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OPTICAL STRESSING OF 4H-SiC MATERIAL AND DEVICES

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Motivation

Performance and lifetime of bipolar devices limited by Basal Plane Dislocations (BPDs) and stacking faults (SFs)

- Bipolar degradation due to recombination enhanced dislocation glide mechanism [1]
- Injection of excess carriers electrically (device operation) or optically (UV illumination)

Identification of defective areas of the wafer and degrading devices

- Electrical stress test typically performed at current density of J_{el} = 140 A/cm² for 45 min. [2]
  - On wafer level: impossible due to cooling
  - Devices in modules: electrical stressing possible but expensive (cost and time)
  - → Not usable for in-line quality and process control measurements as well as device reliability
- UVPL imaging proven for prediction of degrading bipolar devices based on presence of BPDs and SFs in epilayers [2]

→ **Establish an optical stress test to support BPD and SF identification by UVPL**

Experimental details

UVPL imaging with Defect Luminescence Scanner (DLS)

- UVPL imaging system suitable for SiC wafers up to 150 mm diameter [2]
- UV excitation by HeCd laser with λ = 325 nm, continuous wave
- UVPL image recording by CCD camera in wavelength range from 400 nm to 1 000 nm (panchromatic) or with long-pass filter (λ > 750 nm)

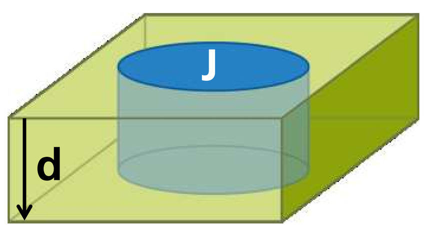
Optical stressing with DLS

- Scanning mode used for partially processed pn diodes (designed for 6.5 kV)
  - → Injection level comparable to electrical stressing, but time-consuming
- Static mode used for unprocessed epiwafer (thickness 60 µm, doping n = 1 x 10^{15} cm^{-3})
  - → Lower injection level than for scanning mode and electrical stressing, but on larger areas

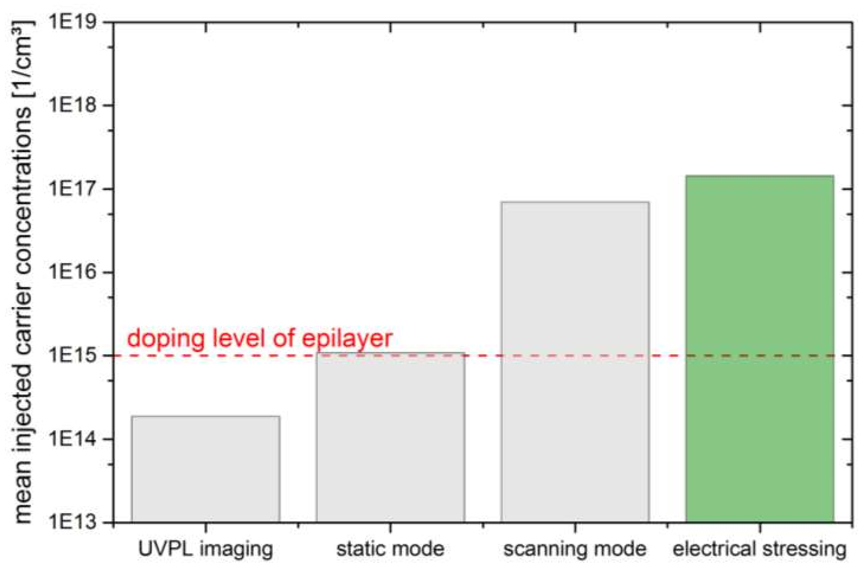
Injected carrier concentrations

Electrical stress test:

$$\bar{n}_{el} = \frac{J_{el} \cdot \tau}{q \cdot d_{drift}}$$



- Current density J_{el} = 140 A/cm²
- Excess carrier lifetime τ = 1 µs
- Elementary charge q
- Drift layer thickness d_{drift} = 60 µm



Optical stressing:

$$\bar{n}_{opt} = \frac{J_{opt} \cdot \tau}{d_{abs}}$$

- $J_{opt} = P / (E_{ph} \cdot A)$ with laser power P = 60 mW, E_{ph} = 6.1 x 10^{-16} mWs
- Excess carrier lifetime τ = 1 µs
- Absorption length $d_{abs} = \alpha^{-1}$ = 7.5 µm [3]
- Each photon generates an exciton

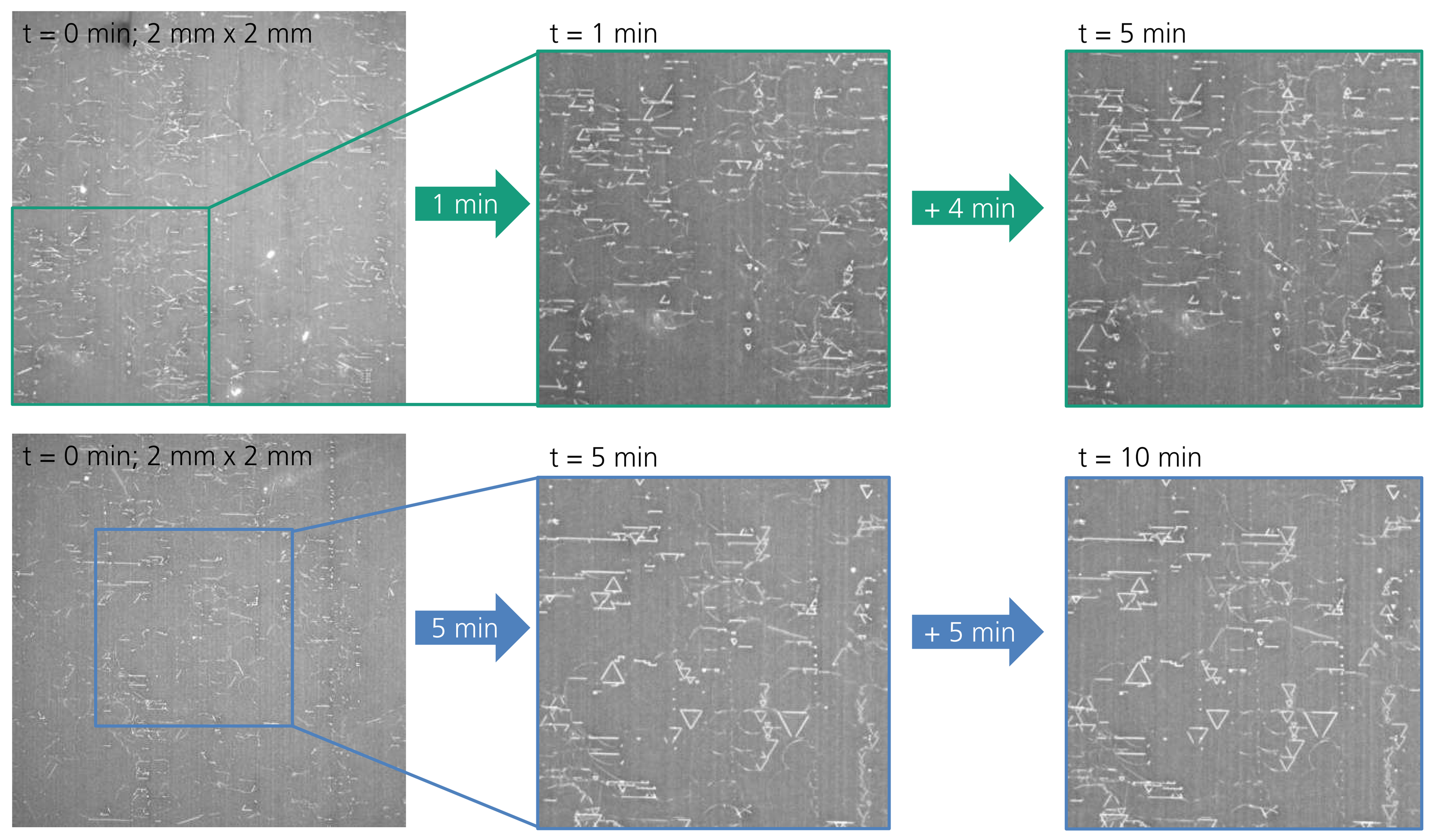
→ Injection level of
- scanning optical stress mode ~ electrical stressing
- static optical stressing ~ doping of epilayer

→ UVPL imaging under low injection conditions

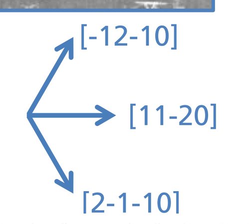
	UVPL imaging	static mode	scanning mode
Beam area A [cm²]	0.75	0.13	0.002
J_{opt} [(s · cm²)$^{-1}$]	1 x 10^{17}	8 x 10^{17}	5 x 10^{19}

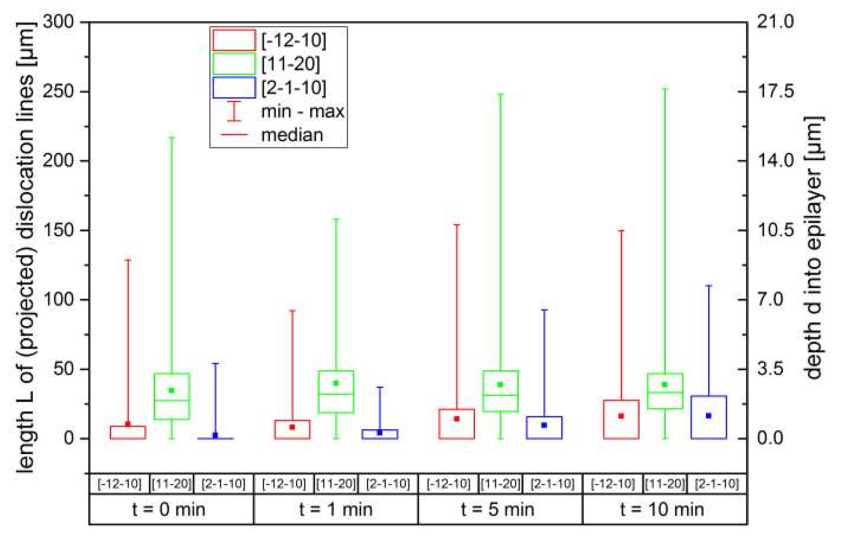
Static mode

UVPL imaging at 400 nm < λ < 1 000 nm (panchromatic mode).

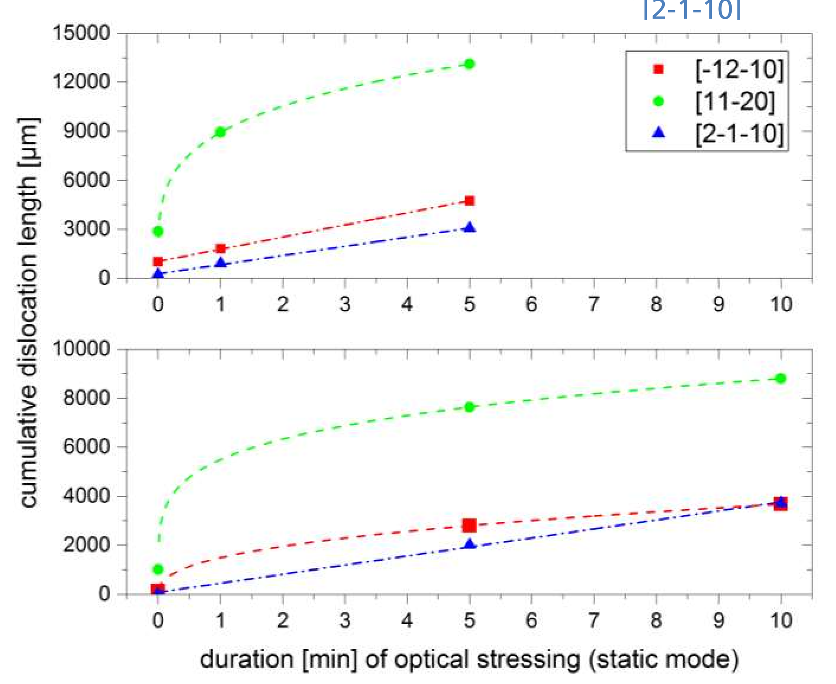


- Dislocation lines along distinct *a*-directions
- Measurement of dislocation line length along these directions for further analysis





- [11-20] dislocations: length hardly changes with stressing time
- [-12-10] and [2-1-10] dislocation: growing with stressing time
- Depth d* into epilayer calculated from length of dislocations L in UVPL images with d* = L · sin(4°)
  - Most dislocations extend < 3.5 µm into epilayer → less than mean absorption length
  - Stressing occurs close to epilayer surface
  - Use different UV wavelength?

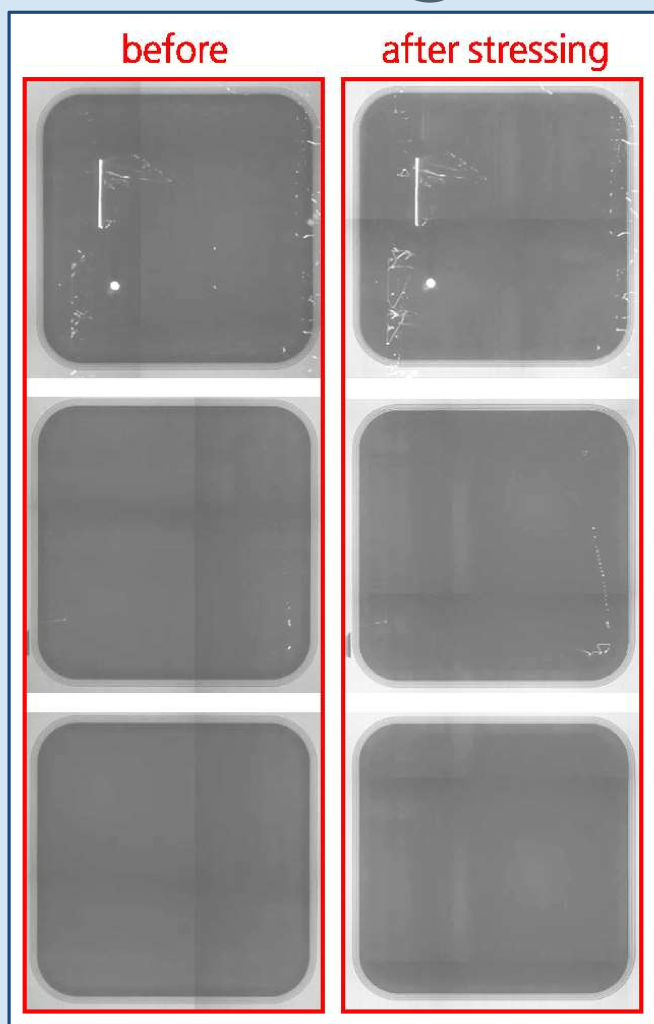


- Cumulative length of dislocations …
  - … increases due to increasing number of dislocations
  - … saturates for [11-20] and [-12-10]
  - … increasing after 10 min for [2-1-10]

→ **Immediate but also lengthy degradation already at low injection level**

- Influence of injection level (future work)
  - Higher injection level for speeding up?
  - Investigation of dislocation dynamics

Scanning mode



Category A: initial BPDs (and other defects) in UVPL imaging

- Defects enlarged due to optical stressing

→ **Bipolar degradation can be triggered optically in a very short time**

Category B: some initial BPDs, hardly visible in UVPL imaging

- Defects enlarged due to optical stressing

→ **Improved identification of defective / defect-free devices**

Category C: no BPDs visible, but truly reliable?

- No change by optical stressing (within top region)
- Free of defects in deeper areas? → other wavelength

→ **No bipolar degradation**

→ **Device reliability tested optically**

UVPL imaging at λ > 750 nm. Device length 3 mm. Scan speed 100 µm/s at 500 µm beam diameter → 30 sec/line, 6 lines per device = 180 sec/device.

References and acknowledgment

[1] A. Galeckas, J. Linnros, P. Pirouz: Physical Review Letters 96 (2006) 025502.
[2] L. Wehrhahn-Kilian et al., Materials Science Forum 858 (2016) p. 410-413.
[3] S. Sridhara, T.J. Eperjesi, R.P. Devaty, W.J. Choyke: Materials Science and Engineering B61-62 (1999) p. 229-233.

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Conclusions

- Optical stressing can trigger bipolar degradation in epilayers and partially processed devices
  - Facilitates further scientific analysis of degradation mechanism and dislocation dynamics
  - Improves in-line quality and process control measurements as well as device reliability

→ **Optical stress test on wafer level demonstrated**