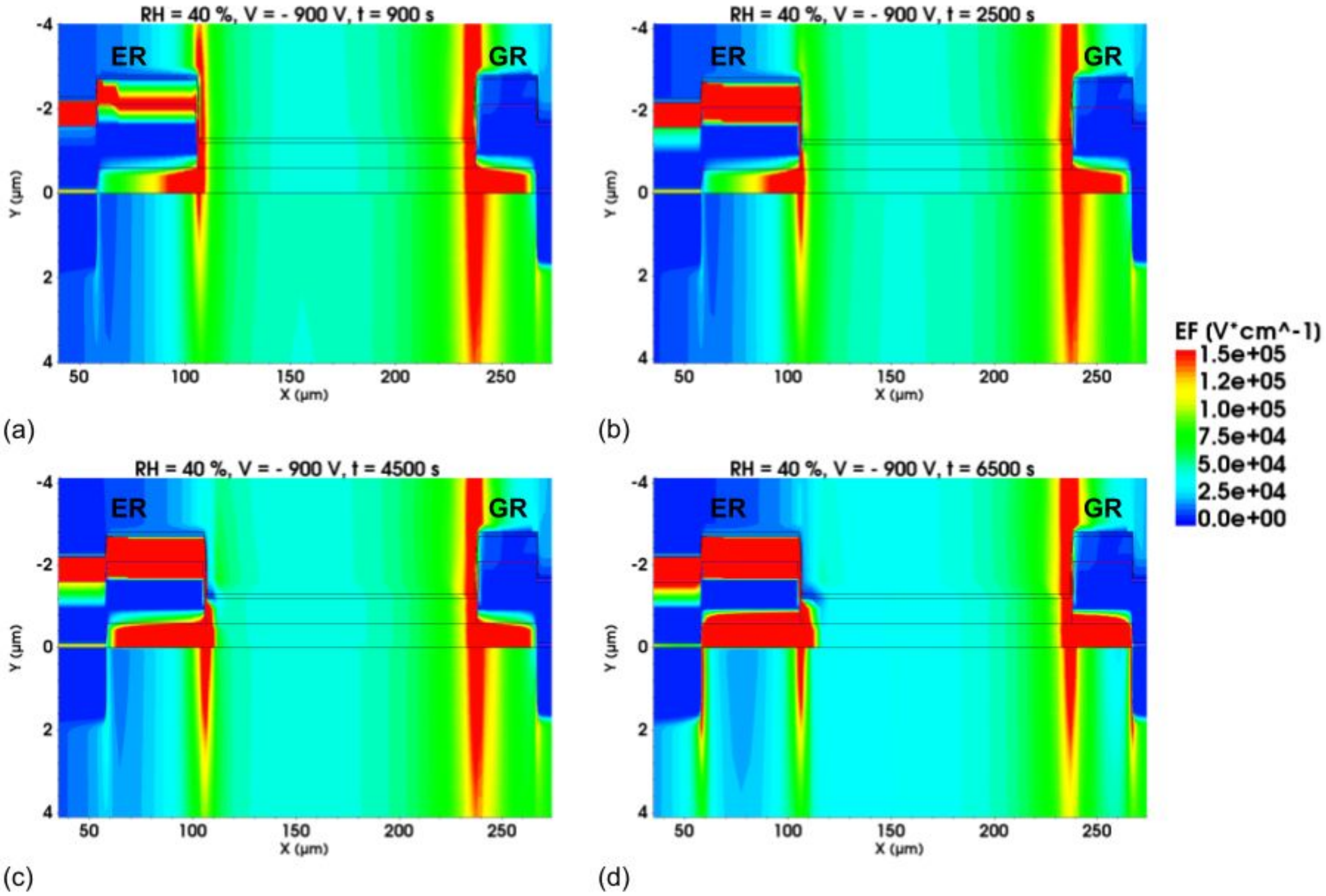
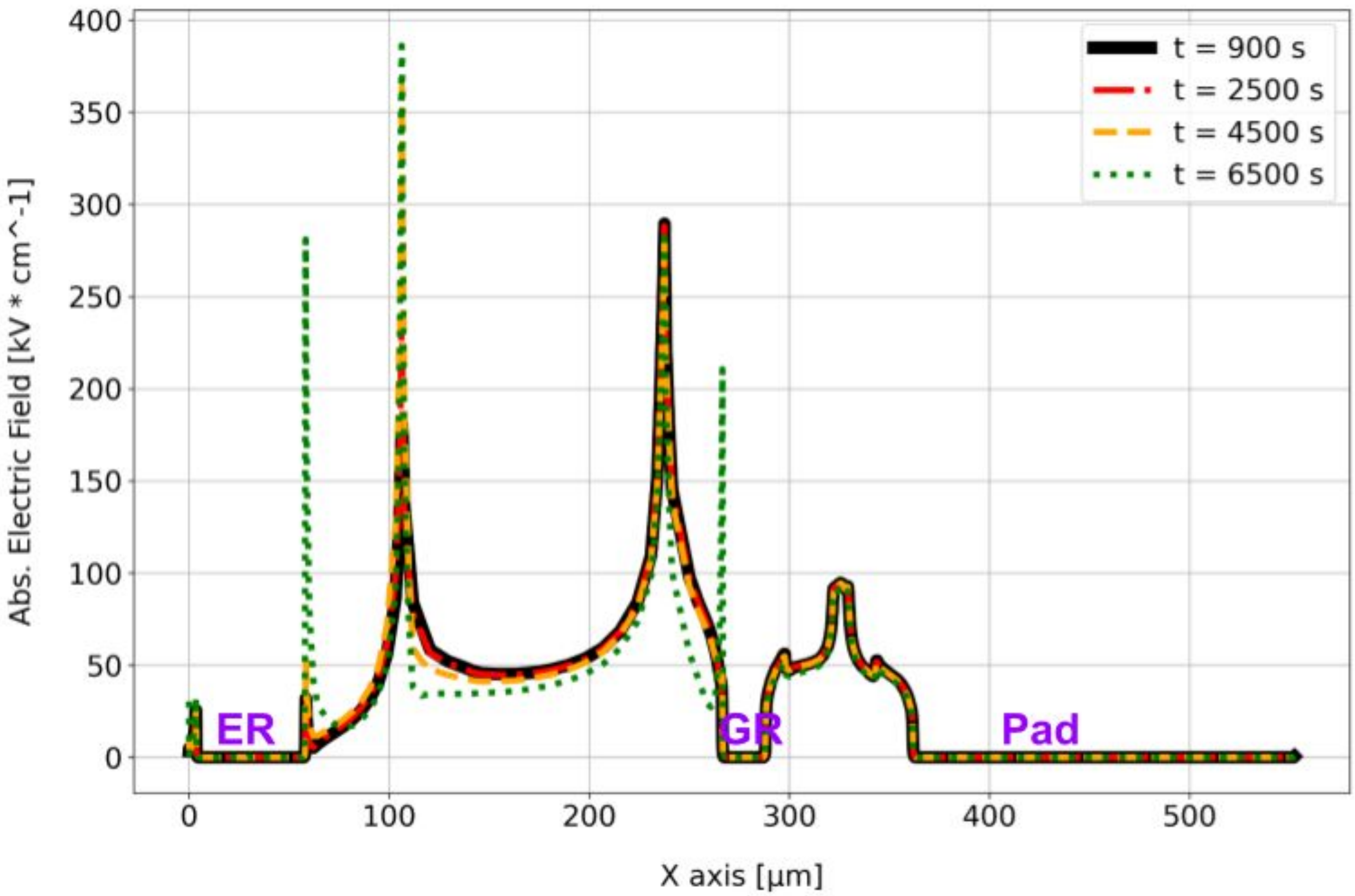


TCAD Simulation



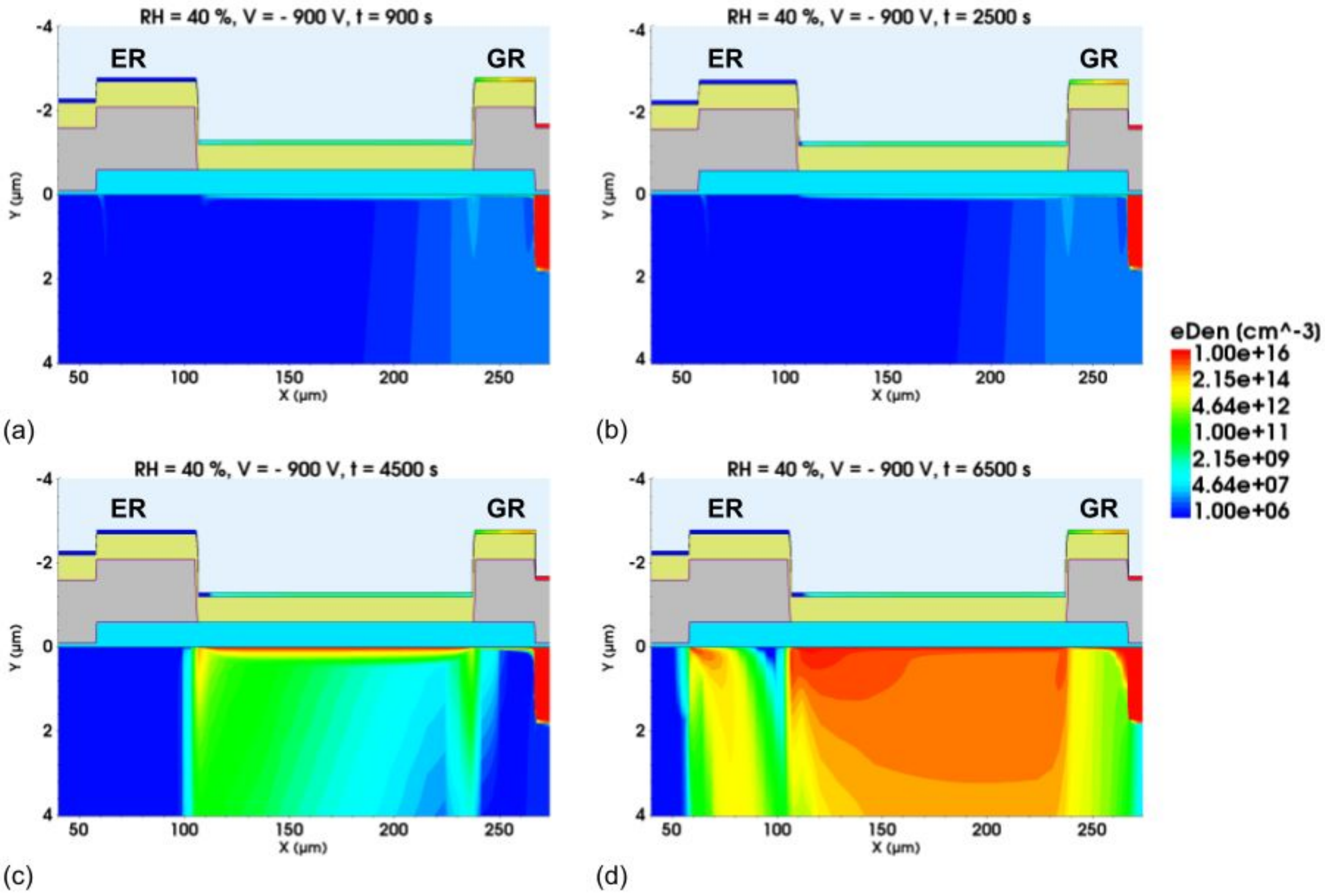
- ★ After ramping (t = 900 s), two high field regions are already formed near the ER and near the GR
- ★ At t = 6500 s new high field region appear near the ER implant and near the GR implant

TCAD Simulation



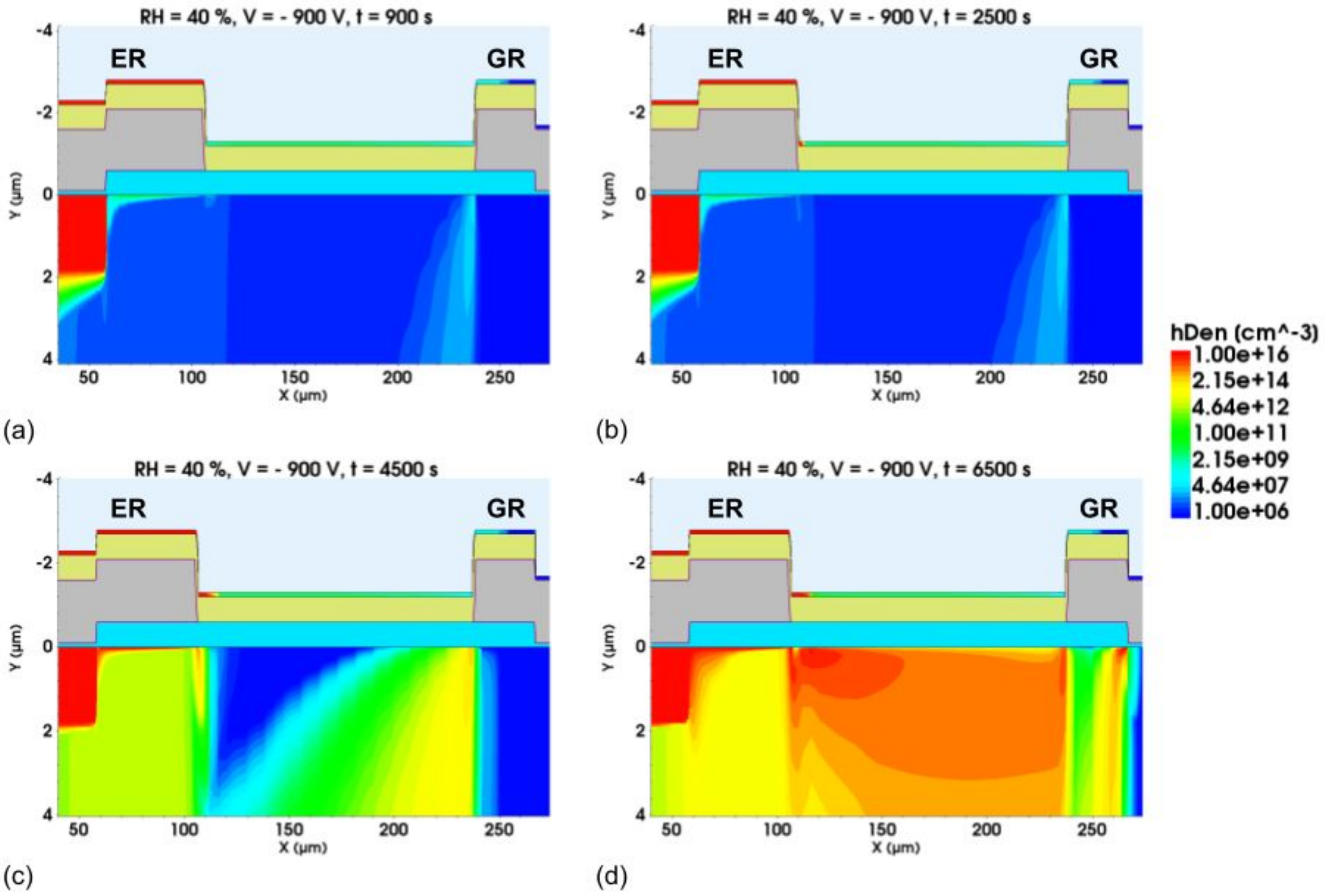
★ TCAD absolute electric field cut line along x for y = 100 nm shows two high field regions, near the ER and near the GR

TCAD Simulation



- ★ 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 SiO_2 and Silicon
- ★ The electron density at the interface increases when the current starts rising

TCAD Simulation



- ★ 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

Outlook

- ★ 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.

Thank you!

Contact

DESY.
Deutsches Elektronen-Synchrotron

www.desy.de

Ilona Ninca
ATLAS Upgrade (Zeuthen)
ilona.ninca@desy.de
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