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Imaging Defect Luminescence Measurements of 4H-SiC by UV-PL

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Outline

- Motivation
- Photoluminescence in SiC
- Measurement setup: Defect luminescence scanner
- Photoluminescence measurement of
  - 4H-SiC epitaxial layer
  - 4H-SiC substrate
- Conclusion
- Outlook

Motivation: SiC for power electronics

Performance of SiC electronic devices limited by structural defects in **epitaxial layers** and **substrates**

- **Stacking faults**
- **Basal plane dislocations**

} leads to bipolar degradation in pin diodes [1]

- Threading dislocations → Reduce effective lifetime, leakage current

Established characterization methods:

- Optical light microscopy (no proof for dislocations)
- Defect selective etching (destructive)
- Synchrotron X-ray topography (time-consuming, cost-intensive)

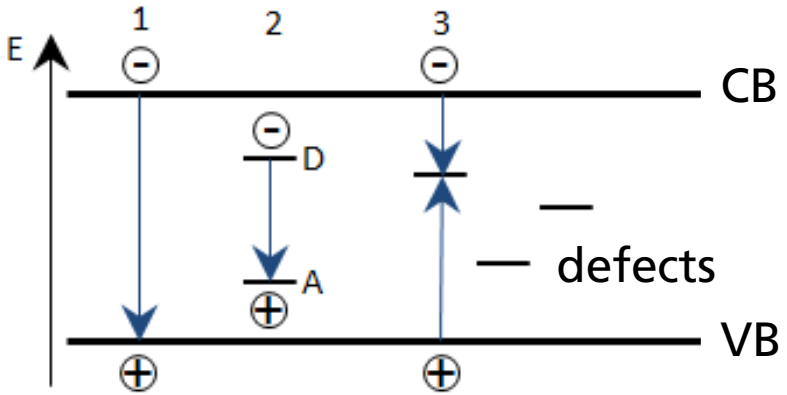
- Need for a non-destructive, fast, high-resolving, imaging method of full wafer scale, without sample preparation
- Enables quality control in substrates/ epilayers and devices

→ Photoluminescence technique [2]

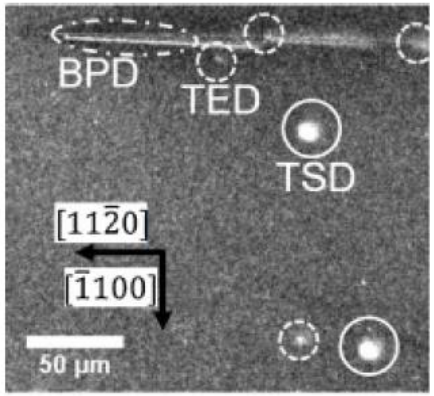
[1] Ha S. et al., Phys. Rev. Lett. 92, 175504 (2004)
[2] Stahlbush et al, MSF 556-557 (2007) p 295-298

Photoluminescence: Physical fundamentals

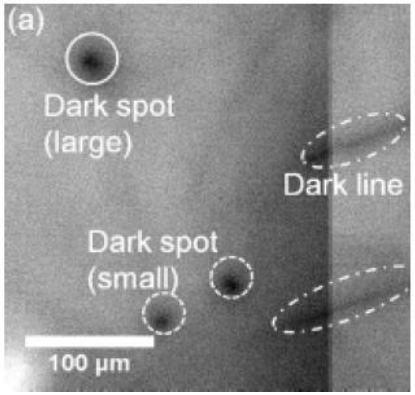
- Excitation by absorption of photons (hv > Eg)
- Generation of electron-hole-pairs
- Recombination: band-to-band or through defect levels in band-gap
- Radiative (luminescence) resp. non-radiative recombination
- Defects as radiative resp. non-radiative recombination centers
- Defect-specific PL-wavelength (spectral fingerprint)



Recombination paths in semiconductors



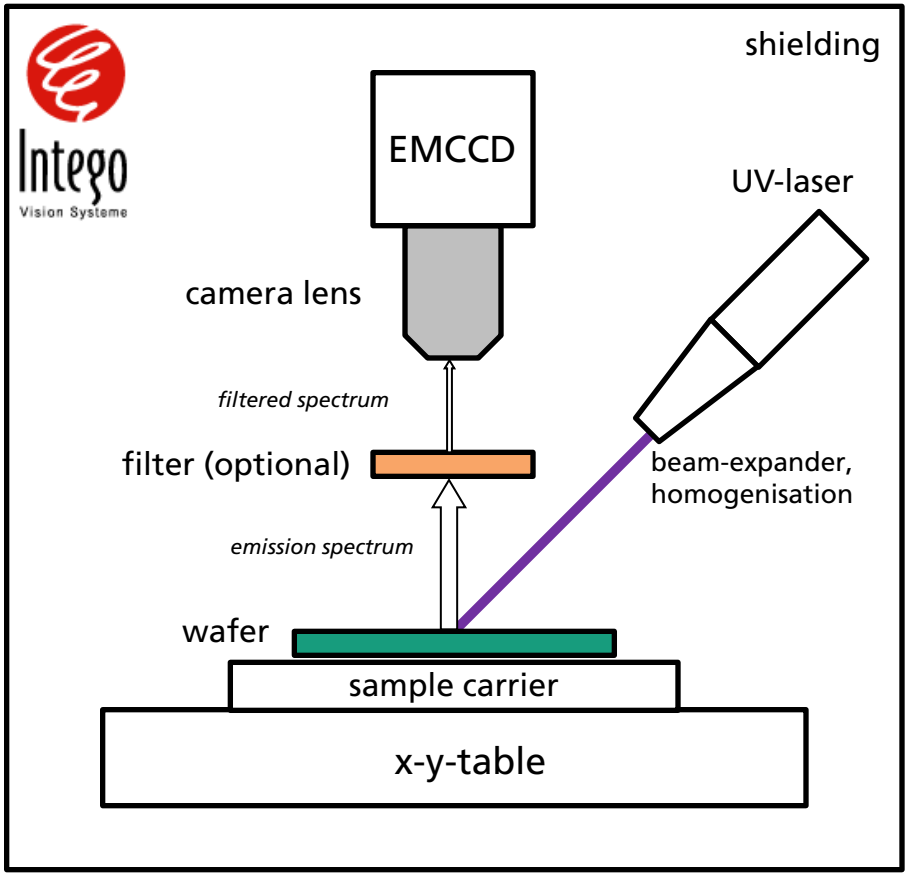
Epilayer [3]



Substrate [3]

[3] Kawahara et al., JJAP 53, 020304 (2014)

Measurement setup: Defect Luminescence Scanner



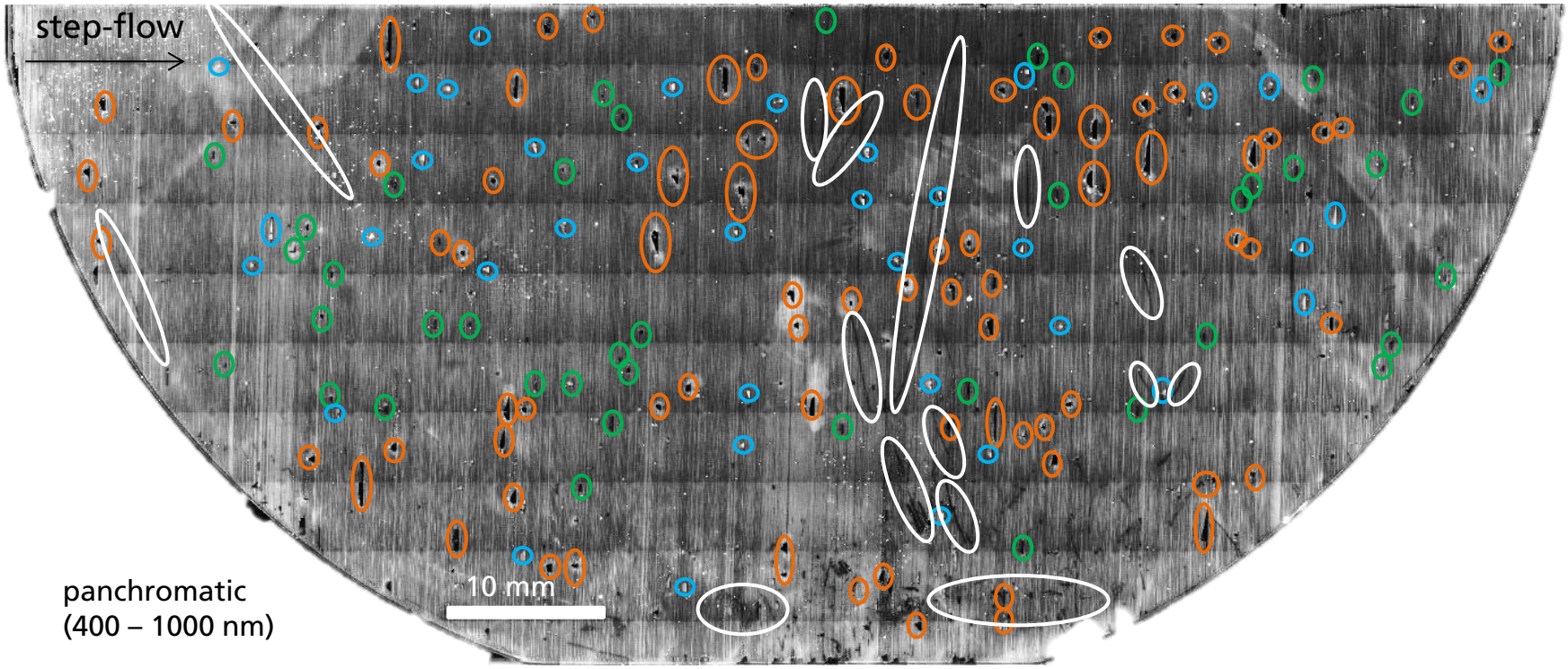
Class 1 laser system

- UV-Laser: 325 nm (cw)
- Penetration depth: approx. 8 µm
- EMCCD-camera (400 - 1000 nm)

- Band-pass filter:
- $\lambda = 450 \pm 40$ nm
- $\lambda = 540 \pm 40$ nm
- Long-pass filter: $\lambda > 590$ nm

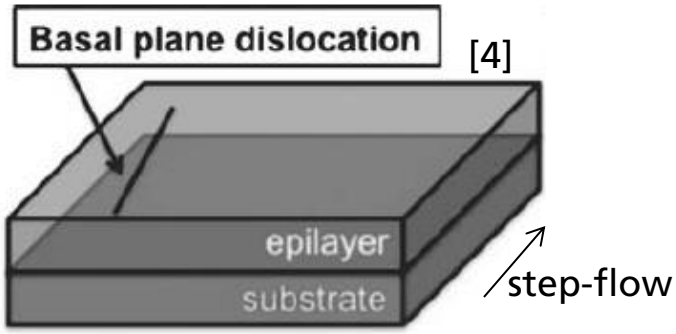
- x-y-table (up to **8''**)
- Lateral res.: **5 µm**
- Meas. time: **10 - 30 min**

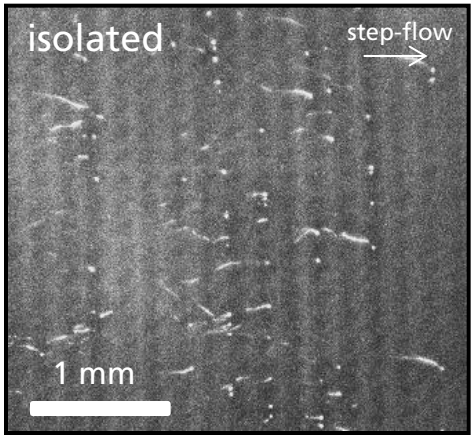
PL of epitaxial layers: Overview

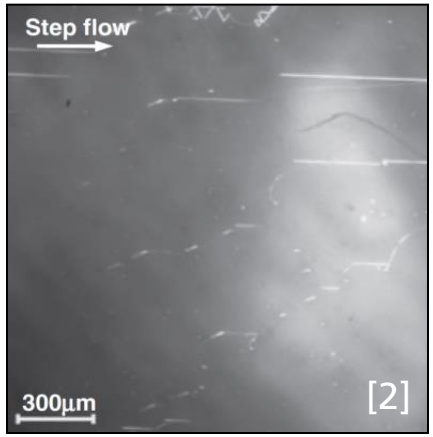


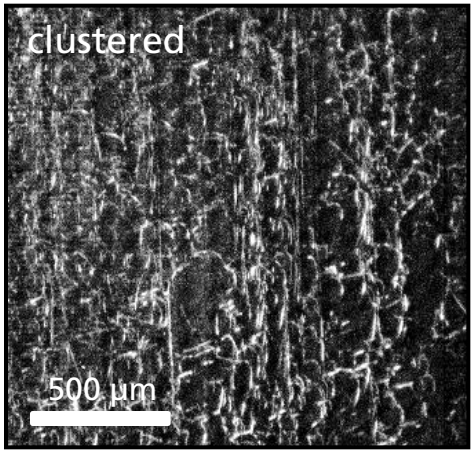
- Various structural defects → **Classification**

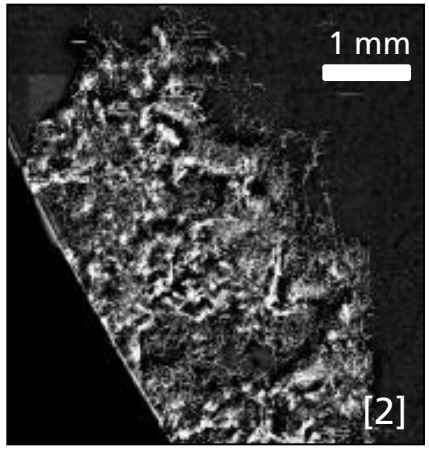
PL of epitaxial layers: Basal plane dislocations (BPDs)











- BPDs appear as bright lines
- Mostly orientated in step-flow direction
- Lines often bent
- Some with bright endpoint

BPDs not visible in optical light microscopy mapping → *Advantage of DLS!*

[4] Canino et al., ESSL 14 (11), H457-H459 (2011)

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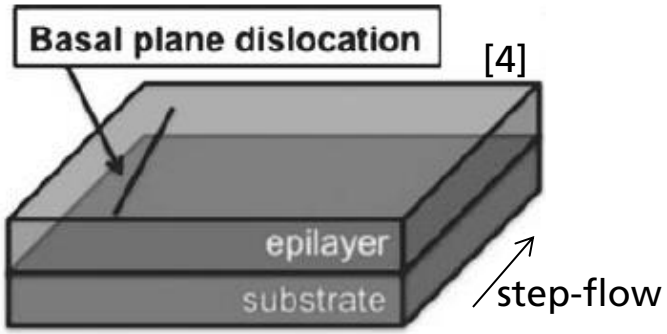
PL of epitaxial layers: Triangular defects (SFs)



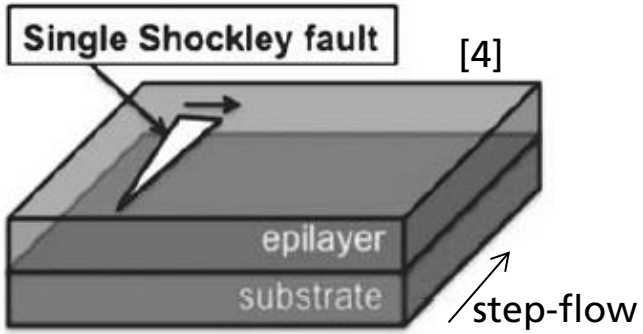
Burgers vector:

$$\frac{1}{3}[11\bar{2}0]$$

Basal plane dislocation

Burgers vector length:

$$a^2$$



$$\frac{1}{3}[10\bar{1}0]$$

Shockley-partials

$$\frac{1}{3}[01\bar{1}0]$$

$$\frac{a^2}{3}+\frac{a^2}{3}=\frac{2}{3}a^2$$

Stacking fault formation energetically favourable

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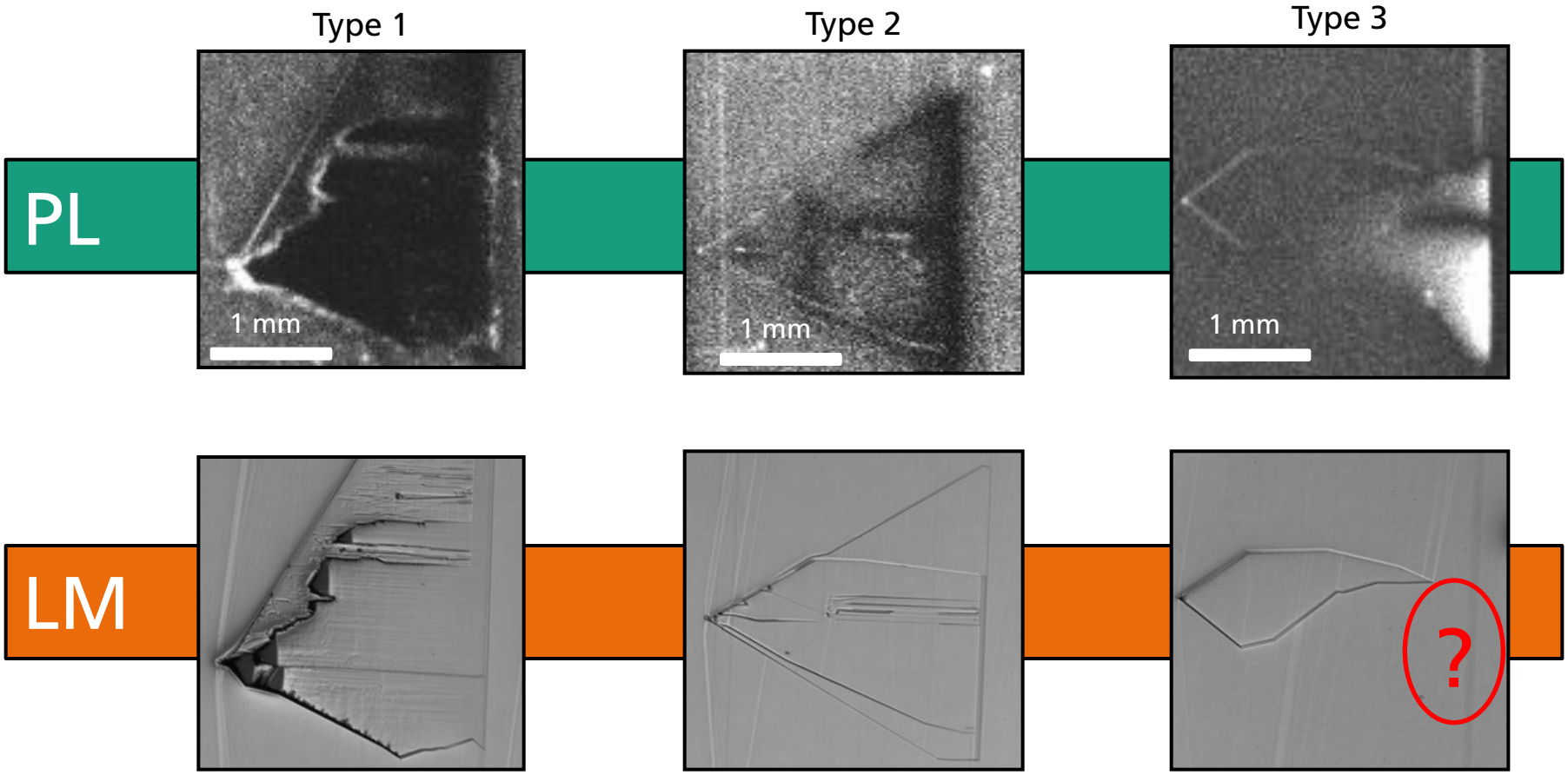
PL of epitaxial layers: Triangular defects (SFs)



Type 3 triangular defects not visible in light microscopy → *Advantage of DLS!*

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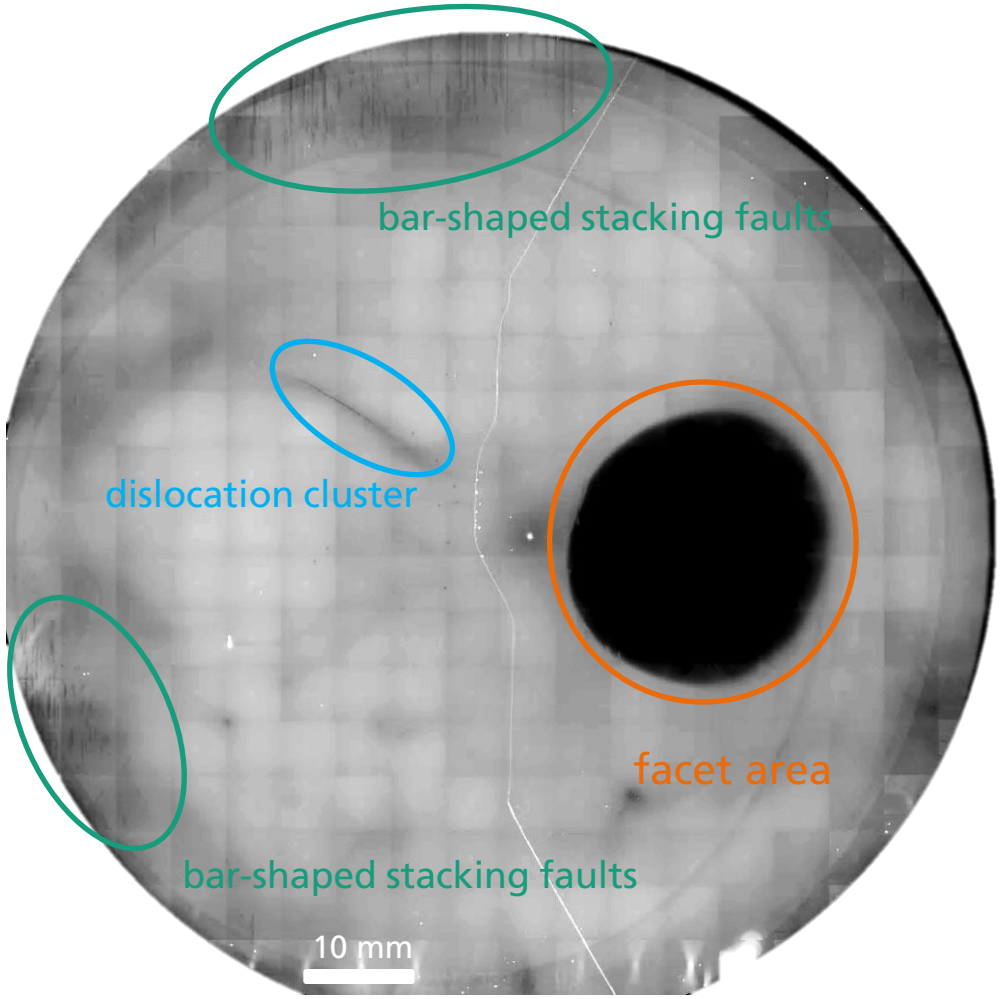
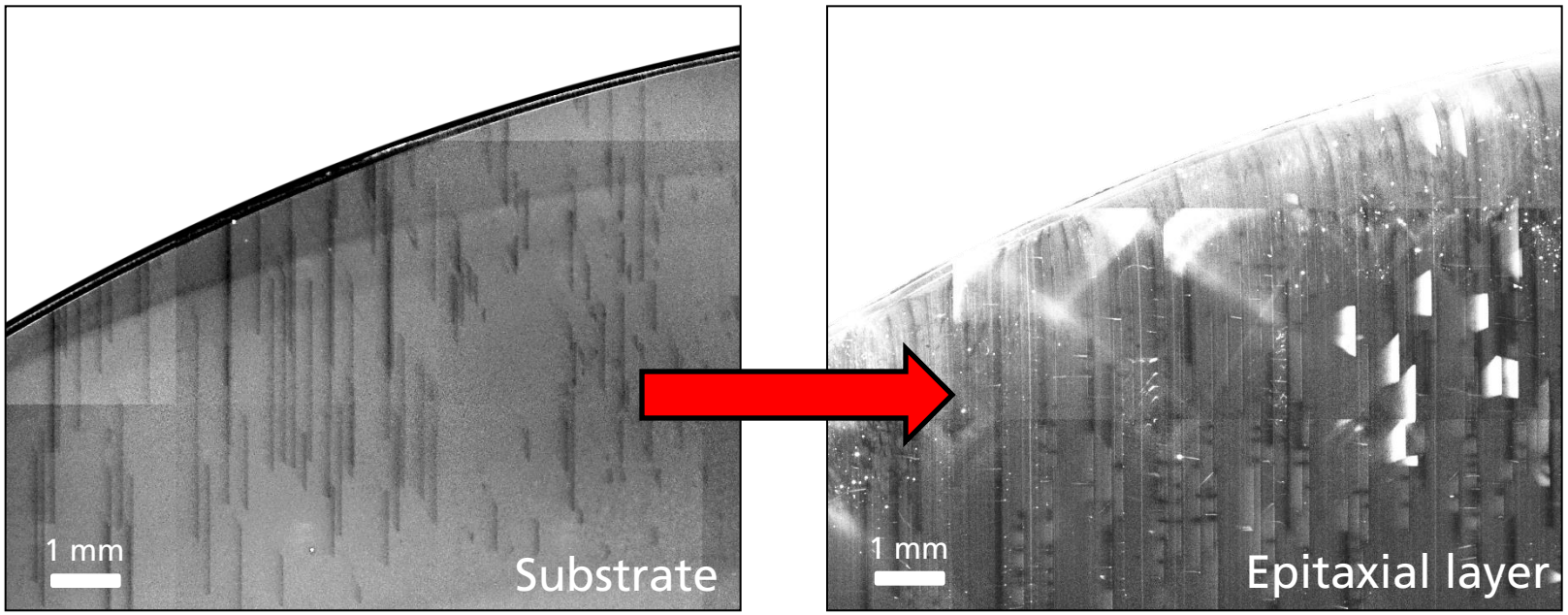
PL of substrates: Overview of defects

- Various features detectable
  - Facet area
  - Threading dislocation cluster
  - Dark bar-shaped stacking faults
  - Bright and dark spots
- Visibility of features strongly depending on substrate
- Further improvement of UV-PL measurement system
- **Successful measurement of substrate for the first time**



PL of substrates: Dark bar-shaped stacking faults



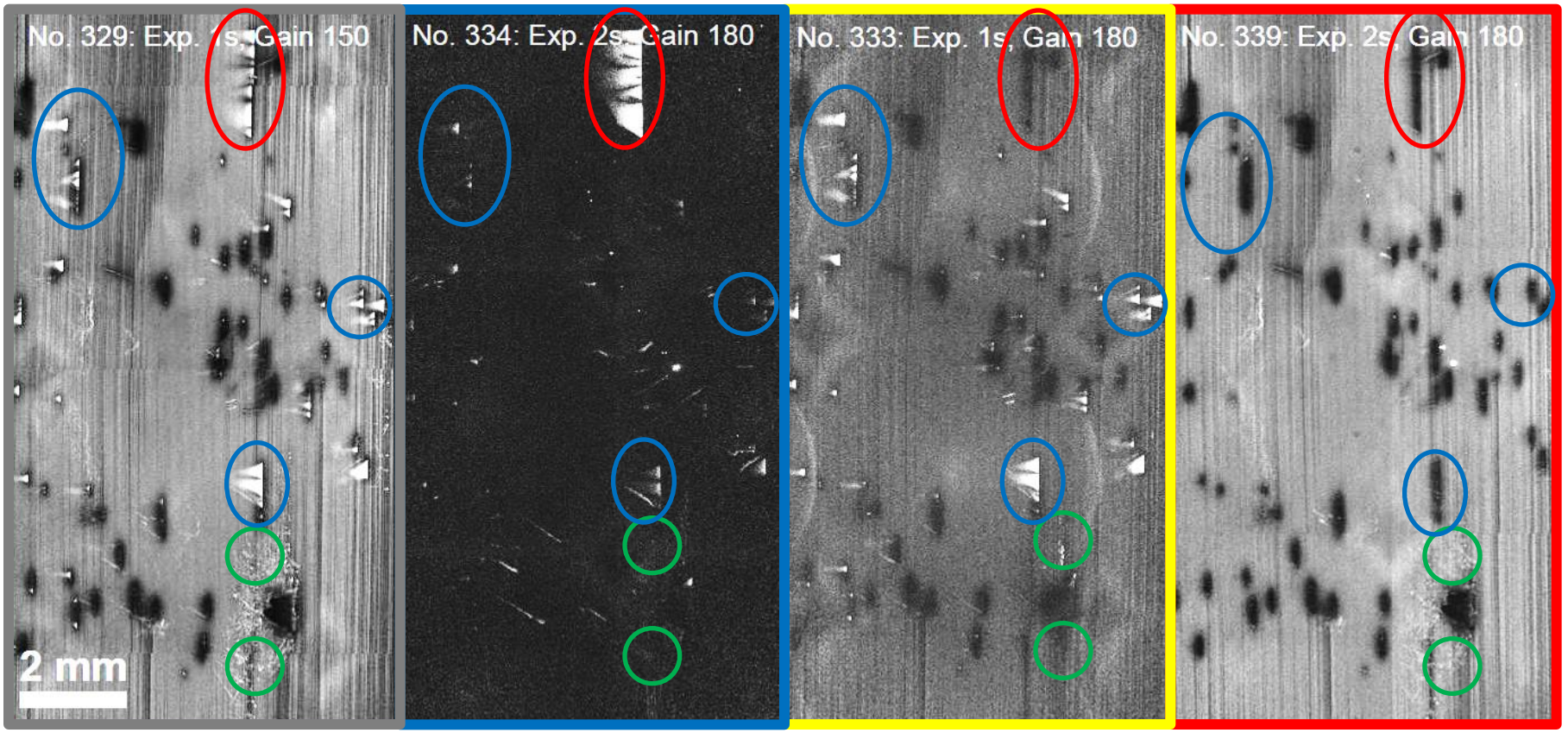
- Stacking faults (dark bar-shaped) already present on substrate
- Increased amount of dark bar-shaped stacking faults on epitaxial layers in same area
- Propagation in epitaxial layer during epitaxial layer growth

Conclusion: Visibility of features in epitaxial layers

Defect/Feature			Visibility		
			DLS	OLM	DSE
Stacking faults	Triangular	Disturbed			
		Dark			
		Bright			
	Line-shaped	Straight			
		Non-straight			
Dislocations	Simple	BPDs			
		TSDs			
		TEDs			
	Combined	TD-clusters			
		HLA			
Other defects		Step-bunching			
		Particles			
		Scratches			
		Facet area			

Outlook

Spectral fingerprints of various stacking faults



400-1000 nm | 410-490 nm | 510-590 nm | 540-740 nm

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Acknowledgment

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