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「InGaN 発光の点滅現象の特性」
"The phenomena of photoluminescence blinking in InGaN materials"

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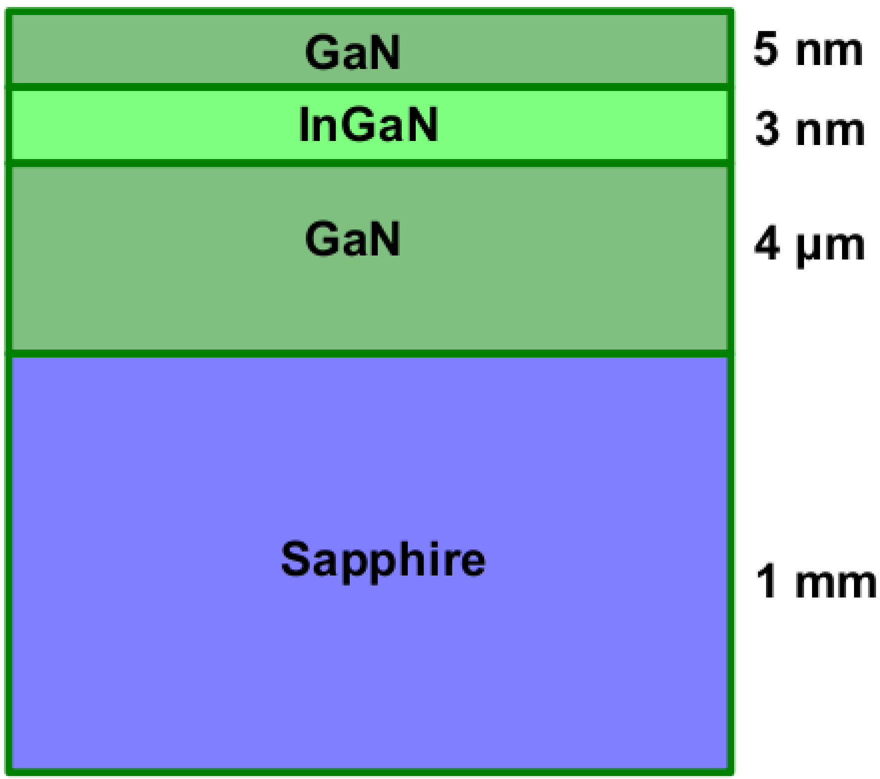
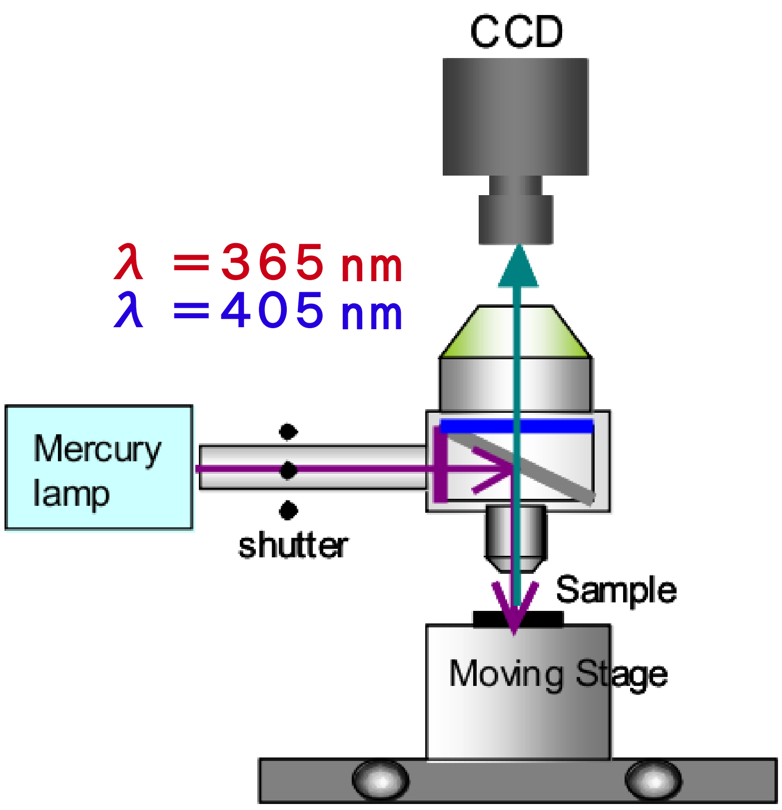
ナノシステム科学専攻

InGaN の点滅現象

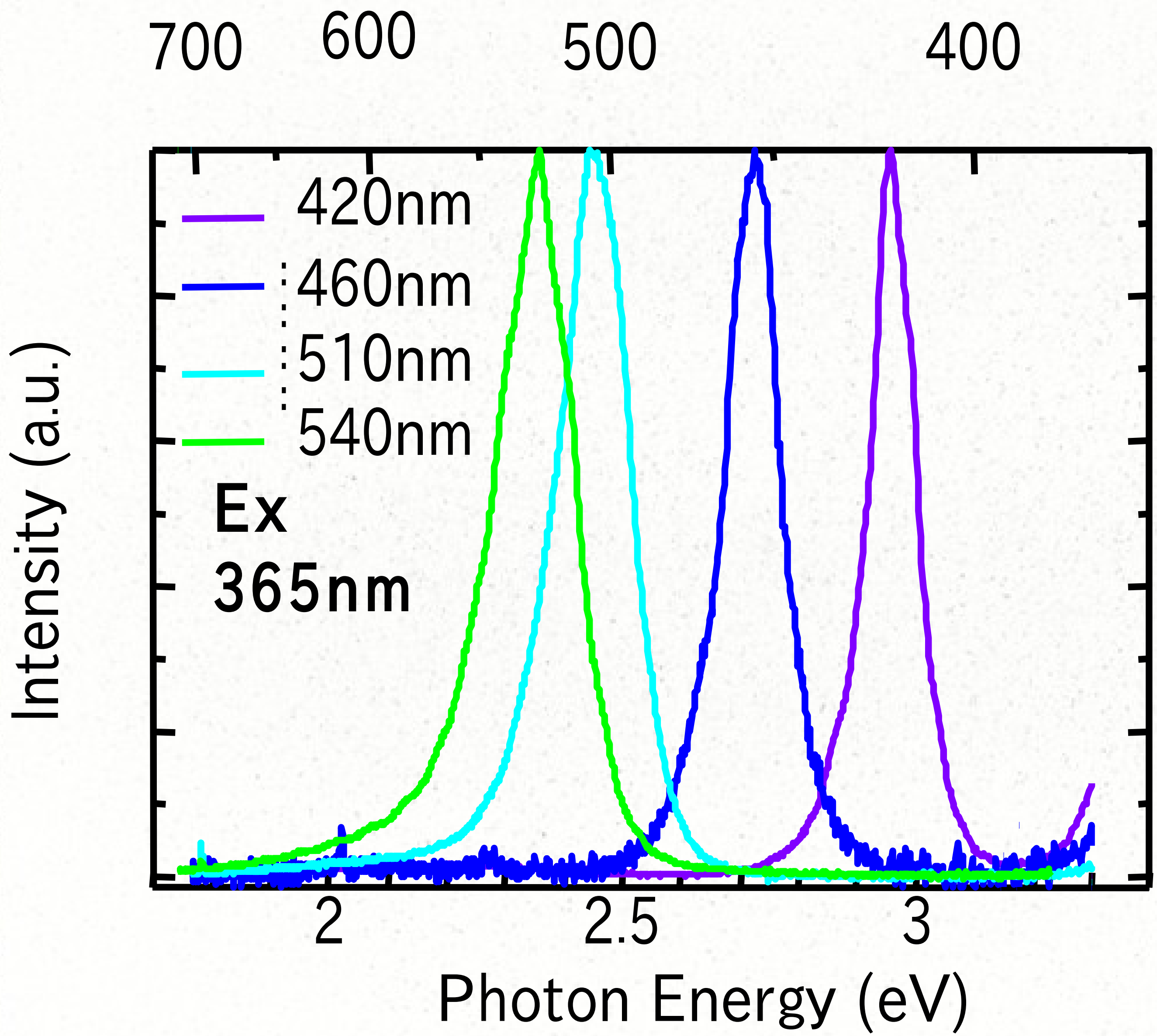


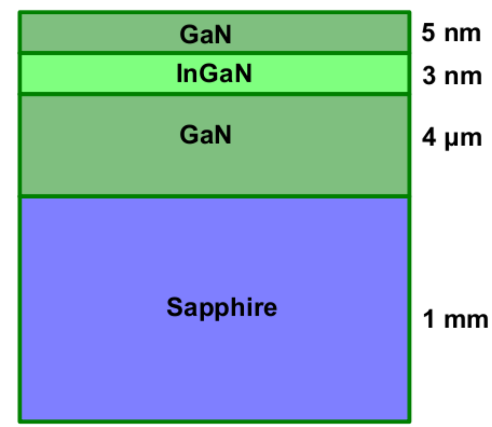
- Materials commonly used in LEDs
- InGaN between GaN forms single quantum well
- Sapphire as base

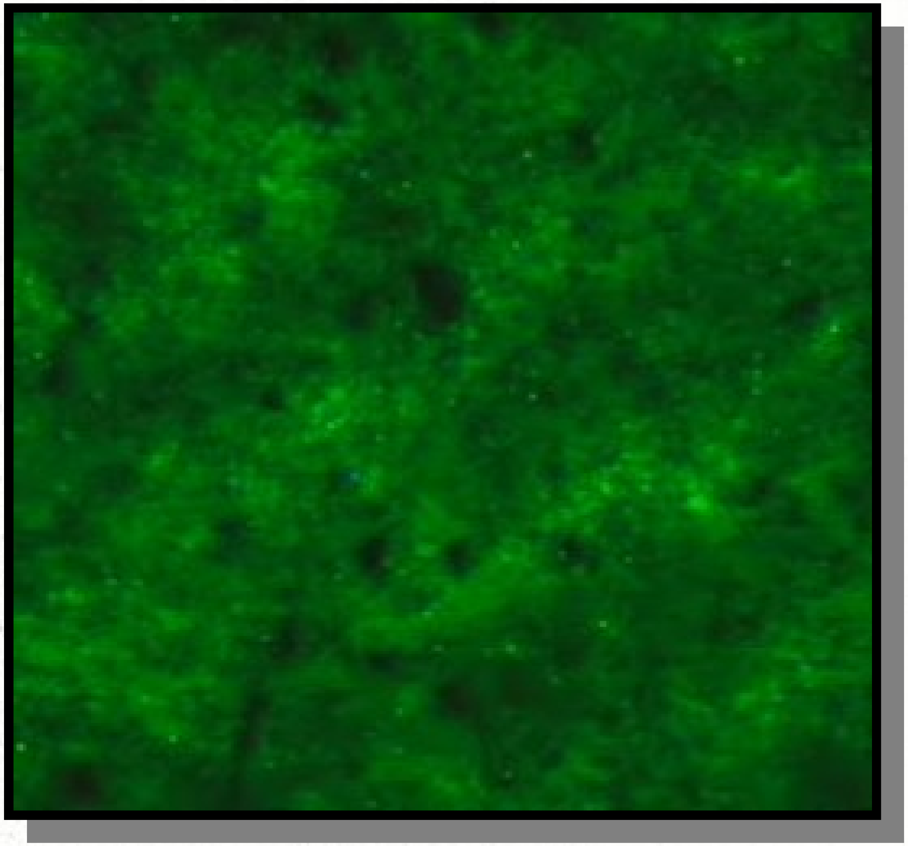
Observing the blinking – photoluminescent microscopy



- Excitation and observation of the samples using a photoluminescent microscope
- Filming the behaviour with a camera

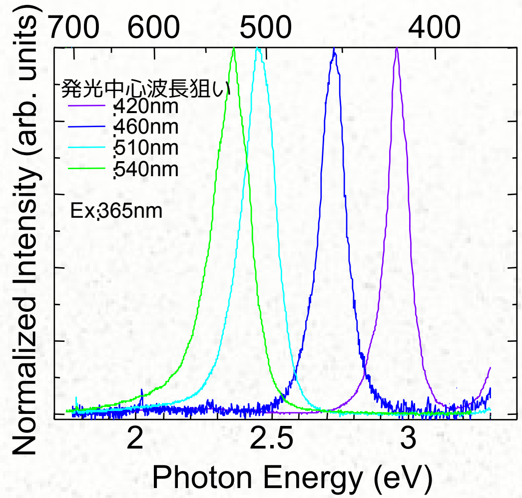

700
600
500
400
420nm
460nm
510nm
540nm
Ex
365nm
Intensity (a.u.)
2
2.5
3
Photon Energy (eV)

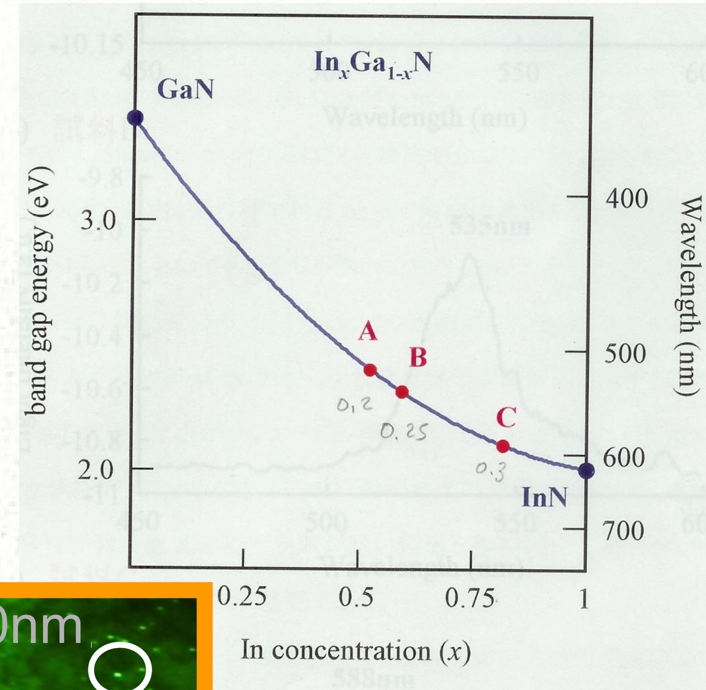

GaN
5 nm
InGaN
3 nm
GaN
4 μm
Sapphire
1 mm



After few seconds the PL image change structure

GaN (undoped) 5nm
$In_xGa_{1-x}N$ 3nm
GaN (undoped) 4μm
Sapphire

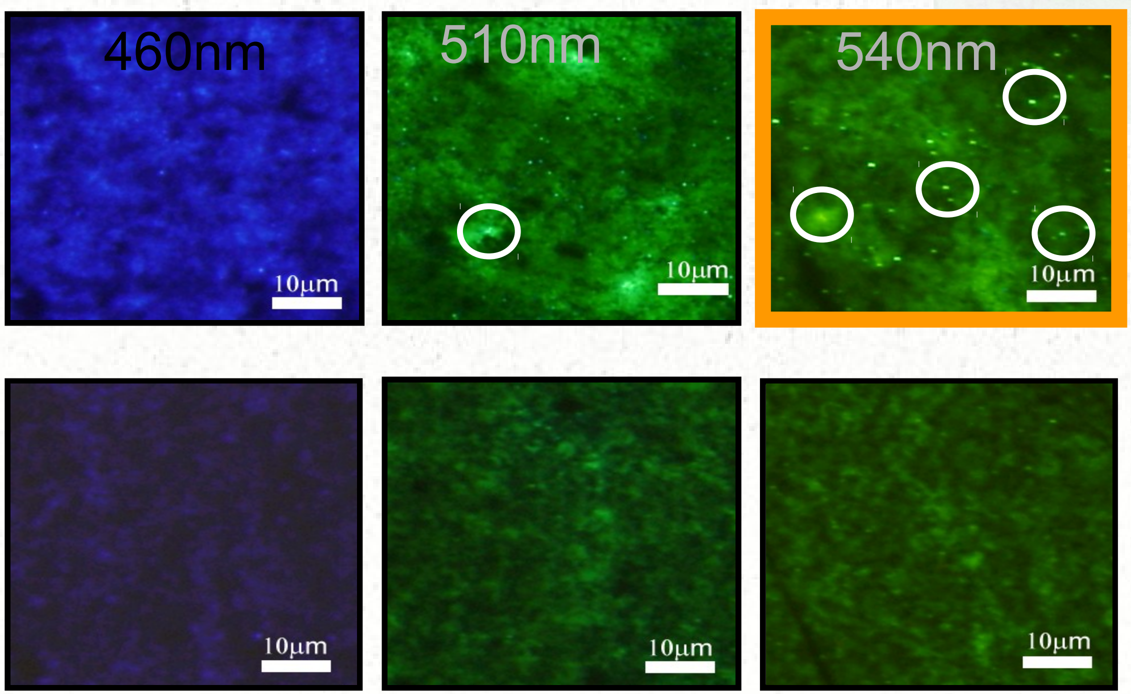




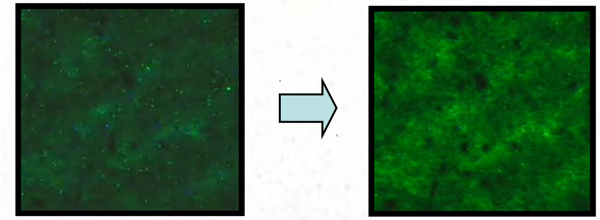
Ex: 365nm

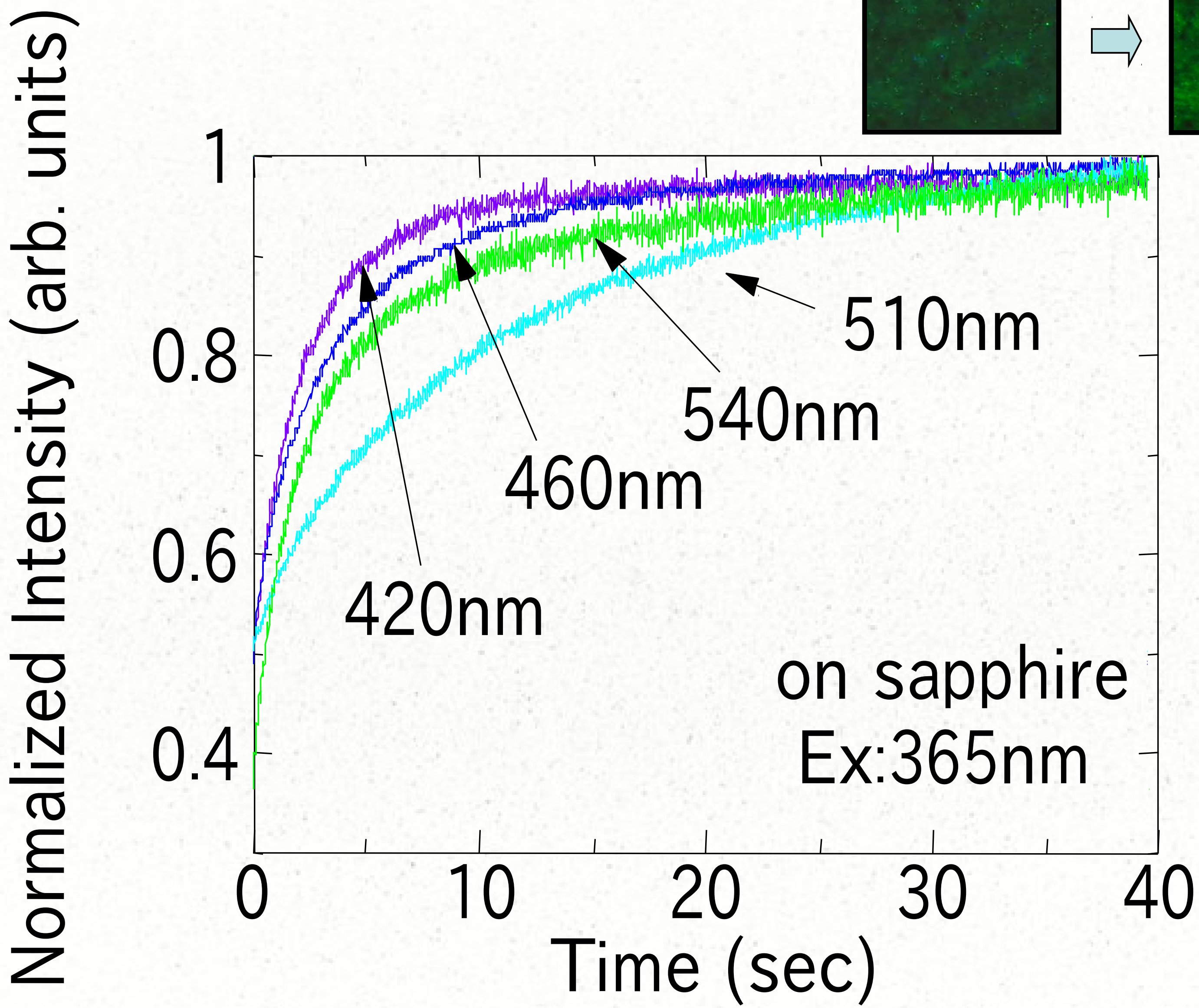
Ex: 405nm

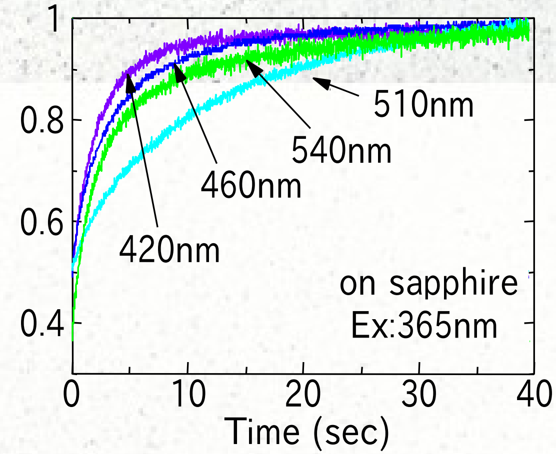
λ_{ext}



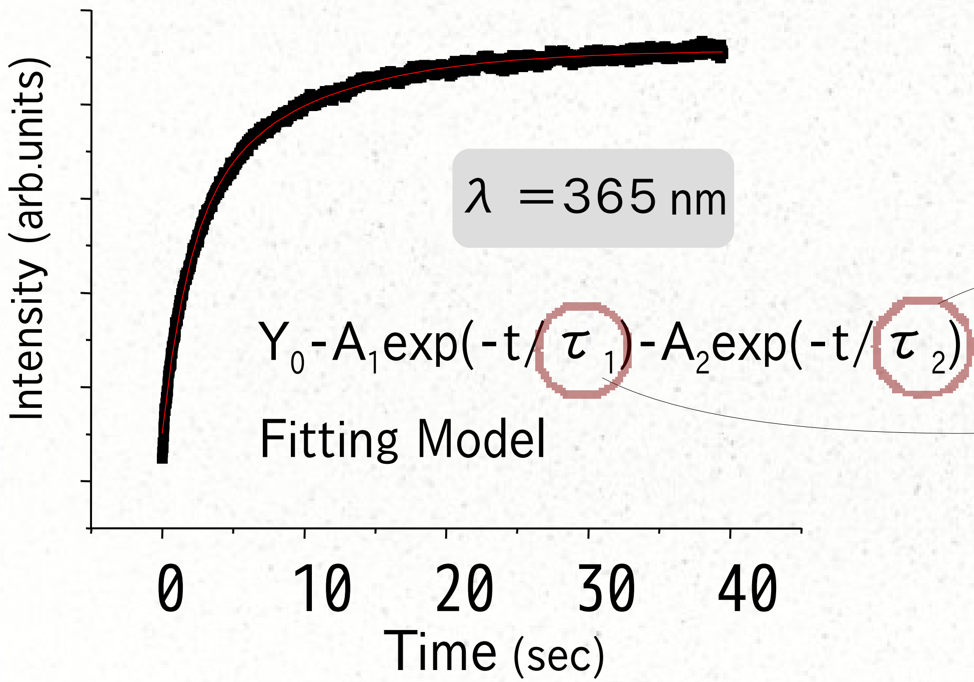
Indium Concentration



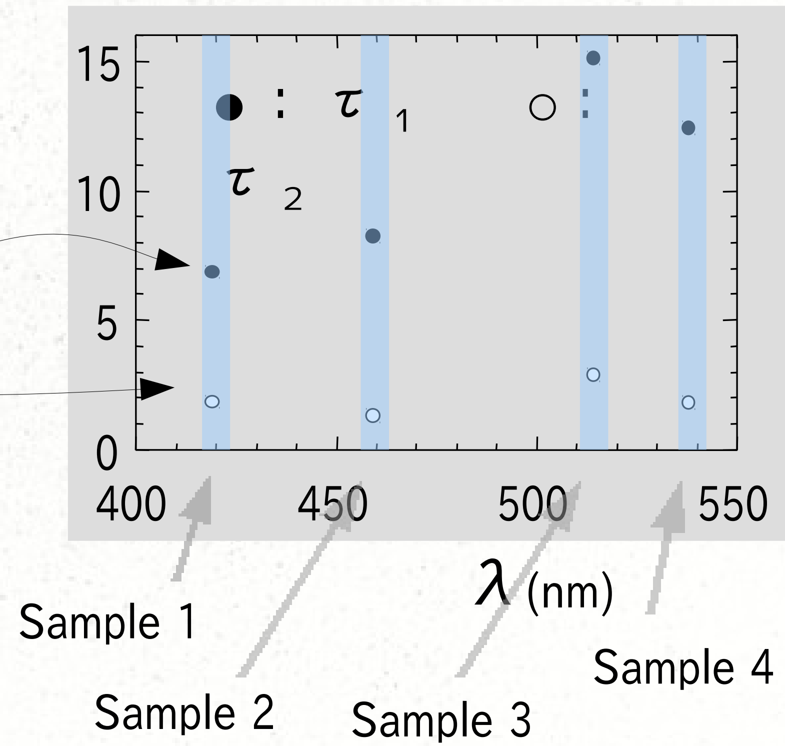

Normalized Intensity (arb. units)
1
0.8
0.6
0.4
0
10
20
30
40
Time (sec)
420nm
460nm
540nm
510nm
on sapphire
Ex:365nm



Time characteristics:

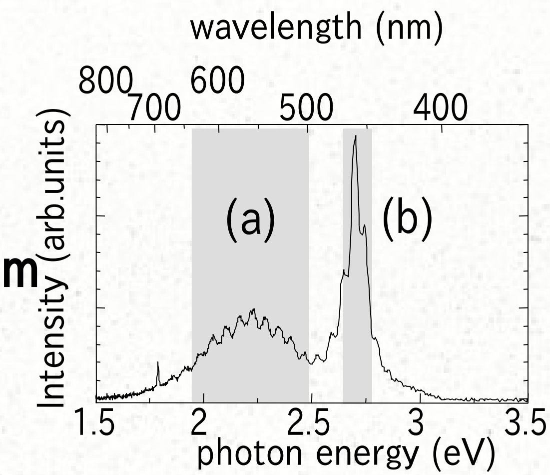


Center wavelength of samples

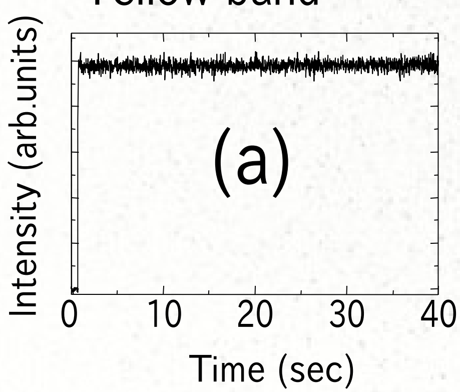


Yellow Band

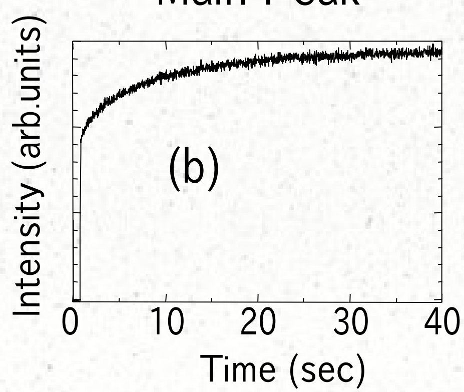
PL Spectrum



Yellow band



Main Peak



There is a steep rise at the beginning

The yellow band peak appears to be steady and unchanged

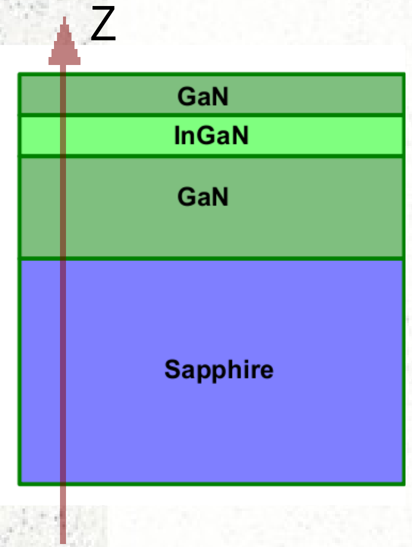
The first rise shape and timing can be an artifact related to the shutter mechanism.

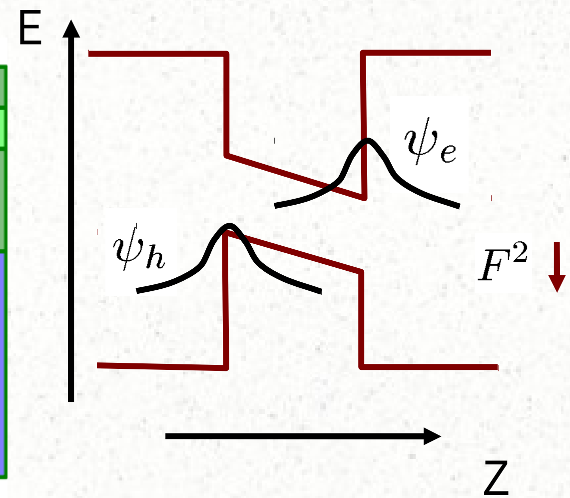
λ ＝365 nm

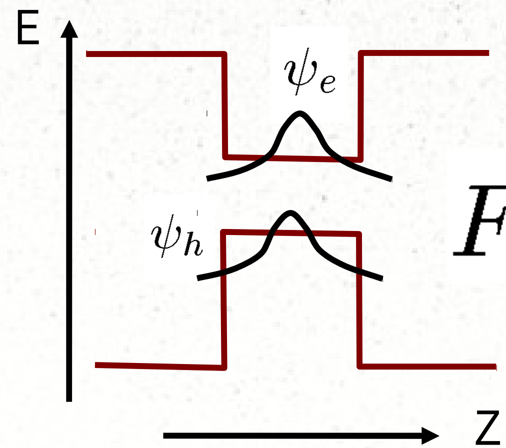
どうしてPL像は変わりますか？

- Distortion of the band can induce observable PL intensity variations

Model concepts







$$F^2 \uparrow \quad \eta_i \uparrow$$

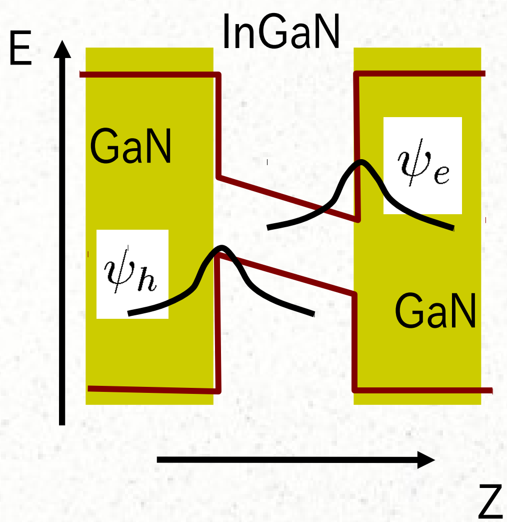
$$\frac{1}{\tau_{pl}} = \frac{1}{\tau_{rad}} + \frac{1}{\tau_{no-rad}}$$

$$\eta_i = \frac{\frac{1}{\tau_{rad}}}{\frac{1}{\tau_{rad}} + \frac{1}{\tau_{no-rad}}}$$

$$\frac{1}{\tau_{rad}} \propto F^2$$

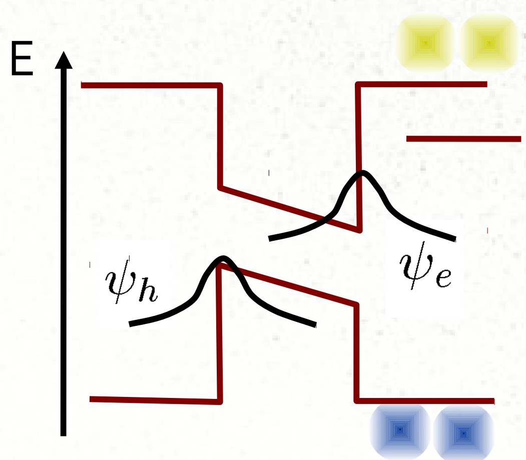
$$F = <\psi_e \mid \psi_h>$$

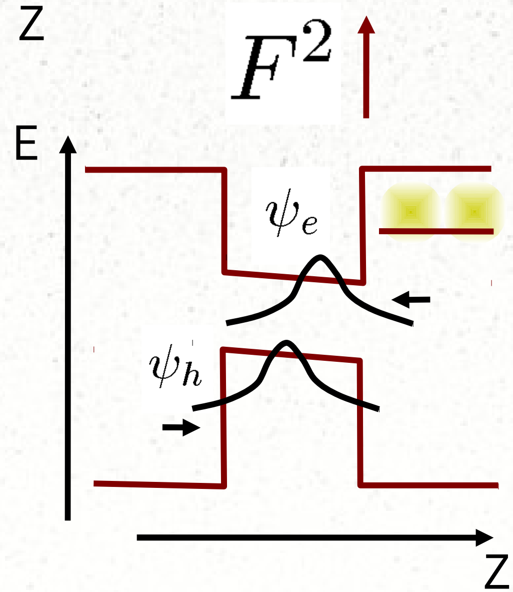
どうして PL 像は変わりますか？

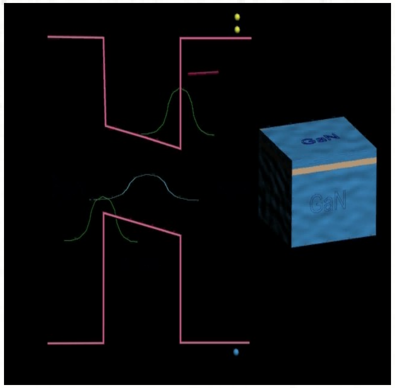


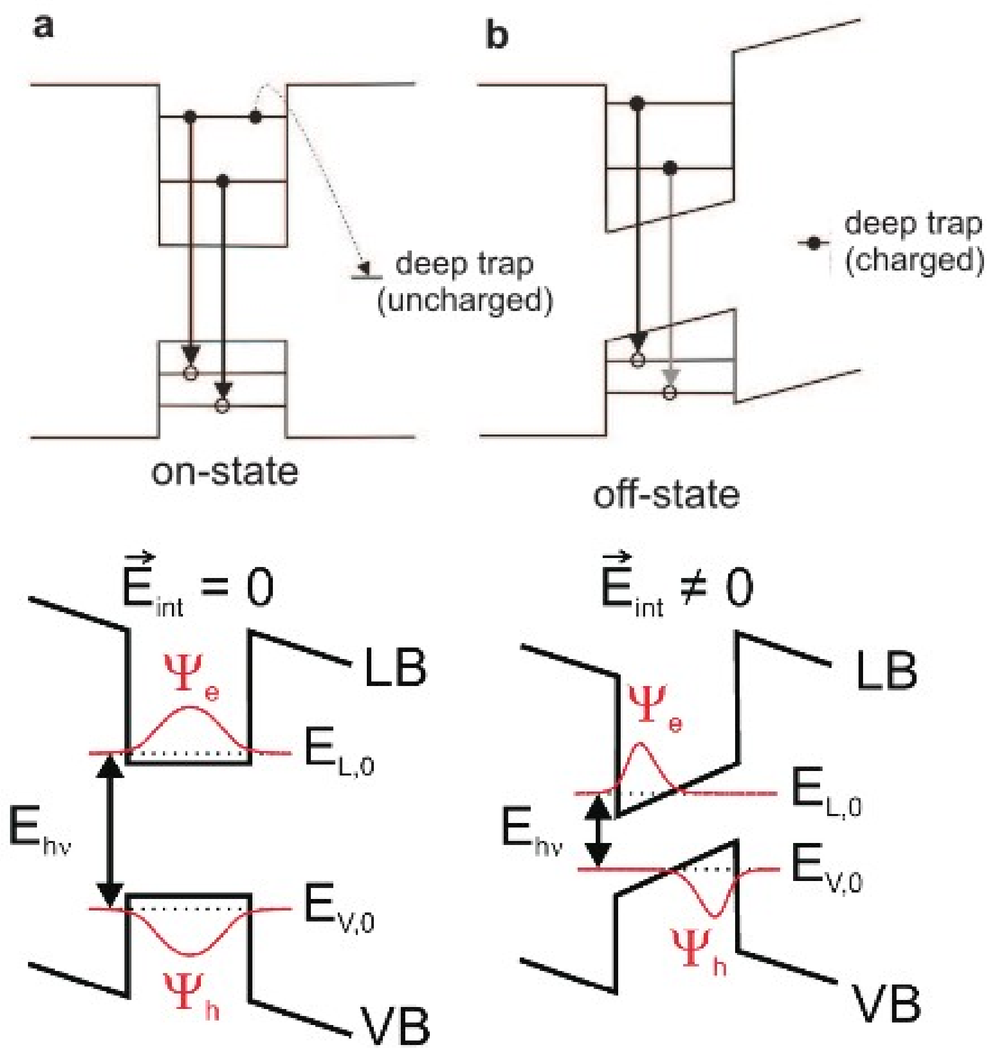
λ =365 nm

- Distortion of band due to trapped carriers
- Band overlap is induced, F^2 increase and PL increase
- We are observing the time constant of this deformation process









Blinking mechanism for InGaN QW.

Strain incoherently grown InGaN QWs between GaN barriers causes a strong piezoelectric field of the order of 1 MV/cm to 3 MV/cm.

As a consequence the transition is red-shifted (quantum confined Stark effect, QCSE) and the transition matrix element is reduced.

Exposition "History" was found to be important

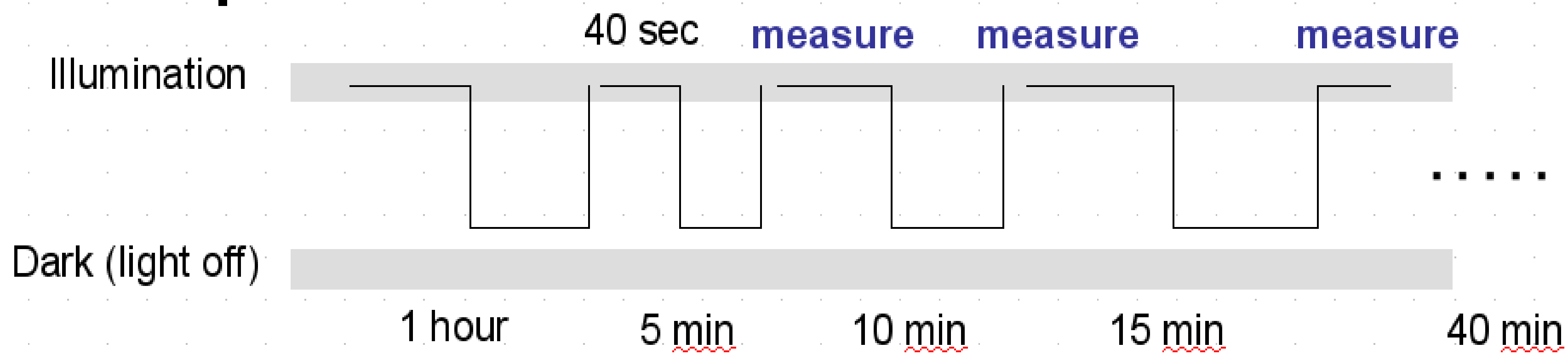
↓

Design of *ad hoc* experiment

↓

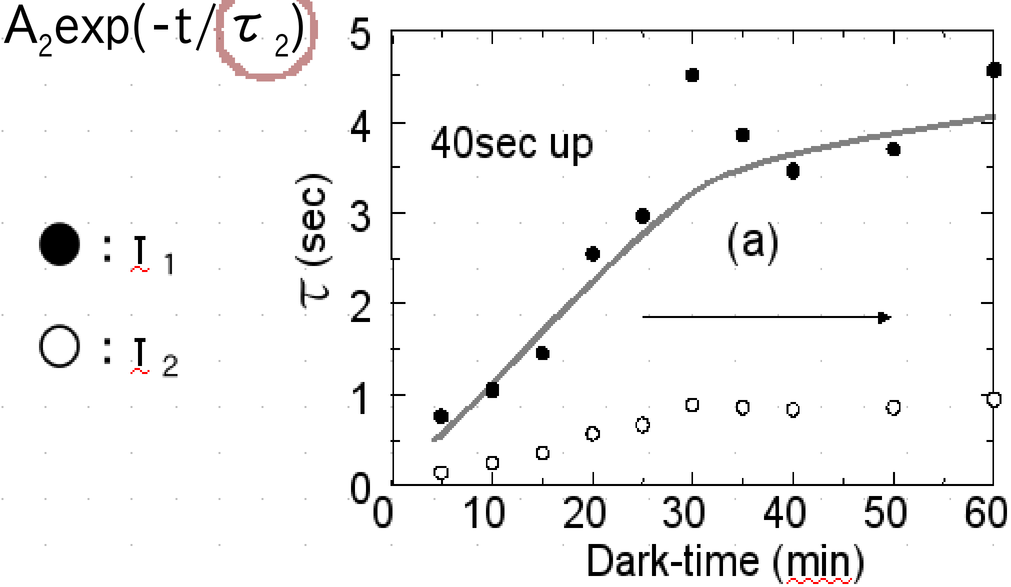
A routine of illumination and darkening Intervals

Sequence



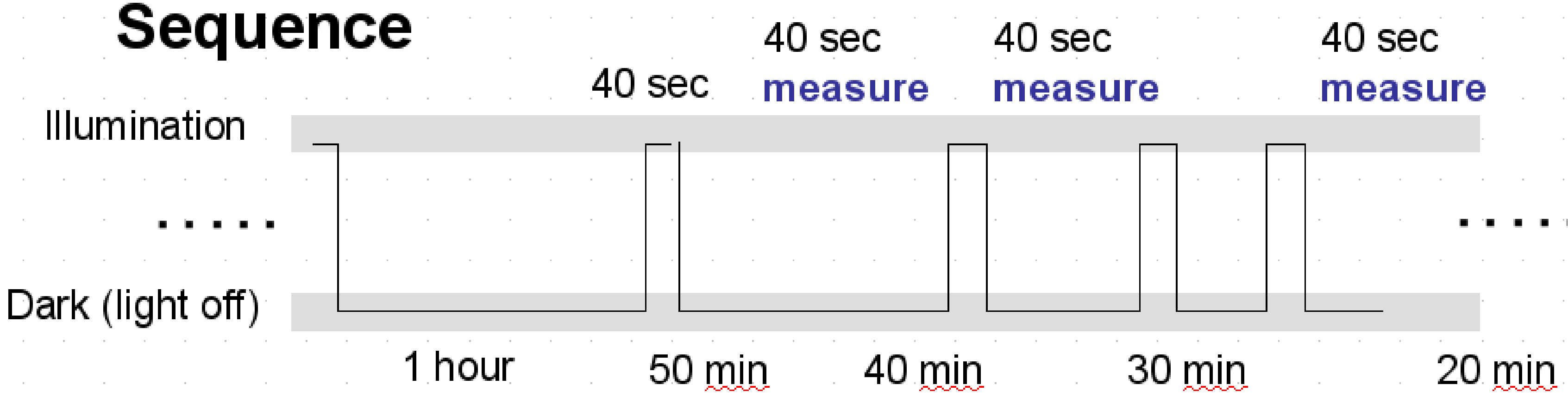
$Y_0 - A_1\exp(-t/\tau_1) - A_2\exp(-t/\tau_2)$

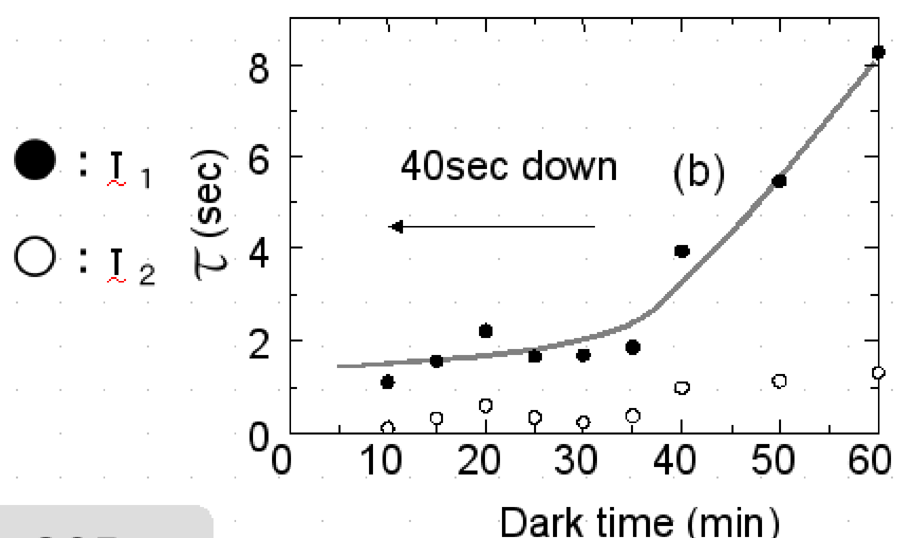
Fitting Model



λ = 365 nm

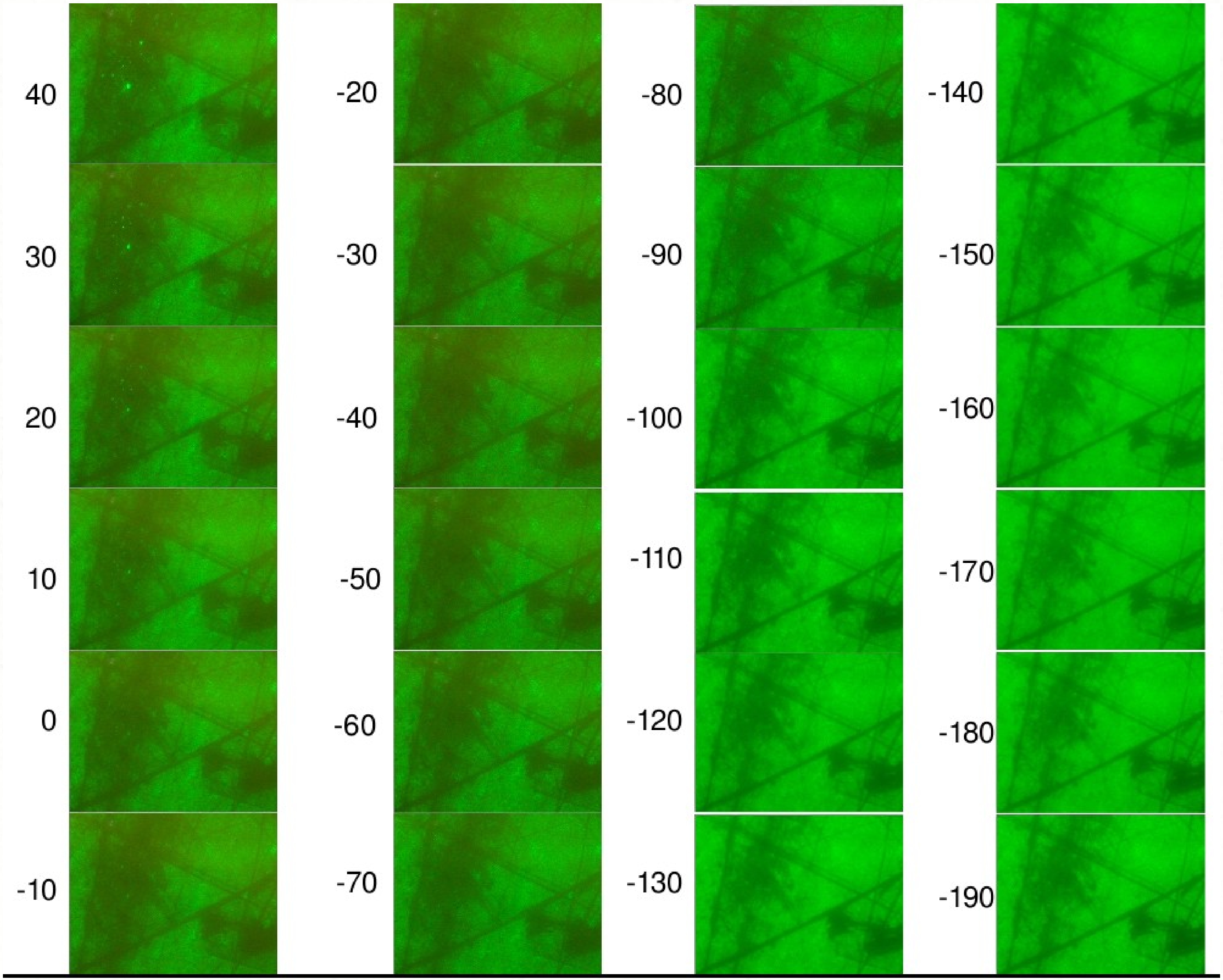
Sequence





λ =365 nm

- Increase of dark-time provoke a longer time constant
- Graph (b) is the same as (a) in **reverse** time order
- At corresponding times, in (b) the time constants are almost double.
- This demonstrate an evident **memory** of the process history.


40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
-180
-190

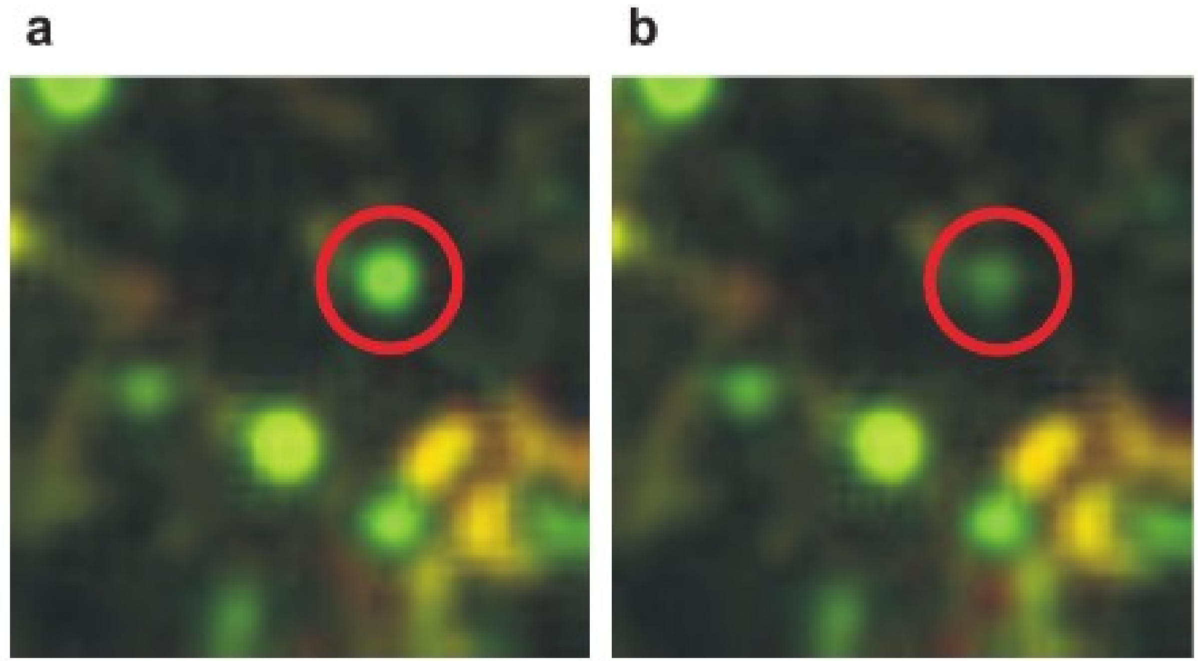


FIG. 1: **InGaN QW with blinking dot.** The photoluminescence map of InGaN quantum wells emitting in the green to red spectral region consists of bright, diffraction limited spots, many of which are blinking on a millisecond to second time scale at room temperature **(provide length scale)**. Excitation wavelength is 380 nm, the area is $3 \times 3\,\mu m^2$. The red circle marks a spot in its on–state (a) and off–state (b). In contrast to most systems exhibiting telegraphic blinking, the off–state is not completely dark. A movie of this blinking spot is included as supplementary material.

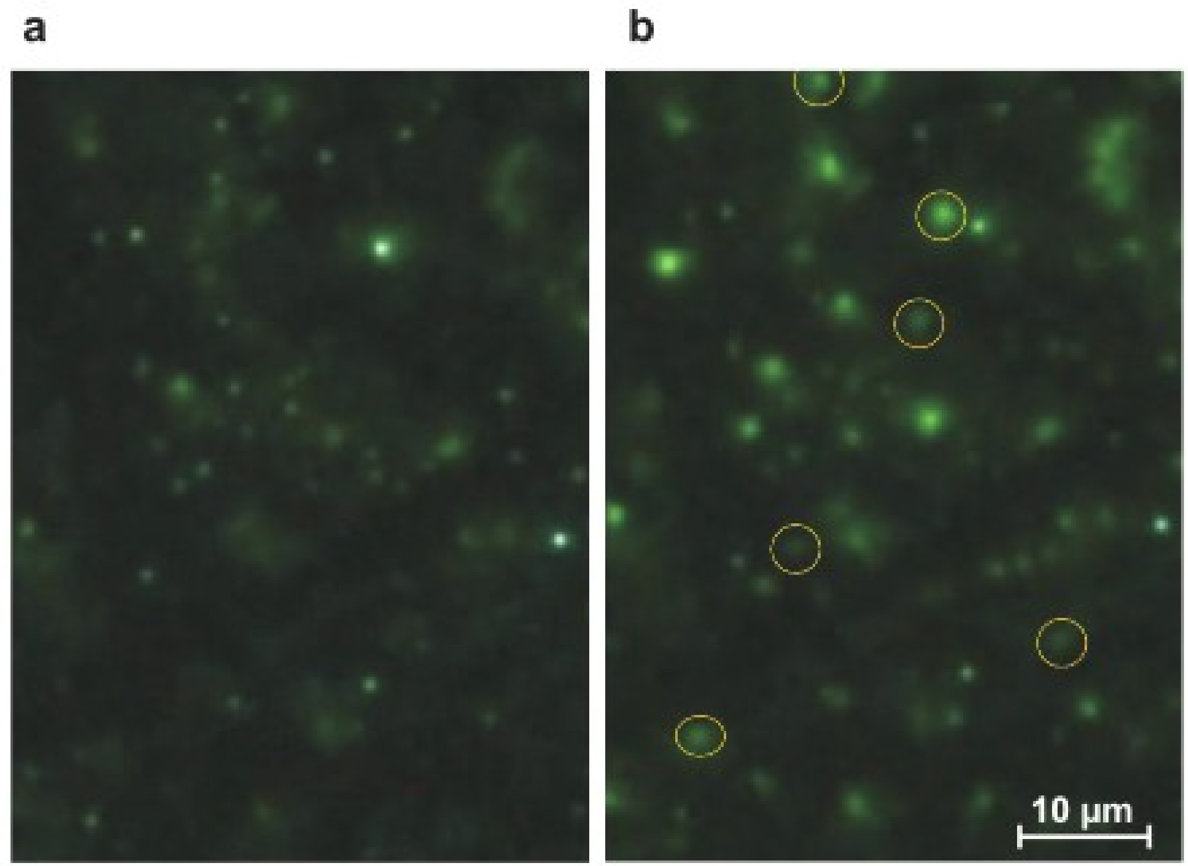
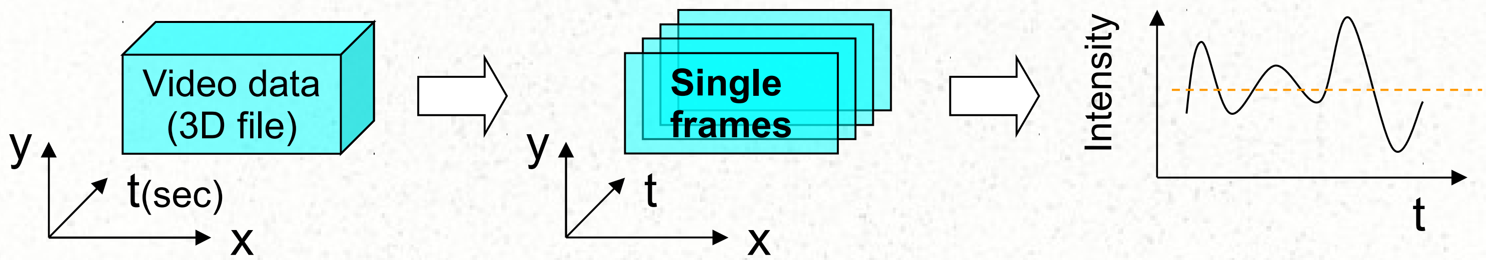


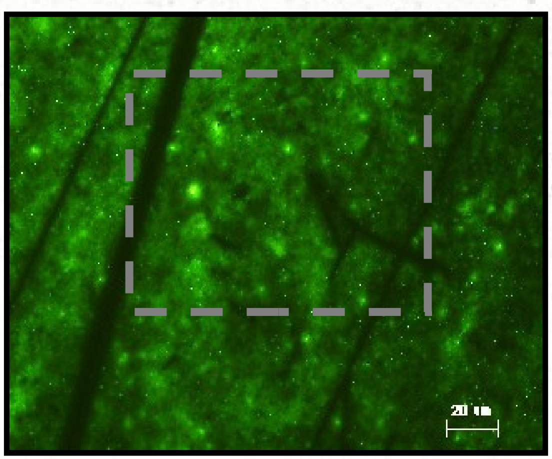
FIG. 5: **Blinking induced by gold nanopheres.** (a) and (b) show the same area of the sample before and after redistribution of gold nanospheres, causing a variation of positions, number, and photoluminescence intensity of bright spots. Yellow circles mark blinking spots which appear only after the redistribution.

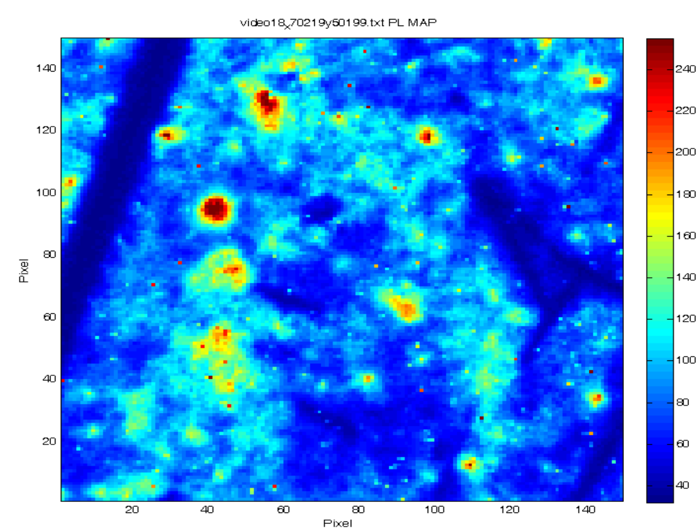
Systematic analysis of single pixel time profile

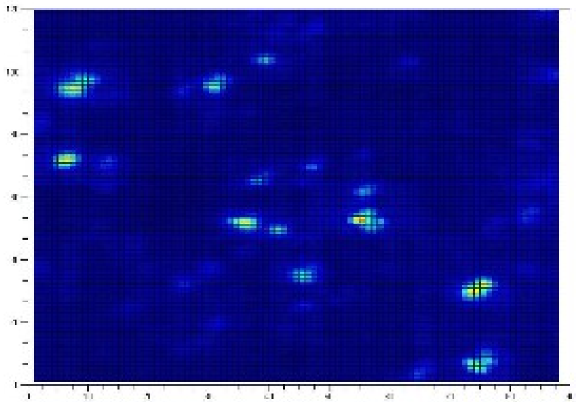


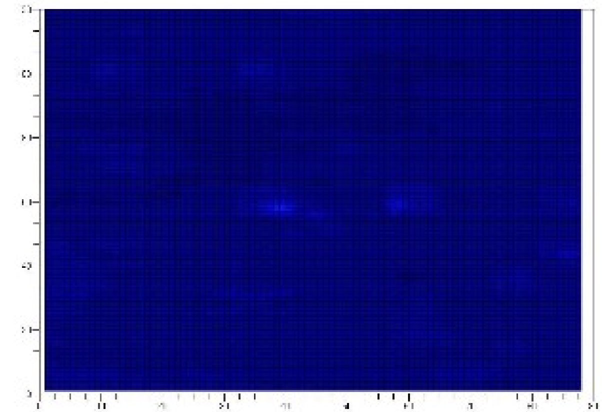
①Image is decomposed in 6 variables: **time, x, y, R, G, B**

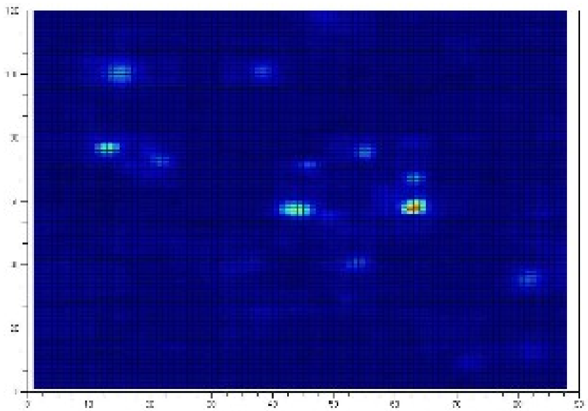
② A single point (x,y) on sample is isolate and its time profile recorded

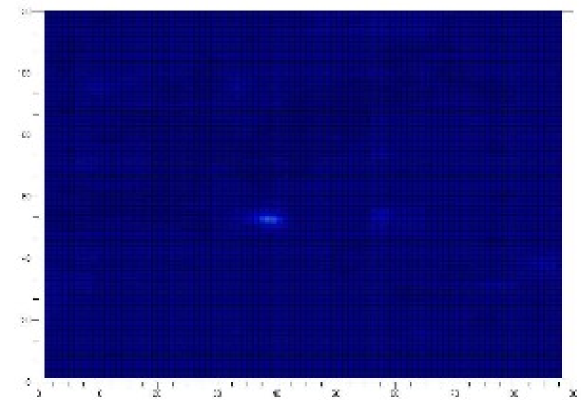


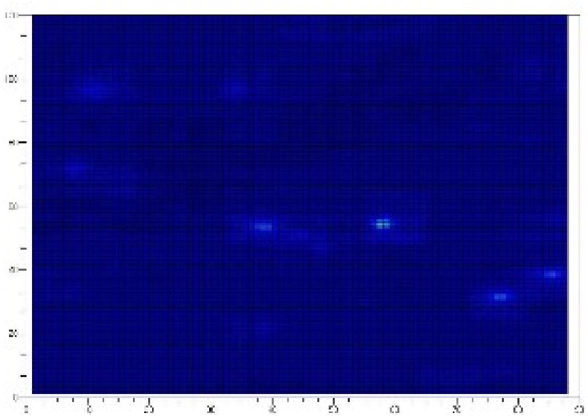


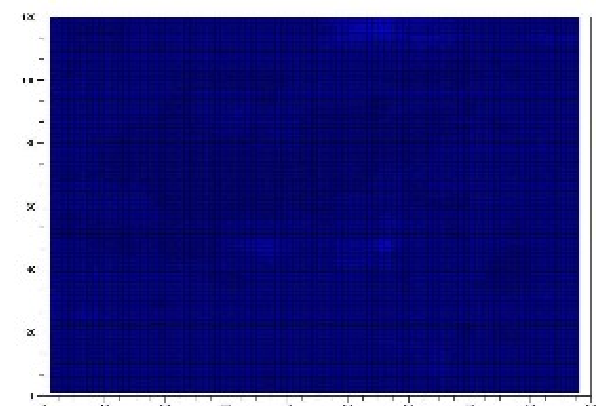


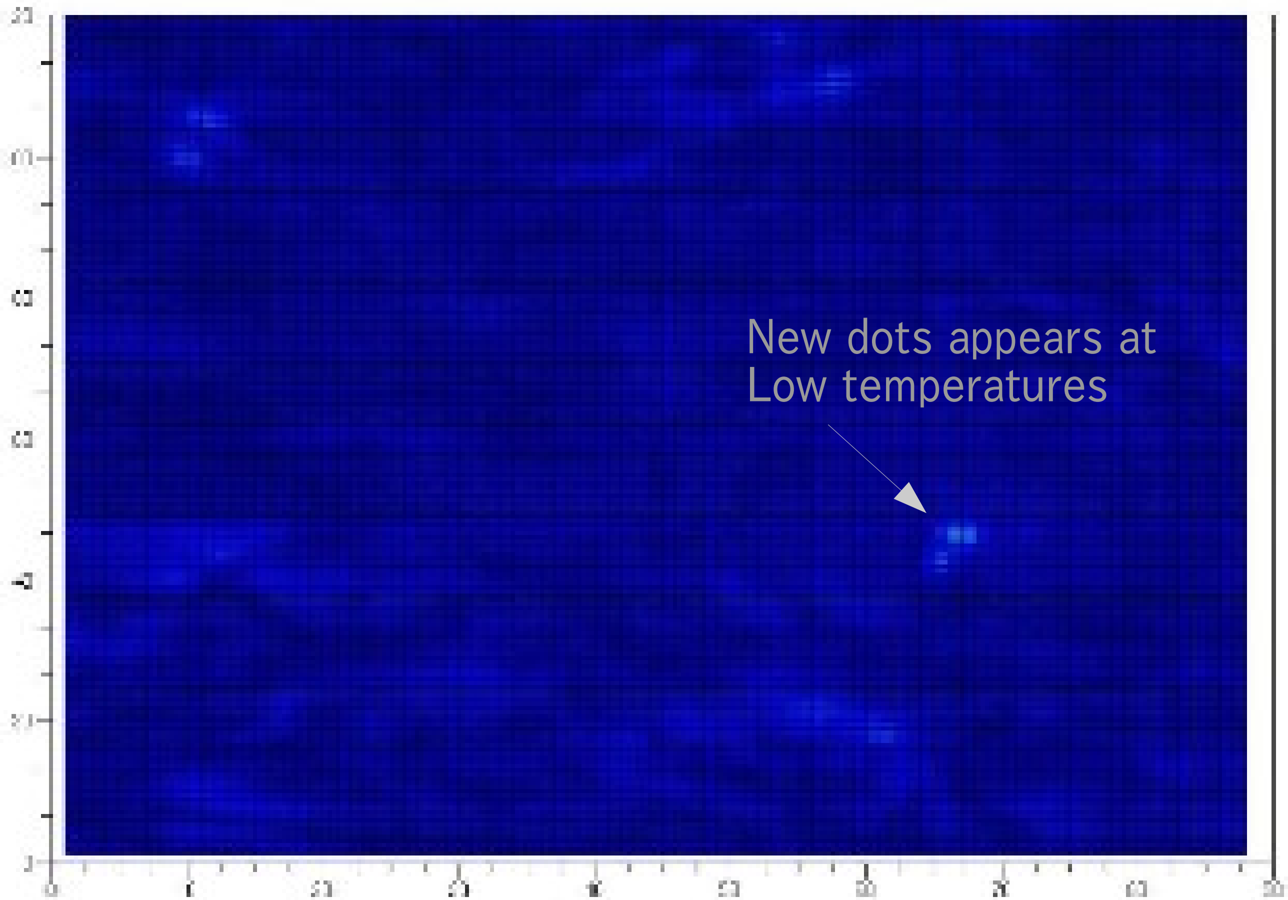












-190 degree

まとめ

- We detected **intermittency** in PL fluorescence in GaN/InGaN sample
- We found dependence with Indium concentration, Excitation wavelength, excitation **power**, **temperature**
- Blinking is **not a random** process, it is not pure chaos.
- We found several domains that show **autocorrelation**.
- There is **correlation** between distant blinking domain.
- Correlation depends on **time lag**, suggesting space drift

- **We found new spatial structures in the crystal that manifest themselves only in the blinking phenomenon**.