LEDs
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The optical instabilities and blinking phenomena in the emission of InGaN quantum wells

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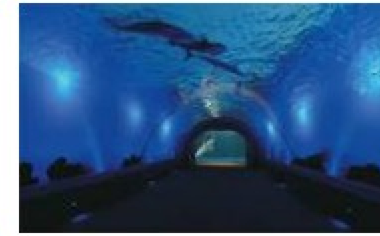












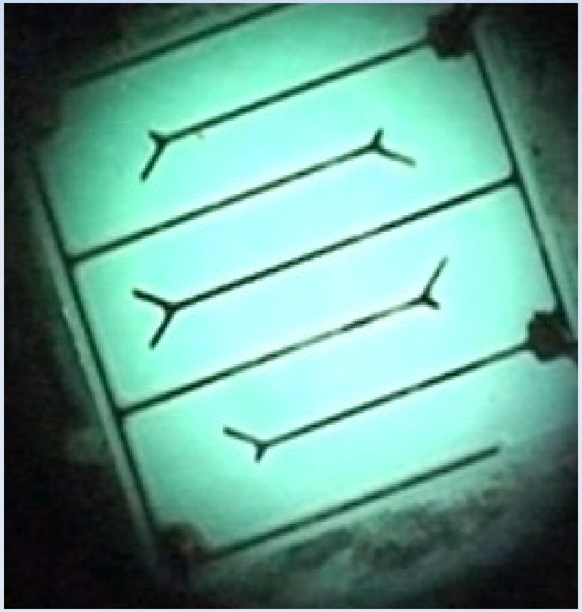



Commercial InGaN device

This is a commercial InGaN device with high output.

There are many dislocation because of mismatch in the lattice parameters for substrate and crystal.

Many dislocation



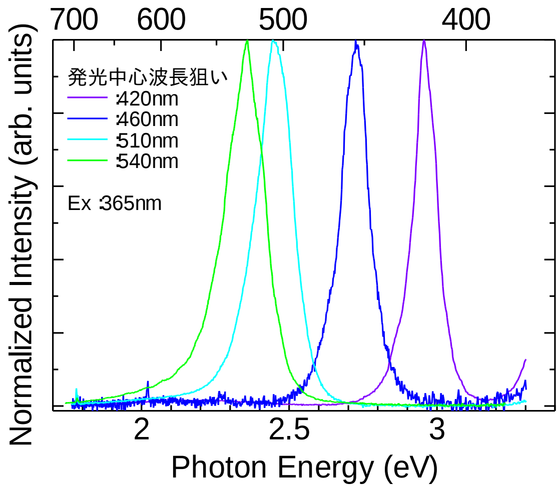
Growth on Sapphire

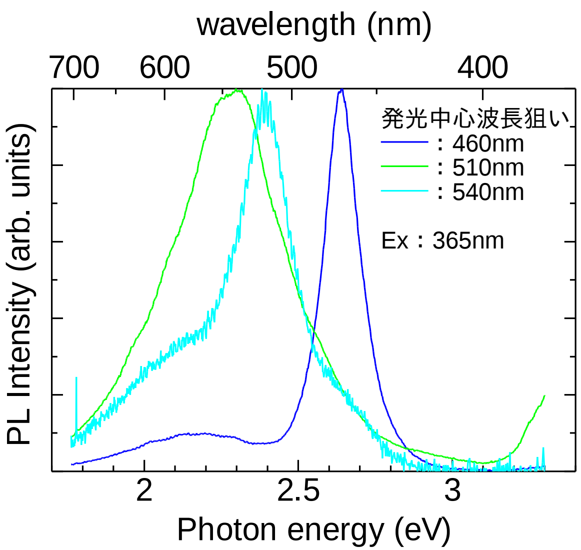
Spectral characteristics of InGaN device

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

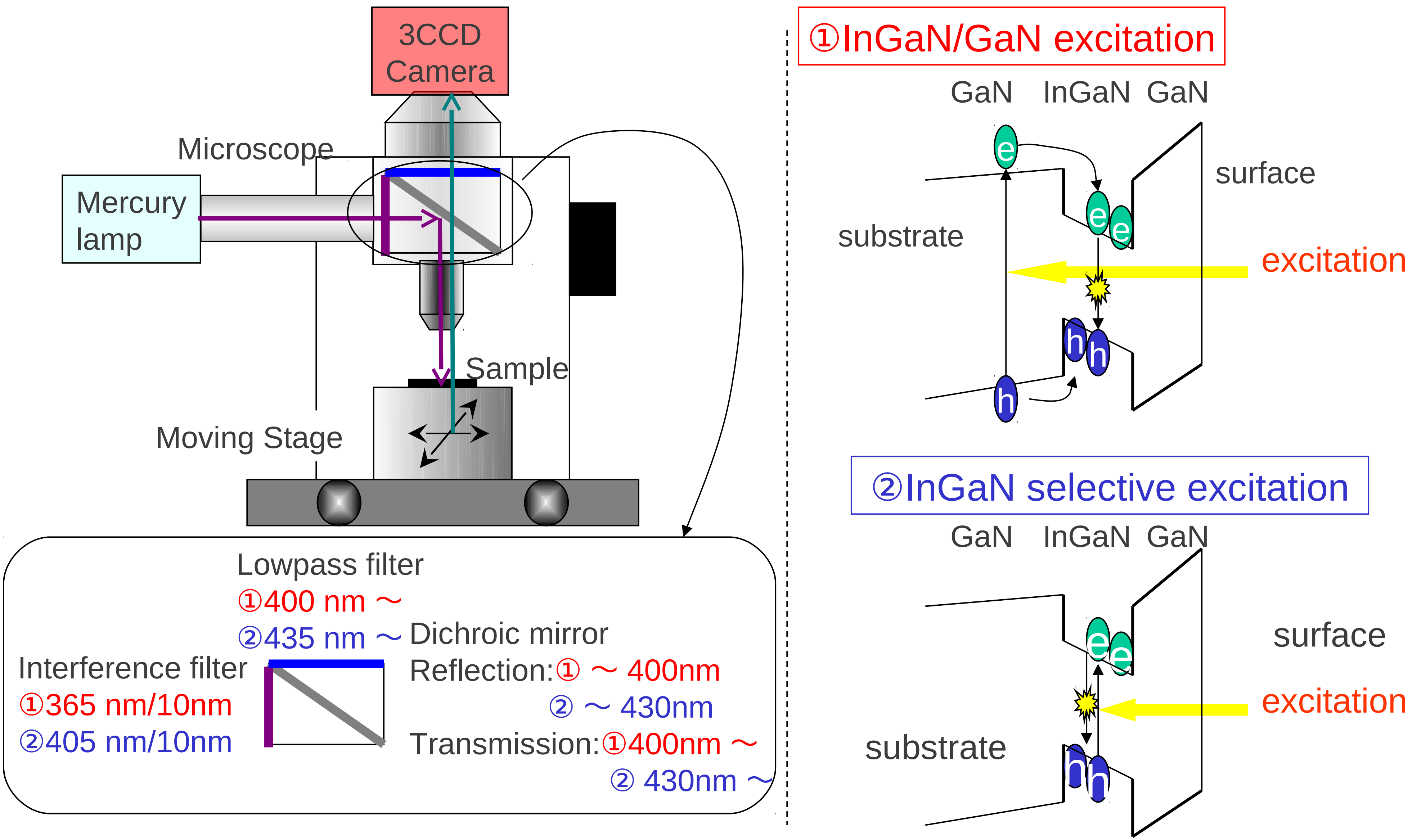
Samples central emission peak ：

420nm,460nm,510nm,540nm





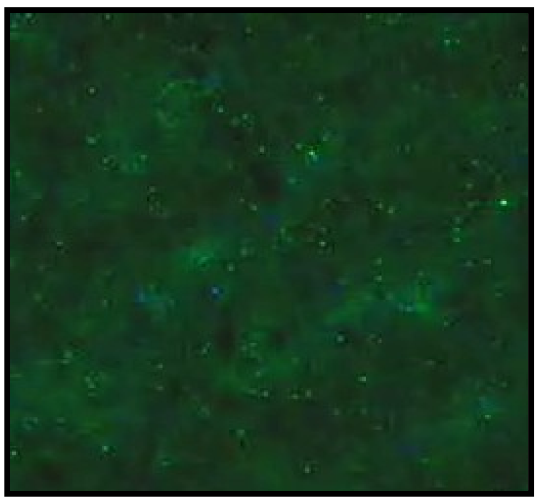
Selective Excitation



Photoluminescence temporal variation

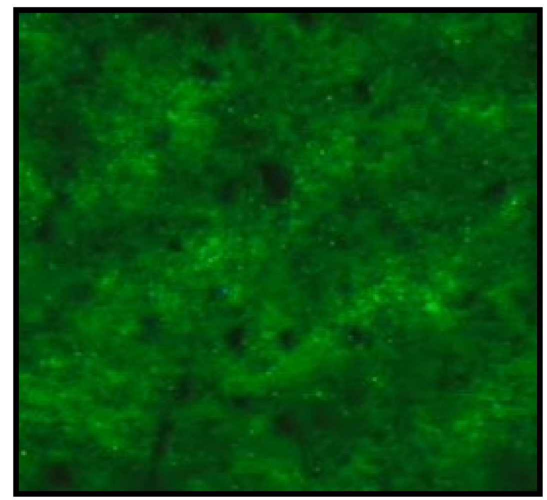
A sample of **510nm central emission**, Room temperature,

Continuous excitation Hg lamp **365nm**



After one

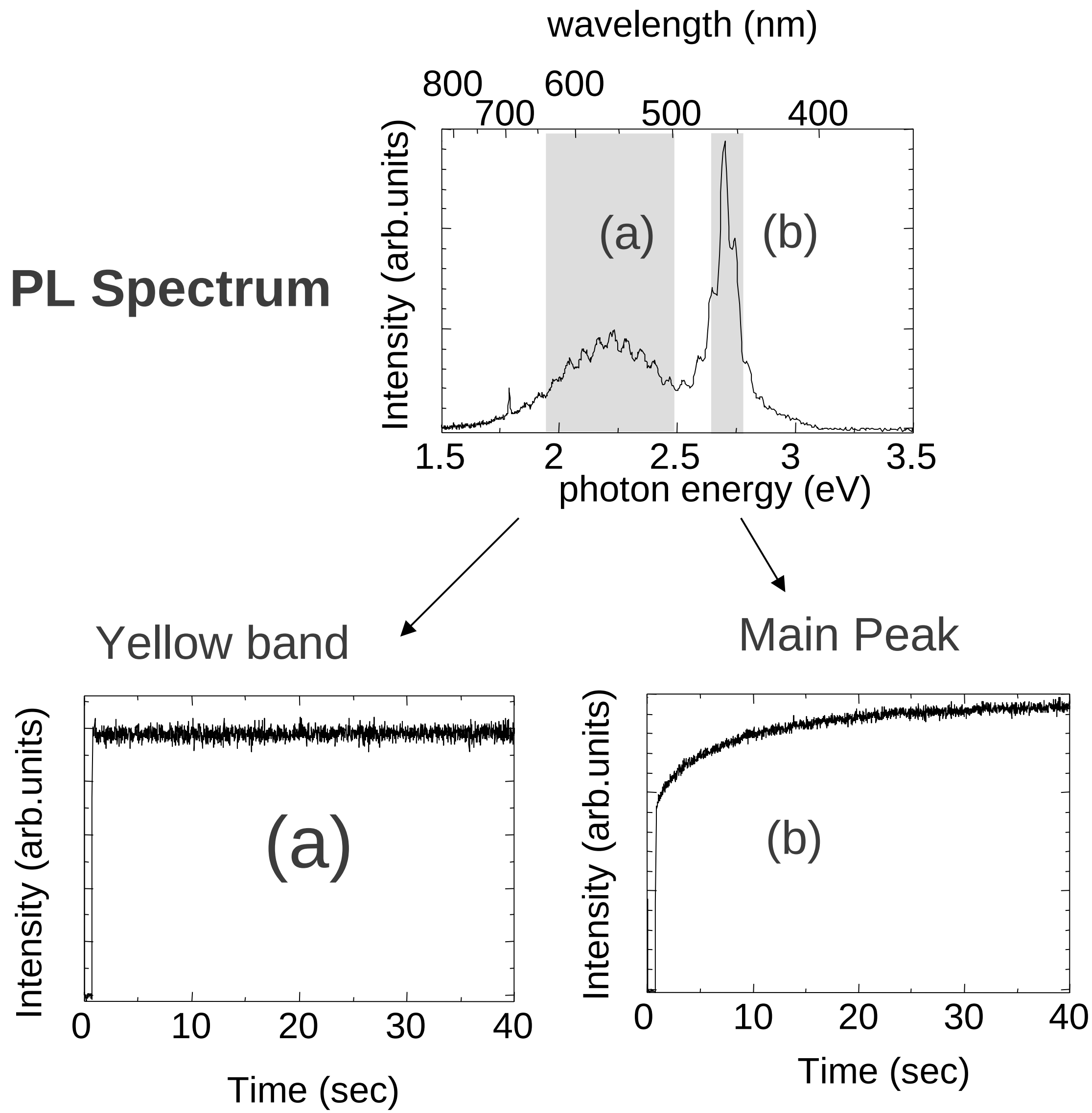
minute



Excitation start

After one minute of continuous illumination

Yellow Band



There is a steep rise at the beginning

The yellow band peak appears to be steady and unchanged

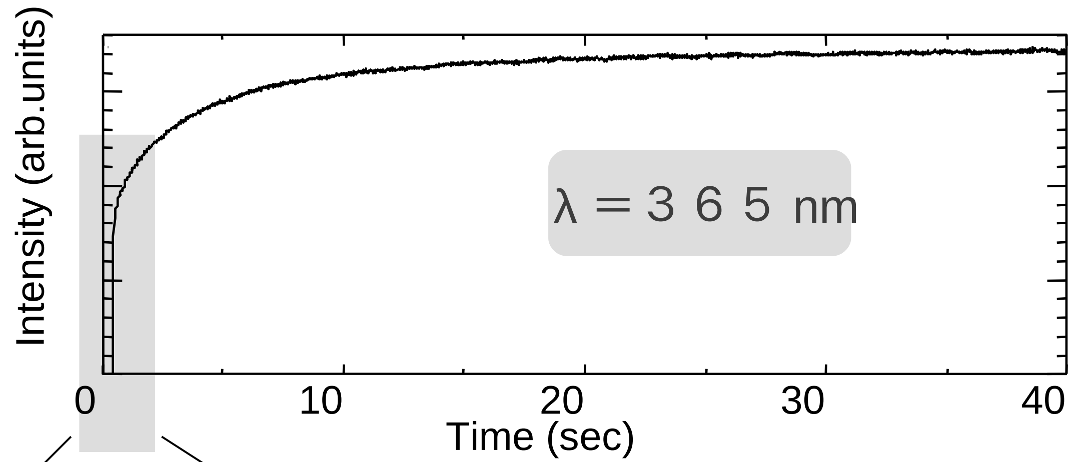
The first rise shape and timing can be an artifact related to the shutter mechanism.

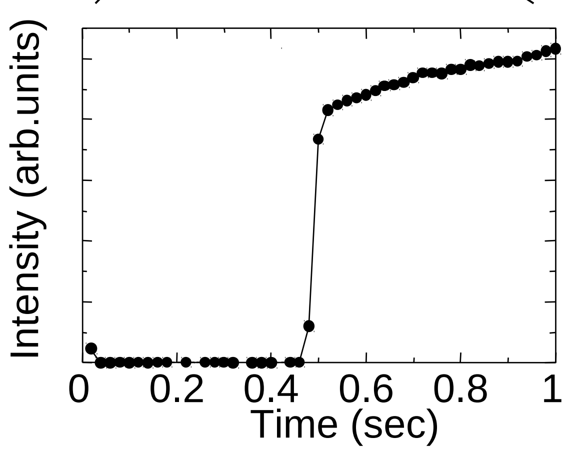
$\lambda = 365$ nm

PL Main peak rise behavior

The behavior of the main peak

（Center at **460nm** sample）

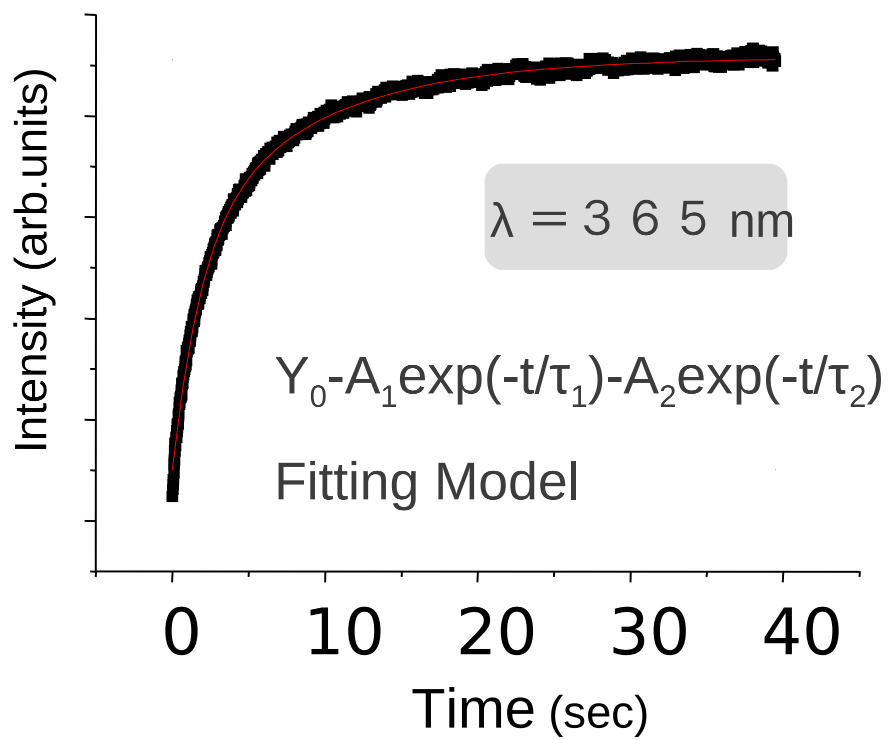




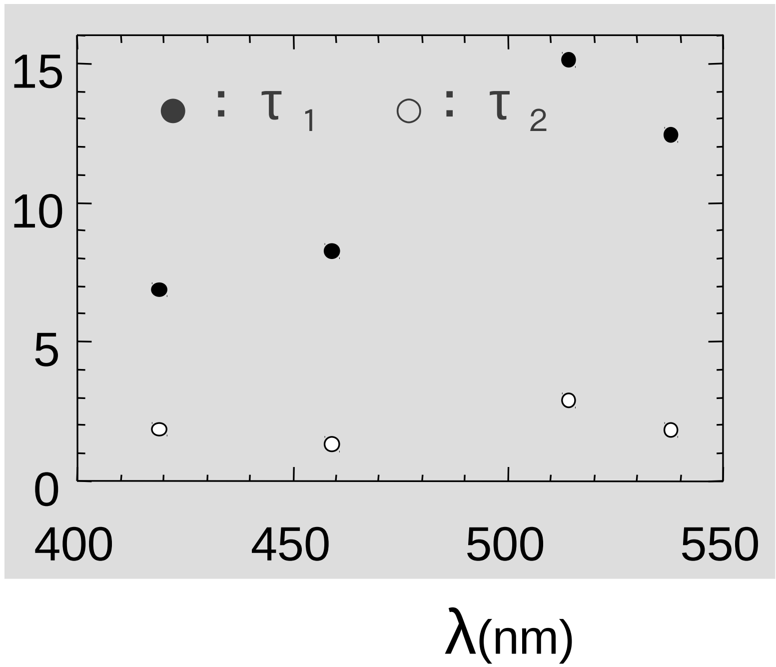
PL Rise (expanded)

Steep rise and then slow constant profile

The rise characteristics

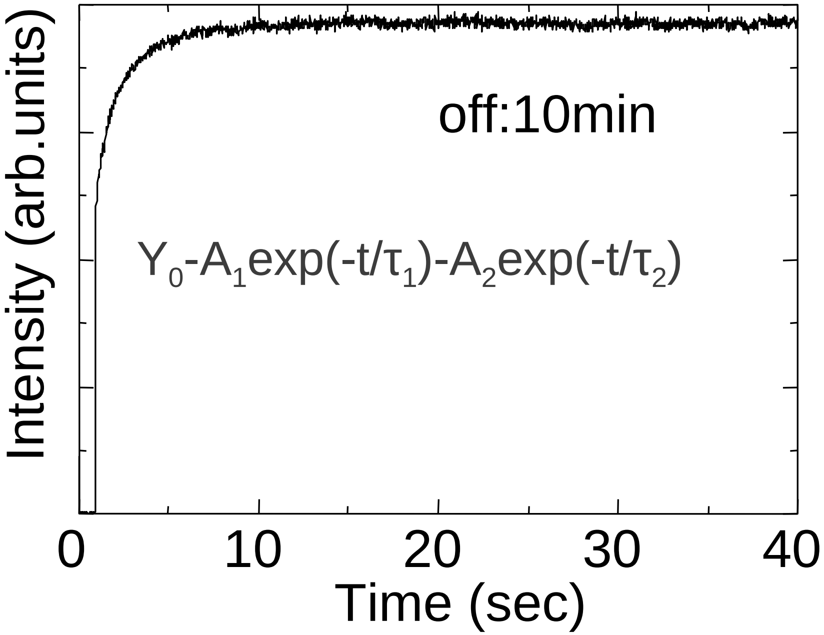


Center wavelength of samples

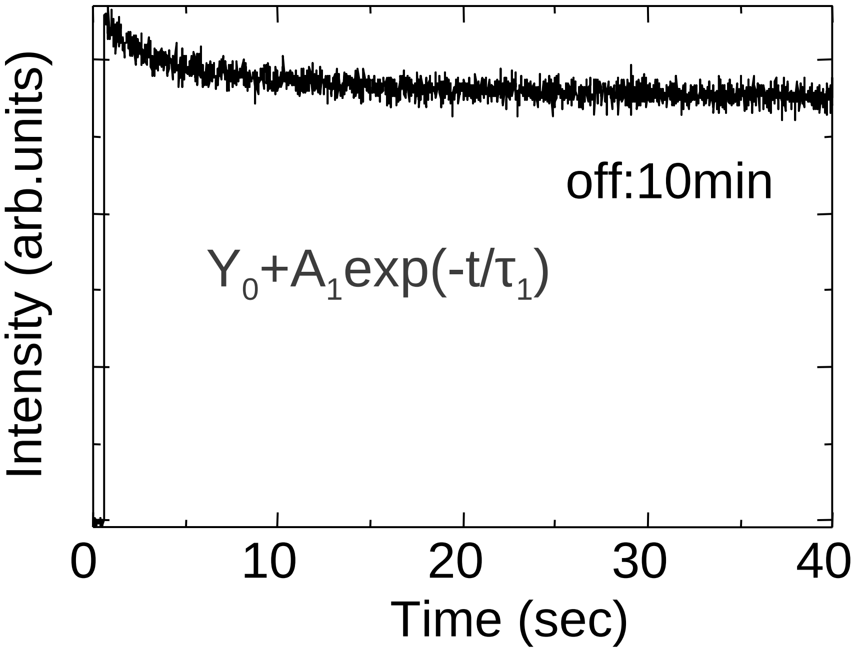


Wavelength dependence

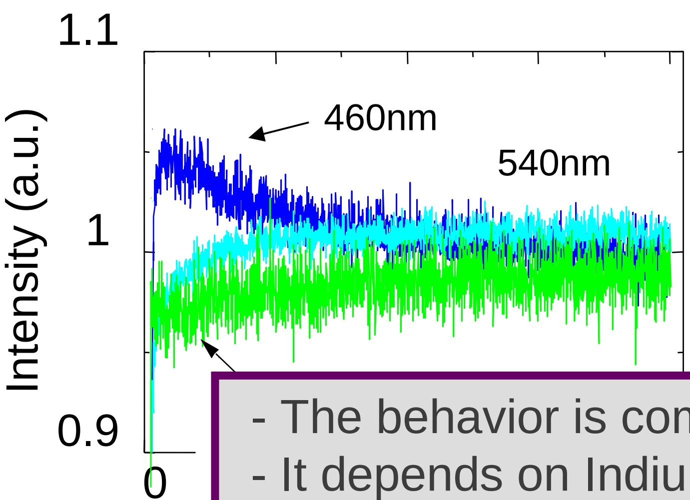
Ex:365nm

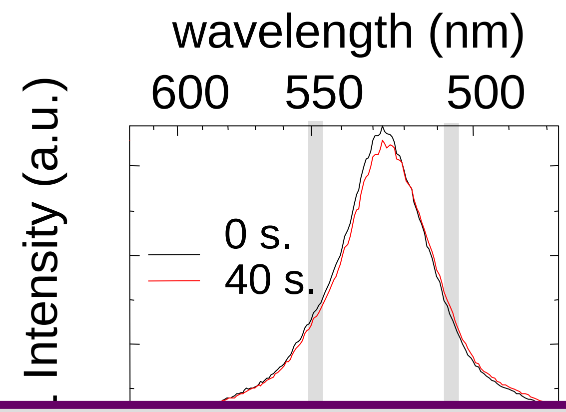


Ex:405nm



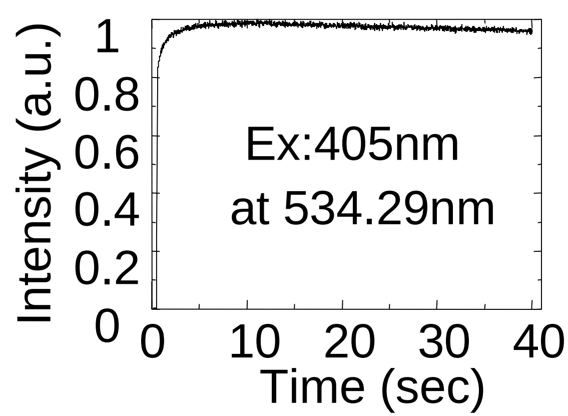
Selective excitation at $\lambda = 405$nm

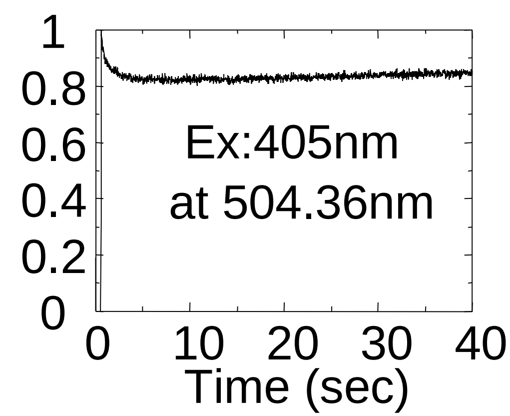




510 nm sample

- The behavior is complex
- It depends on Indium concentration.
- Differences are small in value, but curves have dissimilar profile



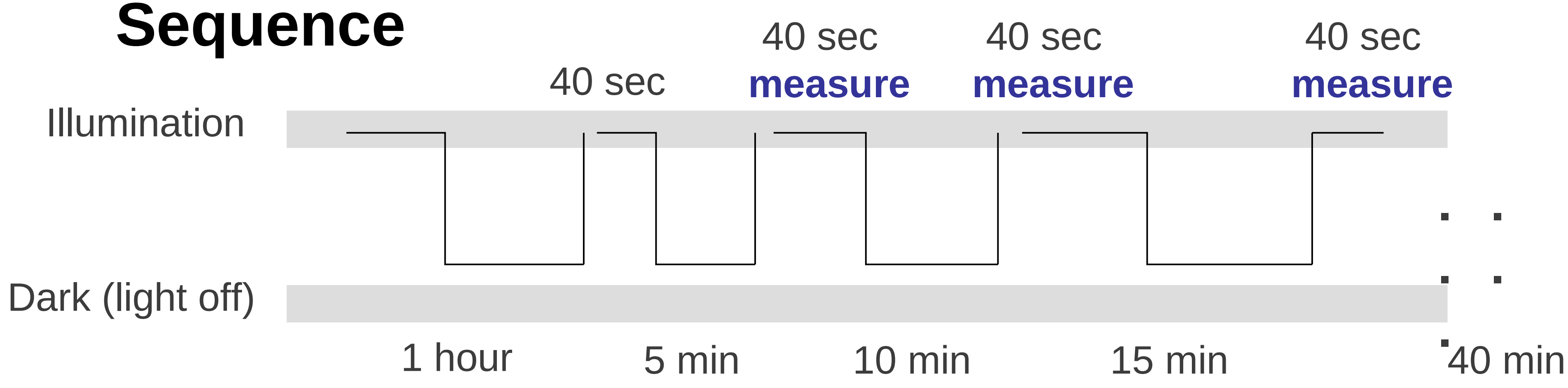


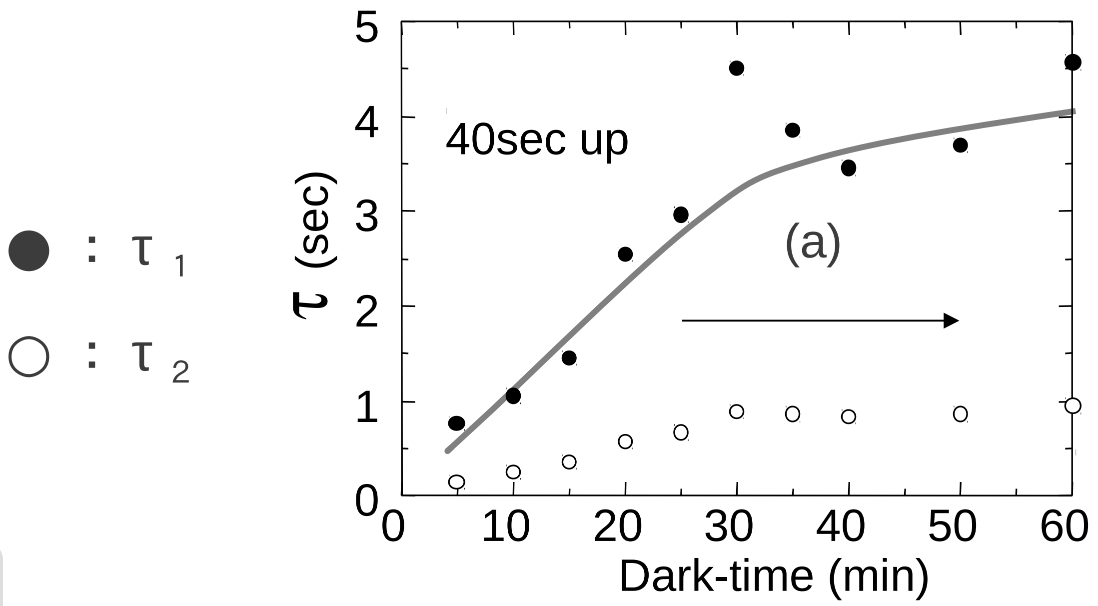
Exposition “History” was found to be important

Design of *ad hoc* experiment

A routine of illumination and darkening Intervals

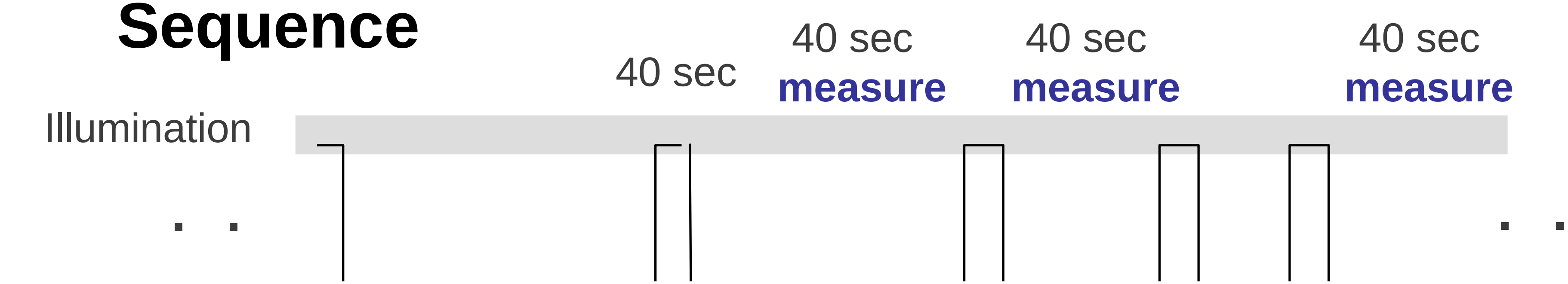
Sequence



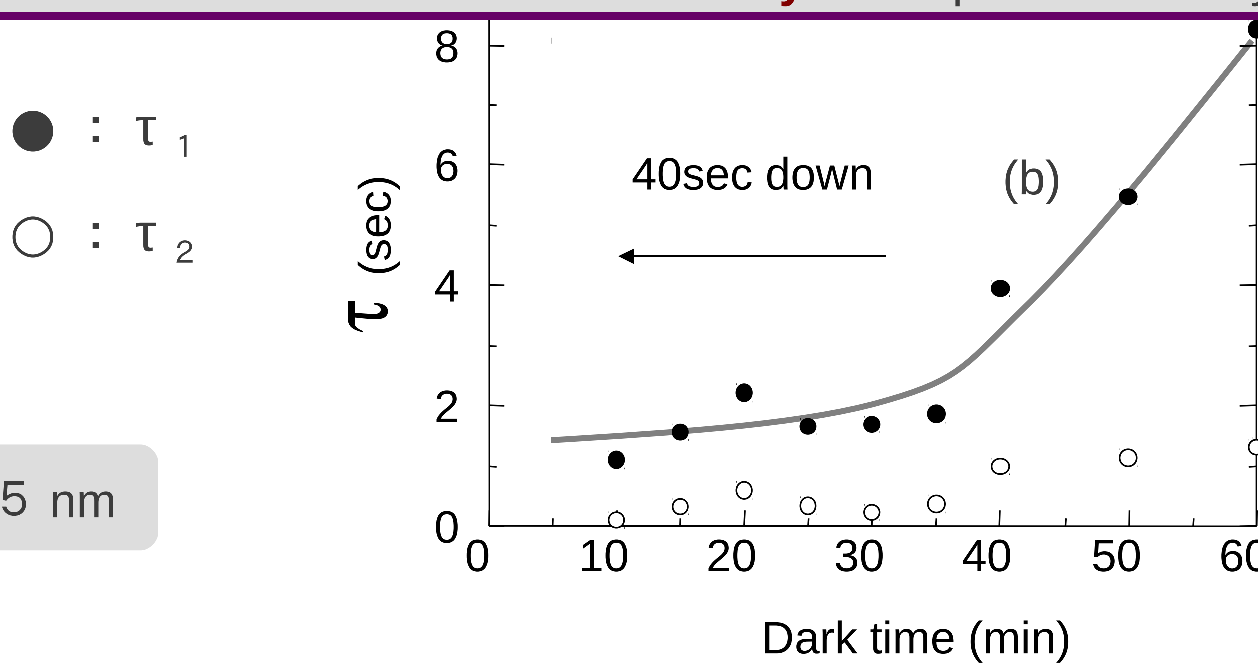


λ = 3 6 5 nm

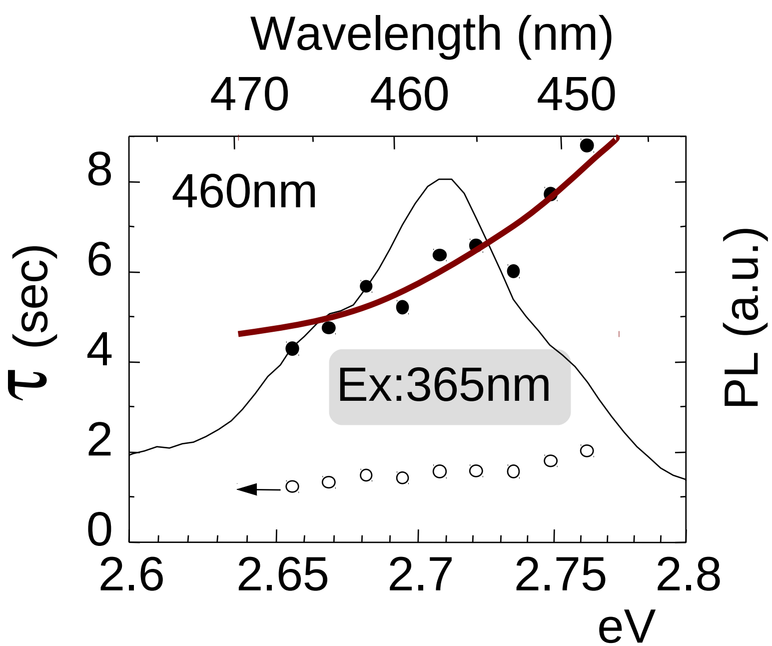
Sequence

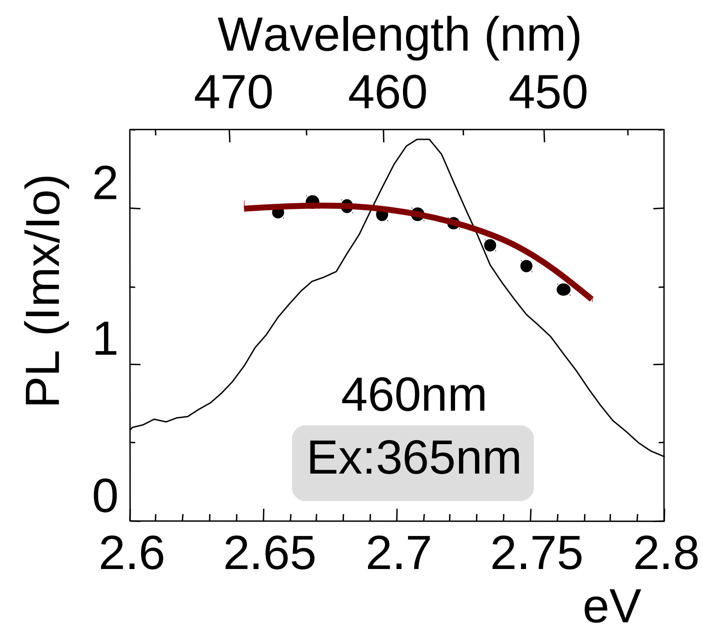


- Increase of dark-time provoke a longer time constant
- Graph (b) is the same as (a) in **reverse** time order
- At corresponding times, in (b) the time constants are almost double.
- This demonstrate an evident **memory** of the process history.



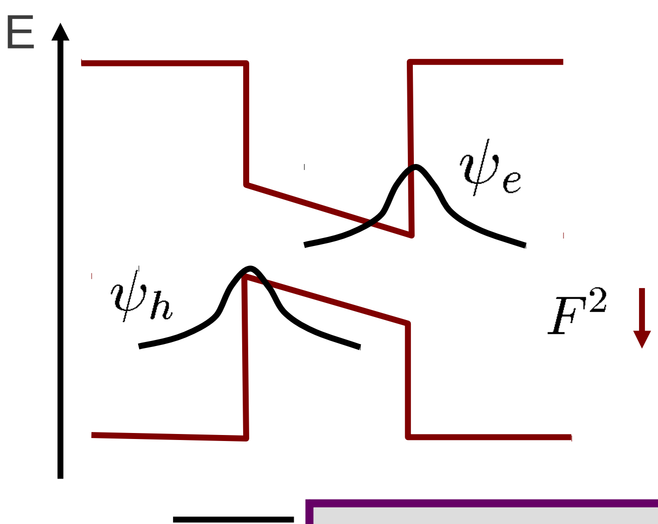
$\lambda = 365$ nm





- For higher energies, we have higher time constants
- Opposite behavior for intensities

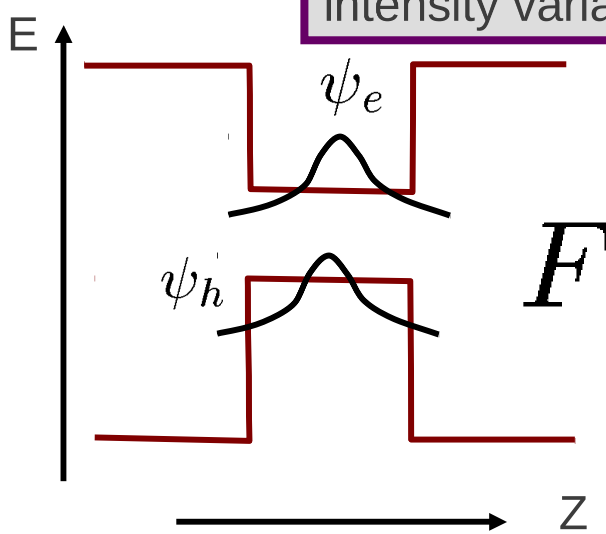
Model concepts



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

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

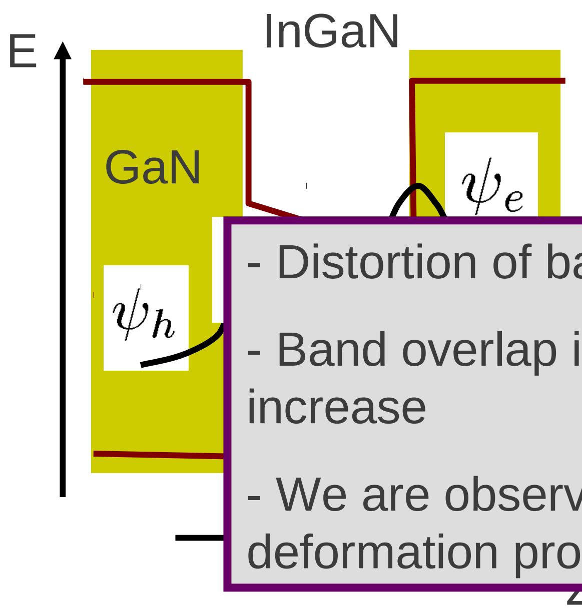
- Distortion of the band can induce observable PL intensity variations



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

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

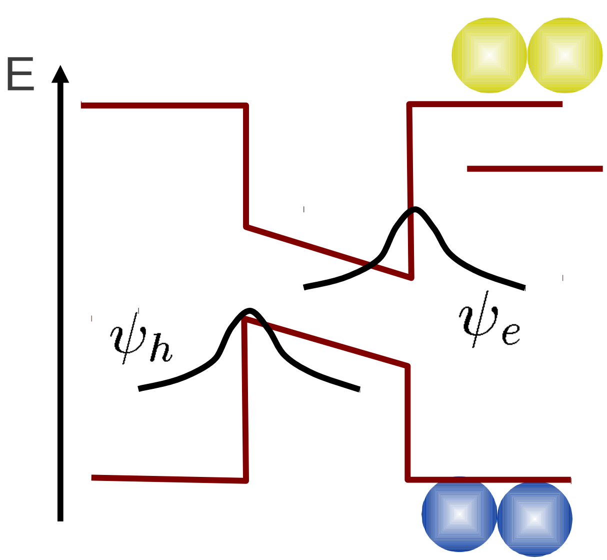
$$F = <\psi_e \mid \psi_h>$$

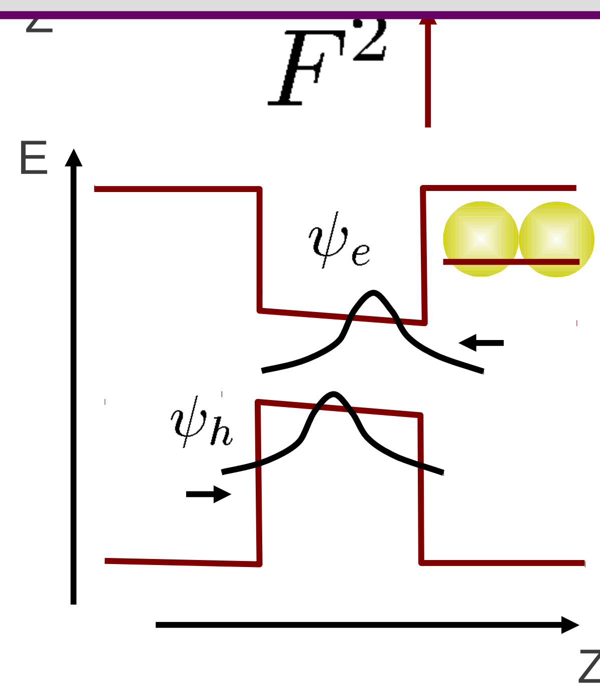


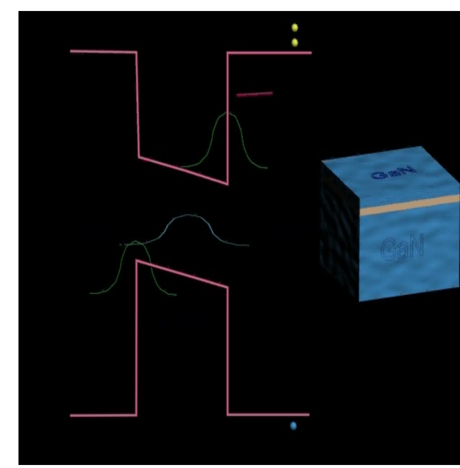
$\lambda = 3\ 6\ 5$ nm

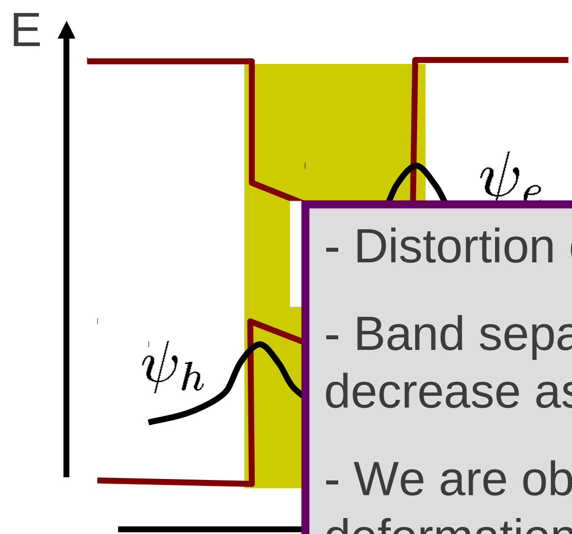
GaN (undoped) 5nm
$In_xGa_{1-x}N$ 3nm
doped) 4μm
pphire

- 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







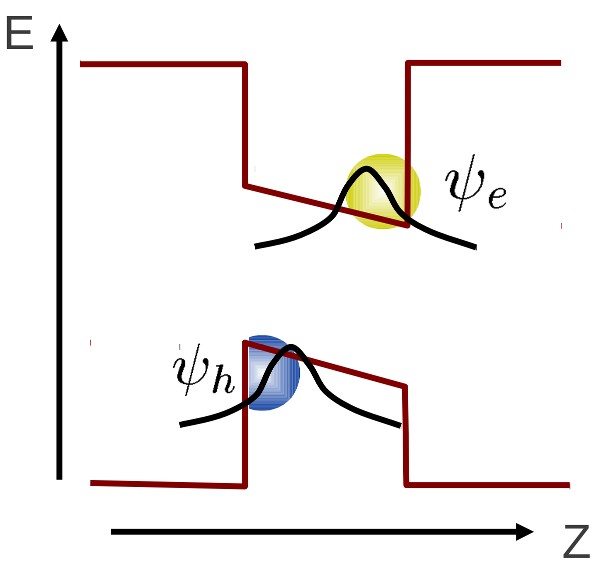


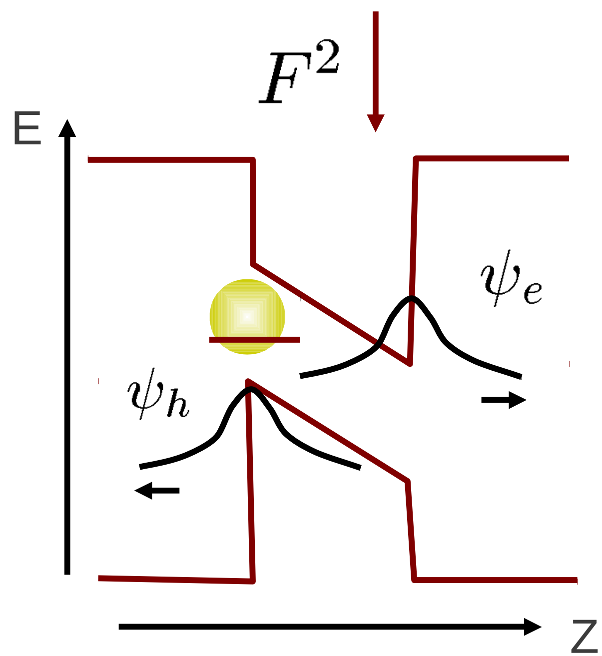
- Distortion of band due to trapped carriers

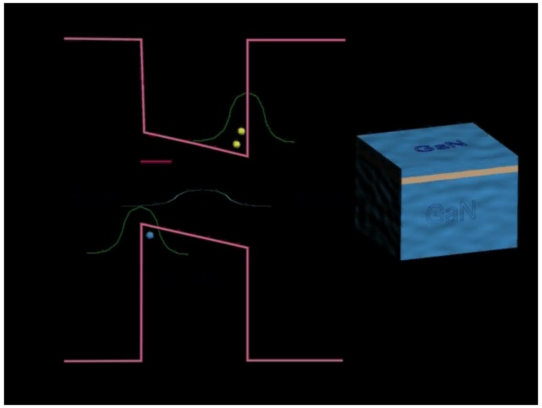
- Band separation is induced, F^2 decrease and PL decrease as well

- We are observing the time constant of this deformation process

GaN (undoped) 5nm
In Ga x N 3nm
doped) 4μm
pphire







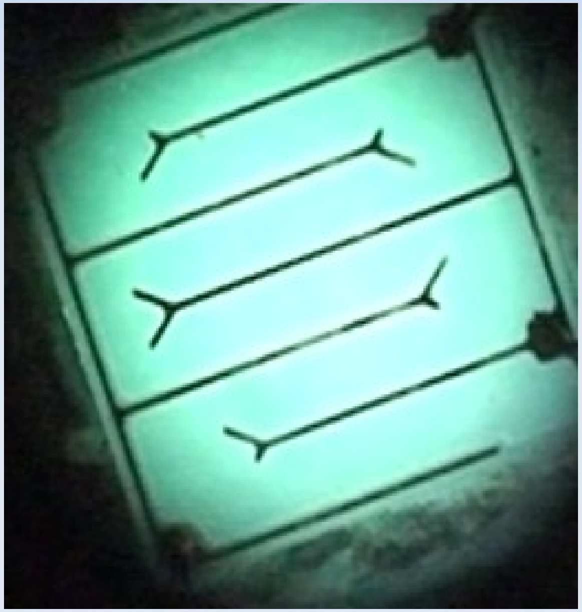
Commercial InGaN device

This is a commercial InGaN device with high output.

There are many dislocation because of mismatch in the lattice parameters for substrate and crystal.

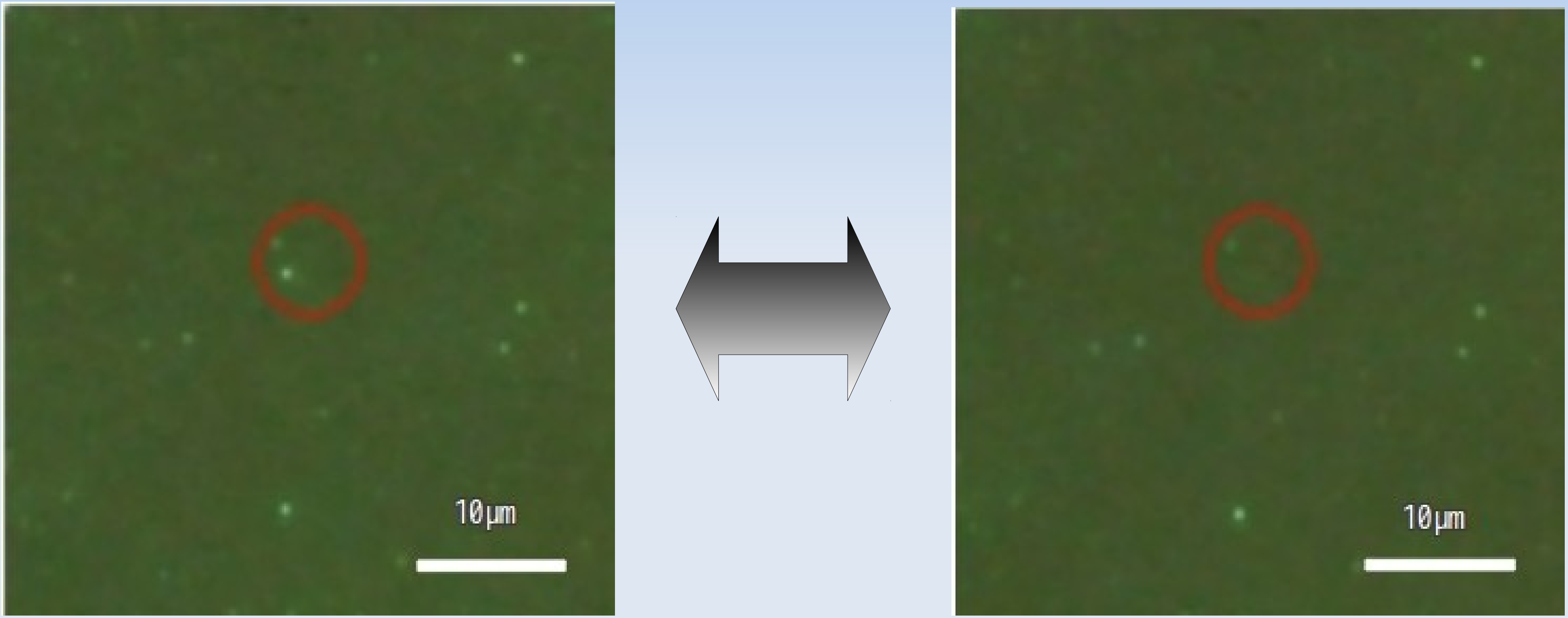
↓

Many dislocation



Growth on Sapphire

Instability Blinking Phenomena)



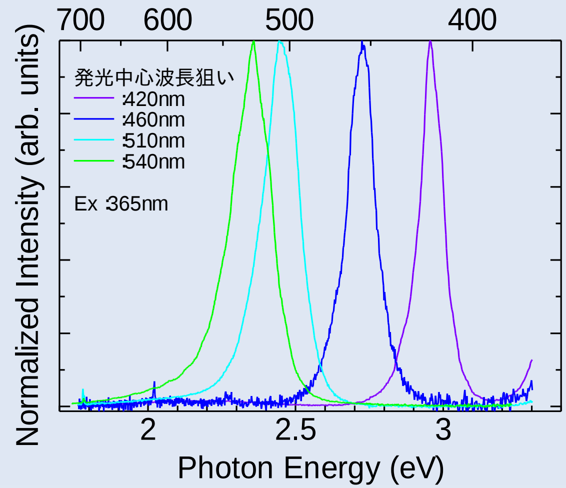
Two images taken from the CCD camera few seconds apart

micro Blinking in InGaN LEDs

micro Blinking in InGaN LEDs

A 540nm emitting InGaN LED test material

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

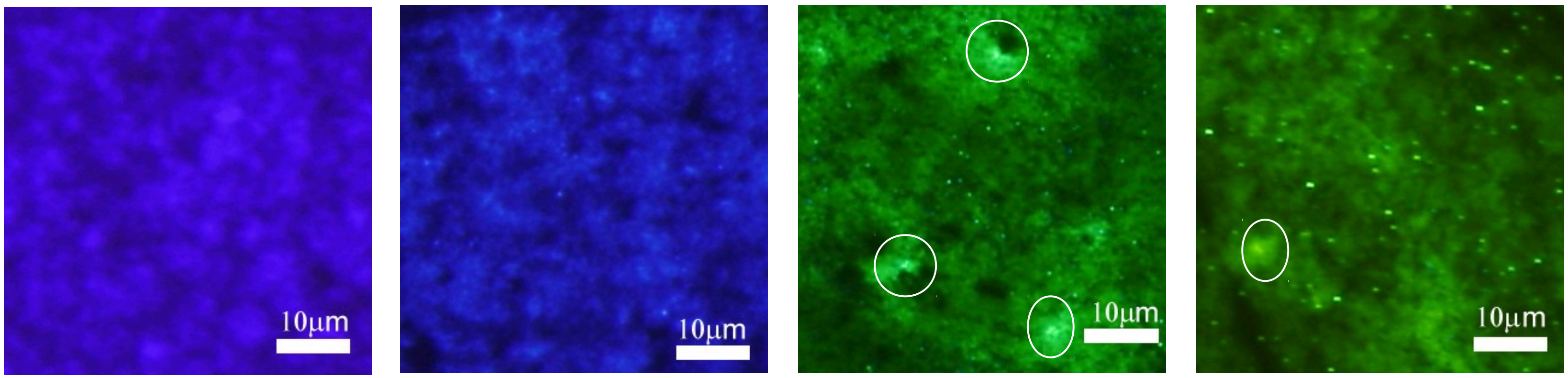


Optical microscope images

Central emission | 420nm | 460nm | 510nm | 540nm

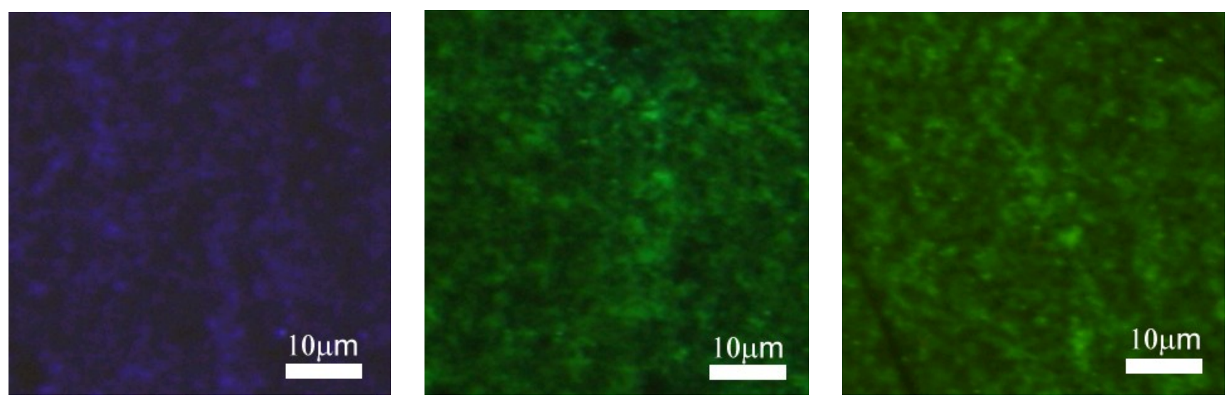
ext. 365nm

power $7.5 W/cm^2$



ext. 405nm

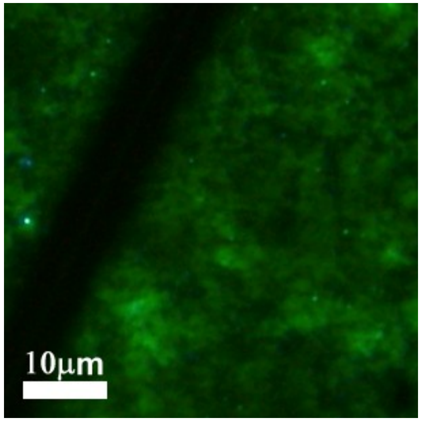
power $2.65 W/cm^2$

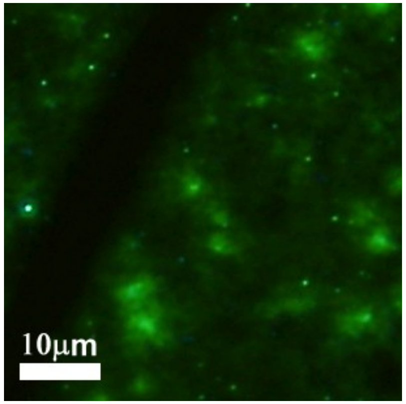


Optical images Dependence on power

1.4W/cm^2 | 0.23W/cm^2

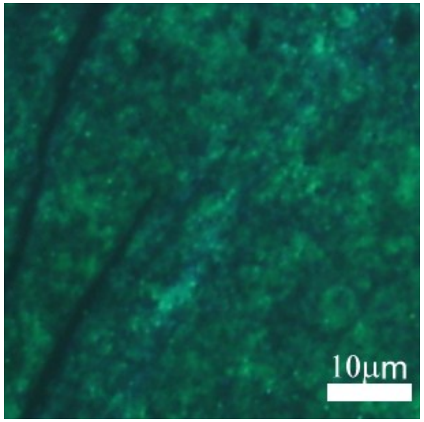
exc. 365nm

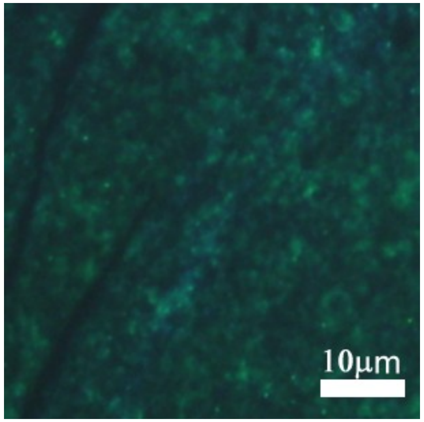




Intense domains appears more dominant

exc. 405nm





No prominent changes

Some quantitative parameter

What parameter to measure?

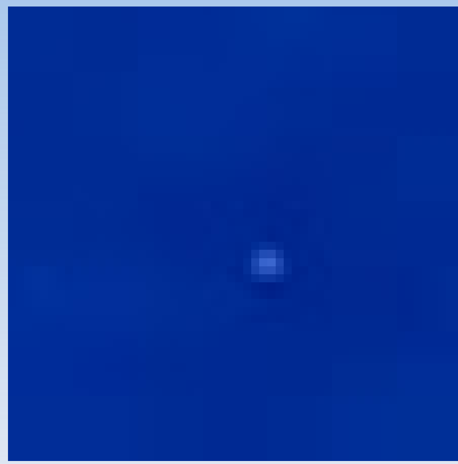
Quantitative analysis

This is a real system with a non ideal 3D potential

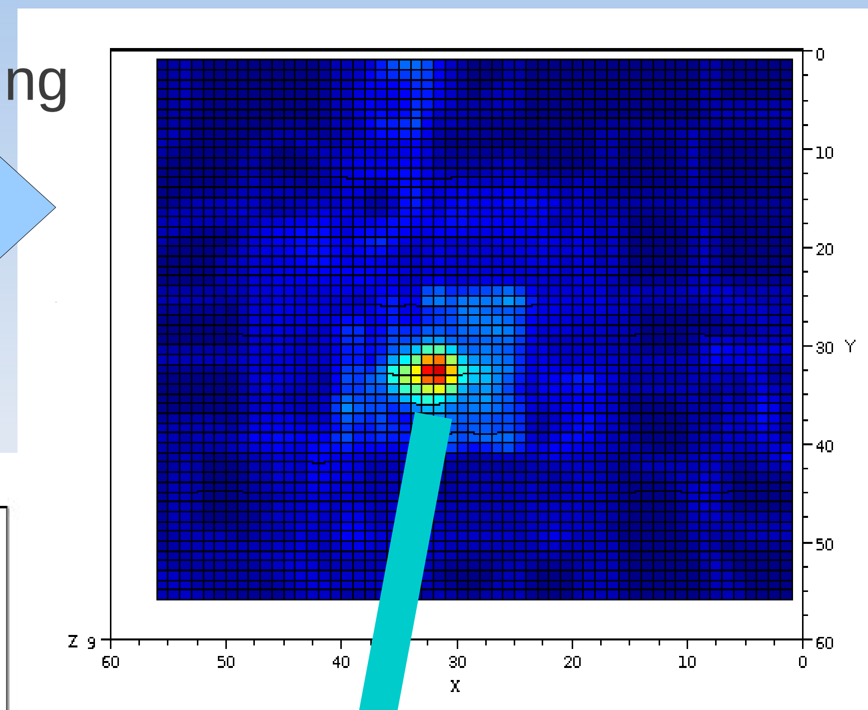
Not clear explanation of slow behavior and multi-level blinking

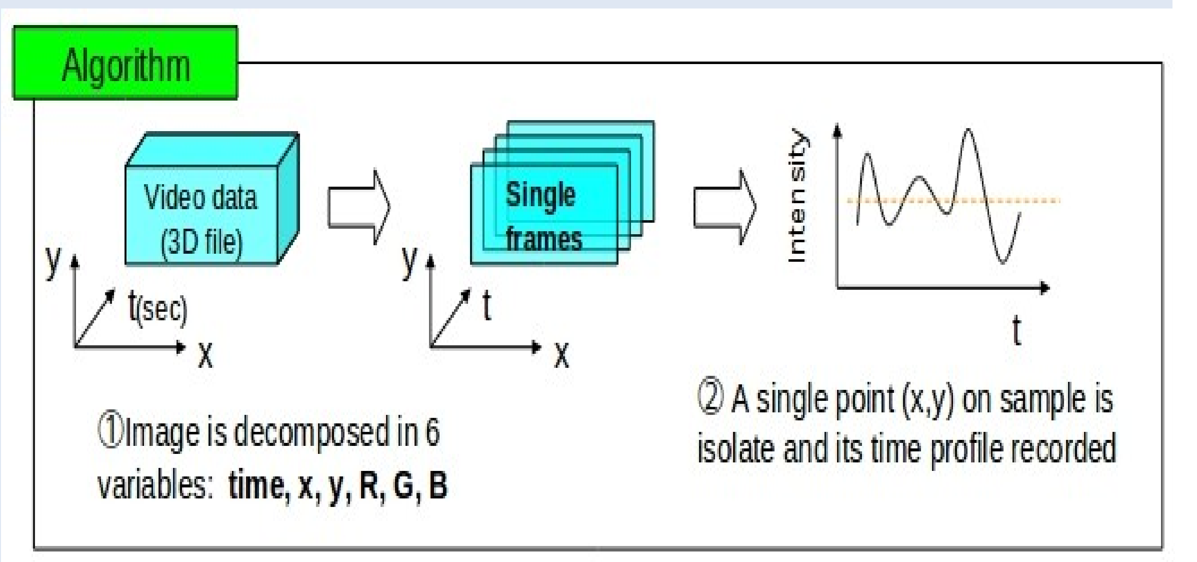
- Observe and analyse with CCD
- Observe in near-field with a SNOM device
- Measure the time-series characteristics.
- Avoid instrumental artifacts

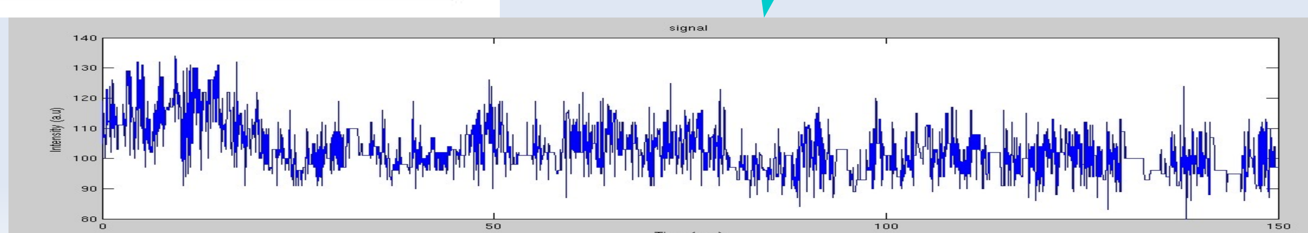
CCD data analysis method



Deviation Mapping



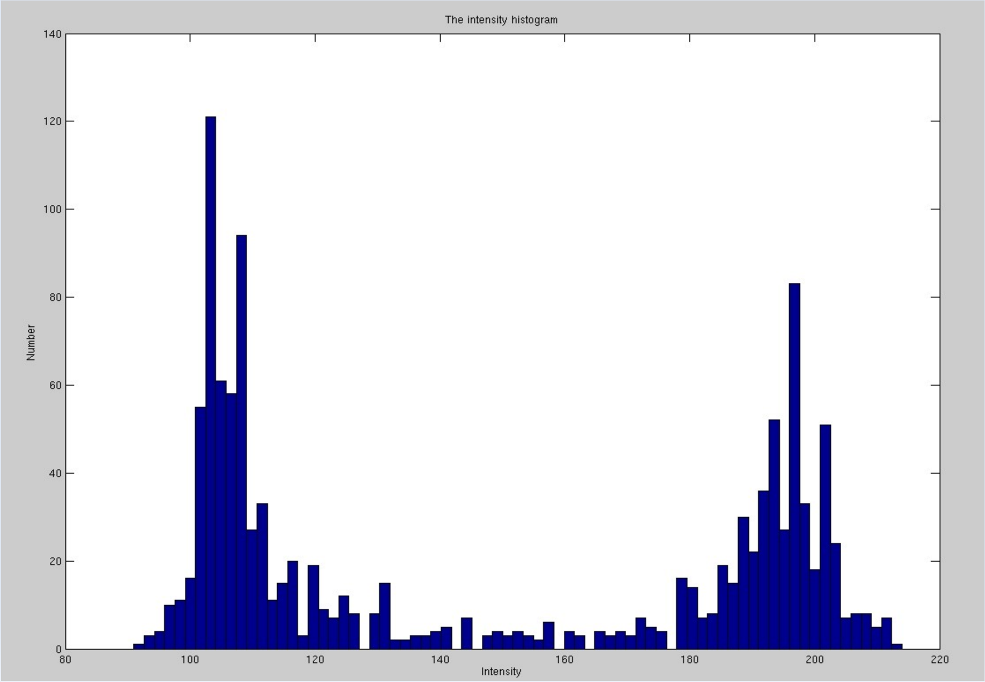




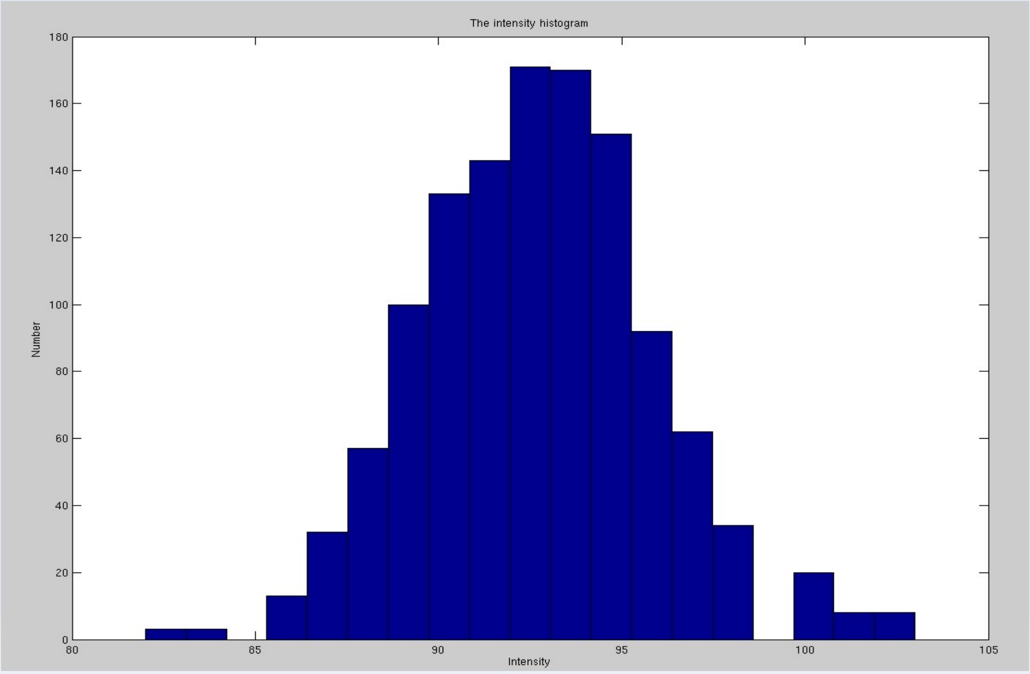
The time-histogram of blinking

- a ”Telegraphic” signal of on/off bits separated by few seconds
- a ”multilevel” random-noise like signal

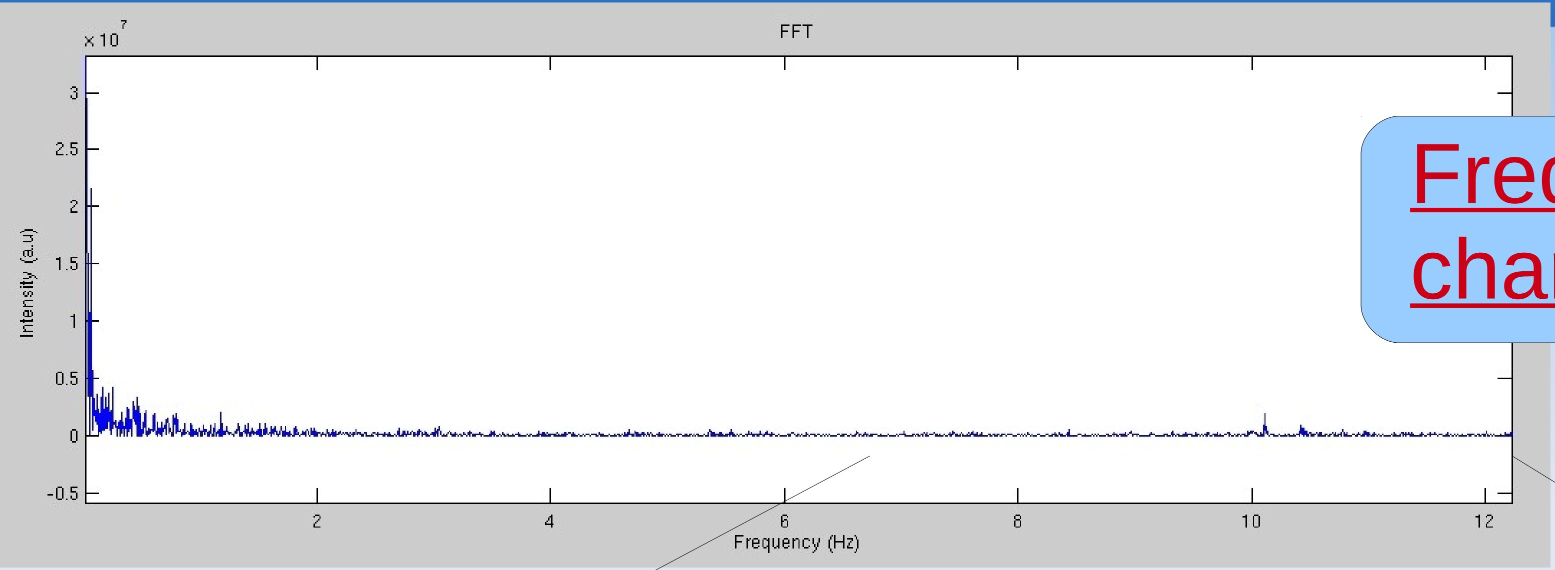
Bistable signal



Noise-like signal

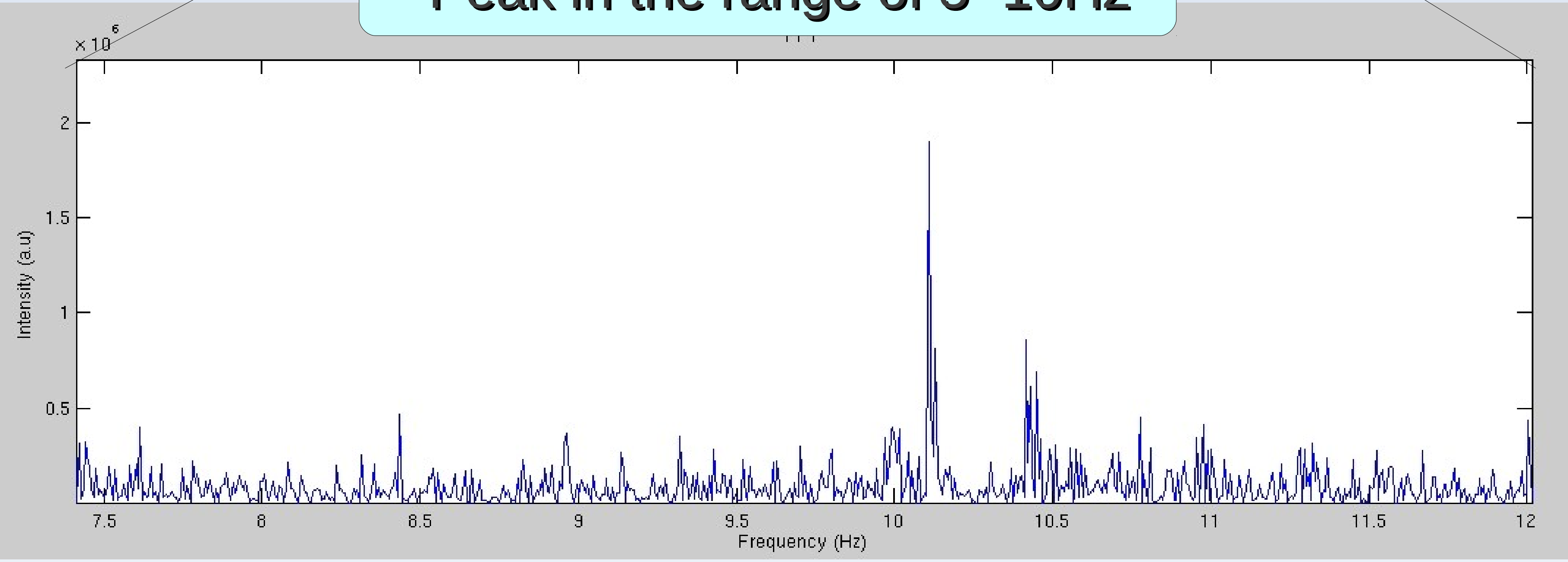


Fast Fourier Transform(FFT)



Frequency characteristics

Peak in the range of 5~10Hz



Are blinking points ”interesting”?

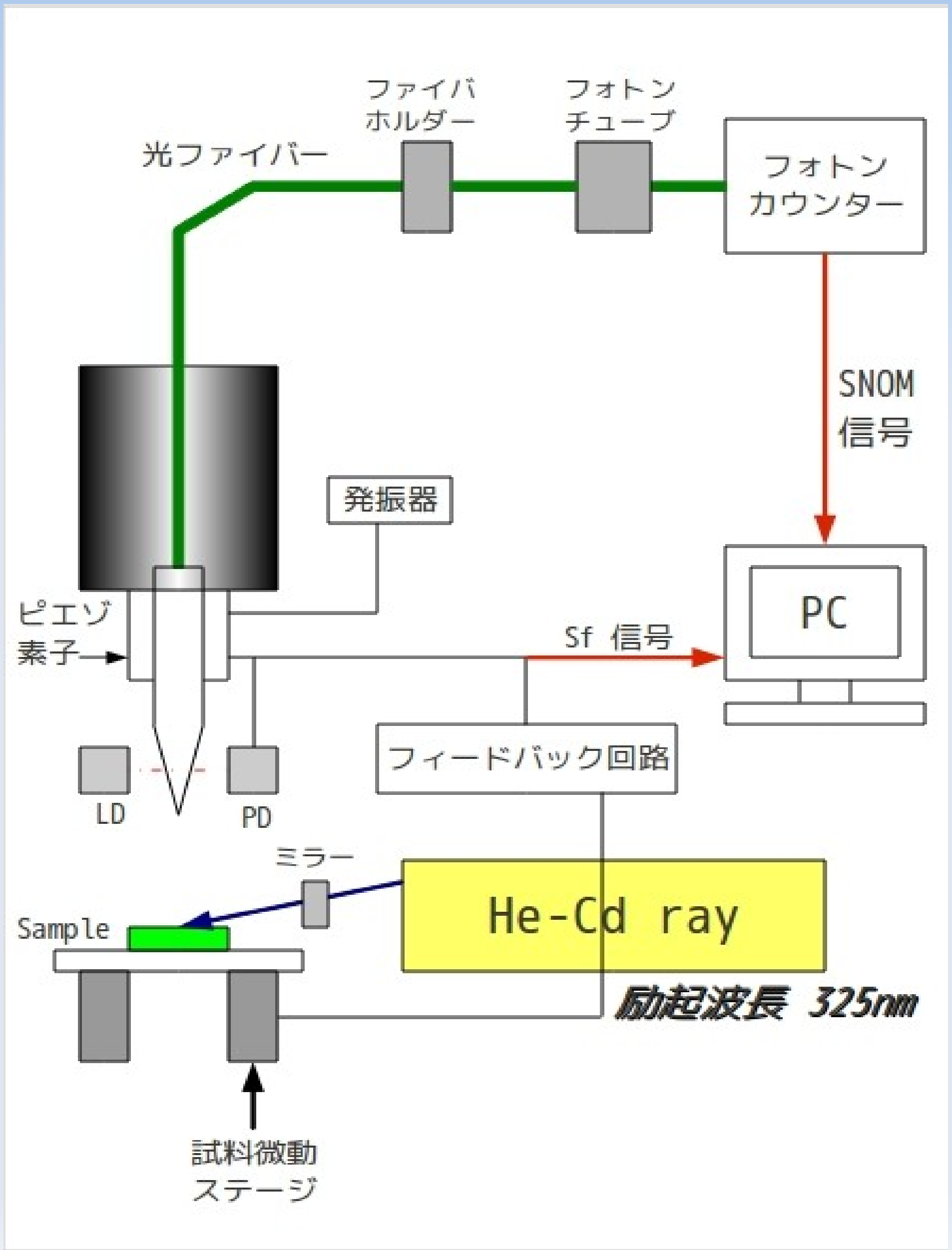
Studying the blinking phenomena on LED device is important somehow?

We found blinking points on LED just bought in the local shop (Akihabara)

If we understand the mechanism involved we can imagine to improve LEDs and make them more efficient

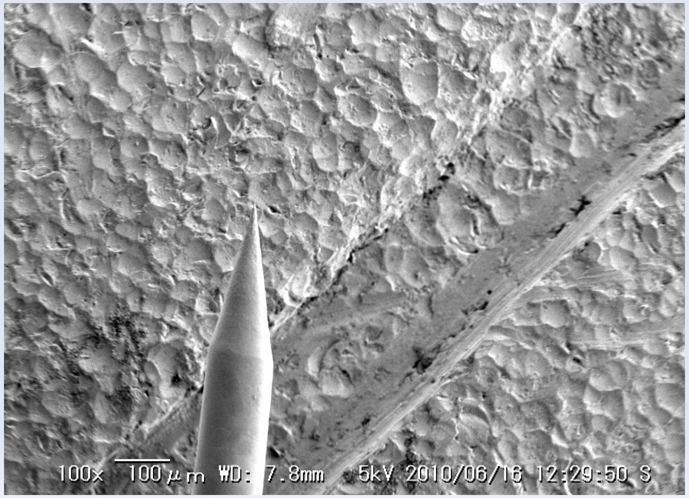
Hi-res Measurements Scaning Near-field Optical Microscope(SNOM)

３、 SNOM (Setup)

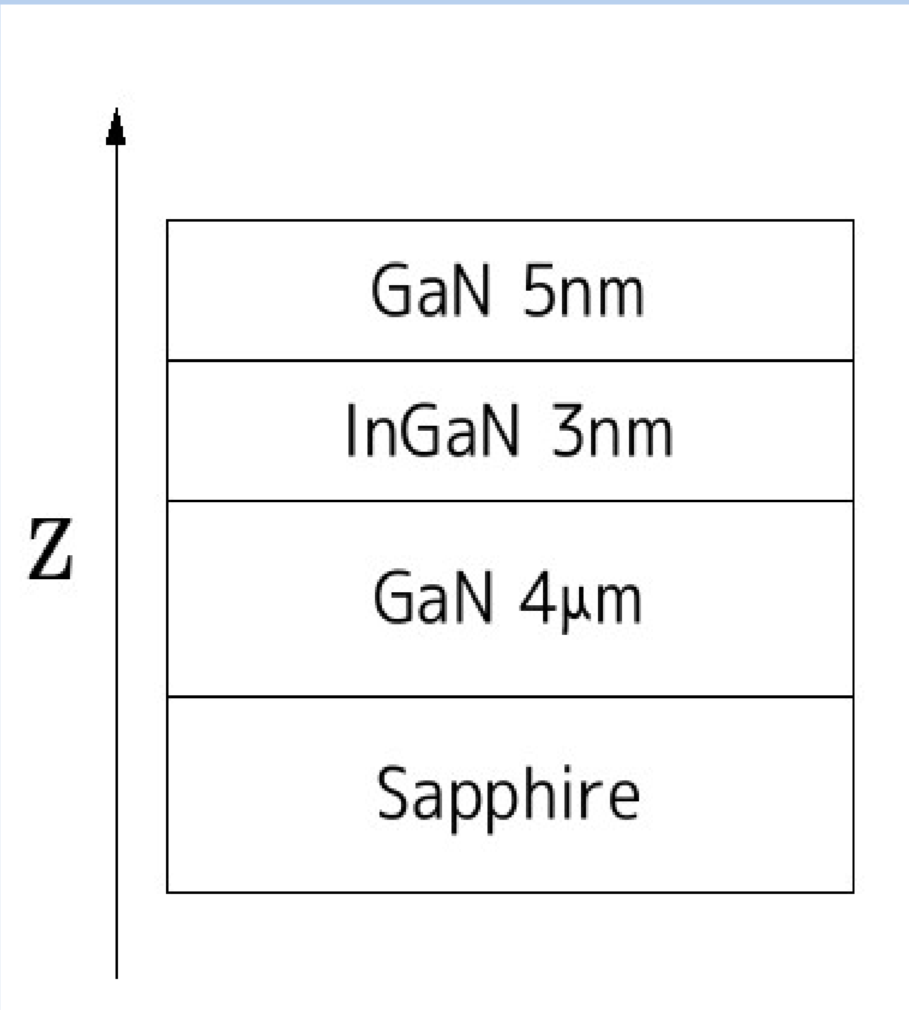


・ UV laser （３２５ nm）
（collection mode）

・ pensil type probe
・ room temperature



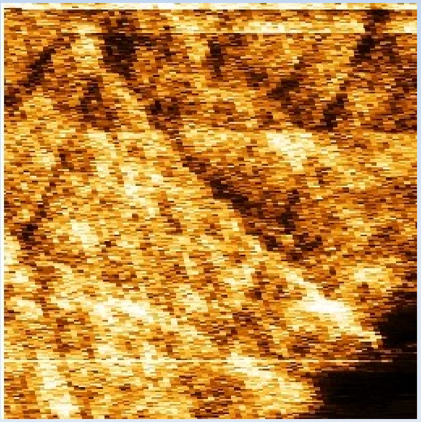
4、 sample structure (Sample Data)



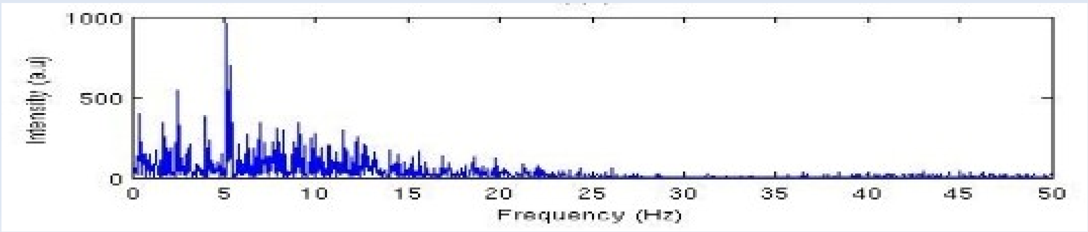
- We used 540nm, 510nm centered samples

5、 Results

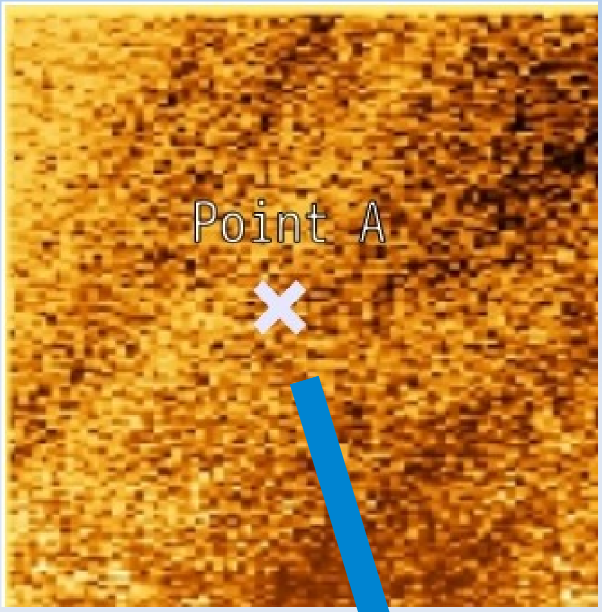
（1） We could see the typical optical emission spatial distribution of InGaN devices.

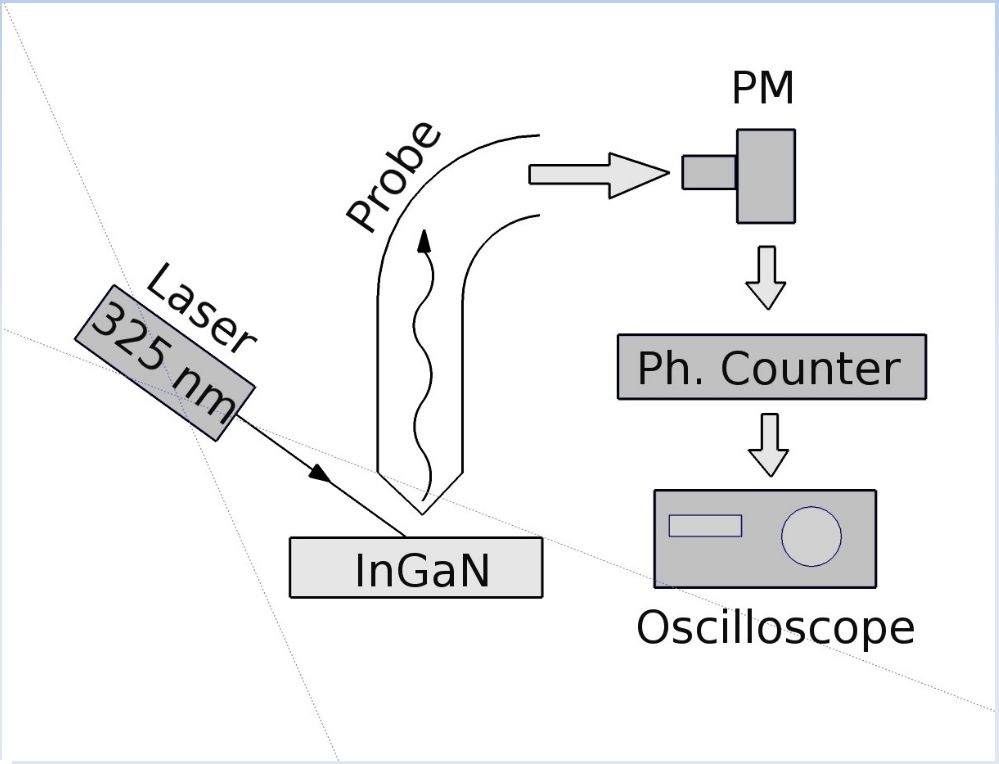


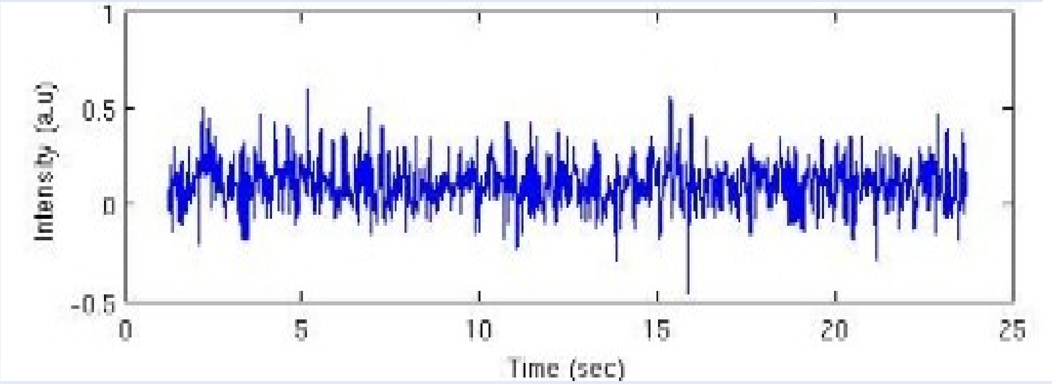
（2） Fixing the optical fiber in one single point, and recording the change in intensity, FFT analysis shows similar peaks around 5-10 Hz



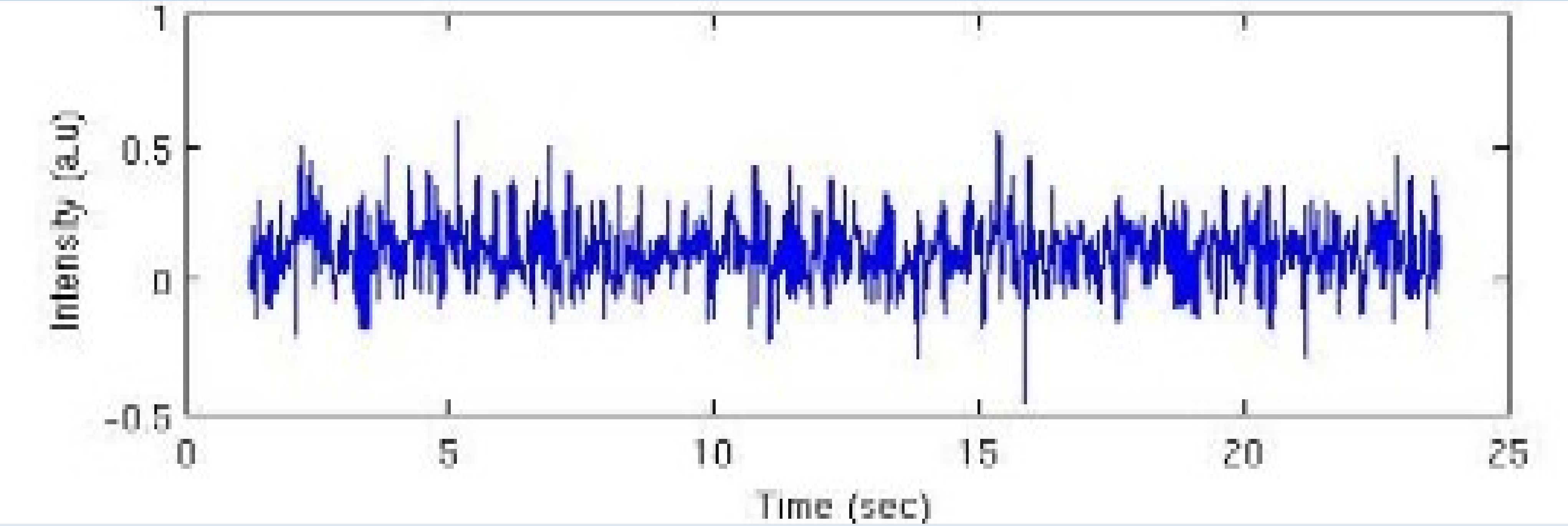
Signal (Time/Intensity) by SNOM







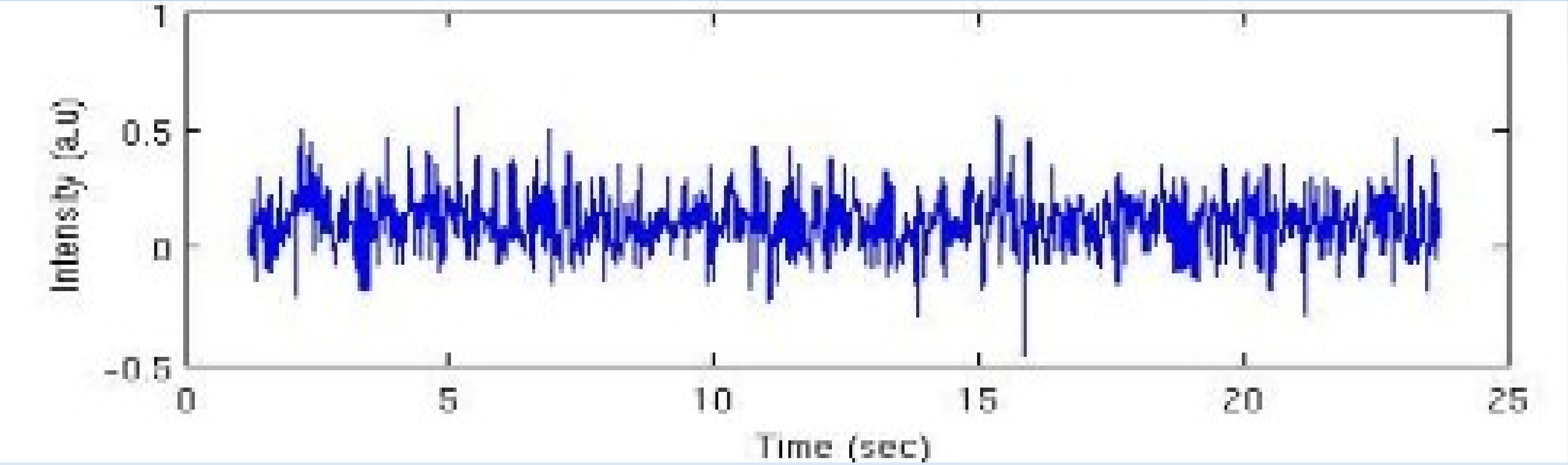
Signal by SNOM (Time/Intensity)



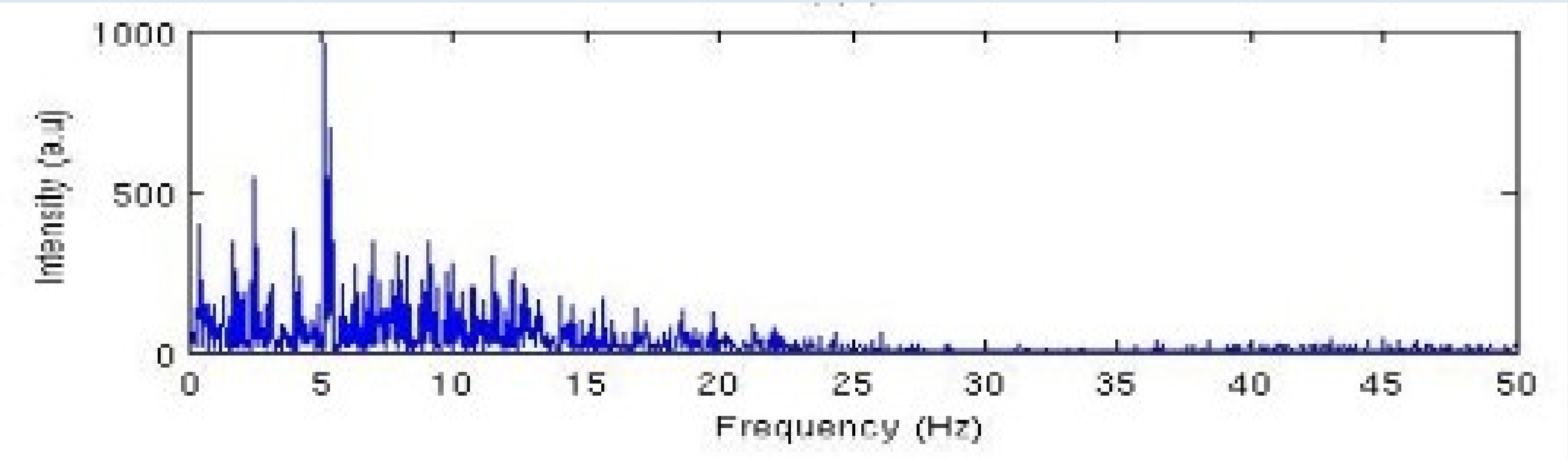
This is a blinking point before FFT analysis. There are 2250 samples in this plot. (12 ms rate)

Results （2）

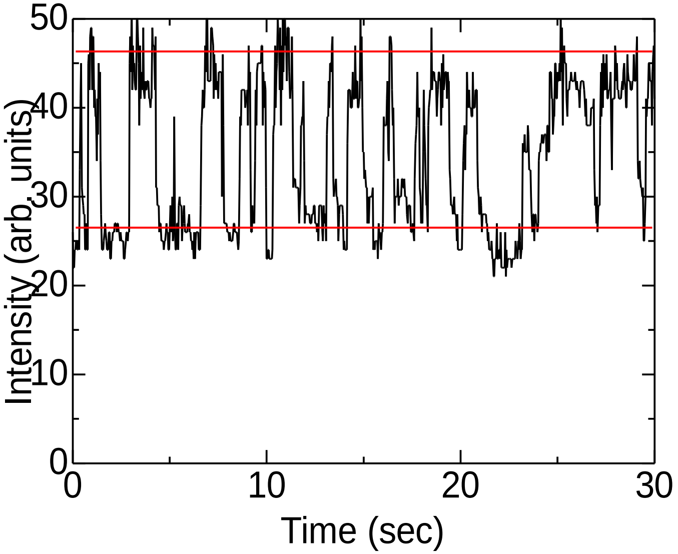
Signal by SNOM (Time/Intensity)



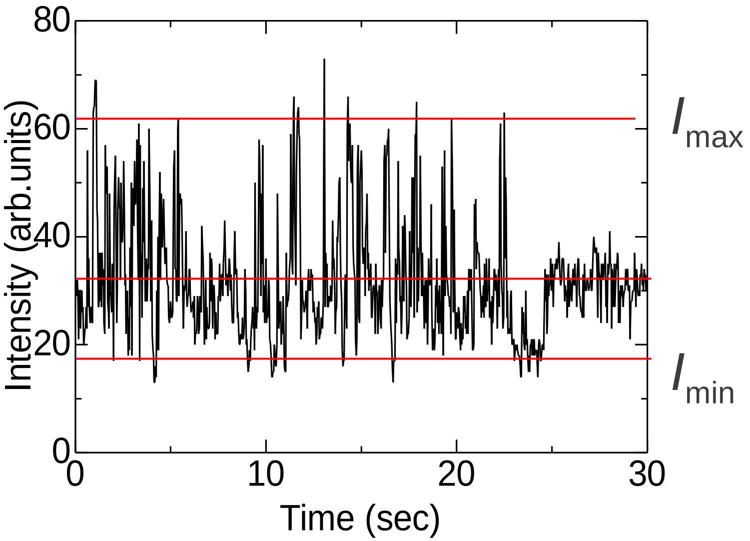
FFT (Frequency/Intensity)



Signal shapes



telegraphic



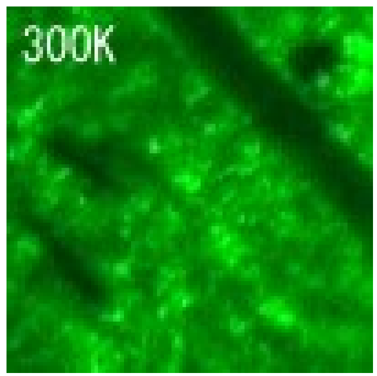
multilevel

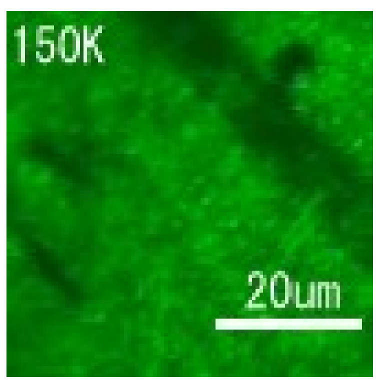
Maybe the quantum localization is degenerated in some domain.

Temperature dependence

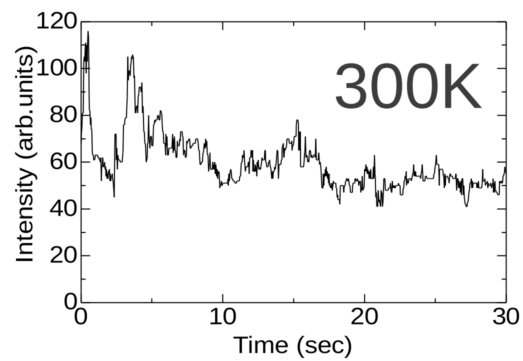
Sample 510nm, room temperature and low temperature

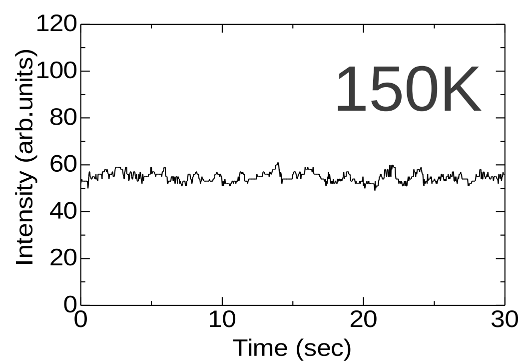
冷却





Difference of behavior at lower temperature

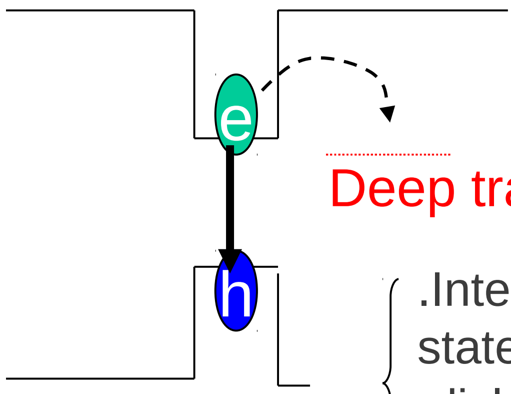




Trap seems to loose effect a lower temperature

The process of recombination

Quantum dot



.Interface state
.dislocation
.migration

The carrier is trapped in the QD

- Non-radiative re-combined process with long longevity
- Auger non radiative process
- Quantum confinement Stark effect by internal electric field

Reduced optical emission

Our samples

In-rich areas play a role, do they behave like a QD?

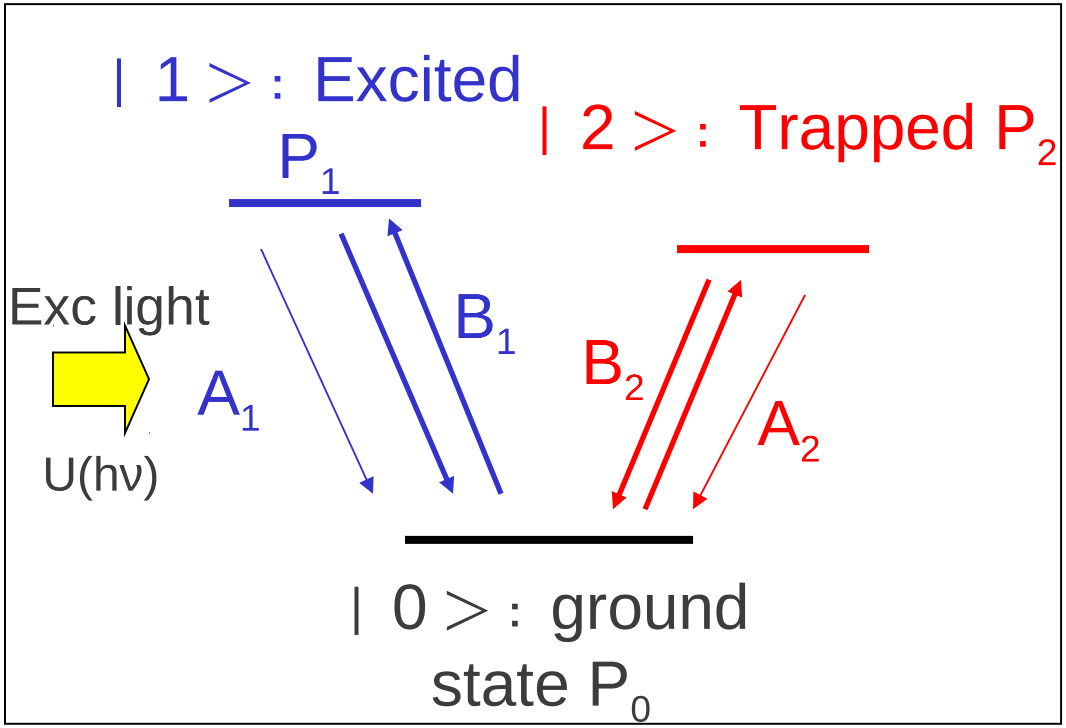
At the GaN/InGaN interface is there a trap or semi-trap , does migration play a role.

Quantum Jump model

[5]R. J. Cook and H. J. Kimble, Phys. Rev. Lett., **54** 1023 (1985)

Two types of transition

Ex) |0 ＞ : QD minimal state
| 1 ＞ : QD excited state
|2 ＞ : trapped state



・ normally transition from |0> to |1>

(from exited state to ground $U_1 \rightarrow \infty$)

・ rare jumps to state 2

A(B) : Einstein A(B) coefficients

P : probability

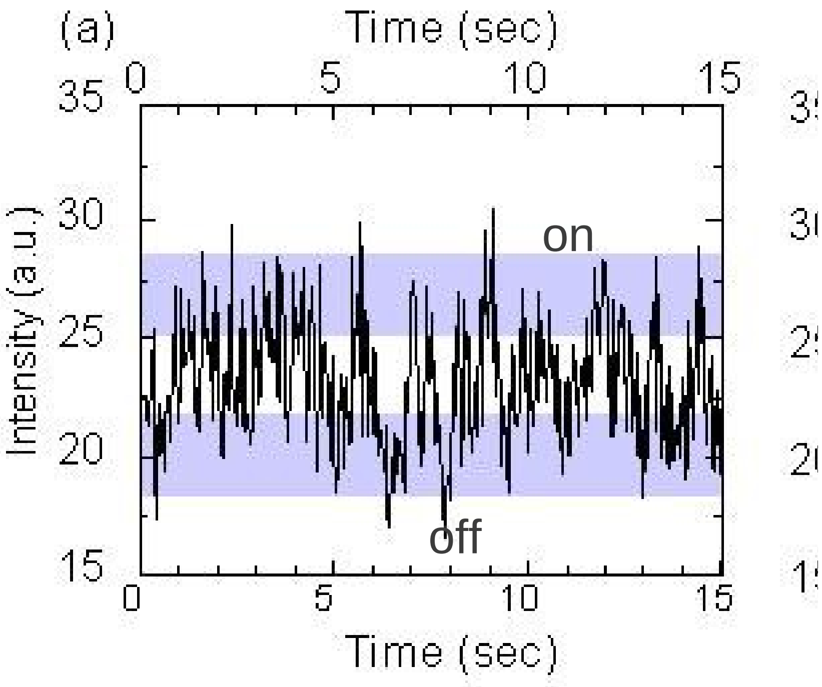
U : Energy potential

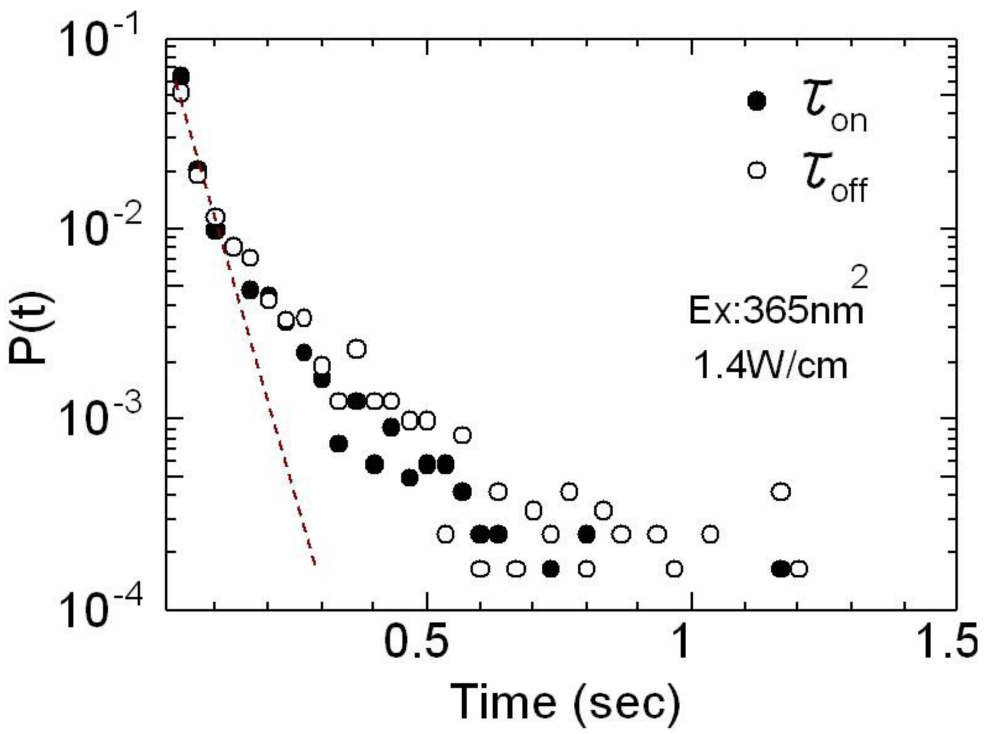
Rate equations

$$\begin{cases} \dfrac{dP_1}{dt} = -A_1P_1 + B_1U_1(P_0 - P_1) \\ \dfrac{dP_2}{dt} = -A_2P_2 + B_2U_2(P_0 - P_2) \end{cases}$$

Quantum Jump model

[5]R. J. Cook and H. J. Kimble, Phys. Rev. Lett., **54** 1023 (1985)

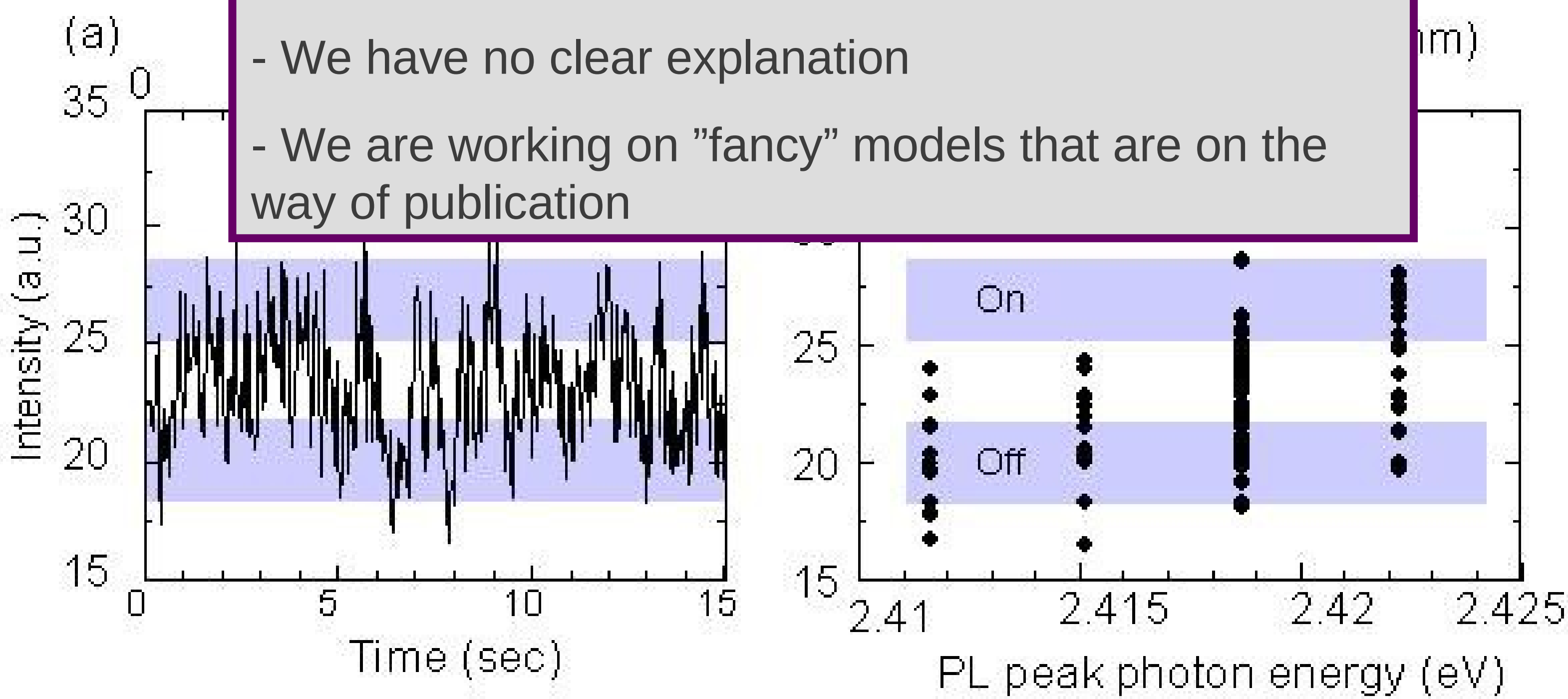




Energy dependence

[5]R. J. Cook and H. J. Kimble, Phys. Rev. Lett., **54** 1023 (1985)

- Our phenomena does not fit standard QD models
- We have no clear explanation
- We are working on "fancy" models that are on the way of publication



APPLIED PHYSICS LETTERS **88**, 061118 (2006)

Observation of optical instabilities in the photoluminescence of InGaN single quantum well

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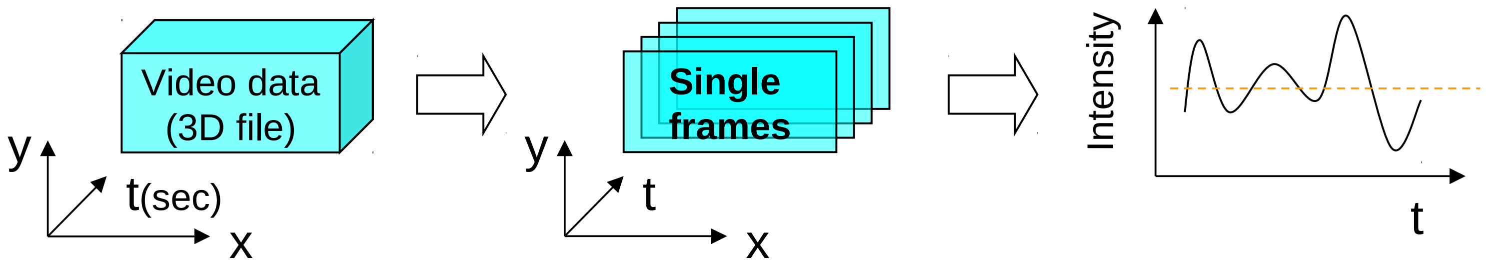
(Received 14 November 2005; accepted 11 January 2006; published online 9 February 2006)

We investigate a peculiar optical instability (blinking) phenomena associated with spatial inhomogeneity in $In_xGa_{(1-x)}N$ single quantum well systems. We studied the time dependence of this dynamic phenomenon and tested a "quantum jump" single exponential model on the system. A comparative analysis of the behavior of different samples suggests that indium-rich localized centers participate in the mechanism of blinking and that the instability behavior differs with the excitation wavelength. Our study indicates that the trapping and de-trapping process between the localized-luminescent centers and surrounding less luminous regions plays important roles in the carrier recombination mechanism.
[DOI: 10.1063/1.2172144]

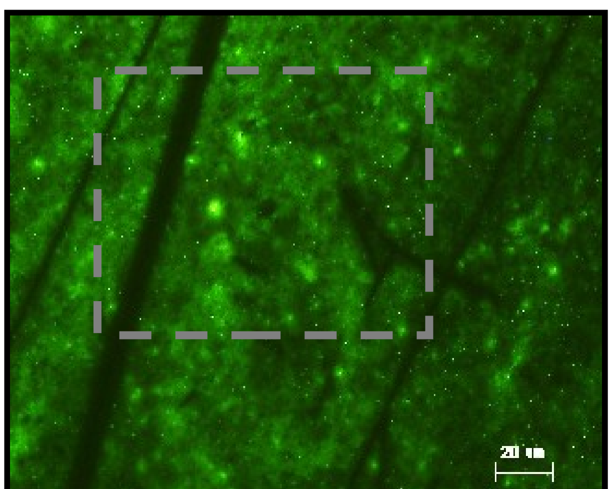
Systematic analysis of single pixel time profile

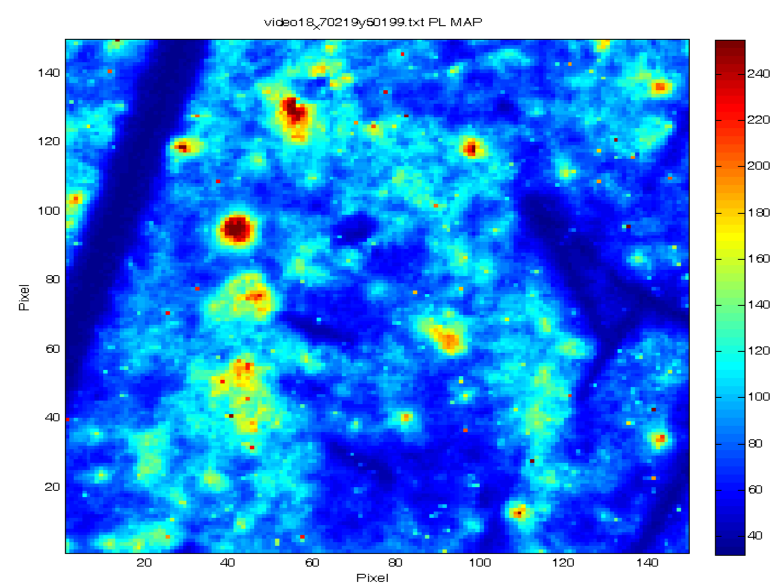
Algorithm



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

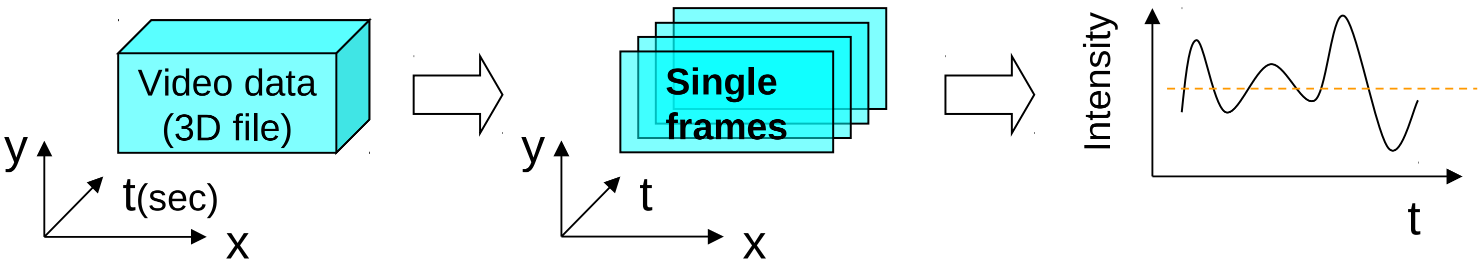
② A single point (x,y) on sample is isolate and its time profile recorded





Systematic analysis of single pixel time profile

Algorithm



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

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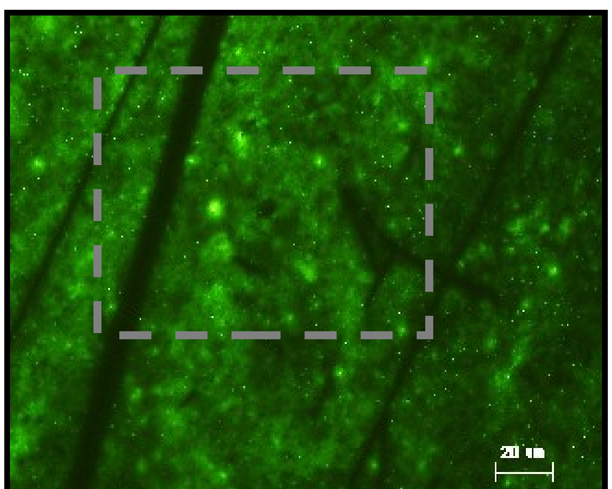
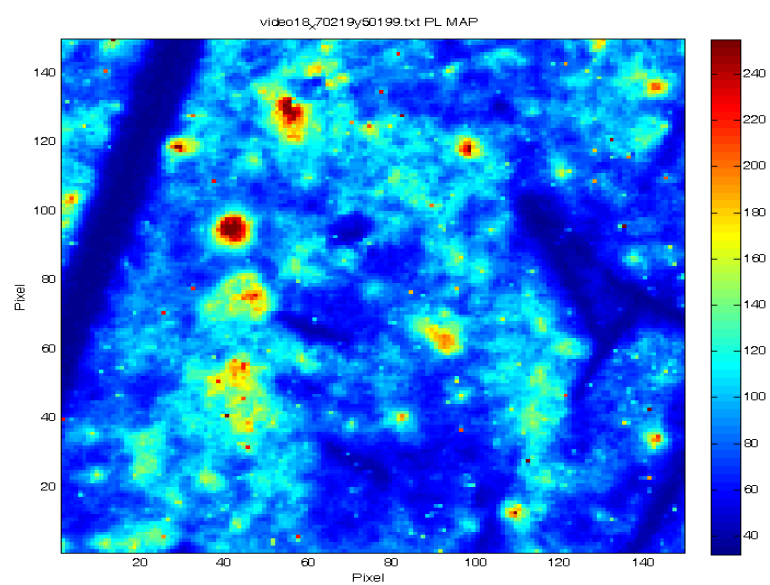
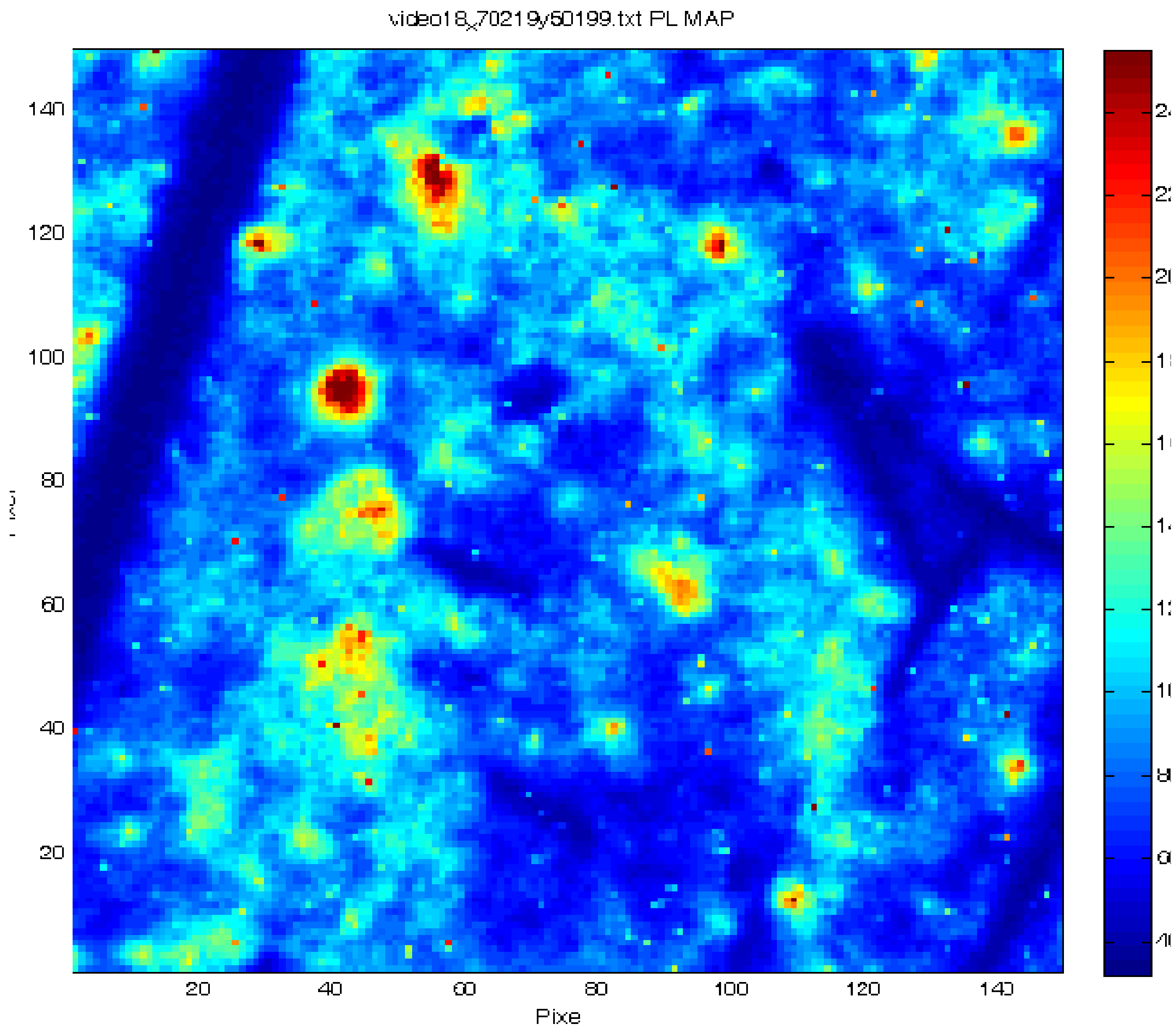


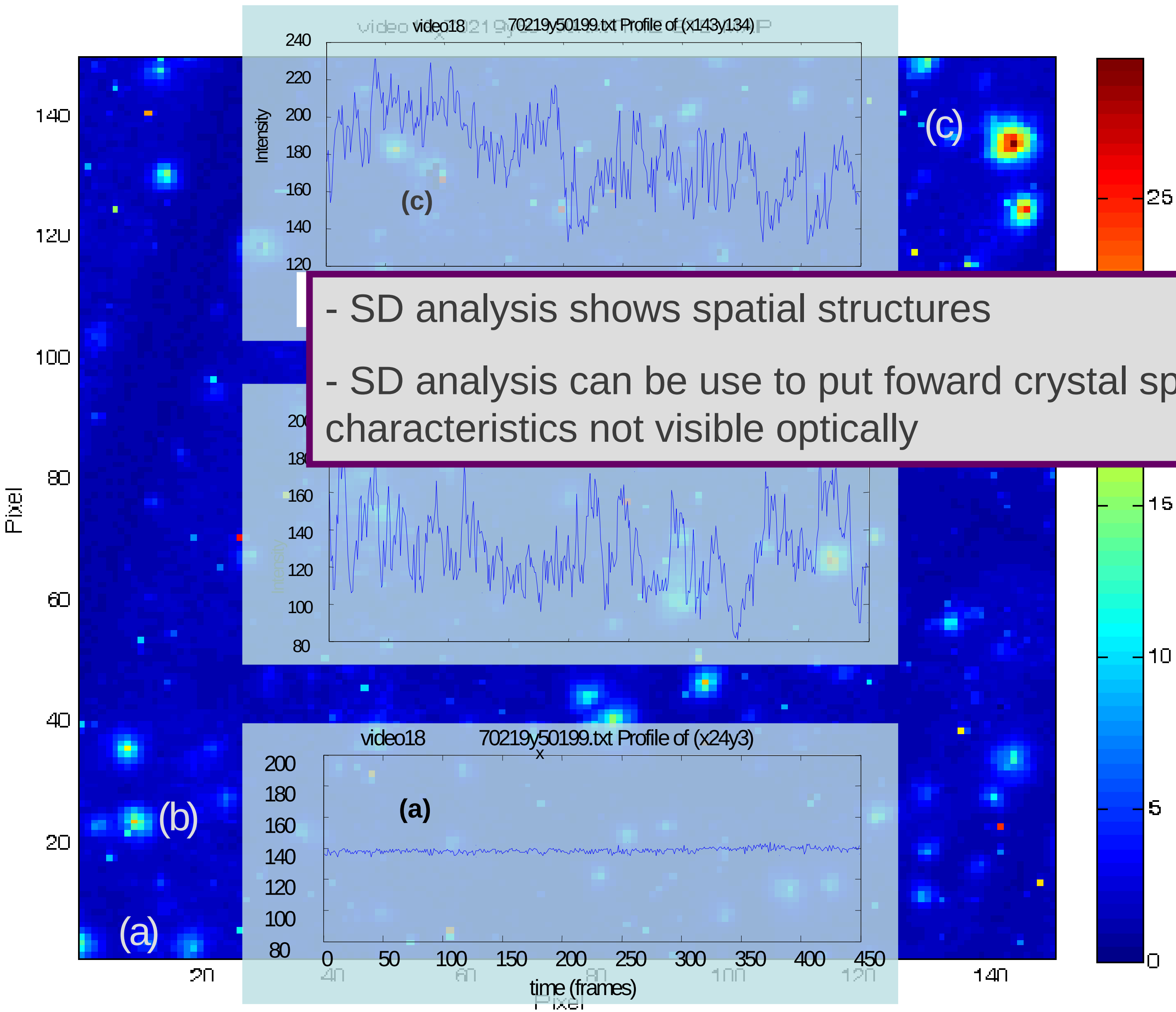


Map of Intensity captured from movie file



Every pixel on this map is the intensity of the light at t=0. The region is the one in the grayed dashed box, 150x150 pixels, about 60x60 µm large. Each pixel is about 400x400 nm.

Map of standard deviation



- SD analysis shows spatial structures

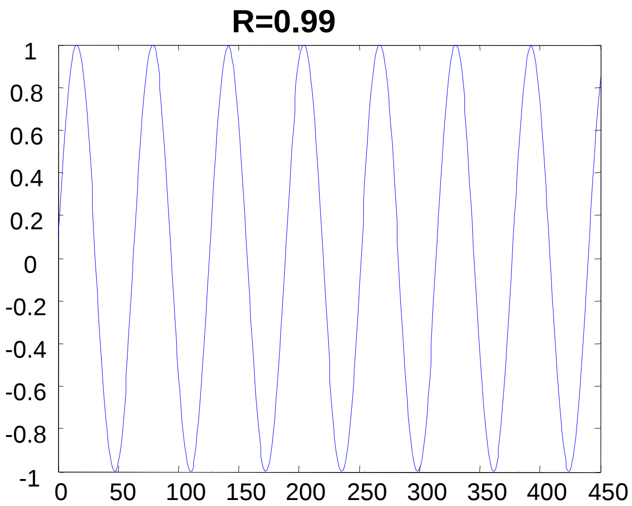
- SD analysis can be use to put foward crystal spatial characteristics not visible optically

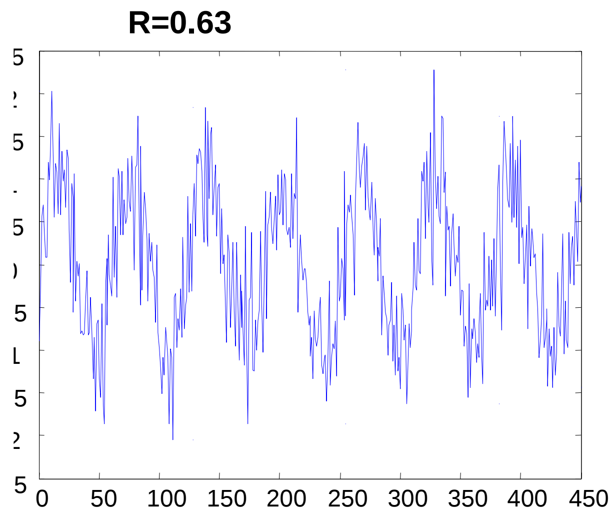
This map is the standard deviation of each pixel time profile. For each pixel we have 450 data (frames) for one …nute of …cording. The …gion is same as …ove, 150x150 pixels. In simple words: blue points do not blink, bright points blinks and intensity gives a measure of the of blinking vigor in standard deviation units.

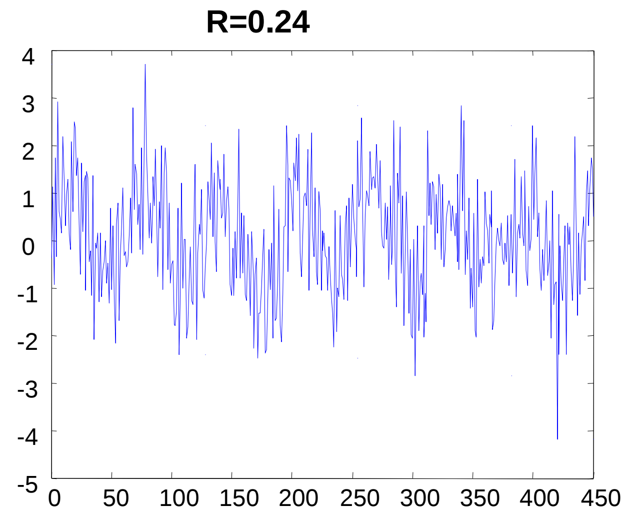
Time-Autocorrelation of Photoluminescence

$$Cov(xx_l) = E[xx_l] - E[x]E[x_l] = < xx_l > - < x >< x_l >$$

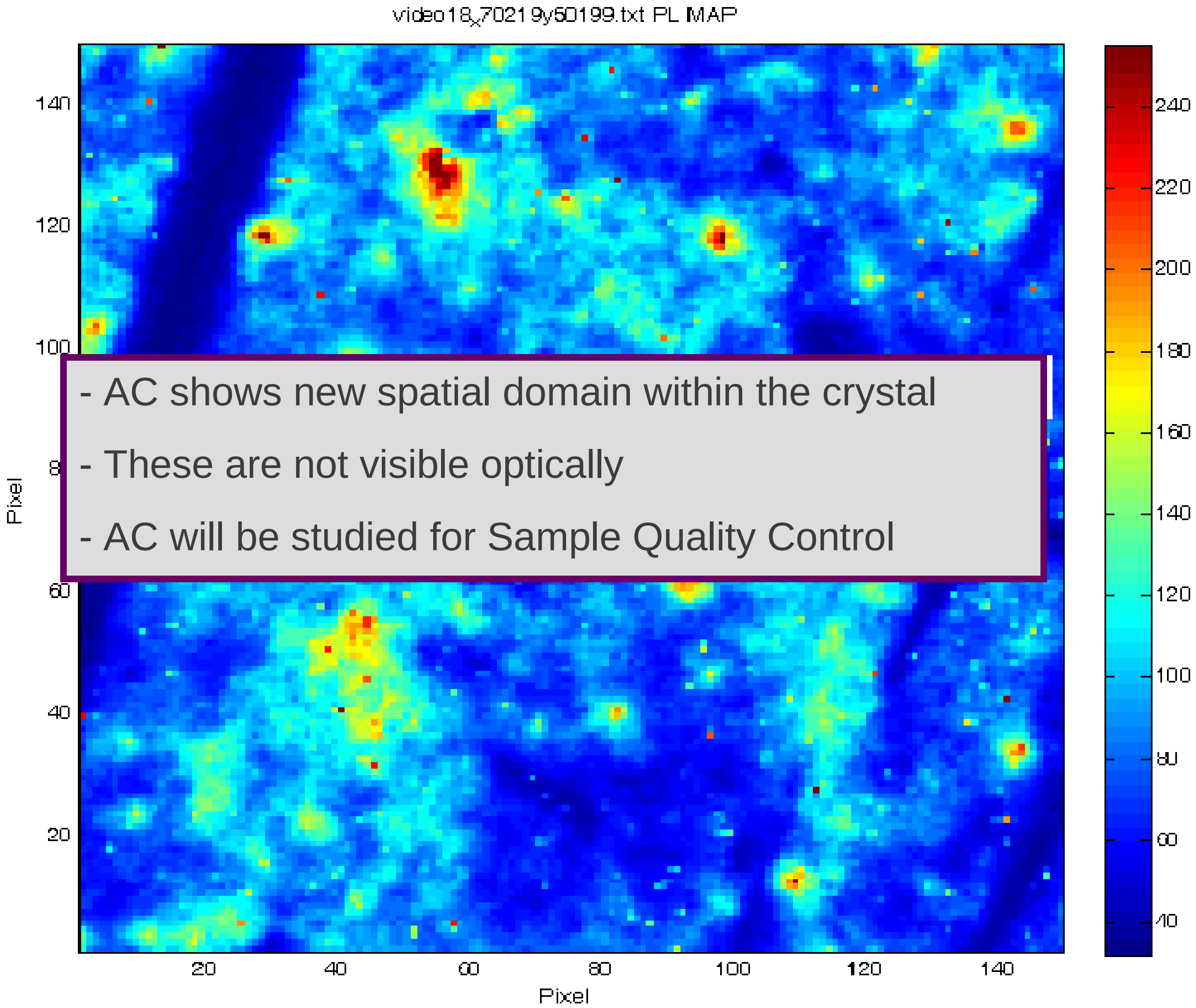
$$\sigma_x = \int (x - < x >)dx \qquad R = \frac{Cov(xx_l)}{\sigma_x^2}$$







Map of Autocorrelation



- AC shows new spatial domain within the crystal
- These are not visible optically
- AC will be studied for Sample Quality Control

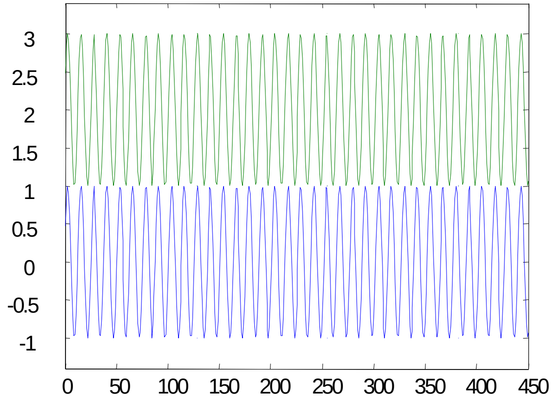
In this map ach pixel is the utocorrelation oefficient of he pixel time rofile. Also this nap show clear lomains and tructures ompatible with he PL map. (a) nd (b) points re shown as xample of ighly utocorrelated ixels.

Time-correlation between different Photoluminescence domains

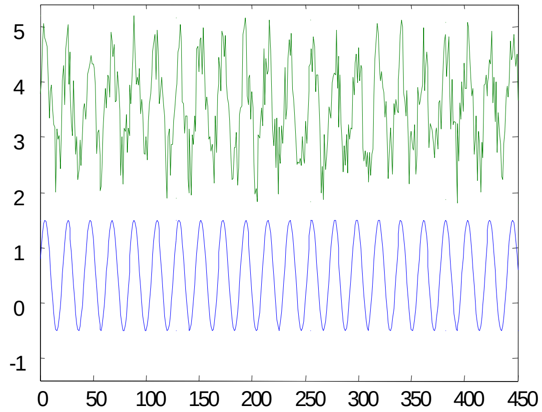
$$Cov(xy) = E[xy] - E[x]E[y] = <xy> - <x><y>$$

$$\sigma_x = \int (x - <x>)dx \qquad R = \frac{Cov(xy)}{\sigma_x \sigma_y}$$

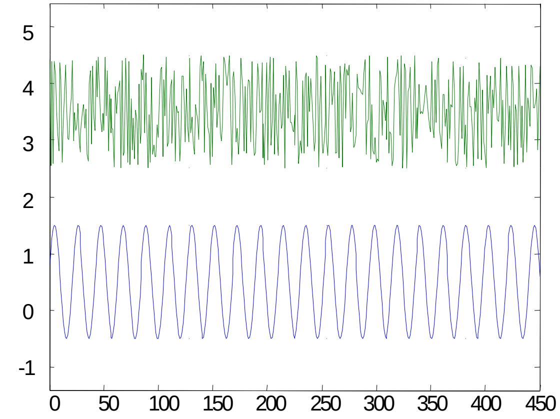
R=1.00



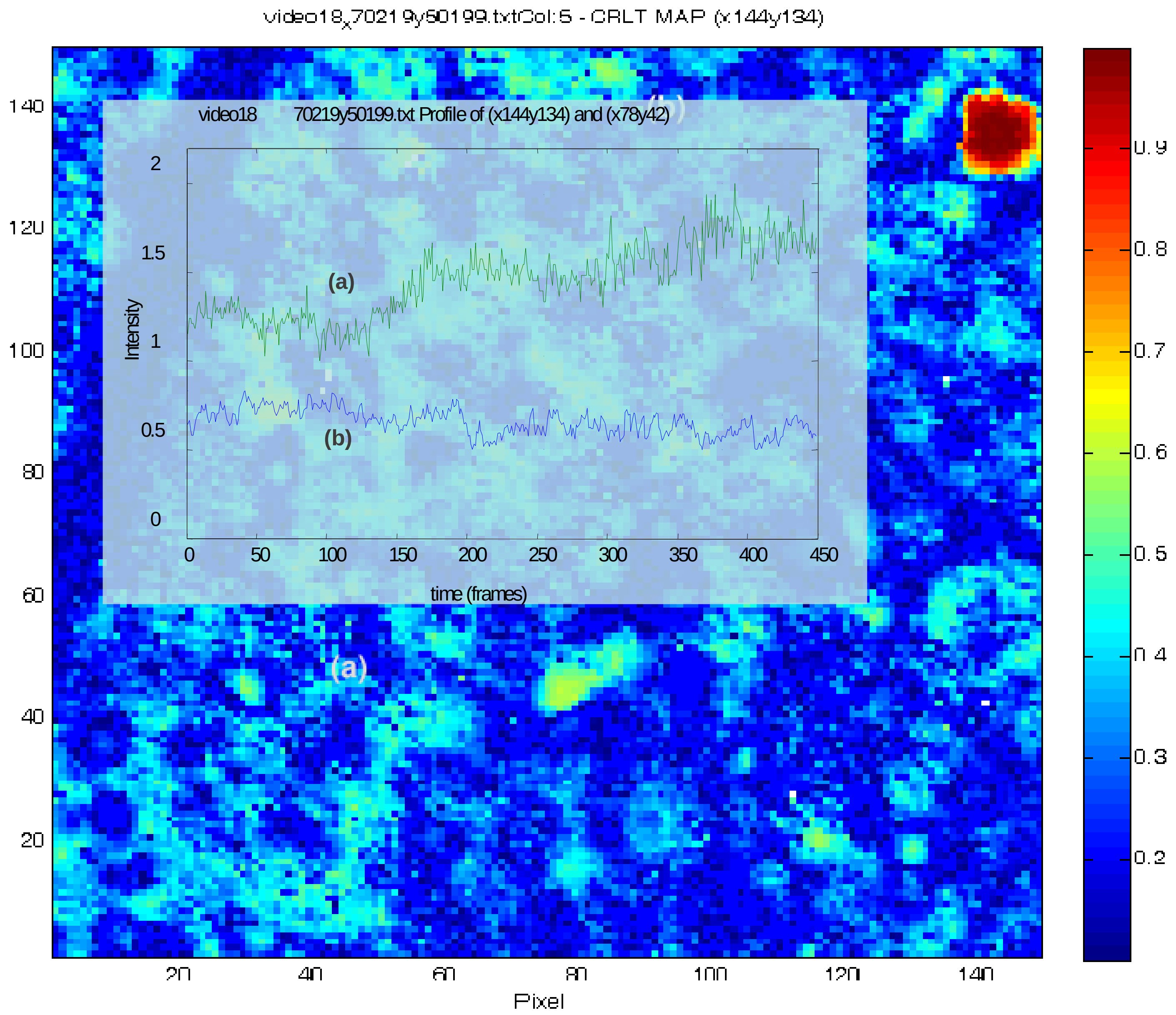
R=0.85



R=0.02



Map of Correlation



In this map each pixel is the correlation coefficient of the pixel time profile with the time profile of point (144,134). For each pixel we have 450 data (frames) for one minute of recording. The region is same as above, 150x150 pixels. Distant blinking domains that show correlation better than 60% are noted. The map show structures compatible with the PL map.

- 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**.