By emitter degradation analysis of high-power diode laser bars

Eric Larkins and Jens W. Tomm

Outline Part II

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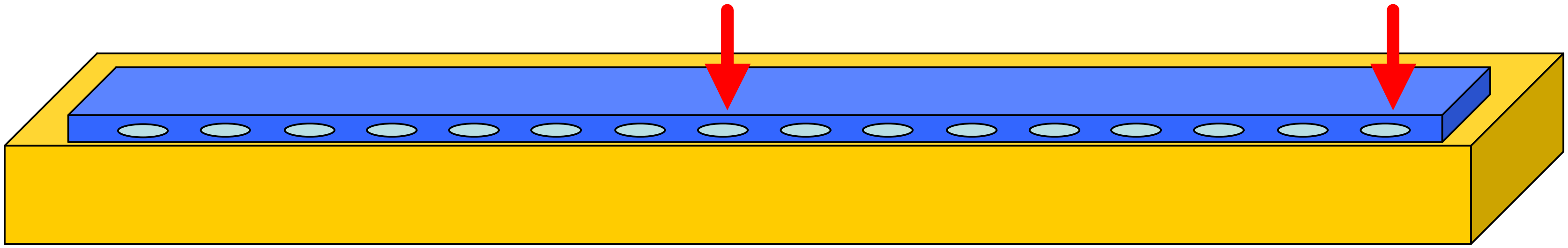
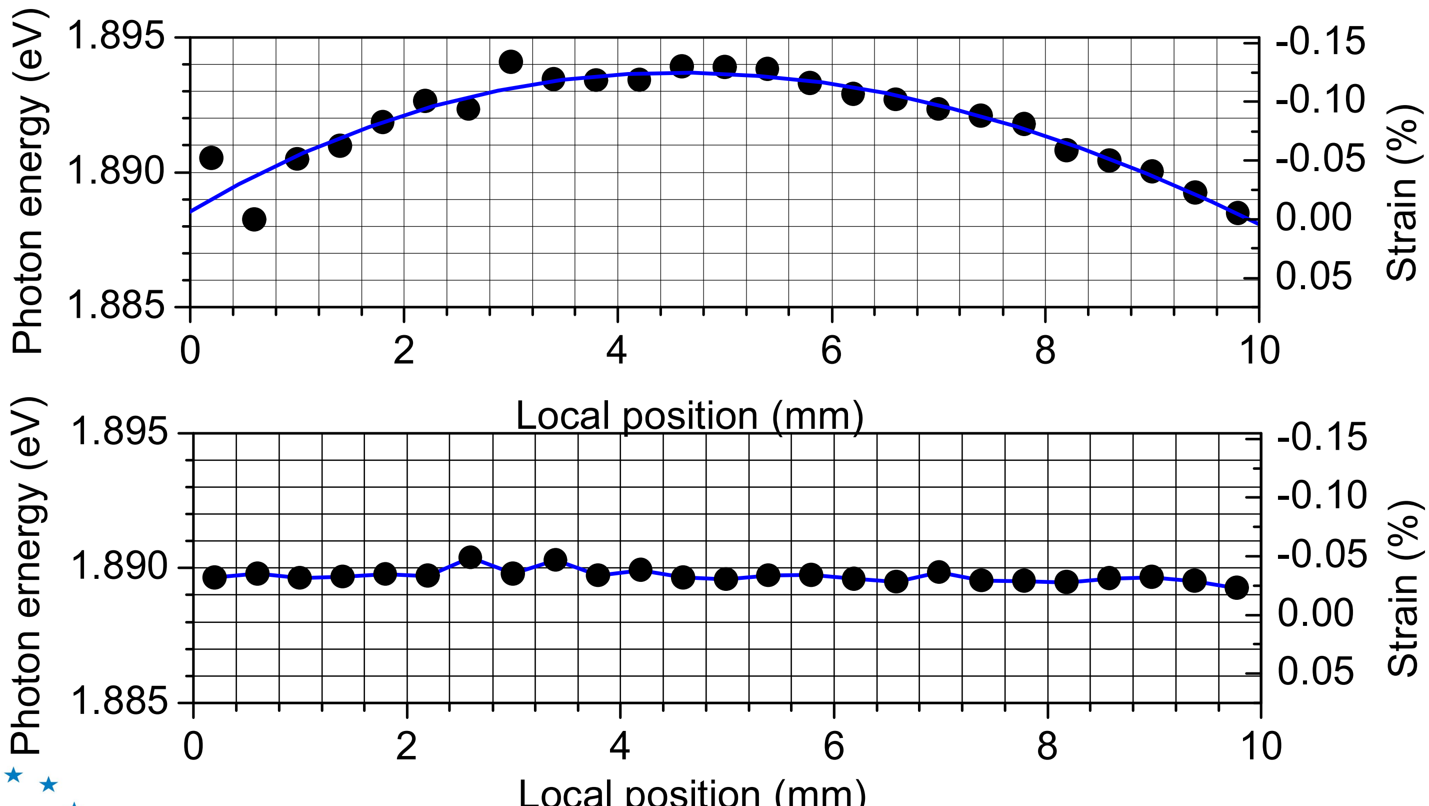
II. 1. Introduction





5 meV ~ 0.12%

Biermann et al. *JAP* **96**, 4056 (2004).

How to detect strain?

Directly: X-ray spatially resolved or imaging

1. Scanning techniques

4164 Appl. Phys. Lett., Vol. 83, No. 20, 17 November 2003

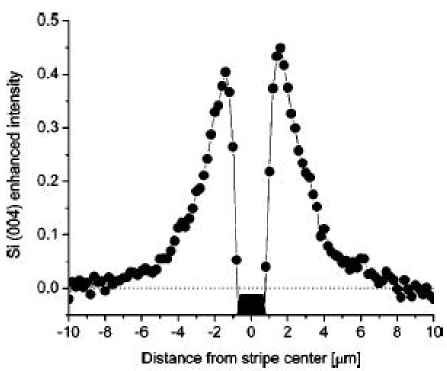


FIG. 1. Si (004) enhanced intensity vs position across the 1.5 μm wide SiGe/Si feature.

Y. Tsusaka et al. *Jpn. J. Appl. Phys.* **39**, L 635-7 (2000). "Formation of parallel X-ray microbeam and its application"

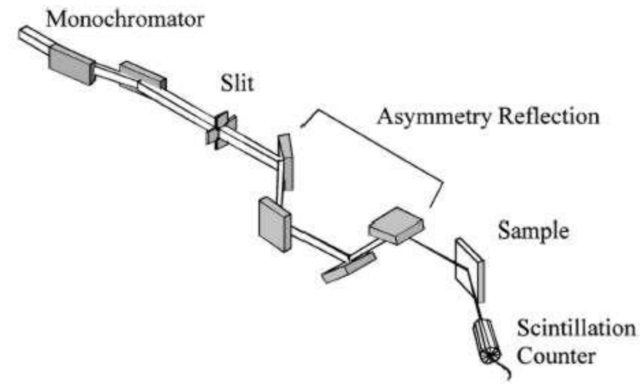


Fig. 1. Optical system of the parallel X-ray microbeam.

C. E. Murray et al.
Stripes etched into an $Si_{0.85}Ge_{0.15}/Si$ epilayer
$\varepsilon = 0.63\%$

2. Topography

D. Lowney et al.
J. Mat. Sci. Eng. **12**, 249-53 (2001).
Examination of LEDs …using synchrotron X-ray topography"

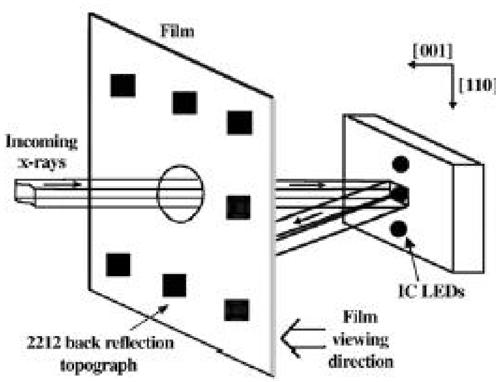
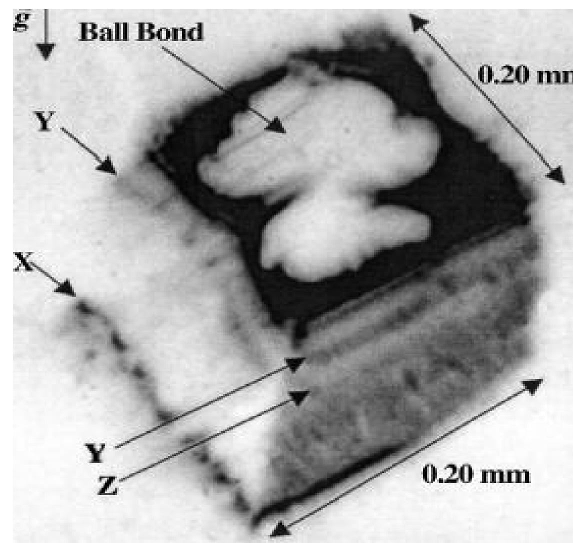


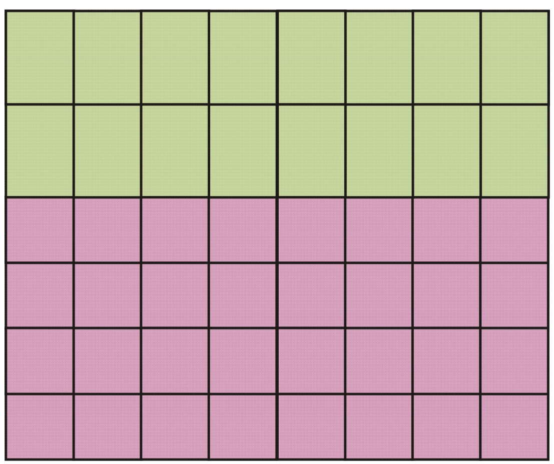
Figure 1 Back reflection geometry in large-area mode–only one diffracted beam has been drawn for clarity.



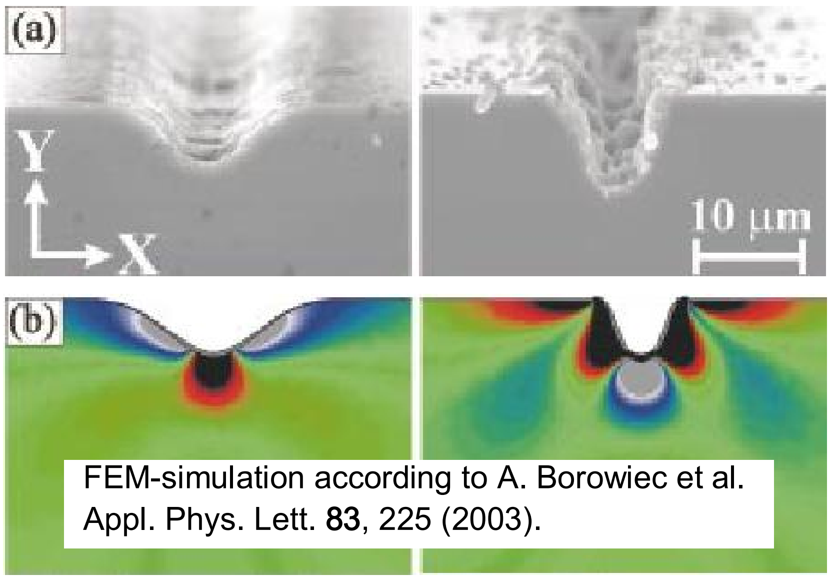
II.1.1 Strain measurement in semiconductors and devices

Strain creation within the structure or device, e.g., during

1. crystal growth



2. processing

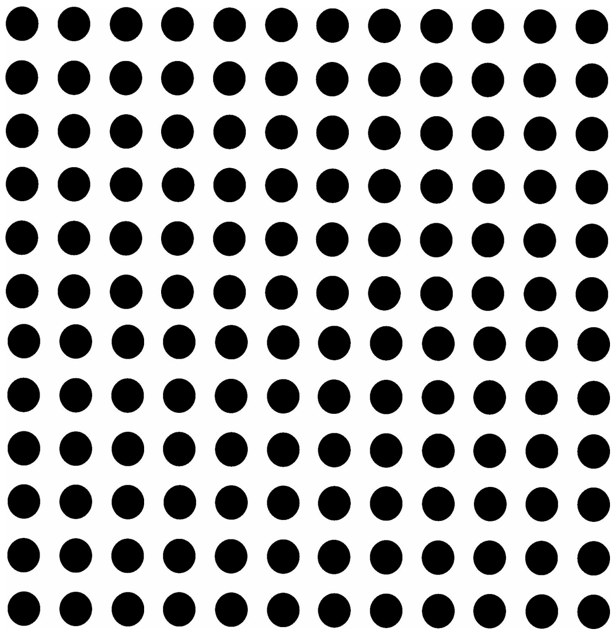


FEM-simulation according to A. Borowiec et al. Appl. Phys. Lett. **83**, 225 (2003).

intrinsic or built-in strain extrinsic processing-induced strain

II.1.1 Strain measurement in semiconductors and devices

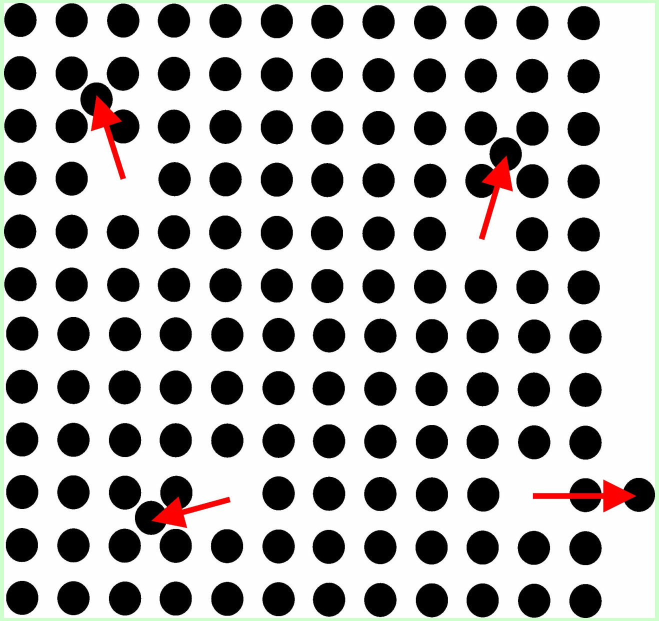
3. creation of native point defects



extrinsic strain caused by <u>defect creation</u>

II.1.1 Strain measurement in semiconductors and devices

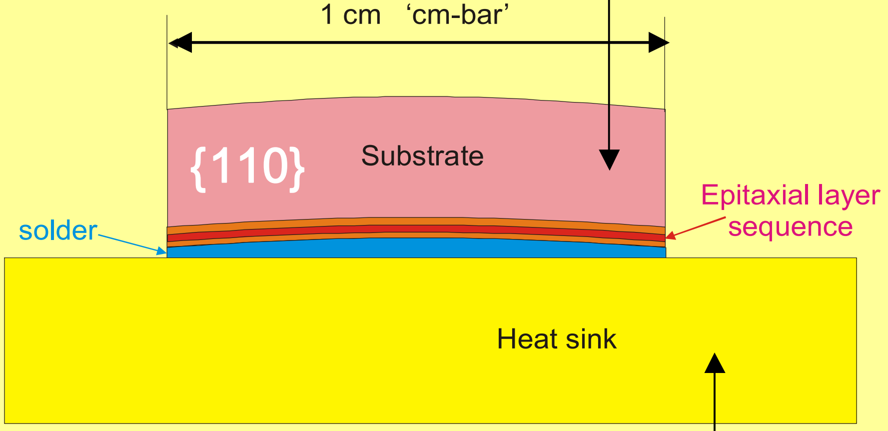
3. creation of native point defects



extrinsic strain caused by defect creation

4. packaging

α_{GaAs} = 6.9×10^{-6} K^{-1}



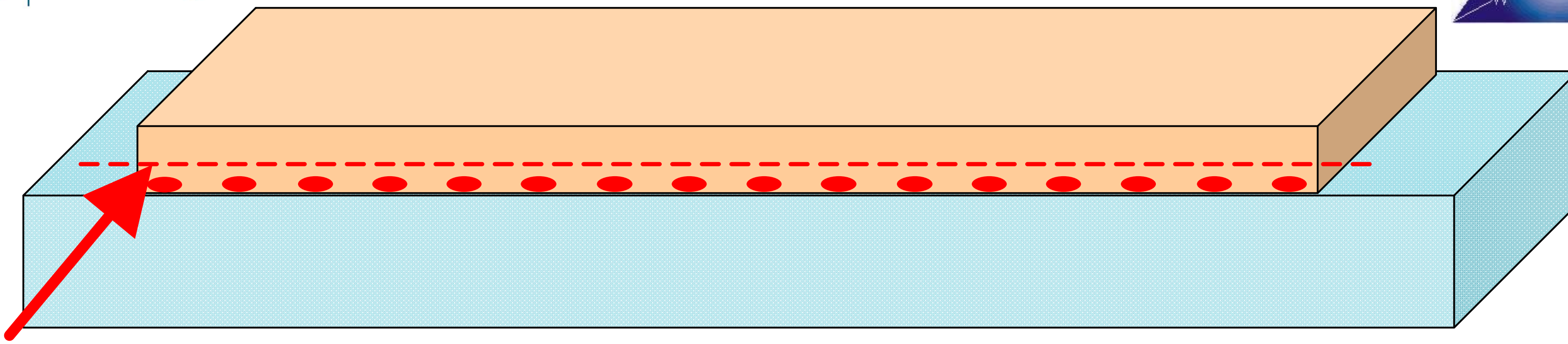
soldering temperature > 157 °C

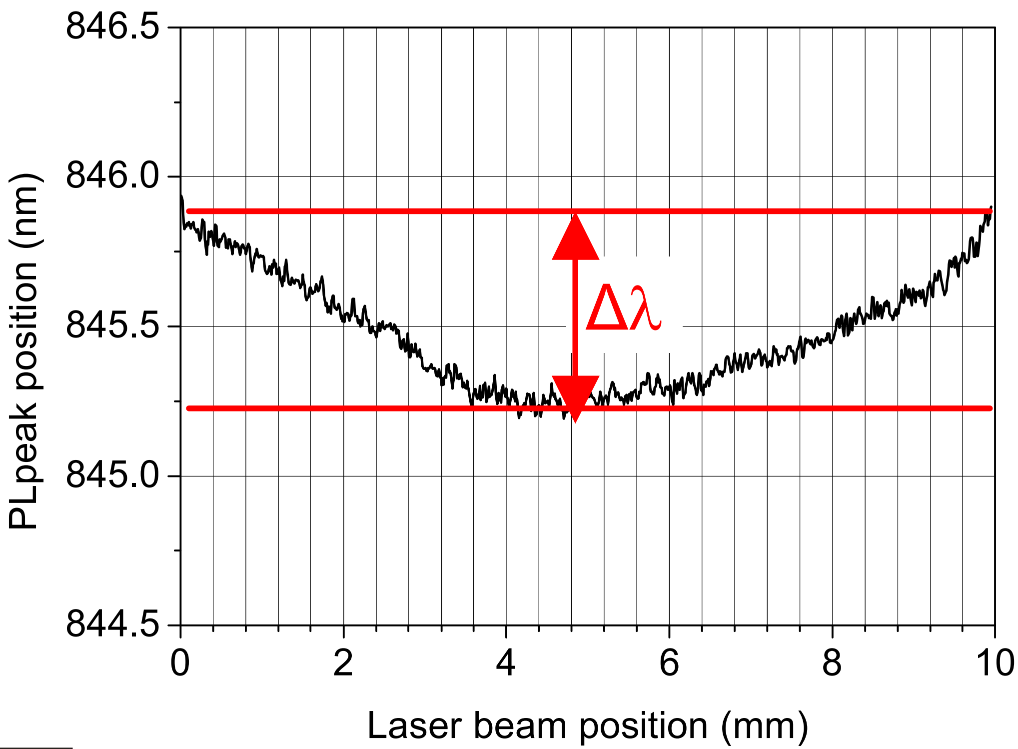
α_{Copper} = 16.7×10^{-6} K^{-1}

extrinsic packaging-induced strain

Spectroscopic strain analysis by checking the electronic bandstructure

II.1.1 Strain measurement in semiconductors and devices





- Micro-PL scan along the middle of the substrate
- Plot: PL peak vs. position along the bar
- Stress assessment of a mounted bar by the total bent (Δλ in nm) of the curve.

P. Martin et al. *Appl. Phys. Lett.* **75**, 2521 (1999).

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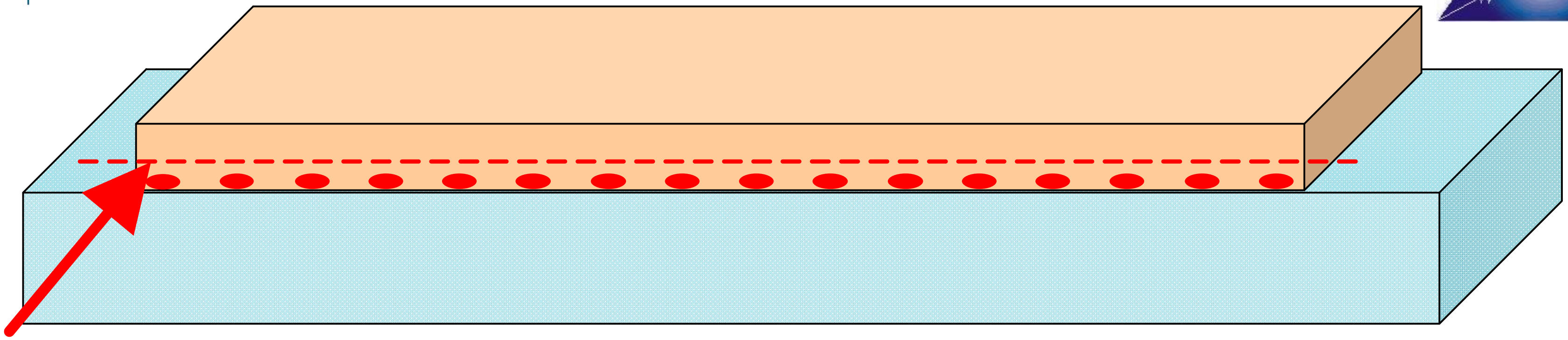
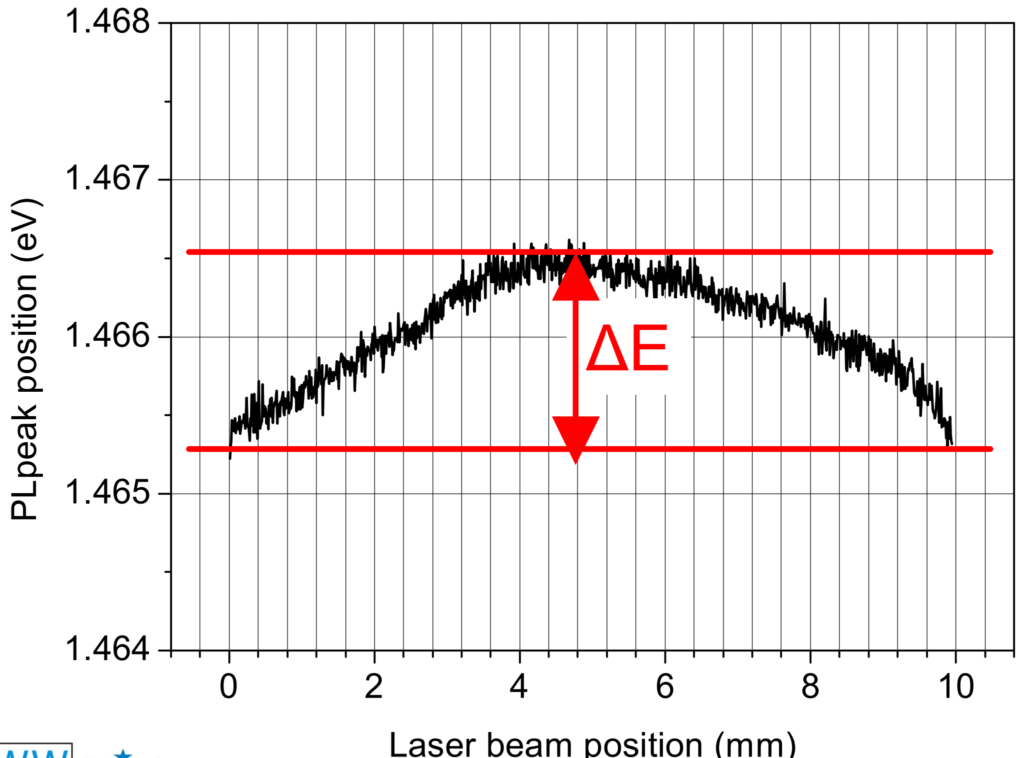
II.1.1 Strain measurement in semiconductors and devices





- Micro-PL scan along the middle of the substrate
- Plot: PL peak vs. position along the bar
- Stress assessment of a mounted bar by the total bent (ΔE in nm) of the curve.

P. Martin et al. *Appl. Phys. Lett.* **75**, 2521 (1999).

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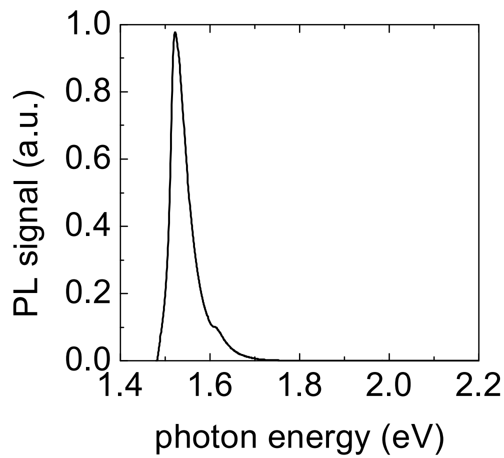
II.1.1 Strain measurement in semiconductors and devices

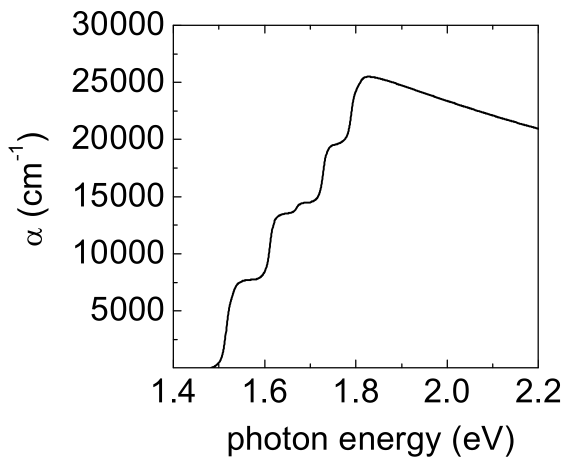
Methodology: Analysis of packaging-induced strains by photocurrent spectroscopy

Classical optical spectroscopy

Photoluminescence (PL)



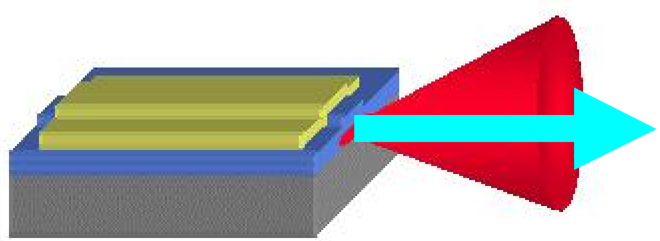
Absorption



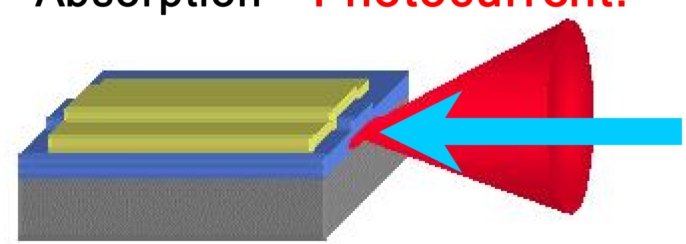
We can not place a detector behind the device.

Device analysis

PL or EL emission



Absorption ~ Photocurrent!



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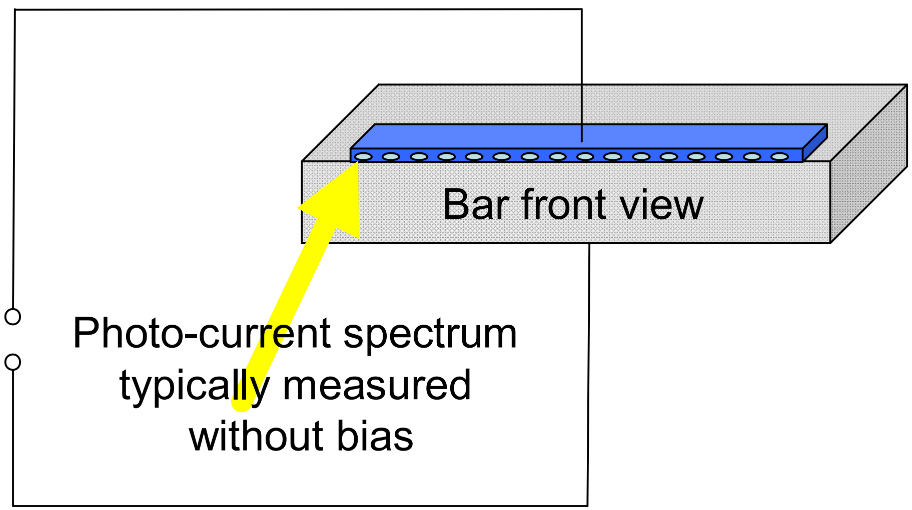
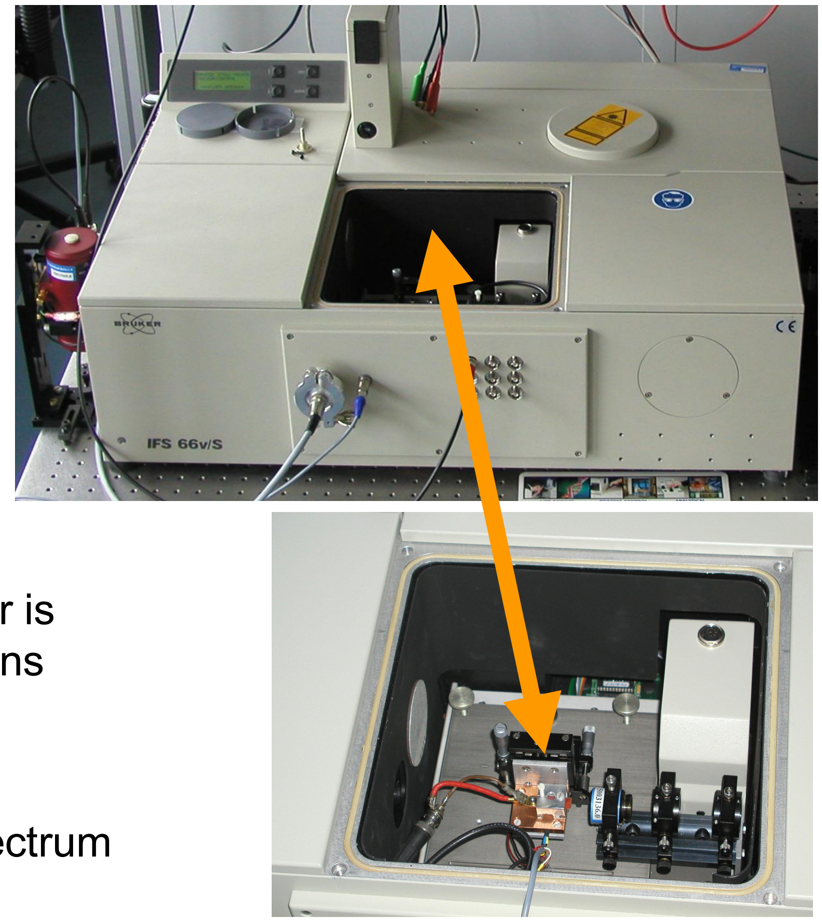
II.1.1 Strain measurement in semiconductors and devices

Spatial resolved photocurrent measurement



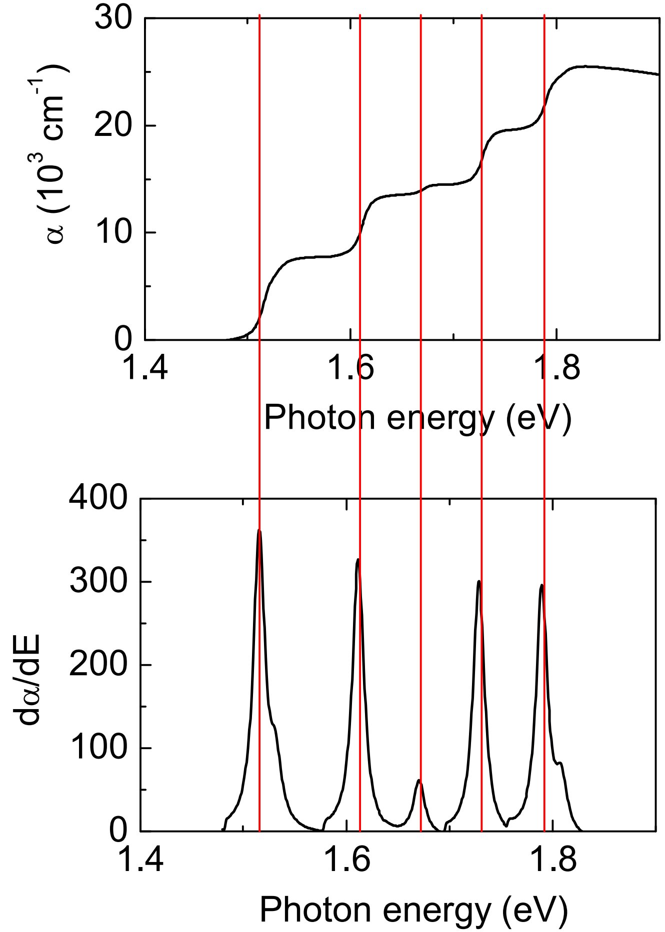


Excitation light: Typically the whole emitter is excited. But information comes from regions with potential gradients only.

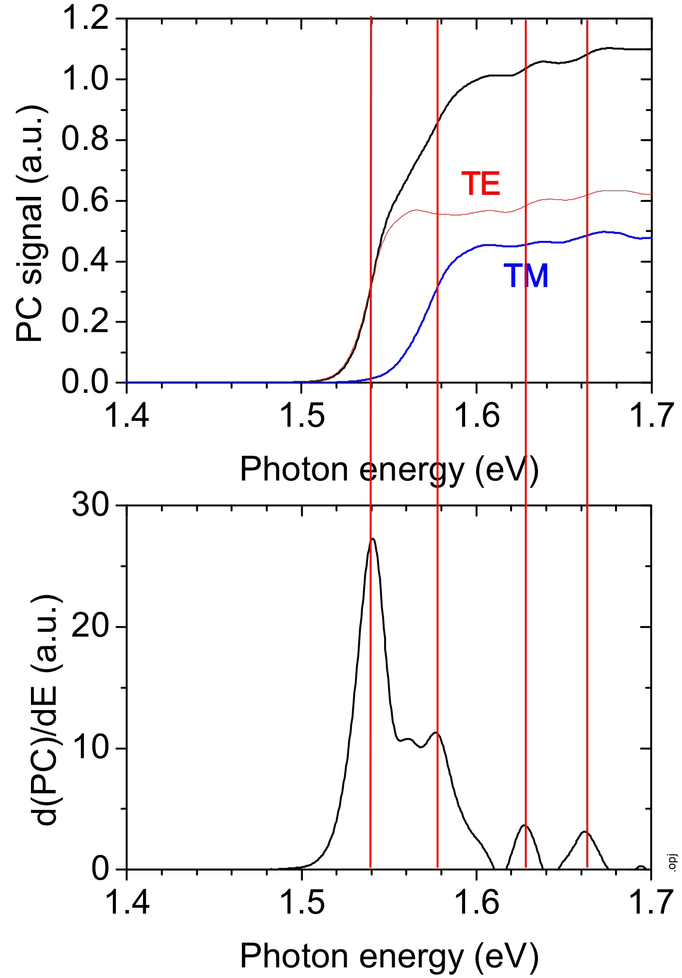
$\varnothing_{FWHM}$ ~ 100 µm, I=2 Wcm^{-2}
Measuring time ~ several minutes per spectrum (2-3 h per bar)

II.1.1 Strain measurement in semiconductors and devices

Absorption spectrum of a QW



Photocurrent data from a diode laser array



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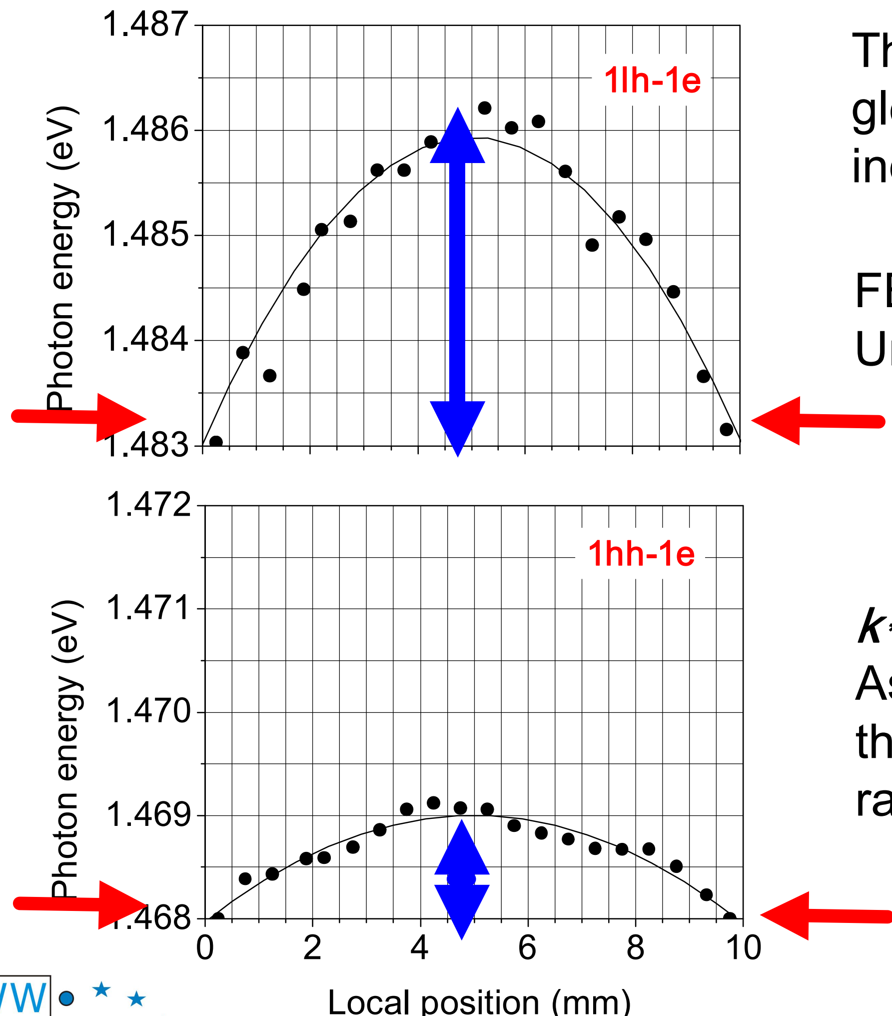
II.1.1 Strain measurement in semiconductors and devices

By-emitter analysis of data collected along an array:



The only strain contribution that varies globally along the device is packaging-induced strain.

FEM-modelling of the soldering process:
Uniaxial compression along [110] direction

J. W. Tomm et al.
Appl. Phys. Lett. **82**, 4193-4195 (2003).

k*p bandstructure calculation:
Assuming uniaxial stress along [110], then the hh/lh-shifts should follow the ratio 1:3

M. L. Biermann et al.
J. Appl. Phys. **96**, 4056-4065 (2004).

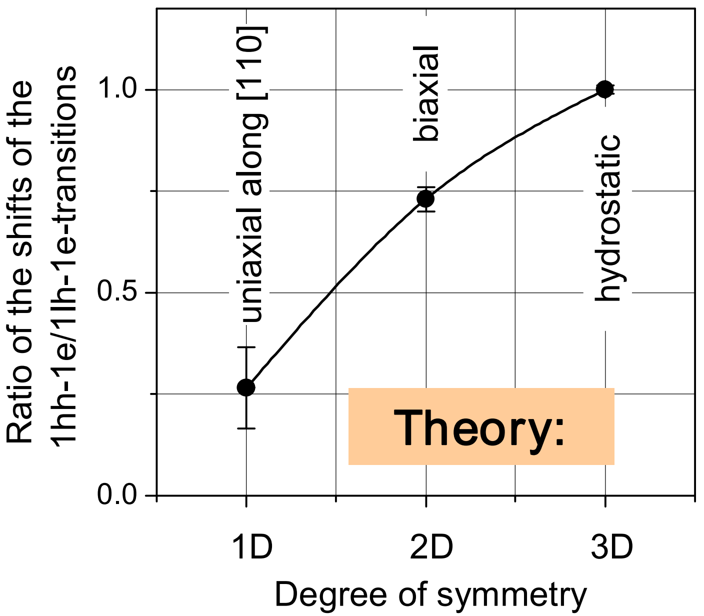
II.1.1 Strain measurement in semiconductors and devices

QW photocurrent reveals:

1. Information on Strain

a) If one knows the strain geometry one can quantify the strain

b) Strain geometry can be estimated



2. Information on Defects

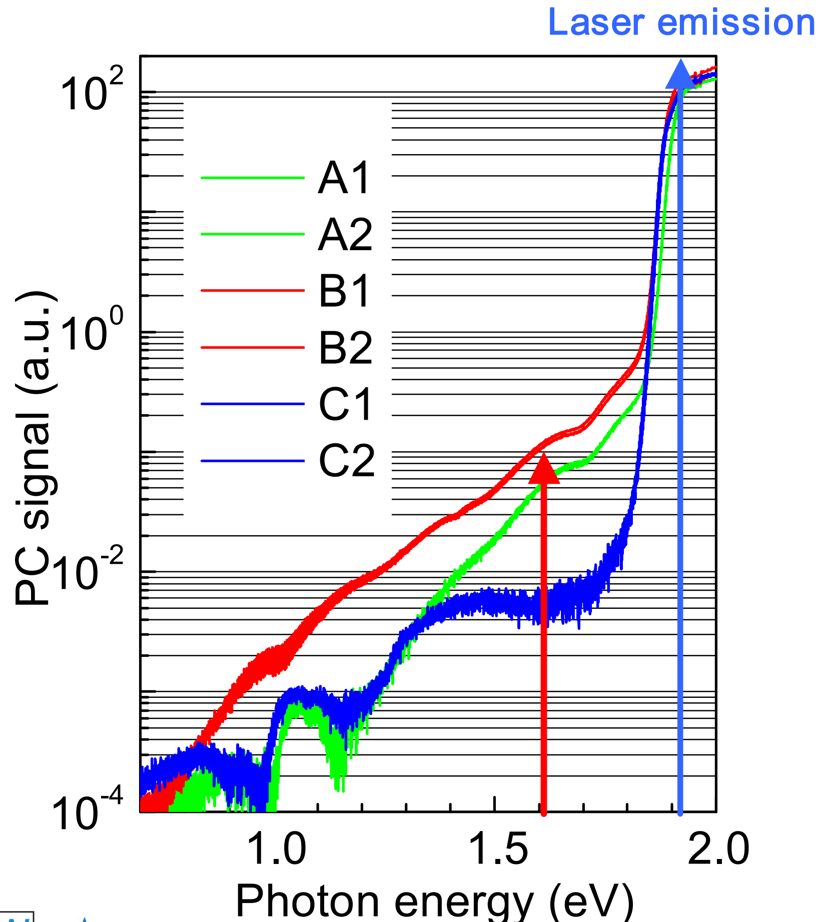
QW-photocurrent ~ population δn

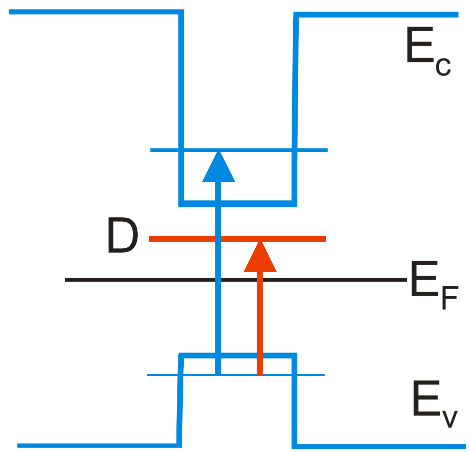
$\tau = \delta n/G$

$\tau \sim \delta n$ " τ - mapping "

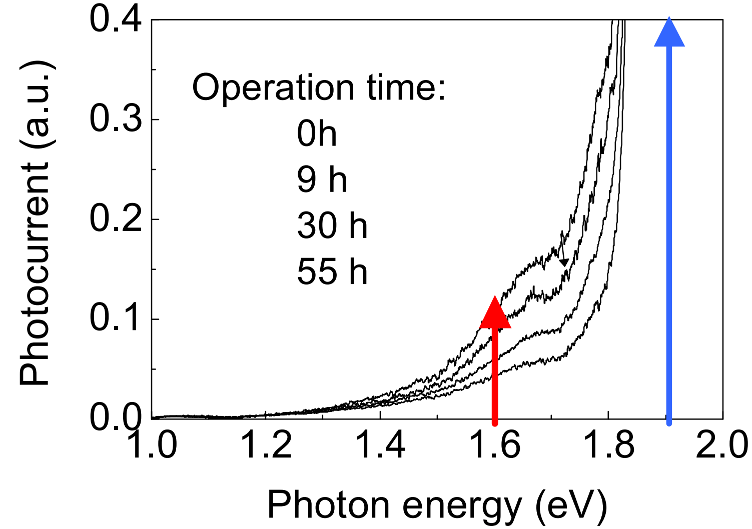
II.1.2 Detection of defects in (semiconductors and) devices

Photocurrent Spectroscopy (PCS)



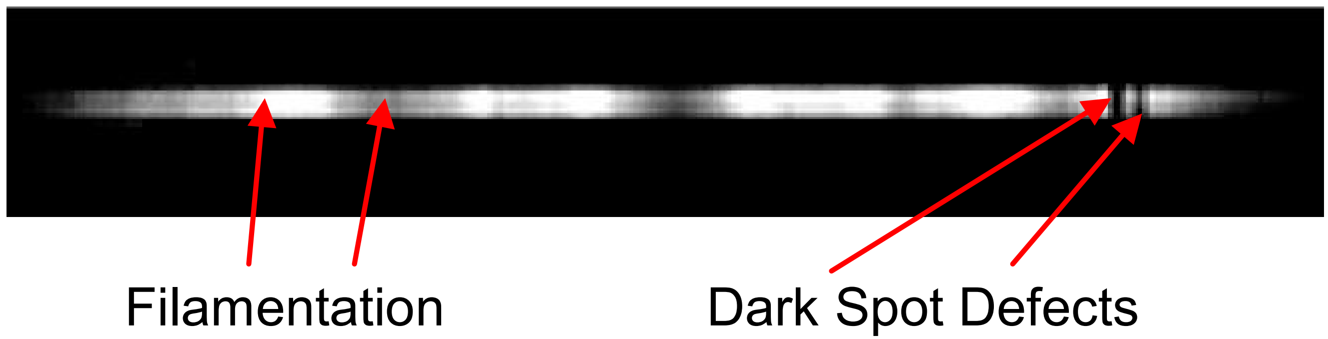


Ropers et al. *APL* **88**, 133513 (2006).

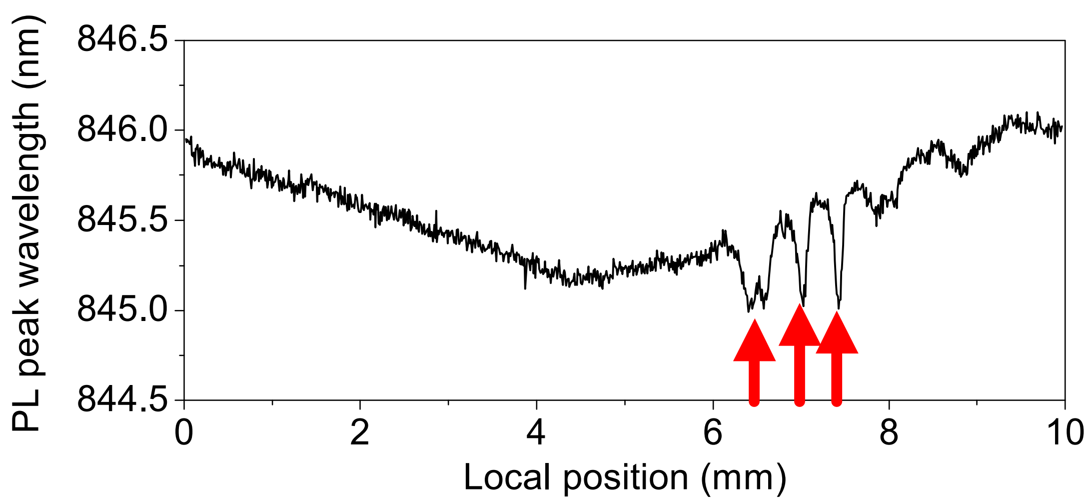


II.1.2 Detection of defects in (semiconductors and) devices

Electroluminescence (EL)



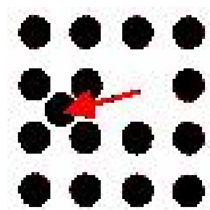
Photoluminescence (PL)



II.1.2 Detection of defects in semiconductors and devices

What type of defects are expected:

a) Point defects (Frenkel pair)



Antisite defects:
Liu et al. *APL* **67**, 279 (1995).

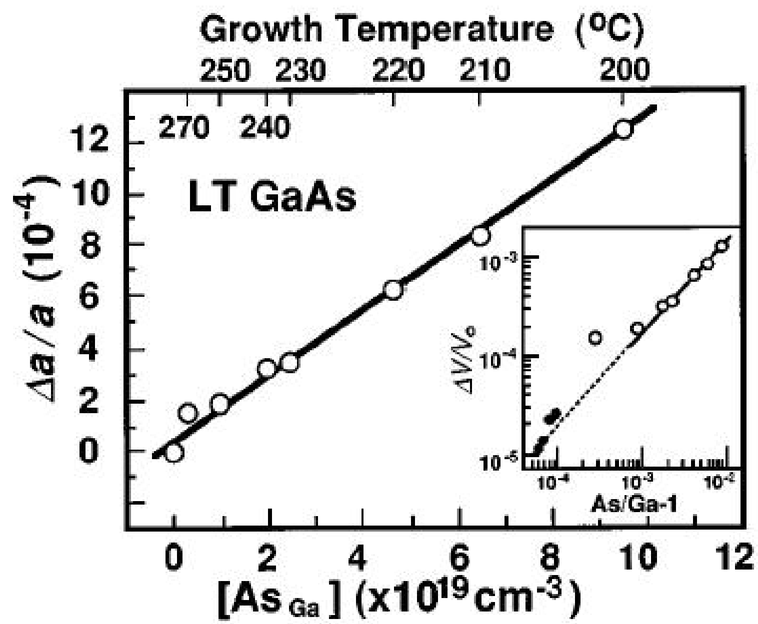
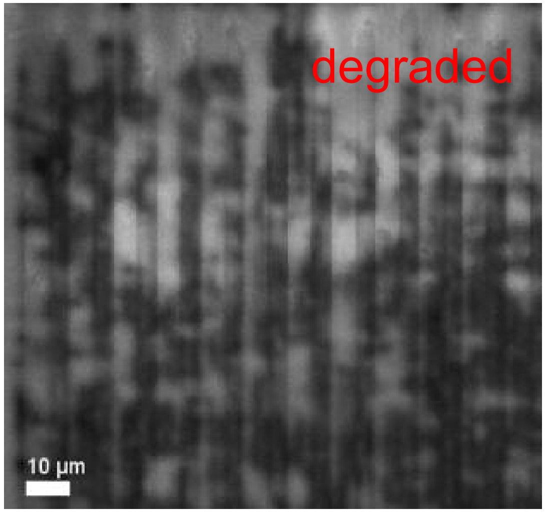
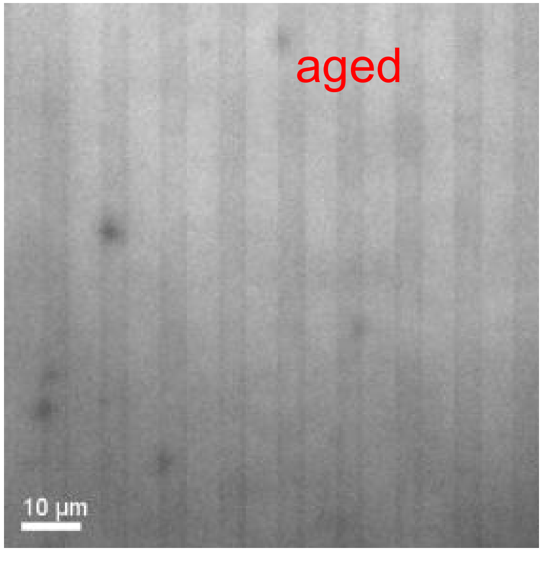


FIG. 2. Relative change of lattice parameter plotted as a function of the concentration of As_{Ga} for LT GaAs grown at different temperatures. The inset shows a log–log plot of both our data of LT GaAs (○) and that from Terashima *et al.* (●) of As-rich bulk GaAs (see Ref. 19).

b) Agglomerates of point defects

II.1.2 Detection of defects in (semiconductors and) devices

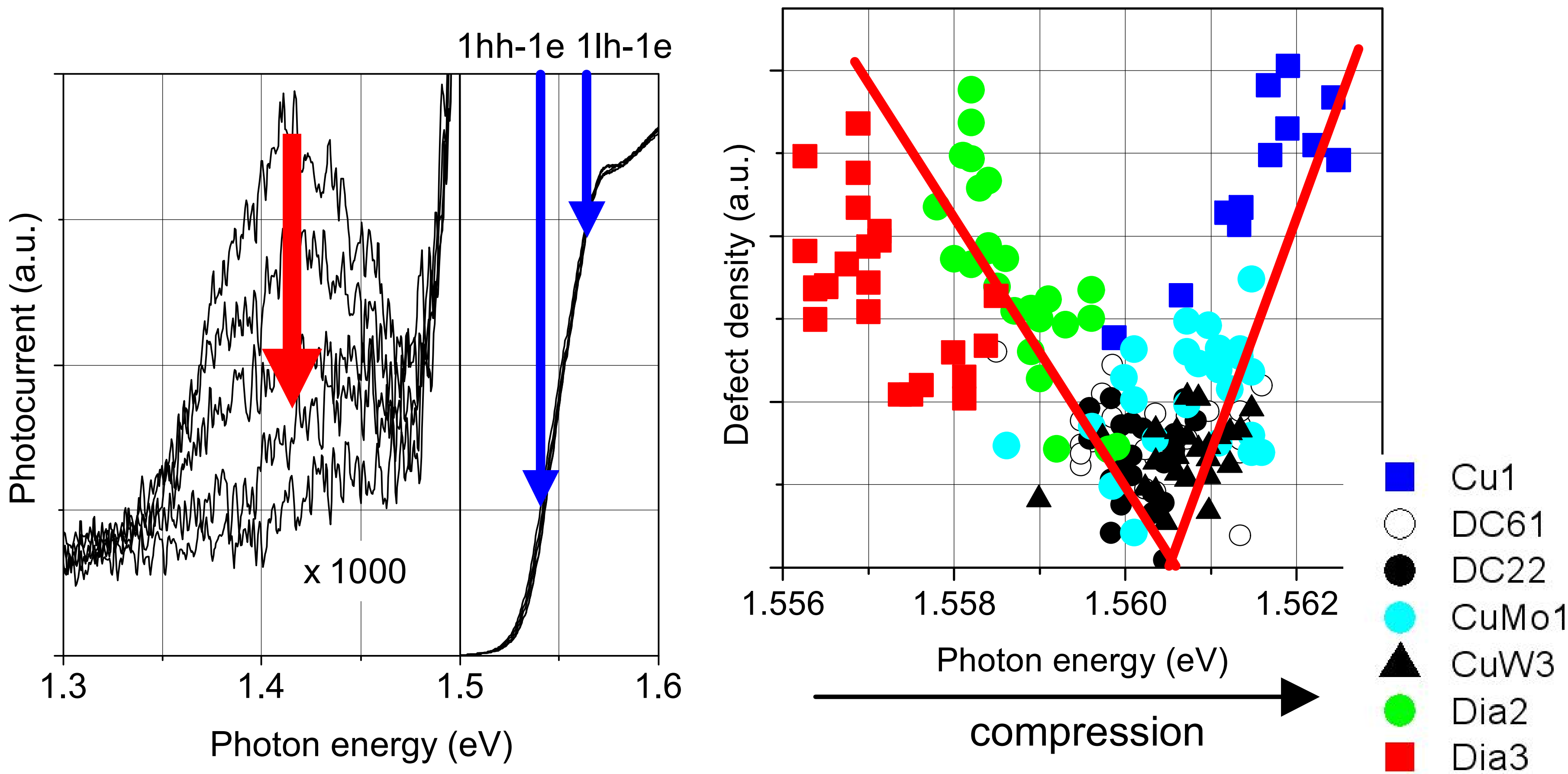




Tien et al.
APL **87**, 211110 (2005)

II. 2. Observation of defects caused by packaging-induced strain

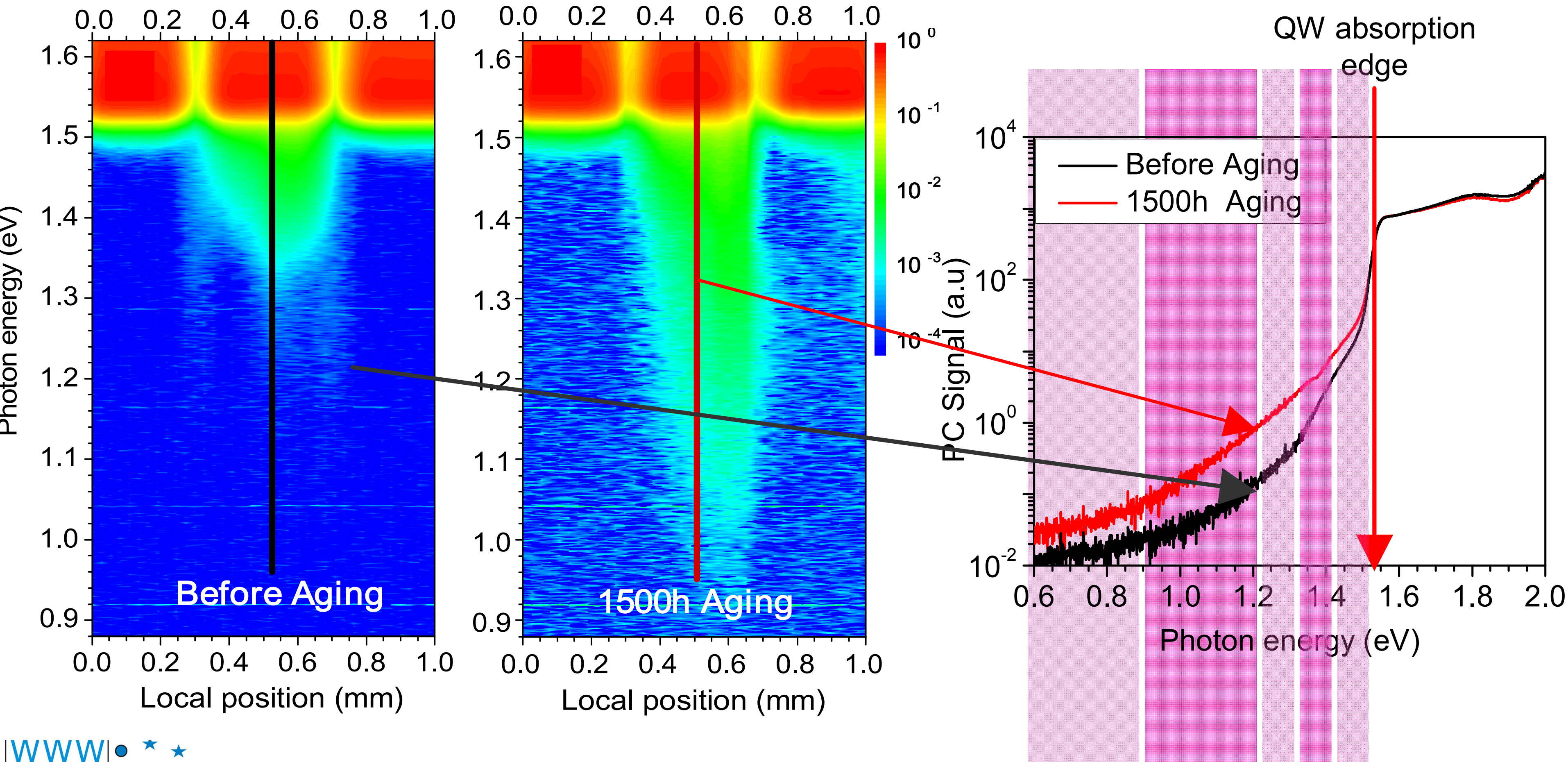
Analysis of the magnitude of defect bands versus spectral positions of the optical transitions for 7 differently packaged bars from the same batch:



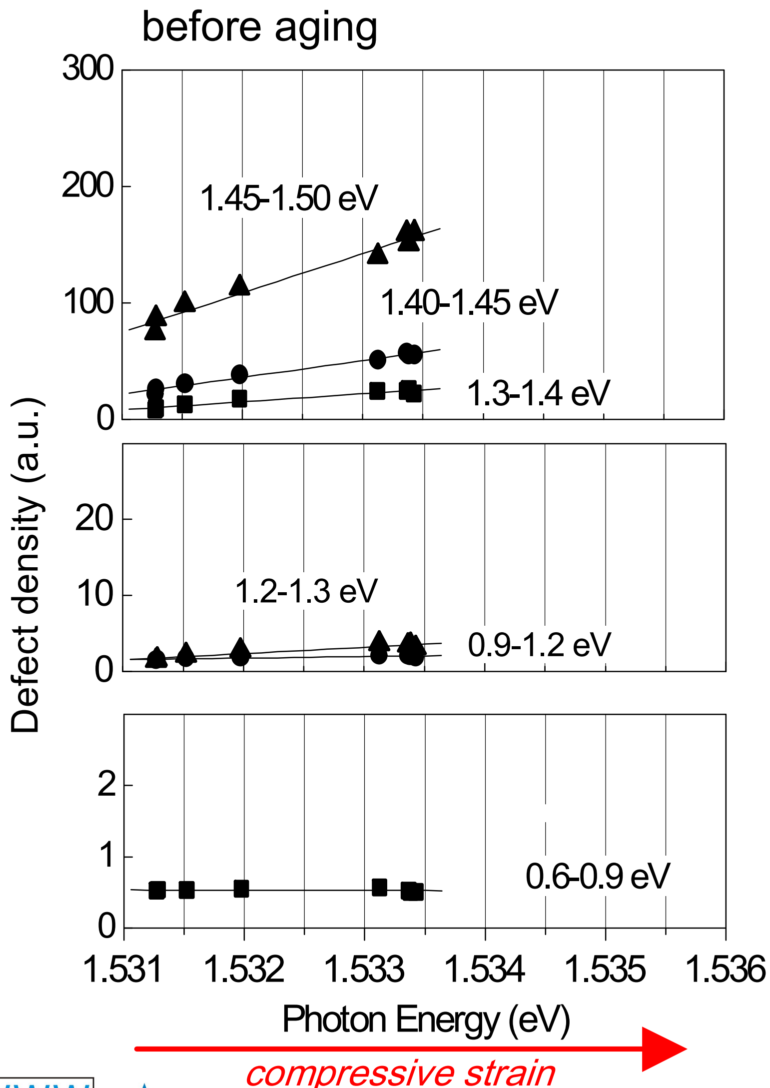
Tomm et al. *APL* **81**, 3269 (2002).

II. 3. Observation of strain caused by defects

By analyzing data within one single emitter, we keep the parameter ‚packaging-induced strain' constant.

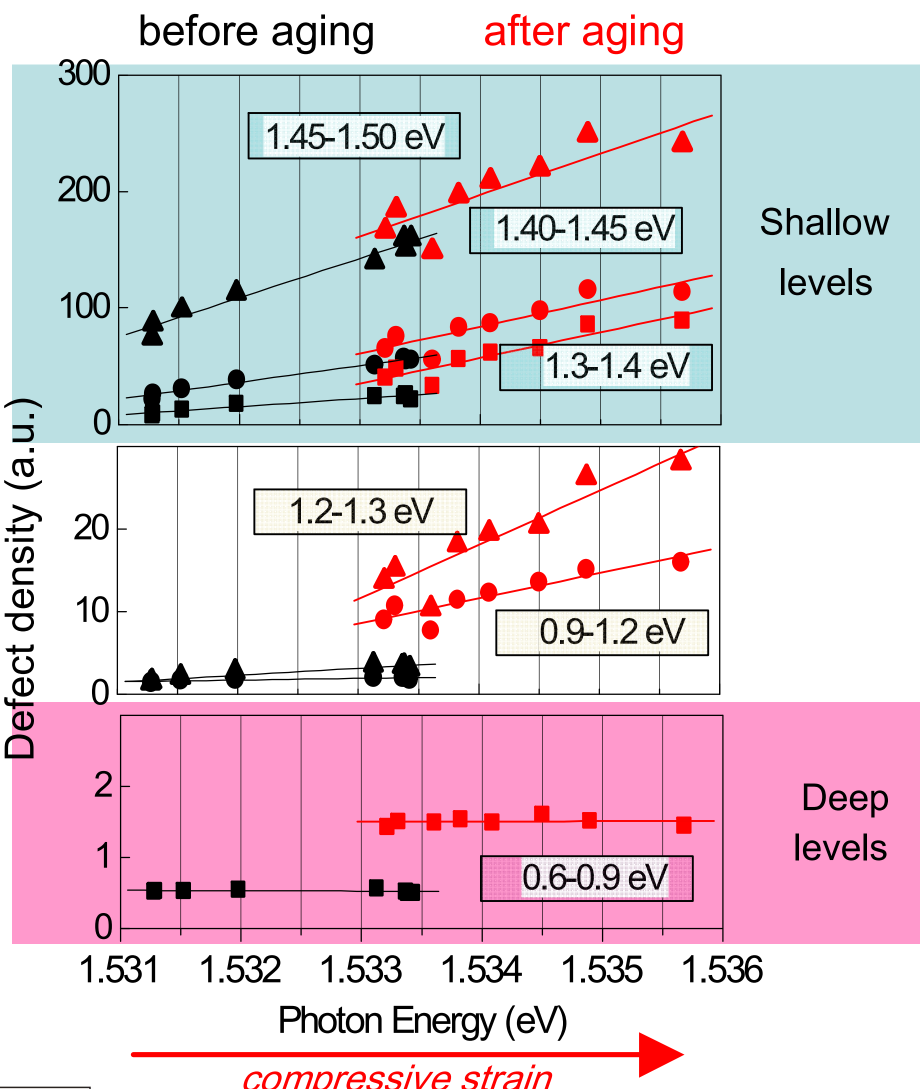


II. 3. Observation of strain caused by defects



T. Q. Tien et al. *APL* **86**, 111908, (2005).

II. 3. Observation of strain caused by defects

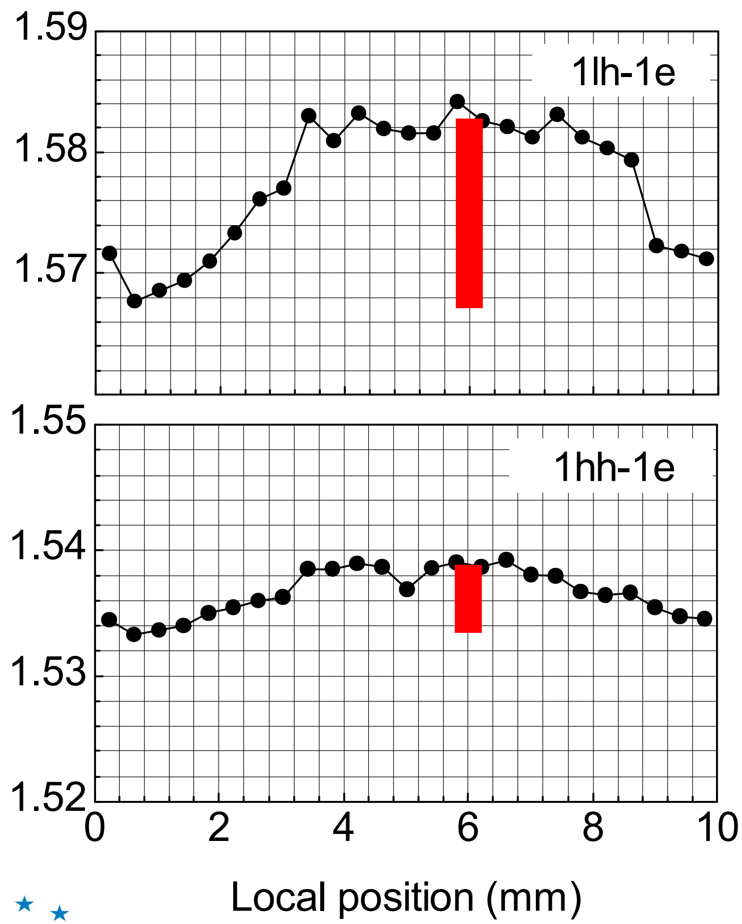


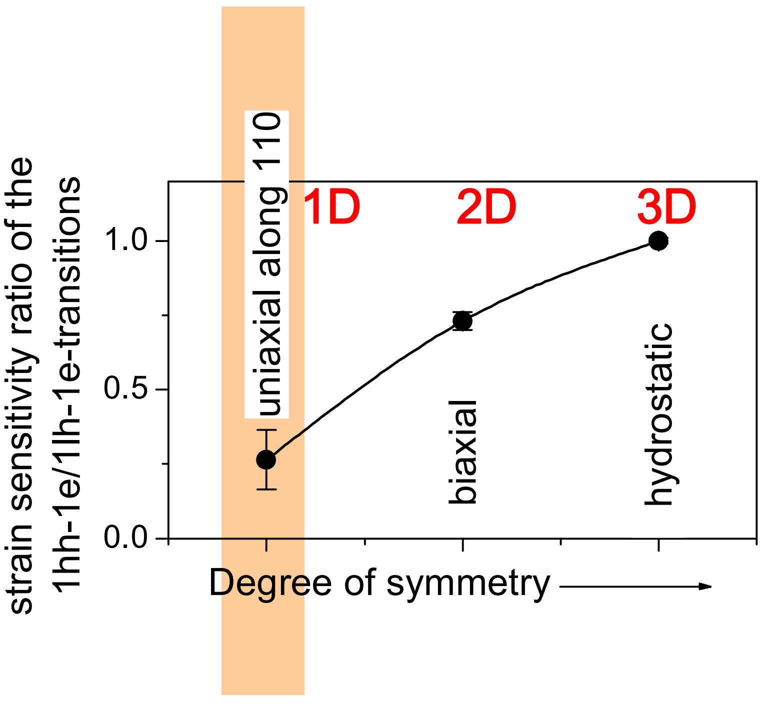
- During aging, the defect concentration increases
- Additional defects act as driving force that enhances internal strain in active region.
- Deep levels: No correlation between strains and defect concentration
- Shallow levels: strong correlation between strains an defect concentration

T. Q. Tien et al. *APL* **86**, 111908, (2005).

II. 4. Interplay between strains and defects as monitored by “by-emitter” analysis

Example I: Strain relaxation during device operation



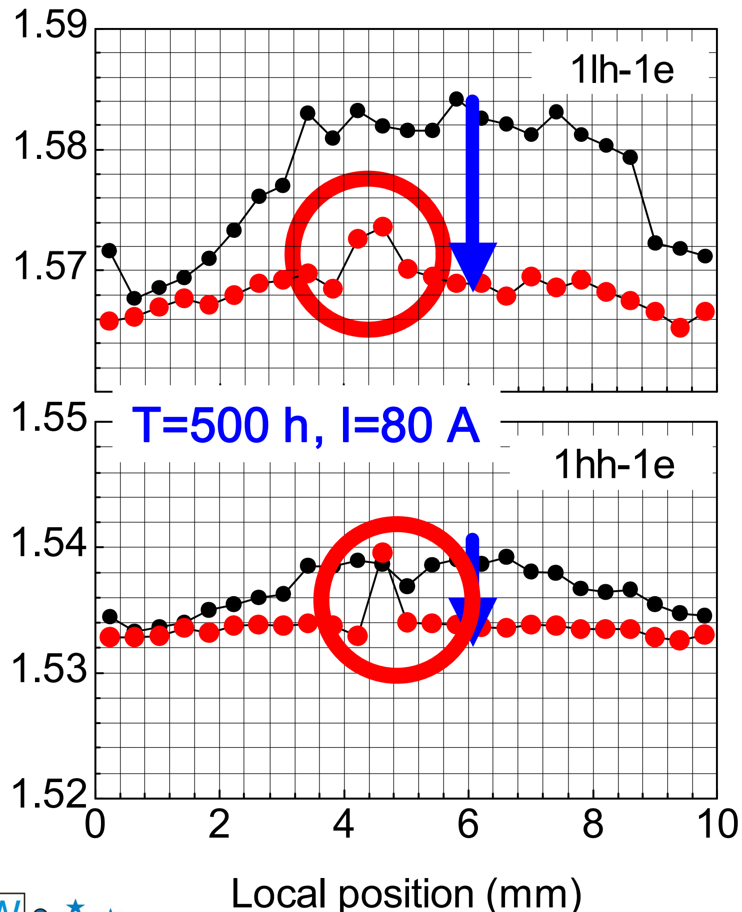


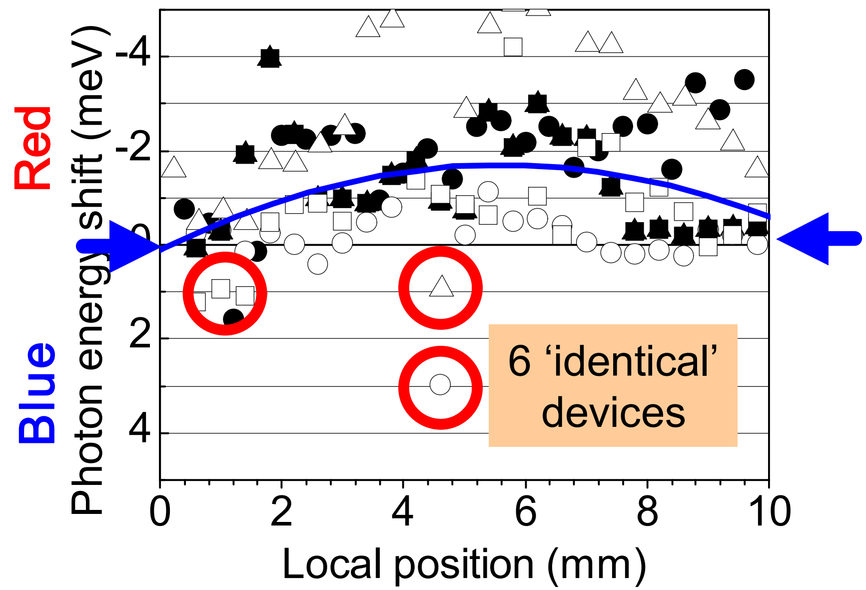
The University of Nottingham

II. 4. Interplay between strains and defects as monitored by "by-emitter" analysis

MBI

Example I: Strain relaxation during device operation





- Almost no strain relaxation at the edges
- Relaxation by about + 0.07% (~half) in center
- Strain symmetry is maintained
- Spikes

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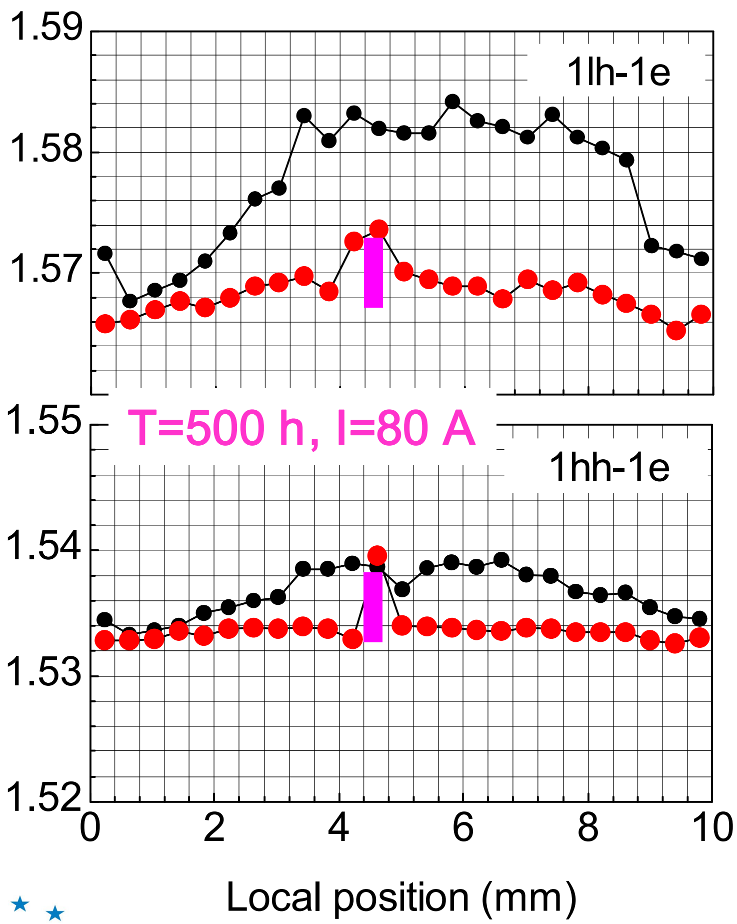
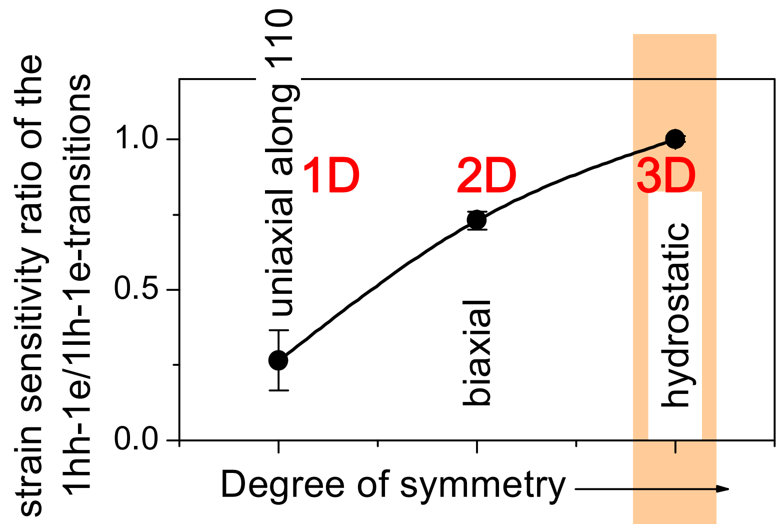
II. 4. Interplay between strains and defects as monitored by “by-emitter” analysis

Example I: Strain ~~relaxation~~ generation during device operation





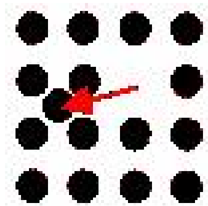
- Local strain field of hydrostatic symmetry likely to be caused by the creation of point defects
- Local hydrostatic compression by - 0.017%

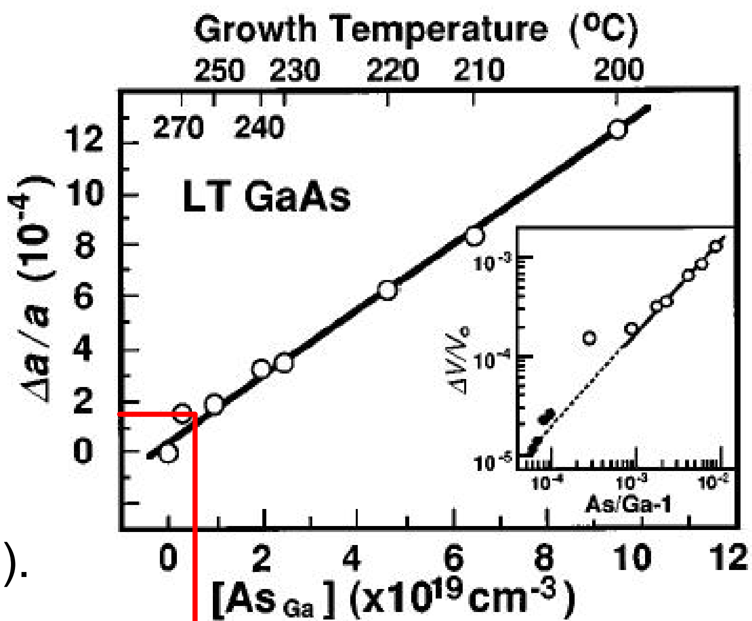
II. 4. Interplay between strains and defects as monitored by “by-emitter” analysis

What type of defects are expected:

?

a) Point defects





Liu et al. *APL* **67**, 279 (1995).

FIG. 2. Relative change of lattice parameter plotted as a function of the concentration of As_{Ga} for LT GaAs grown at different temperatures. The inset shows a log–log plot of both our data of LT GaAs (○) and that from Terashima *et al.* (●) of As-rich bulk GaAs (see Ref. 19).

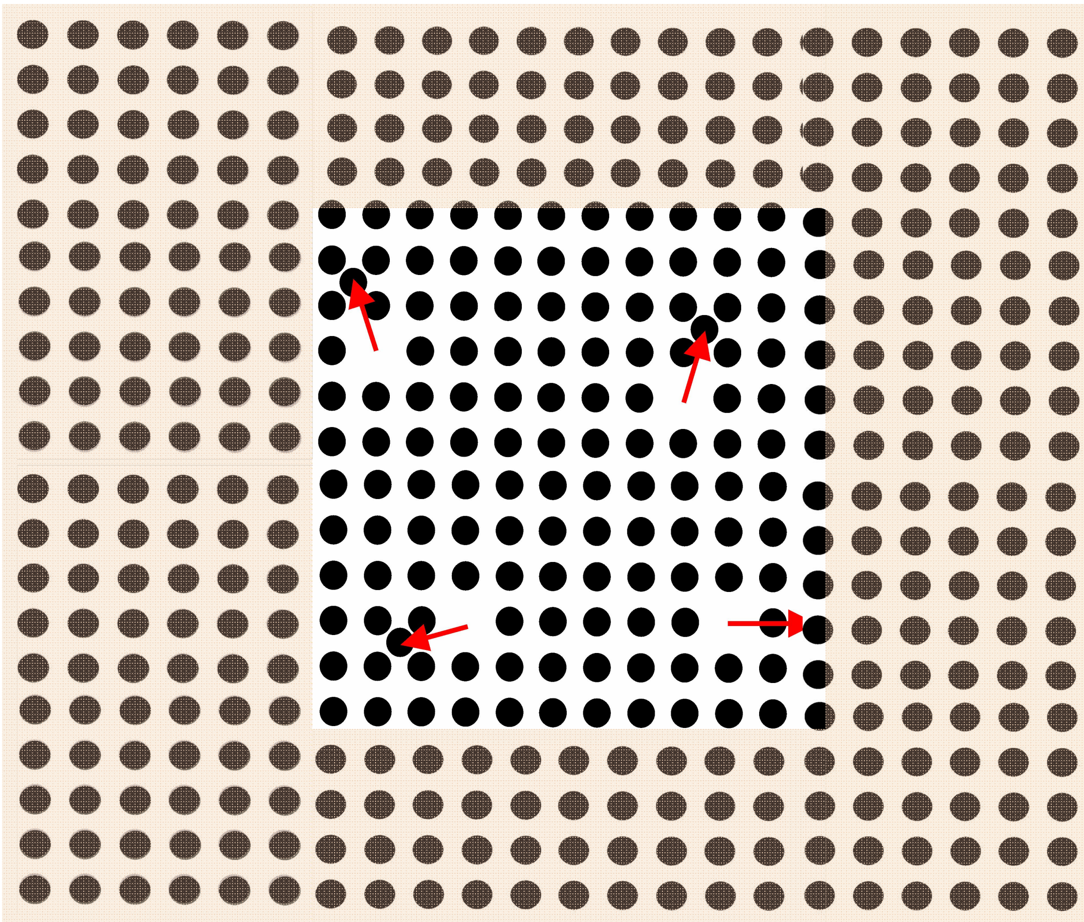
?

b) Agglomerates of point defects

$5 \times 10^{18} cm^{-3}$ **but tension**

II. 4. Interplay between strains and defects as monitored by "by-emitter" analysis

What happens defects become created within the active region of a device?



Defects tense the material because the dense package of the crystal gets disturbed (Δa>0).

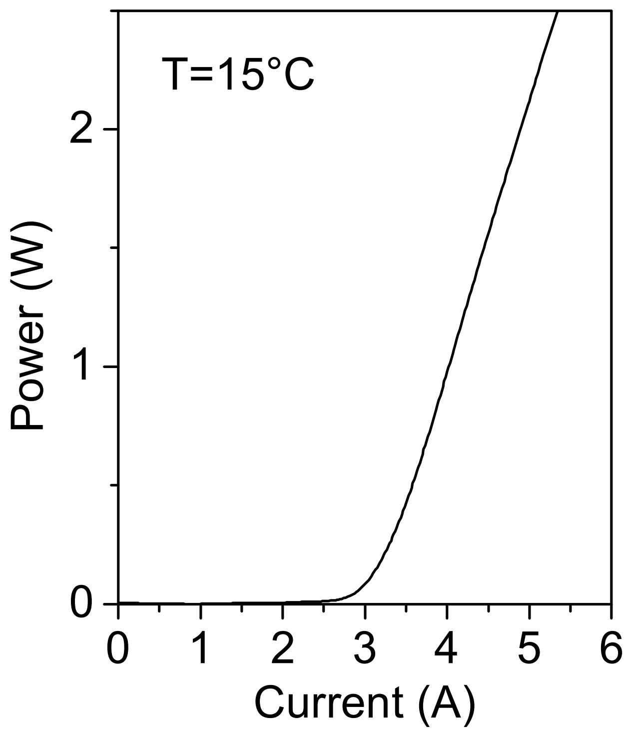
The active region is embedded into less disturbed regions that act like a 'corset' and does not allow any tension.

This results in an effective compression of the active area (Δa<0).
Defects - compressive strain.

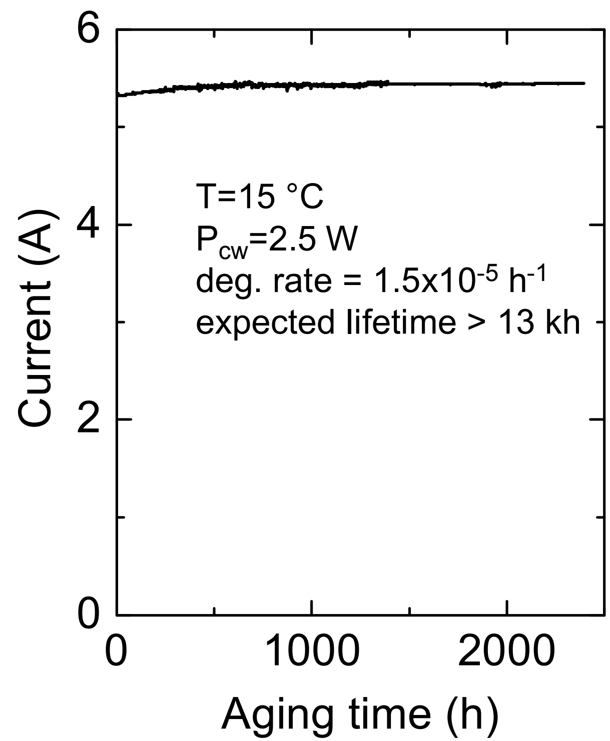
II. 4. Interplay between strains and defects as monitored by “by-emitter” analysis

Example II: Gradual degradation of red-emitting bars

cm-bars,19 emitters, 30 µm stripe width



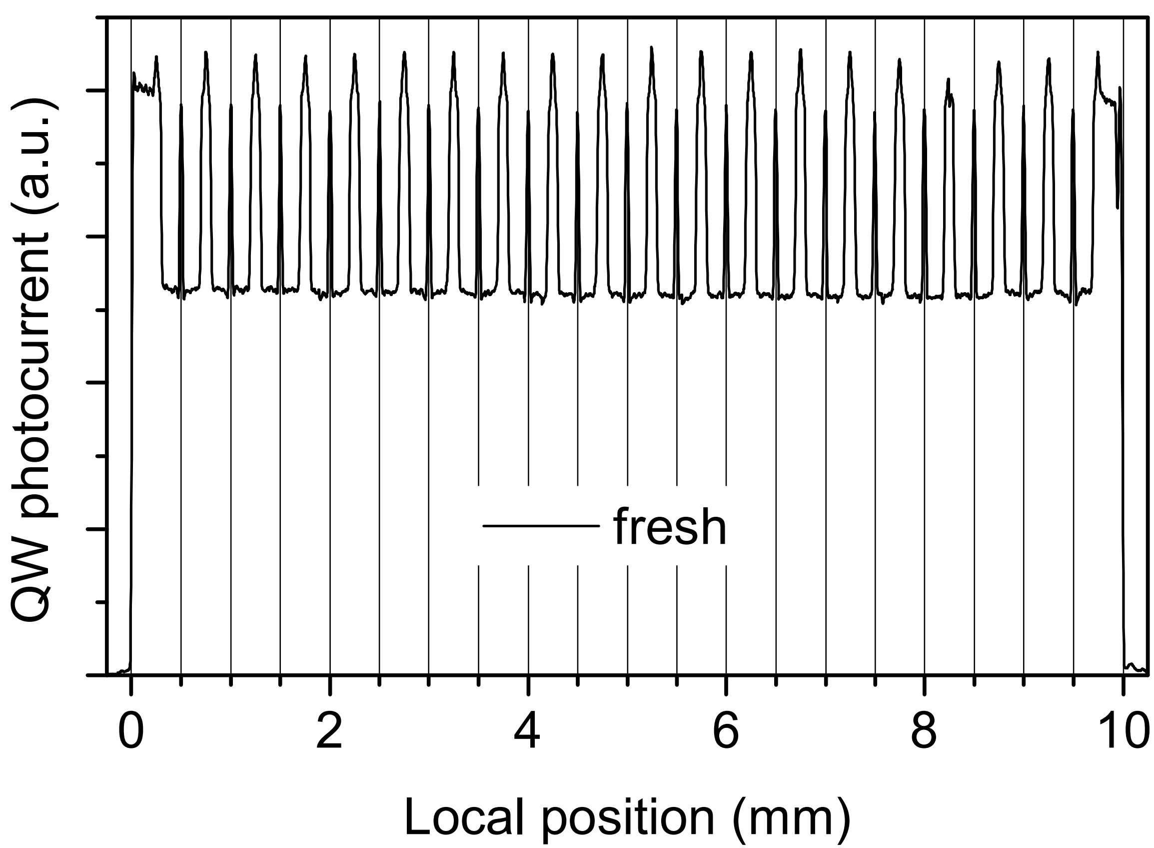
constant current aging



Application of the techniques sensitive to gradual degradation

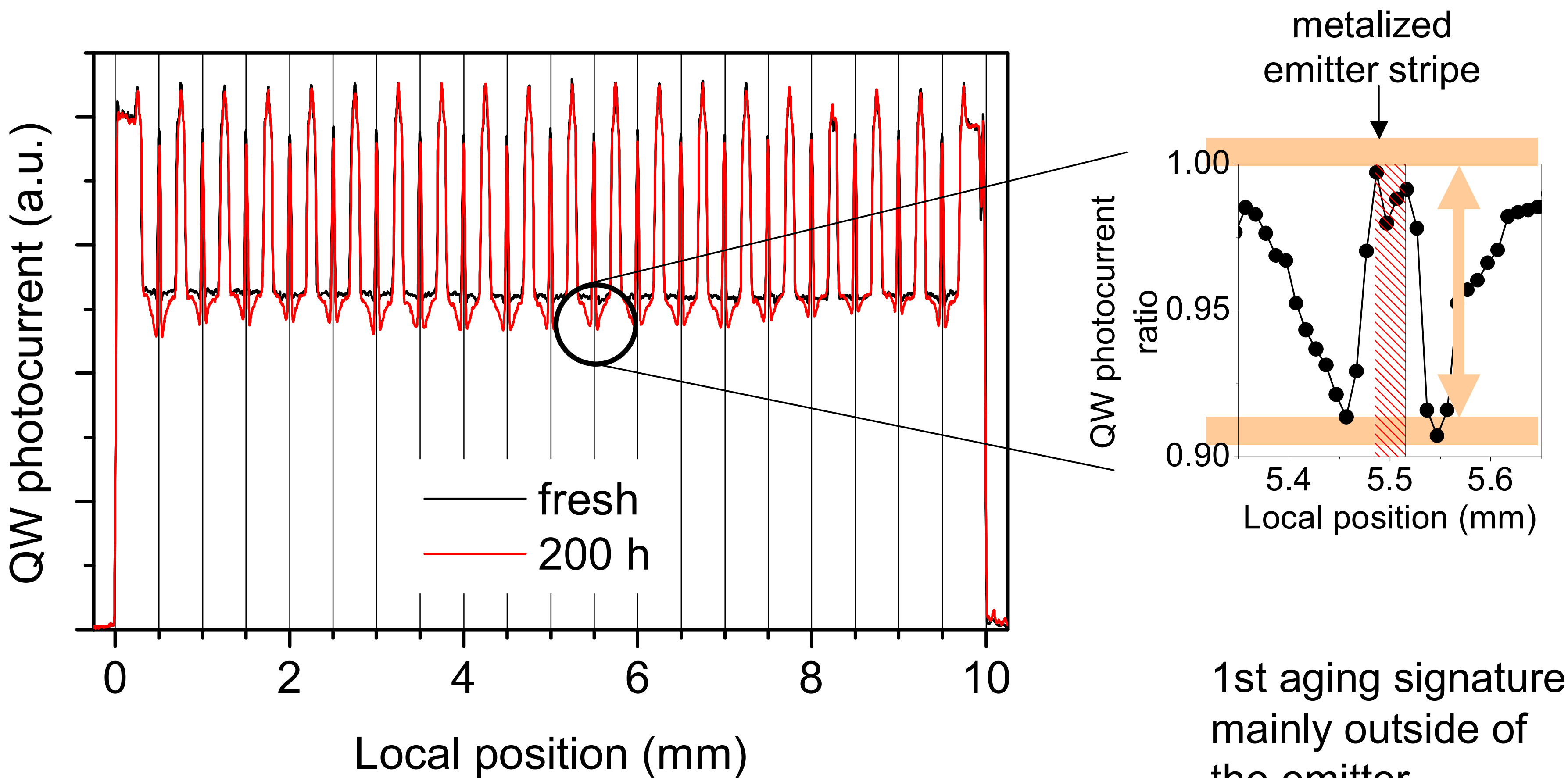
II. 4. Interplay between strains and defects as monitored by “by-emitter” analysis

Example II: Gradual degradation of red-emitting bars



II. 4. Interplay between strains and defects as monitored by “by-emitter” analysis

Example II: Gradual degradation of red-emitting bars



1st aging signature mainly outside of the emitter

Tutorial at the BRIGHTER meeting at LCFIO and THALES TRT, Campus Polytechnique – RD 128, Palaiseau, France, February 13-15, 2008

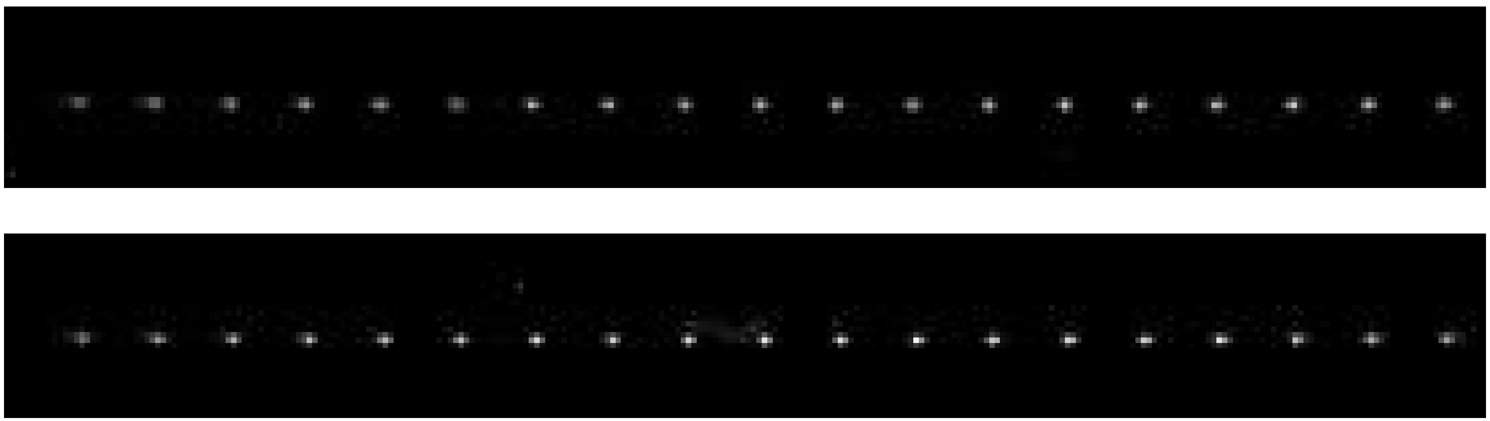
II. 4. Interplay between strains and defects as monitored by "by-emitter" analysis

Example II: Gradual degradation of red-emitting bars

2nd aging signature   Defect-related NIR emission from inside of the emitters

0 h

200 h



What parameter is the driving force for the two degradation signatures?

a) Temperature
b) Packaging-induced strain

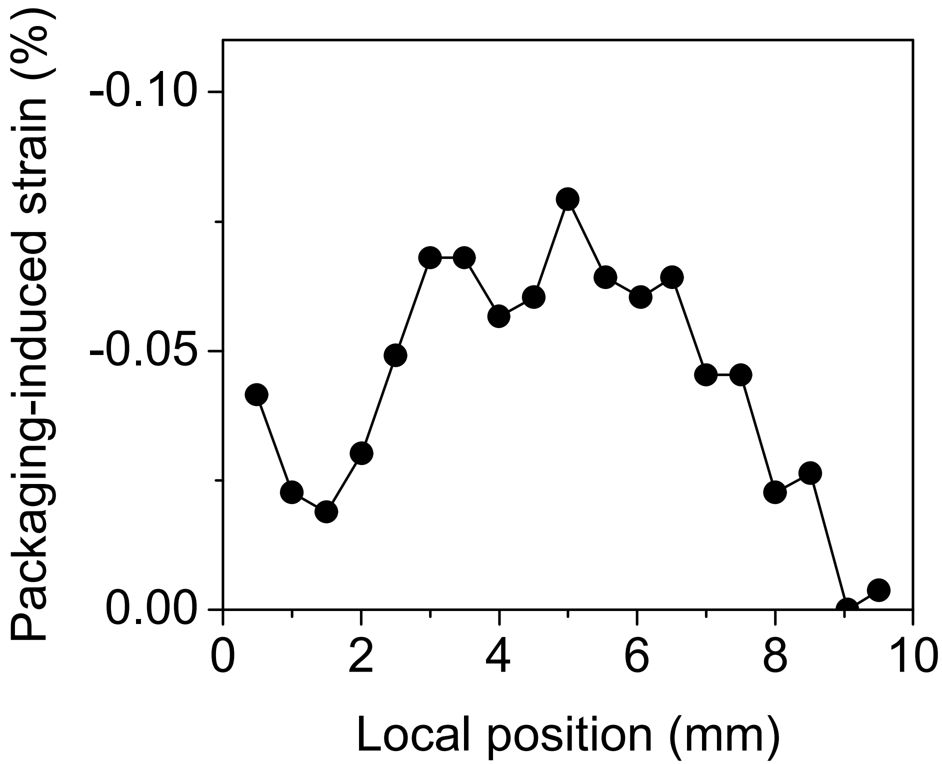
Infrared imaging
Photocurrent

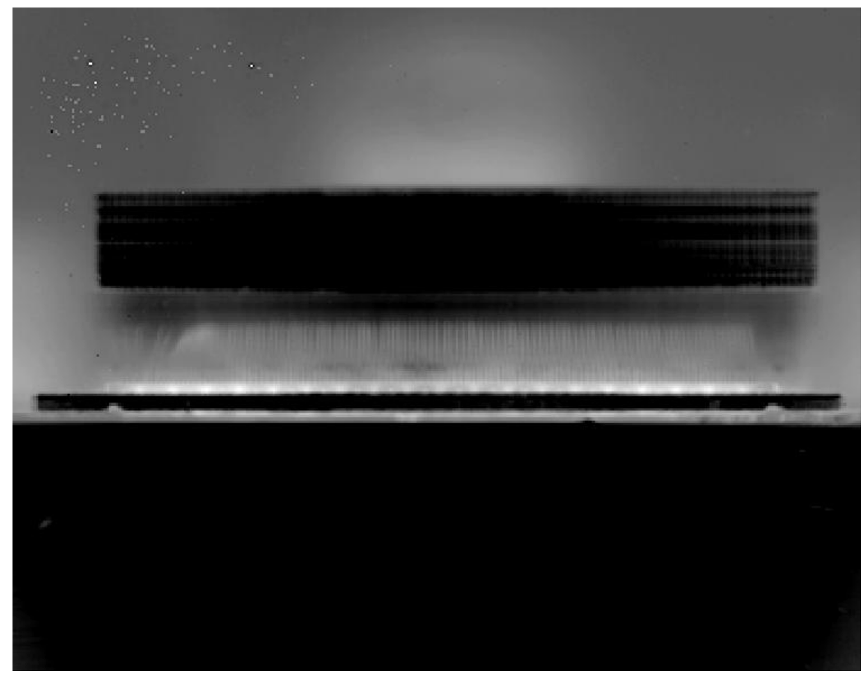
II. 4. Interplay between strains and defects as monitored by "by-emitter" analysis

Example II: Gradual degradation of red-emitting bars

Strain analysis by photocurrent spectroscopy

Thermal analysis by infrared imaging

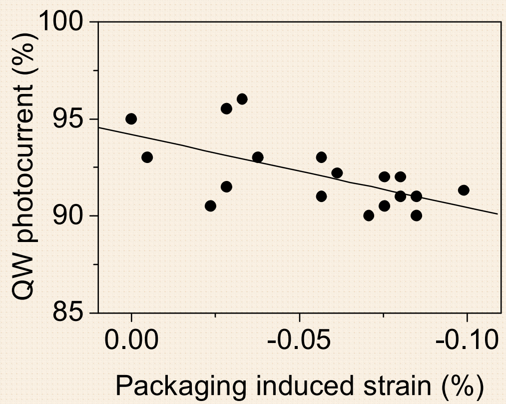




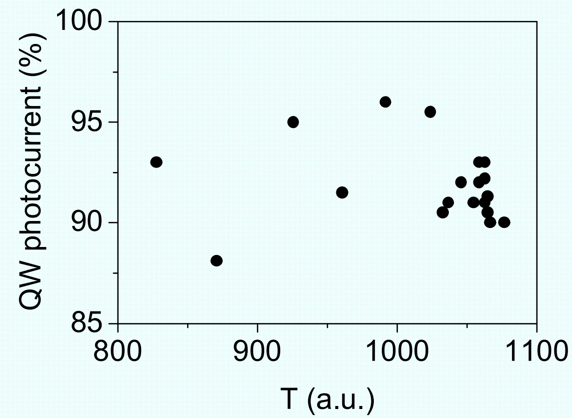
II. 4. Interplay between strains and defects as monitored by “by-emitter” analysis

Correlation analysis

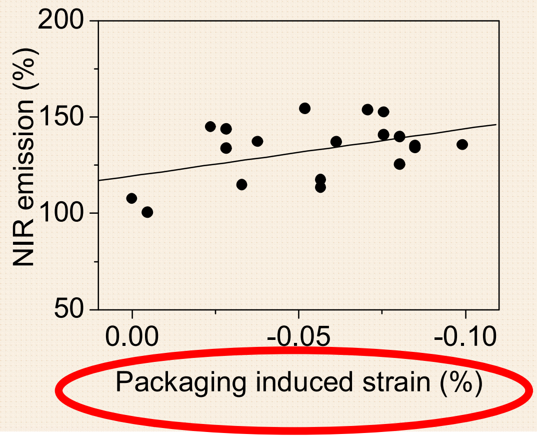
r = - 0.69



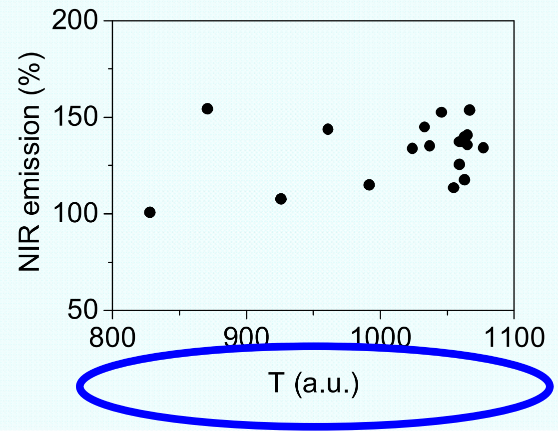
r = - 0.11



r = 0.65



r = 0.32



WWW BRIGHTER EU

II. 5. Summary

By-emitter analysis allows for establishing aging scenarios of laser arrays.

By-emitter analysis allows for improving insight into degradation effects of single emitters by understanding the interplay between strains and defects.

a) Defects created by packaging-induced strain
b) Strain created by accumulation of defects

Have we 'seen' any defects?	No.	- Dark spot areas in PL, CL, … - Shoulders in PCS - Peaks in LBIC.
What are „defects“?	Agglomerates of 'point defects', sometimes even more complex agglomerates.	

Almost no information is available about defects in QWs.

Almost no information is available about defects in QW-active areas in devices.