8 Surface plasmons and the blinking phenomena

As described in section 3 the photoluminescence emission of quantum wells can strongly be enhanced through the coupling to surface plasmons in metals near the quantum well [37]. We investigated the influence of this enhancement on the blinking points by enhancing the photoluminescence through gold nanoparticles on the sample surface. The proceedings and obtained results will be described in this chapter.

8.1 Photoluminescence enhancement

To enhance the photoluminescence intensity of the quantum well through resonant coupling to surface plasmons the right nanoparticles had to be chosen. For our sample we decided to use gold nanoparticles of 50 nm diameter as these particles have a resonance spectrum that was likely to suit our samples. The resonance maximum of gold nanoparticles of a diameter of 48 nm is located at about 533 nm. This coincides almost perfectly with the main emission peak of the 540 nm sample (fig. 3.3) [35]. In addition, gold nanoparticles are very stable compared to other metal nanoparticles. The nanoparticles were fabricated by Nanocs Inc. and dissolved in double distilled water with a gold concentration of 0.01% which corresponds to a density of $4.5 \cdot 10^{10}$ particles/ml.

A drop of this so called colloidal gold was placed on the sample. After the liquid had evaporated completely and only the gold remained, the sample was observed with photoluminescent microscopy.

On the 540 nm sample the area covered by nanoparticles showed significantly enhanced photoluminescence (fig. 8.1) and the drop was easily visible in the photoluminescence picture. The whole area inside the drop appeared much brighter than the surrounding area. All the strong luminescent centers and blinking points that could be observed before disappeared in this strong light emitting area (see fig. 8.2).

The quantum well resonantly coupled to surface plasmons in the gold-semiconductor interface. The gold nanoparticles were separated from the active InGaN layer by a 5 nm GaN cap layer. The penetration depth of the fringing field of surface plasmons in a gold-GaN interface into the semiconductor is about 33 nm [37] and

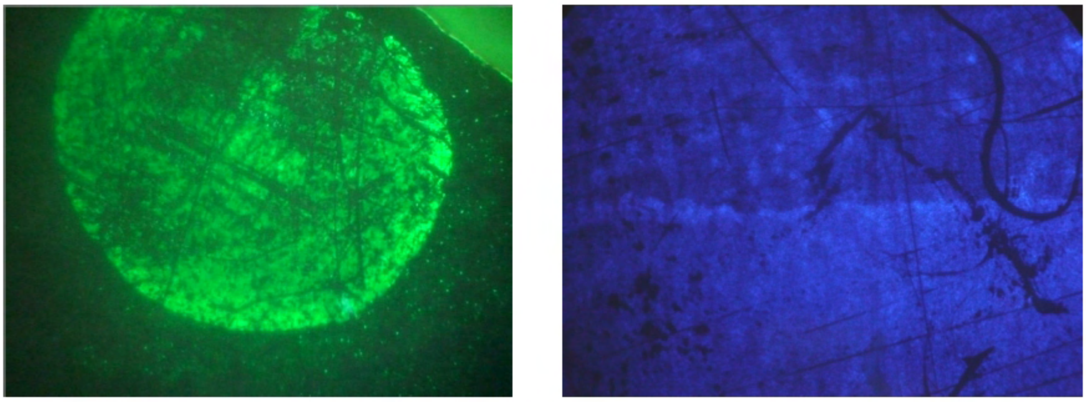


Figure 8.1: The left picture shows the photoluminescence of the 540 nm sample with a drop of gold nanoparticles. Inside the drop the photoluminescence is strongly enhanced by quantum well surface plasmon coupling. The same effect could be observed on the blue 460 nm sample (right). The lower half of the sample is covered with gold, the upper half not. The border of the mask can clearly be seen in the photoluminescence picture.

thus larger than the distance of the gold to the InGaN layer. If additionally the resonance condition between emission spectrum and plasmon frequency is fullfilled the quantum well couples to surface plasmons in the gold-GaN interface. The emission is enhanced when the surface plasmons subsequently couple to light. The inherent curvature of nanoparticles or the roughness of a gold film can efficiently scatter surface plasmons making them loosing momentum and enabling them to couple to light (cf. section 3).
The same experiment was conducted with the 510 nm and the 460 nm samples using the same type of nanoparticles. Also these two samples showed significantly enhanced photoluminescence in the area covered by gold nanoparticles. Fig. 8.1 shows a photoluminescence picture of the blue 460 nm sample, where the lower half is covered with gold. Compared to the upper half photoluminescence enhancement is noticeable.

The green 540 nm sample showed the most and the easiest to identify blinking points. Furthermore, the strongest photoluminescence enhancement was observed on this sample. For these reasons this sample was used for all the following experiments regarding quantum well surface plasmon coupling.

8.2 Changing emission pattern

To analyze the influence of the nanoparticles on the photoluminescence of the sample on a smaller scale than the size of the drop, the particles had to be moved. Through moving them their density was reduced locally and effects on small scales could be observed. For this a aceton soaked cotton bud was rubbed against the

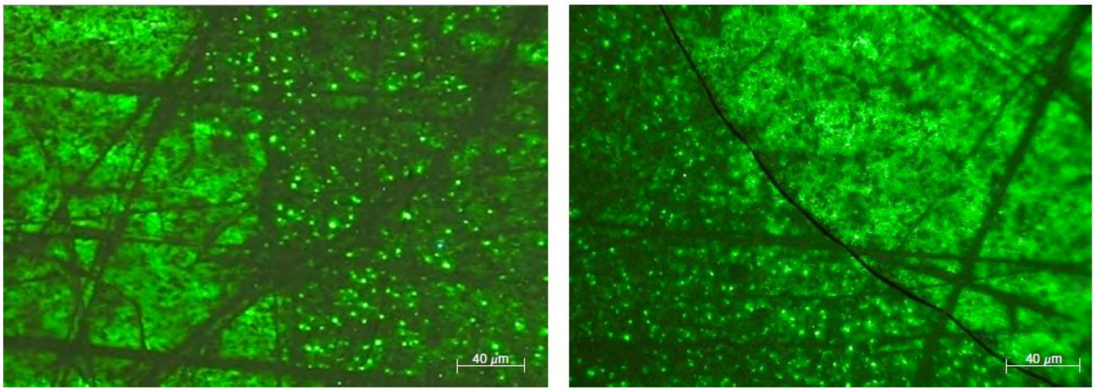


Figure 8.2: Two photoluminescence pictures at the border of a drop of gold nanoparticles on the green 540 nm sample. Outside the drop, intense light emitting centers and blinking points remain, inside the drop they dissapear in a strongly emitting area.

sample. The round strongly emitting area of the drop that could be observed before dissolved and the emission pattern changed. Fig. 8.3 shows different emission patterns after redistributing the gold with the cotton bud. Each picture is taken after rubbing with the aceton soaked cotton bud against the sample. The gold moved and the emission pattern changed strongly each time. Areas covered with gold can clearly be distinguished from 'clean' areas by their strong brightness (cf. fig. 8.1). The photoluminescence enhancement appears in form of extended areas but also in form of small points of high luminescence.

To recognize the same points on the sample, the sample was mapped. At 430 nm excitation many scratches were clearly visible. These scratches and the edge of the sample served as reference lines.

The gold strongly enhanced the photoluminescence of the 540 nm sample that shows the blinking effect, it can be moved easily and the emission pattern changes strongly. The enhanced areas can be extended large areas or only small points of high luminescence. All this are the ideal premises to test if blinking points can be created through surface plasmons.

8.3 SEM images

To confirm that the changing emission patterns were really caused by the nanoparticles scanning electron microscope (SEM) images were taken and compared with the corresponding photoluminescence pictures and movies.

The first SEM pictures where taken after cleaning the sample in aceton in a ultrasonic cleaner for 60 min. The photoluminescence picture showed bright emitting areas which were apparently due to the nanoparticles. The enhanced emission patters could still be observed. However, analysis with the SEM showed

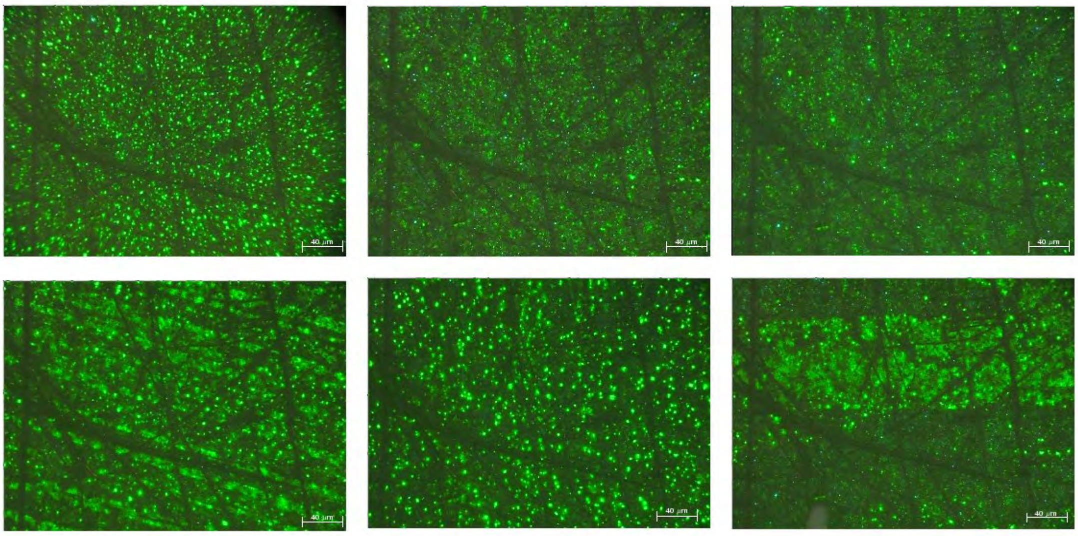


Figure 8.3: After rubbing with a aceton soaked cotton bud the emission pattern of the sample changes. The six different photoluminescence pictures were taken of the same area on the sample but the gold distribution and thus the emission pattern changed.

that no nanoparticles had remained on the sample. As a test a new drop of particles was disposed on the sample and the nanoparticles in this drop could easily be observed with the SEM. Fig. 8.4 shows the border of the drop. In the drop nanoparticles and darker spots can be seen. The darker spots are probably areas of atomic gold. The nanoparticles left 'footprints' of atomic gold on the sample (circled spots in the right picture of fig. 8.4) that have the same size as the nanoparticles.

To investigate on this dark spots, that seemed to play a crucial role in the enhancement process and the changing emission pattern, the sample was cleaned again in aceton in a ultrasonic cleaner for 60 min. By this all nanoparticles were removed. With an aceton soaked cotton bud the emission pattern could still be changed, even though there were no nanoparticles on the sample.
Further SEM analysis revealed that the gold nanoparticles did not only leave small footprints of gold on the sample. Films and extended areas of gold could be found on SEM images. The typical structure of such a gold film can be seen in fig. 8.5. The yellow point in fourth picture of fig. 8.5 has the diameter of the goldparticles and acts as a reference. The sizes of the dots of atomic gold ranged from several μm to sizes much smaller than the nanoparticles.
Quantum well surface plasmon coupling is possible in the interface of GaN with nanoparticles or a metal film. Strong enhancement was observed when the sample was covered by nanoparticles but also when it was only covered by the gold film. This shows that the photoluminescence enhancement is caused by both gold nanoparticles and the film of gold.

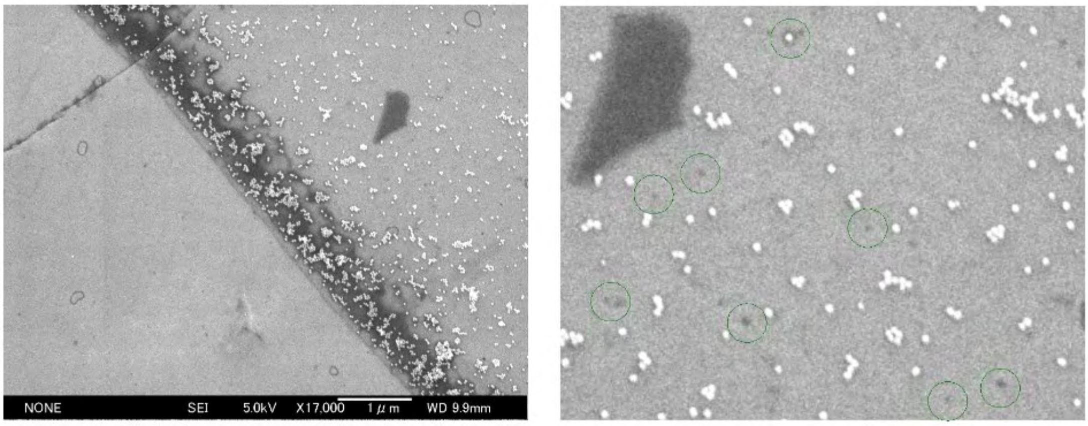


Figure 8.4: The white points show gold particles, the dark areas a gold film. The gold film is especially found at the border of the drop. The circles in the right picture show small areas of atomic gold (gold film) that have about the same area as the nanoparticles. The nanoparticles seem to leave footprints of atomic gold on the sample.

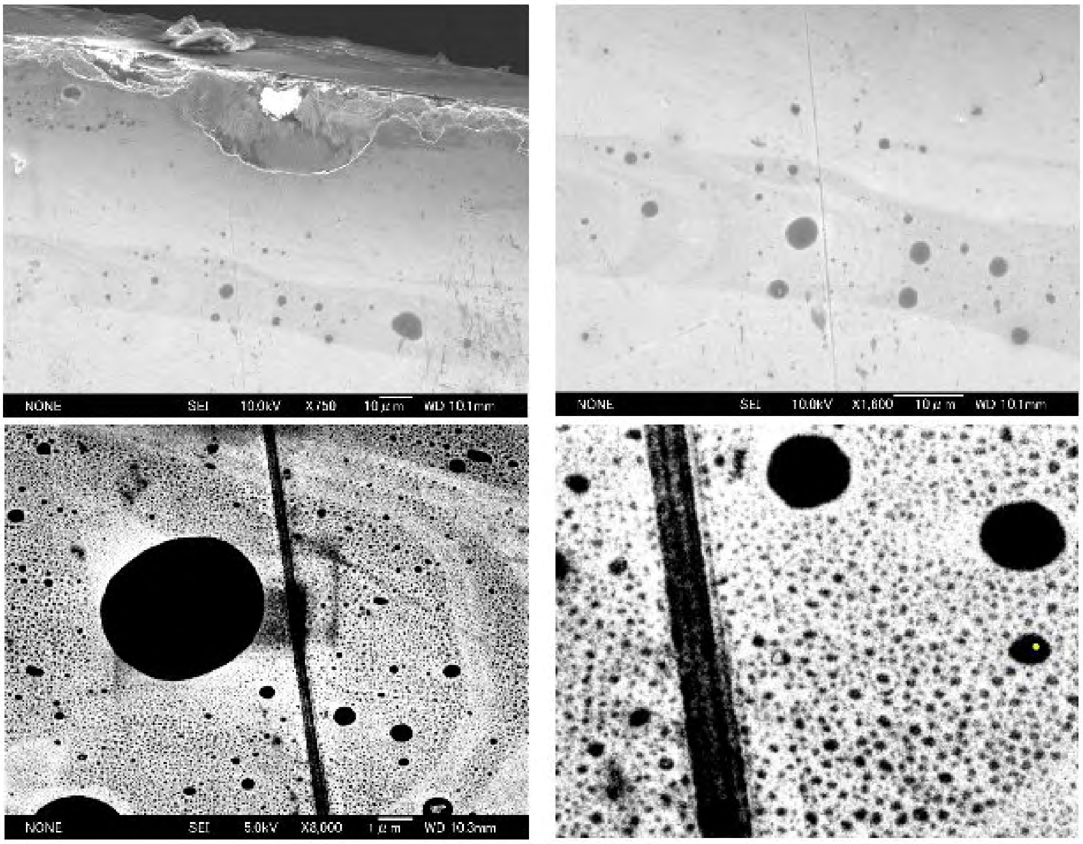


Figure 8.5: Typical structure of a gold film after redistributing the gold with a aceton soaked cotton bud. The gold film occurs in the form of dots of various sizes, ranging from several μm to sizes much smaller than the nanoparticles. The yellow point in the fourth micrograph has a diameter of 50 nm which is the size of the nanoparticles.

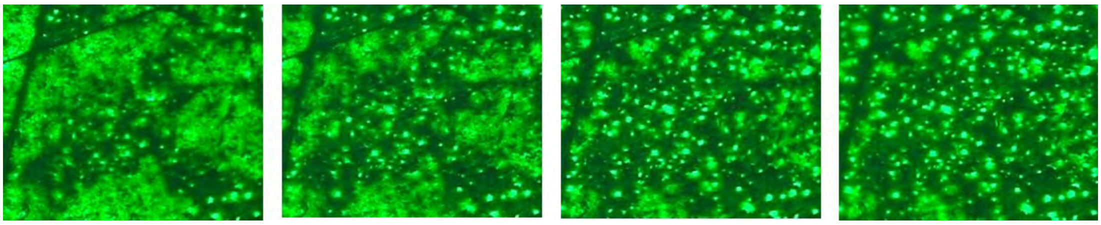


Figure 8.6: The four photoluminescence pictures show a drop of evaporating aceton on the sample and the accompanying changes in the photoluminescence pattern. The left picture was taken right after dropping the aceton, the right picture after the aceton had evaporated.

8.4 Cleaning the sample

As described above the nanoparticles themselves could be removed easily by placing the sample in aceton and a ultrasonic cleaner. After 60 min no nanoparticles could be found on the sample anymore. But SEM images showed that a film of gold remained.
This film couldn't be removed even after applying the same procedure several times. The emission pattern could still be easily changed by rubbing with a aceton soaked cotton bud. Even a evaporating drop of aceton could cause this changes (fig. 8.6). The photoluminescence pictures still showed big areas of enhanced intensity. All this were signs of remaining gold. A check with the SEM confirmed this assumption.

Even though cleaning the whole sample didn't succeed, it was possible to decrease the amount of gold significantly on small areas. For that the sample was cleaned in aceton and ultrasonic for 60 min. After taking the sample out of the aceton the remaining aceton was removed with pressurized air. If doing this before the aceton evaporated, a small area got quite clean. This method was used in the following experiments where the photoluminescence of an area with and without gold was compared.
A promising method to clean the whole sample would be the so called piranha cleaning or using turpentine.

8.5 Photoluminescence changes

The aim of the experiments described in this chapter was to investigate on the influence of the emission enhancement on the blinking points. The best experiment for this purpose would be comparing an area on a clean sample (without gold) with the same area after putting gold on it.
As described above the sample couldn't be cleaned perfectly. For this reason the experiment was conducted with a quite clean area on the sample that was created

by pressurized air. A movie file of the photoluminescence and the blinking points of this area was taken. Then the gold on the sample was moved with the aceton soaked cotton bud and a new movie file of the same area was taken, now with more gold on this area. To recognize the same area the edges and scratches of the sample served as reference points.
The comparison between the movie files before and after moving the gold (fig. 8.7, fig. 8.8, fig. 8.9) shows some interesting results.
In general the whole appearance of the emission pattern is stronger in the second pictures. More gold was moved to the observed area causing more surface plasmon enhanced emission.
Some of the intense luminescent centers that already existed were further enhanced. The circles in fig. 8.7 mark such points that appear brighter in the second pictures. Furthermore new intense emitting centers appeared in areas where they could not be observed before moving the gold. The comparison in fig. 8.8 shows an example for a new not blinking intense emitting point. In contrast the circled points in fig. 8.9 show new strong light emitting centers that blinked.
This means new blinking points could be created through the resonant coupling of the quantum wells to surface plasmons in the gold-GaN interface and the accompanying emission enhancement. This observation confirms the assumption that the blinking is caused by trapping of carriers in localized states. The local electric field of a trapped carrier deforms the quantum well and thus changes transition probability and emission intensity. New intense emitting centers were caused by the resonant coupling of the quantum well to surface plasmons in the GaN-gold interface. The inherent curvature of the nanoparticles and the rough structure of the gold film can scatter the surface plasmons reducing their momentum and enabling them to couple to light. The spontaneous emission into surface plasmons is much faster than the normal spontaneous emission of quantum wells into free space. Therefore this process enhances the emission of the quantum wells (cf. chapter 3.3). If there is a deep trap in the vicinity of such a enhanced bright point, the trapping and detrapping process of a carrier can cause the blinking.

Another observation that was made in this context is that it seems to depend on the size of the bright points if they blink or not. As already mentioned above, intense luminescent centers and blinking points disappear in an extended area of enhanced emission. Fig. 8.10 illustrates this observation. In the highlighted area of the left picture most bright points blink. This blinking points disappear in a extended area of enhanced emission in the right picture. When the blinking points get to large they stop blinking. In fig. 8.11 most bright points in the highlighted area blinked. When they got to big (right picture) they didn't show blinking behavior anymore.

The same experiments were conducted with the blue 460 nm sample. Also on this sample a enhancement of light emission due to the drop of nanoparticles had been

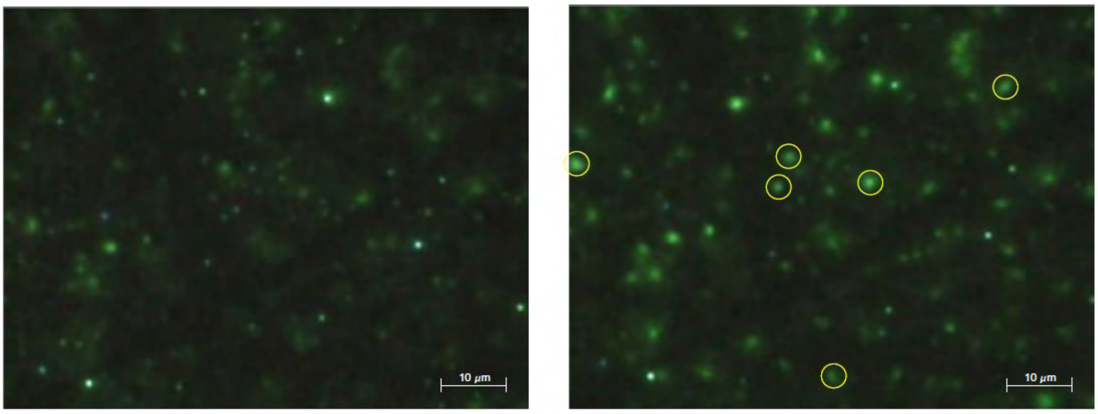


Figure 8.7: Two photoluminescence pictures of the same area on the sample. On the left with less gold than the right one. After rubbing with the cotton bud already existing intense light emitting centers and blinking points get stronger.

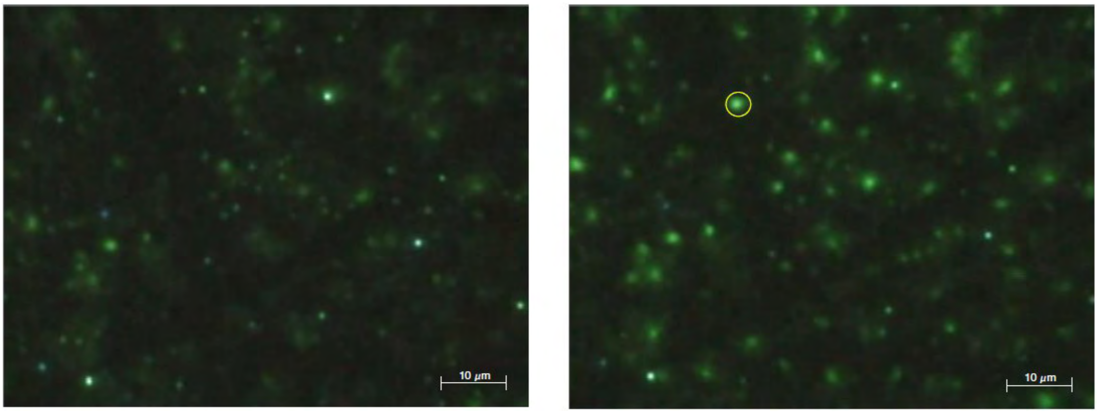


Figure 8.8: Two photoluminescence pictures of the same area on the sample. On the left with less gold than the right one. After rubbing with the cotton bud new intense light emitting centers appear.

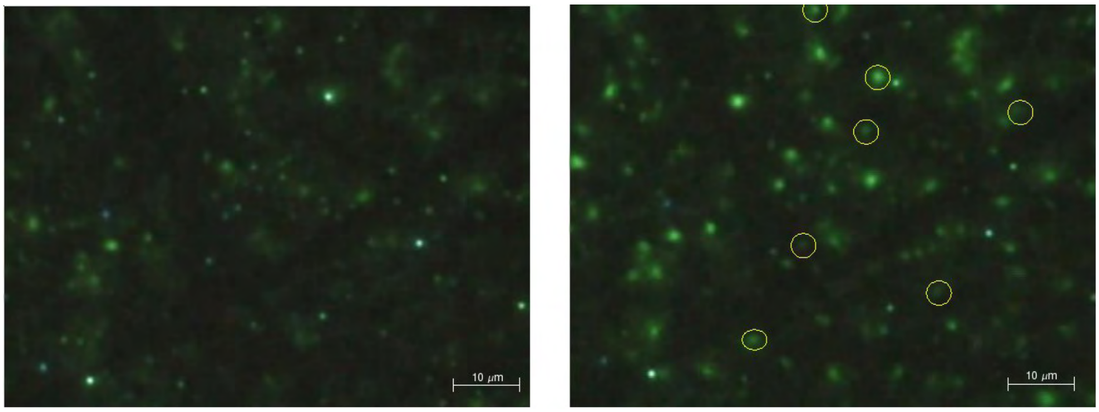


Figure 8.9: Two photoluminescence pictures of the same area on the sample. On the left with less gold than the right one. After rubbing with the cotton bud new blinking points appear.

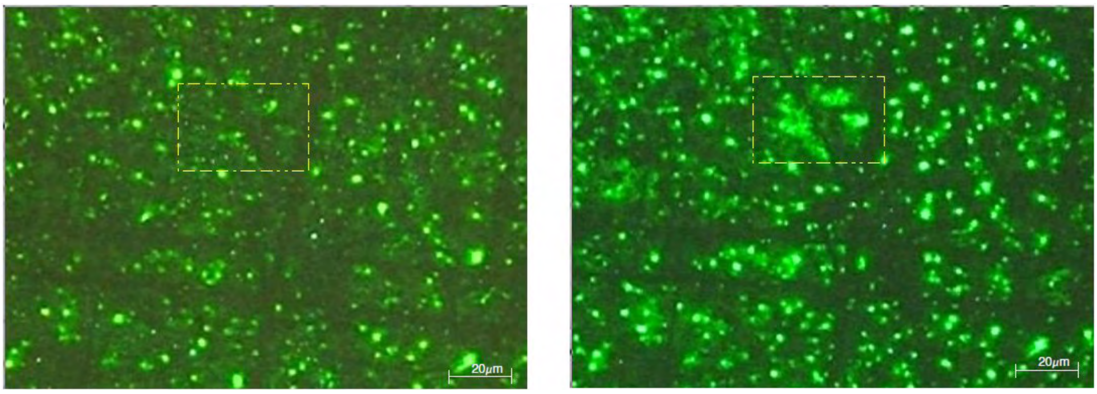


Figure 8.10: Two photoluminescence pictures of the same area on the sample, before and after rubbing with a cotton bud. In the highlighted area of the left picture a lot of blinking points can be observed. In the right picture all the blinking points in the highlighted area disappeared covered by a uniformly strong light emitting area.

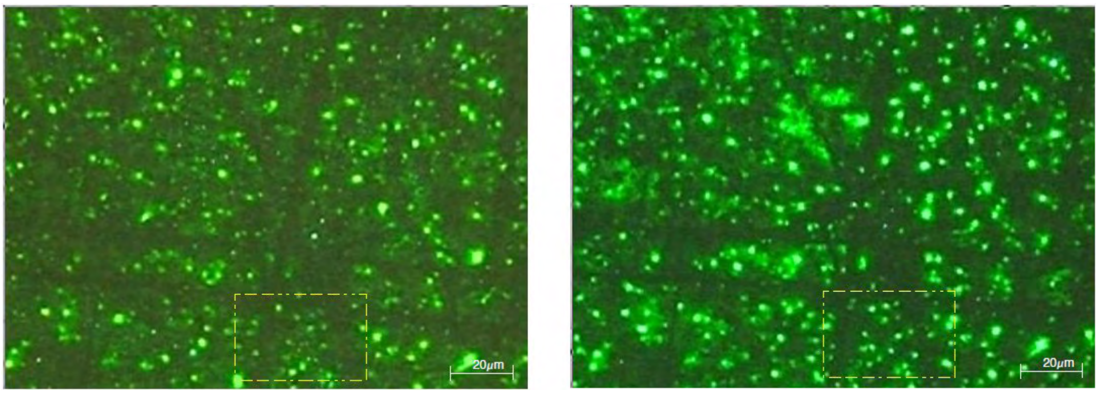


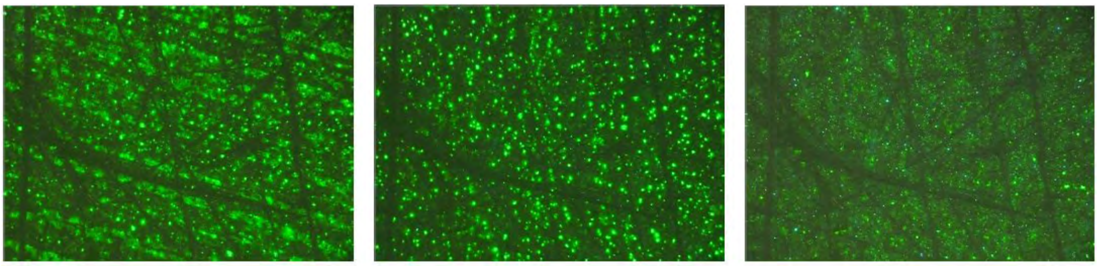
Figure 8.11: Two photoluminescence pictures of the same area on the sample, before and after rubbing with a cotton bud. In the highlighted area of the left picture a lot of blinking points can be observed. In the right picture most of the former blinking points got bigger and stopped blinking.

observed (fig. 8.1). Changes in the emission pattern after redistributing the gold could also be observed on this sample. But, as the blue sample in general shows very low density of intense light emitting centers and blinking points, no changes in the blinking behavior could be found.

8.6 Statistics on the changes

As the sample couldn't be cleaned completely a statistic on the number of blinking points before and after disposing the drop of nanoparticles couldn't be conducted directly.
Instead of that the same area on a sample with different emission patterns was observed (fig. 8.12), everytime with a gold film and nanoparticles on it but under different configurations i.e. different distribution of the film and particles resulting in different emission patterns. For that each movie was divided in squares of 10 μm x 10 μm each. In these squares the number of blinking points was counted and the density of blinking points was calculated. This was done for three different gold distributions. Fig. 8.12 shows that the average number of blinking points per area strongly depends on the emission pattern and thus on the distribution of the gold film and the nanoparticles. This dependence can be caused by two different effects. First, already existing blinking points can disappear in extended areas of strong emission. This reduces the density of blinking points. On the other hand nanoparticles or small dots of gold can locally enhance the emission and thus create new intense emission centers and blinking points. By this the number of blinking points is increased.

Another statistic on the number of blinking points was made by comparing movies



~ 3,8/1000μm^2 ~7,8/1000μm^2 ~ 22,8/1000μm^2

Figure 8.12: The three photoluminescence pictures show the same area on the 540nm sample with different gold distributions resulting in different emission patterns. The corresponding density of blinking points strongly depends on the gold distribution.

of the sample without gold to movies of the sample with gold. As the sample couldn't be cleaned this statistic could not be conducted based on subsequent videos. For this reason old videos that had been taken before the gold was dropped on the sample were used. These movies were taken at Yokohama City University and by Ruggero Micheletto at Kyoto University.

Squares of 40 μm x 40 μm were randomly chosen and the number of blinking points in these areas were counted. This was done for videos of the sample with and without gold. The histogram of the number of blinking points in the squares is shown fig. 8.13. The average number of blinking points per square is almost the same for the situations with and without gold. But in the case with gold the distribution appears broader. This is consistent with the above made observations, that blinking points can be created by dots of atomic gold or nanoparticles but can also disappear in an extended enhanced area. Problems in this statistic were that, in parts, the videos were taken under different conditions such as different excitation intensities. Furthermore the blinking points had to be counted on quite large scale which made it difficult to tell between blinking and not blinking points.

8.7 Comparisons between photoluminescence movies and SEM images

In order to confirm that the new blinking points were really due to the nanoparticles or dots of the gold film on the sample photoluminescence videos and SEM images of corresponding areas were compared. In doing so blinking points that were located at the same places as nanoparticles or dots of atomic gold were searched. The distinctive scratches that had been used as references in the photoluminescence experiments couldn't be observed with the SEM. The only noticeable reference point that could be found both with the SEM and photoluminescent microscopy

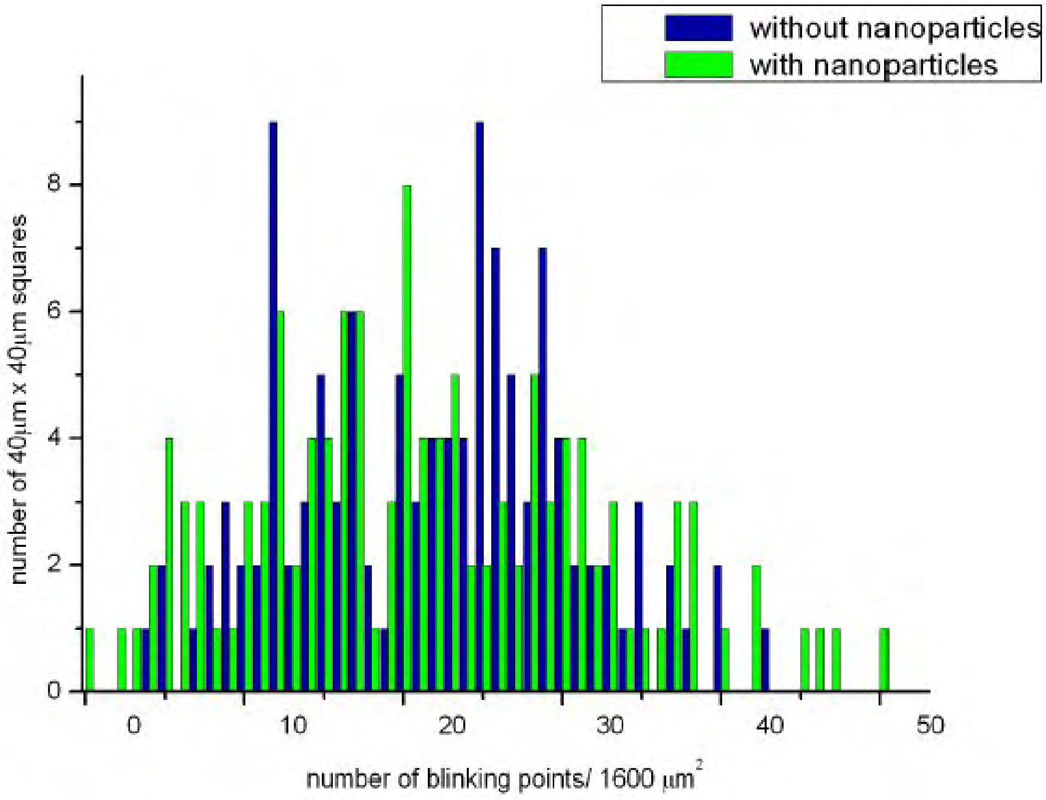


Figure 8.13: The histogram shows the number of blinking points in squares of 40 μm x 40 μm on the sample with and without gold. The average of blinking points in the squares is almost the same, but in the case with gold the distribution appears broader.

was the edge of the sample. For this reason all the comparisons were made at areas near characteristic structures at the edge of the sample. But even with these structures as references, the comparison between photoluminescence movies and SEM images remained difficult. Areas in photoluminescence videos could easily be recognized in the SEM images too, but a exact points could only roughly be located because of the fundamentally different imaging mechanisms.

As seen from fig. 8.4 gold nanoparticles and clusters of gold nanoparticles appear as white points in SEM images, whereas the film of atomic gold and dots of atomic gold appear dark. To find blinking points that are caused by either nanoparticles or dots of gold, an area of low nanoparticle/goldfilm density had to be created. Areas with high densities of nanoparticles and areas covered with an extended film of gold show overall bright enhanced emission but no intense light emitting centers and thus no blinking points. Due to the complicated surface plasmon resonance conditions and the imperfection of the quantum well not every single nanoparticle or dot of atomic gold can cause a blinking point.

However, both small dots of atomic gold and a cluster of nanoparticles were found at places were a blinking point appeared in the photoluminescence video. Fig. 8.14 shows two blinking points at the same place where two dots of atomic gold could be found in the SEM picture (dark points). Fig. 8.15 and fig. 8.16 show the photoluminescence and SEM pictures of the same area on the sample. A blinking point appears in the photoluminescence video at the same point where a cluster of nanoparticles can be found in the SEM image.

These observations support the assumption that the new blinking points are caused by plasmon resonance in the gold on the sample and that both gold nanoparticles and dots of atomic gold can create them.

8.8 Changes in vacuum

For the measurements on the temperature dependence of the blinking in section 7 the sample was put in the vacuum of a cryostat. When venting the sample chamber and removing the vacuum significant changes in the photoluminescence could be observed.

Fig. 8.17 shows the same area on the sample of 540 nm central emission with (left) and without vacuum (right). Two areas with different emitting characteristics could be observed. The uniformly emitting area that doesn't show intense light emitting centers is typical for emission enhancement by an extended film of gold. In this area no blinking points could be found. After venting the chamber the photoluminescence intensity of this area increased. The other area showed many intense light emitting centers many of which blinked. When removing the vacuum the whole pattern of bright points changed. Many of the points disappeared while other new ones appeared. The pressure was about $4.0 \cdot 10^{-5}$ mbar when the

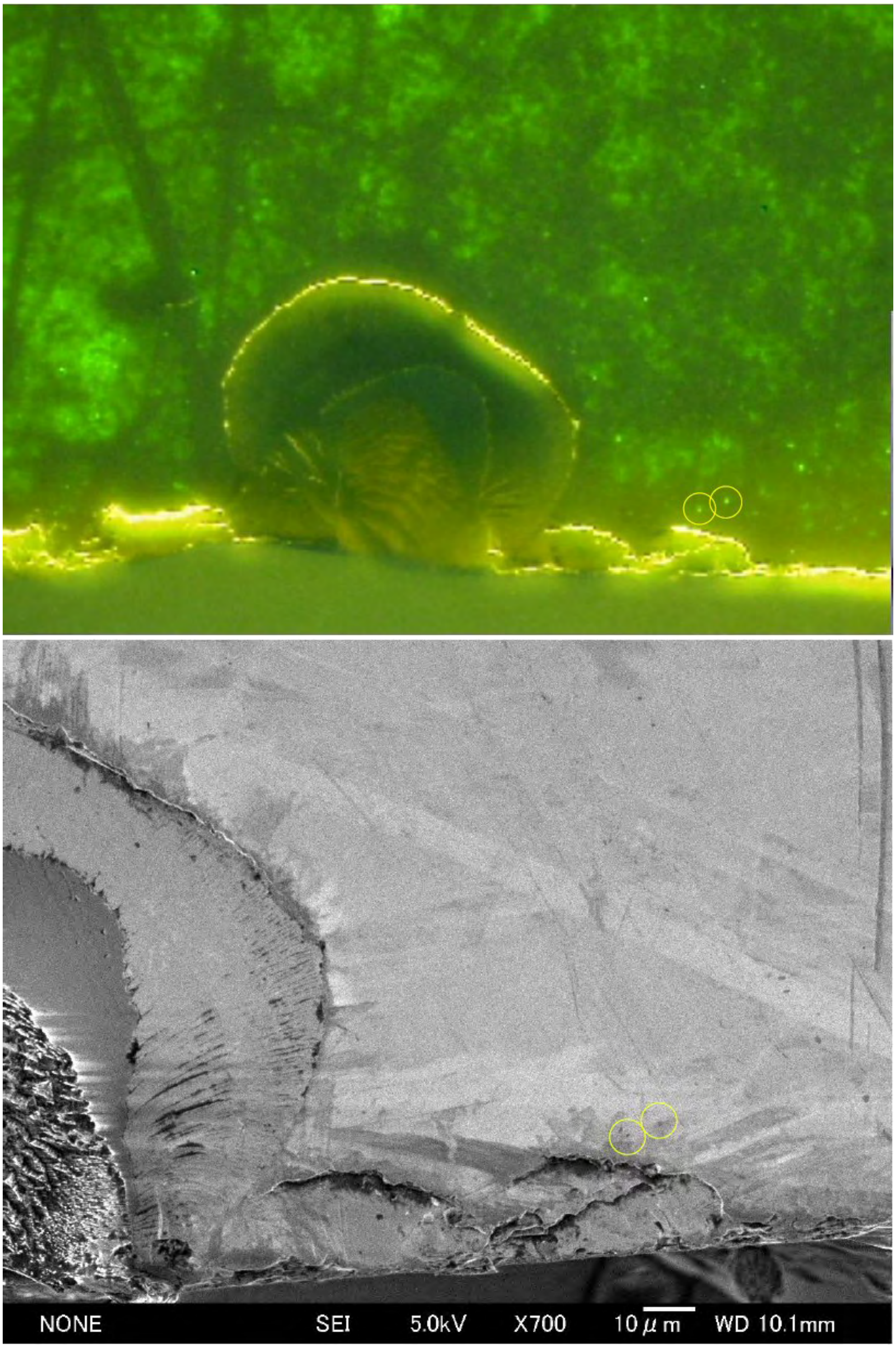


Figure 8.14: The circled points in the photoluminescent microscopy image (top) show blinking points. The same area observed by SEM shows dark spots at the same points. The dark spots indicate dots of atomic gold.

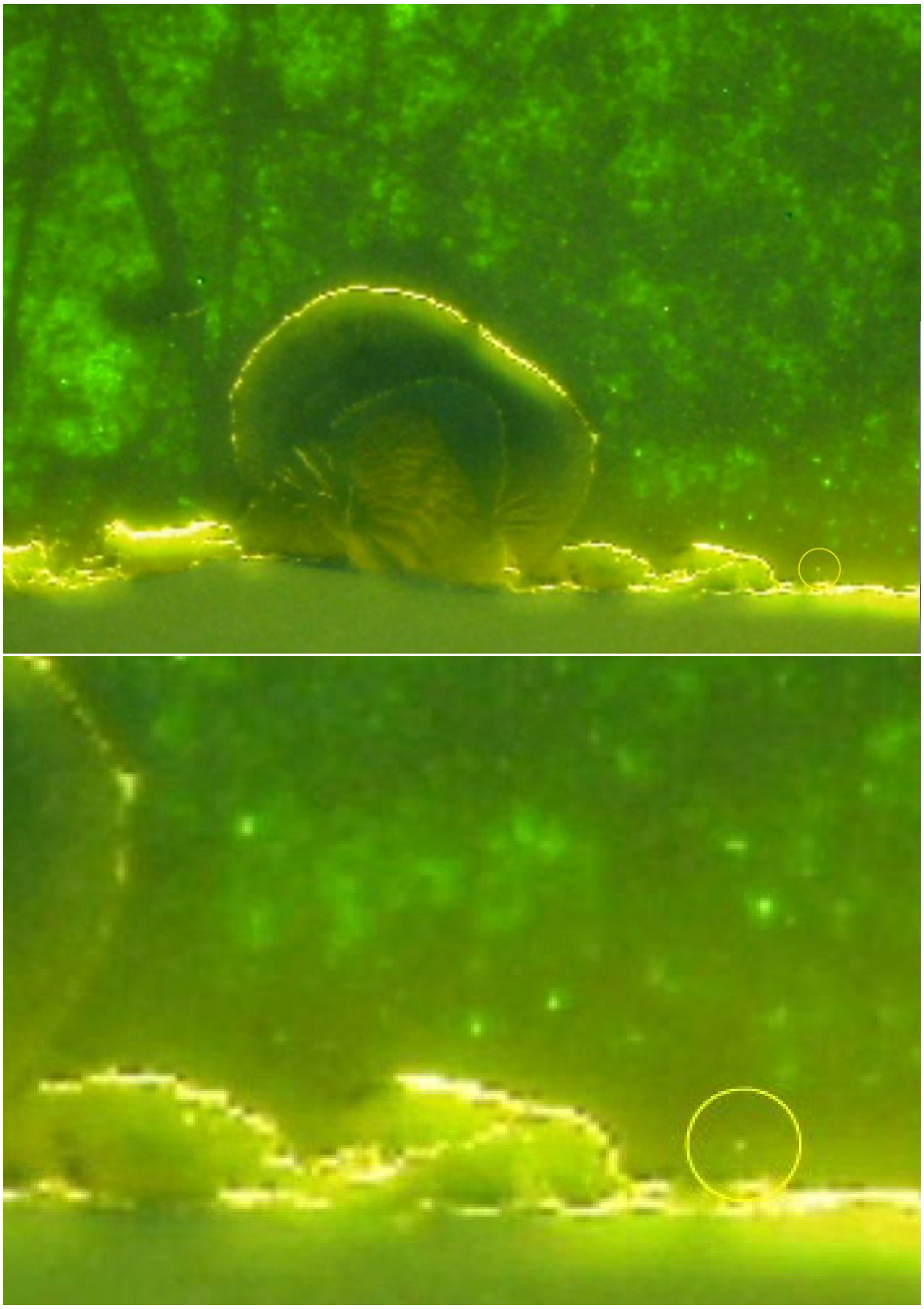


Figure 8.15: The circle in the photoluminescence microscopy image shows a blinking point at the same place were a cluster of nanoparticles can be found in the SEM image (fig.8.16)

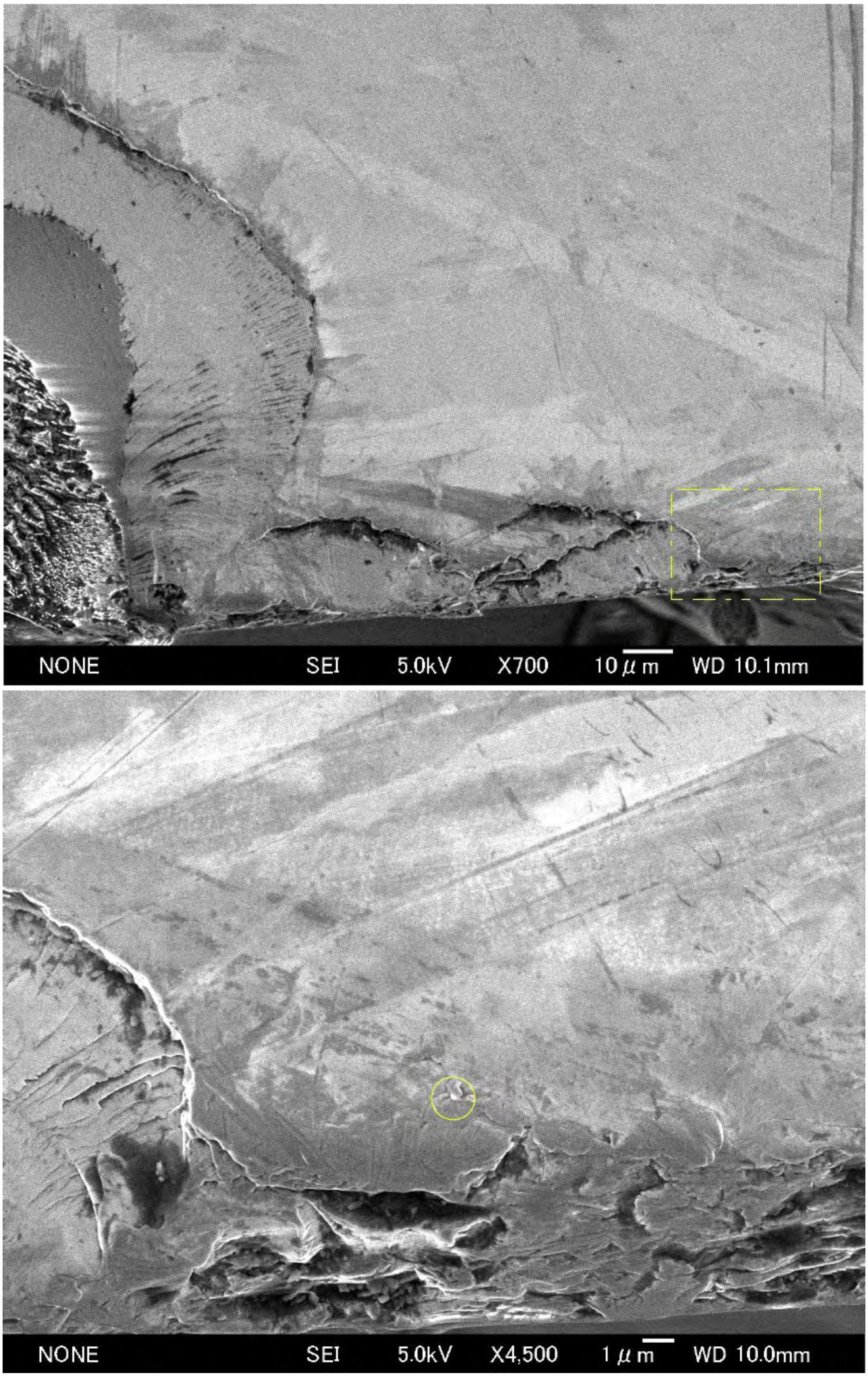


Figure 8.16: The circle in the SEM image shows a cluster of nanoparticles at the same place were a blinking point can be found in the photoluminescence image (fig.8.15)

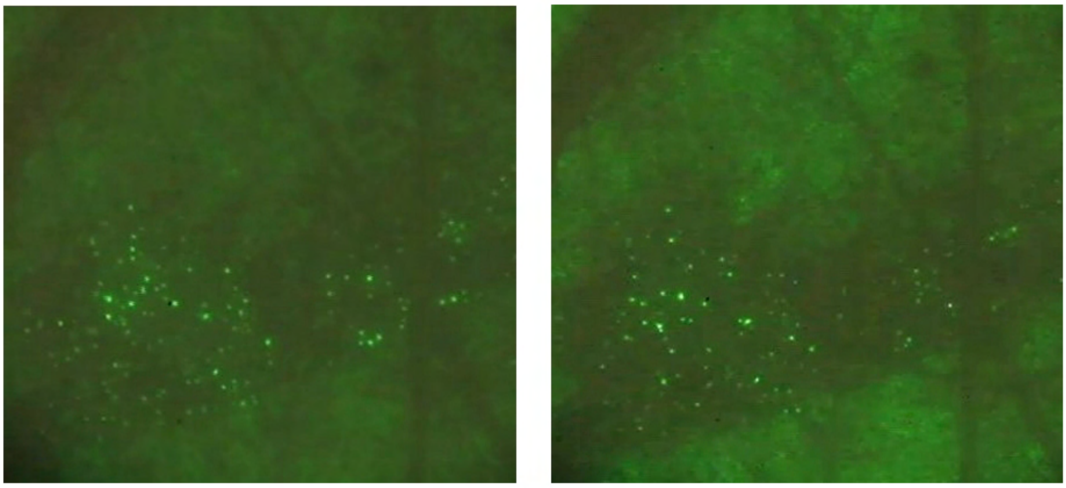


Figure 8.17: The images show the photoluminescence of a area on the sample with 540 nm central emission in vacuum (left) and without vacuum (right). The photoluminescence pattern changes. Blinking points appear and disappear.

chamber was evacuated and $1.0 \cdot 10^3$ mbar after venting.
These observations might be explained by the highly sensitive resonance conditions for quantum well surface plasmon coupling. The resonance depends on many factors such as the size and shape of the nanoparticles, the structure and thickness of the goldfilm, the distance of the metal to the quantum well and the surrounding material (section 3). The conditions can be changed when venting the vacuum chamber and could cause the observed changes.

9 Memory effect

The overall photoluminescence of the 510 nm sample changed strongly right after starting to illuminate the sample. Fig. 9.1 shows the difference between the photoluminescence when starting the excitation and after one minute of continuous illumination with the 365 nm line of a mercury lamp. The emission appears much brighter and the contrast and granularity appear more dominant in the second case. Motivated by this observation the temporal behavior after starting to illuminate the sample was studied. The measurements described in this section were conducted by Masayoshi Abiko at Kyoto University.

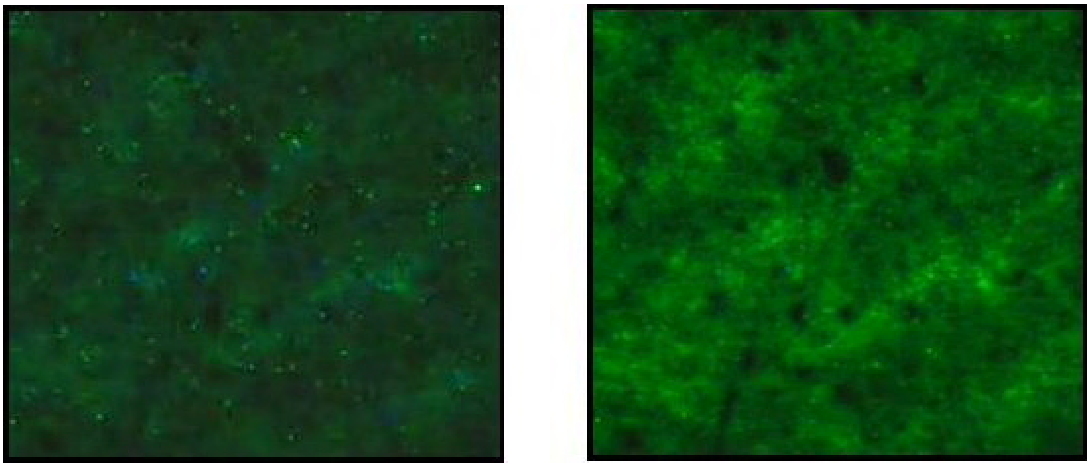


Figure 9.1: The photoluminescence of the 510 nm sample right after starting to illuminate the sample (left) and after one minute of continuous illumination with the 365 nm line of a mercury lamp (right). The overall emission appears brighter and the contrast and granularity appear more dominant in the later case.

9.1 Method

To have a closer look at the temporal behavior of the photoluminescence the experimental setup shown in fig. 9.2 was used. It consisted of a photoluminescent microscope coupled with a monochromator to observe the time-intensity profiles of the photoluminescence at single wavelengths. A CCD camera recorded the intensity changes. The samples were excited with an ultraviolet Hg lamp (365 nm and 405 nm emission lines). As the band gap of InGaN is about 3.4 eV (365 nm) and the one of InGaN is under 2.95 eV (over 420 nm), the 365 nm line excited both the GaN barrier and the InGaN active layer whereas the 405 nm line only excited the InGaN active layer. The illumination intervals could be controlled by a shutter at the mercury lamp.

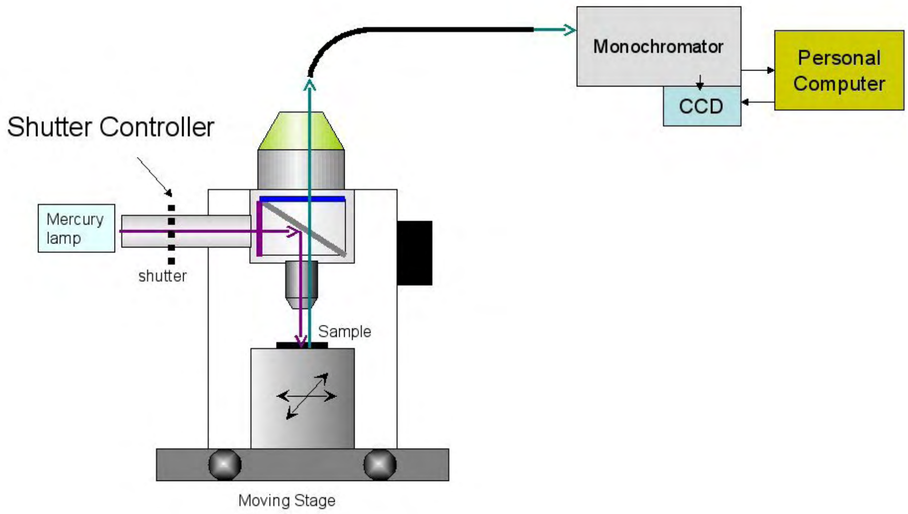


Figure 9.2: The experimental setup used to analyze the photoluminescence changes. A photoluminescent microscope is coupled with a monochromator and a CCD camera.

9.2 Photoluminescence changes

Fig. 9.3 shows the spectrum of the 460 nm centred sample. With the monochromator the temporal behavior of both the main emission peak and the yellow band was recorded. This measurement was done right after starting to illuminate the sample with the 365 nm line. Fig. 9.4 shows that the yellow band reaches a maximal value immediately, whereas the intensity of the main emission peak rises exponentially.

Exciting the sample with the 365 nm and the 405 nm line of the Hg lamp revealed that the behavior of the main emission peak depends on the excitation wavelength. When the sample was excited with 405 nm light a different behavior could be observed (fig. 9.5). The intensity reaches a maximal value and then falls exponentially.

The graphs for 365 nm excitation were fitted with

$$I = Y_0 - A_1 exp(-t/\tau_1) - A_2 exp(-t/\tau_2) \tag{9.1}$$

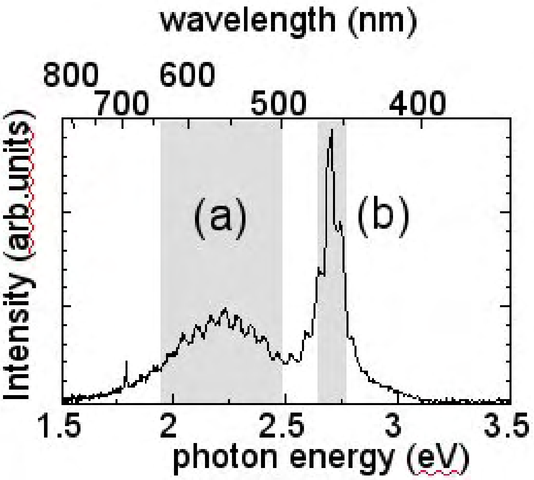


Figure 9.3: The spectrum of the InGaN/GaN sample at room temperature shows the main emission peak at about 460 nm and the characteristic yellow band.

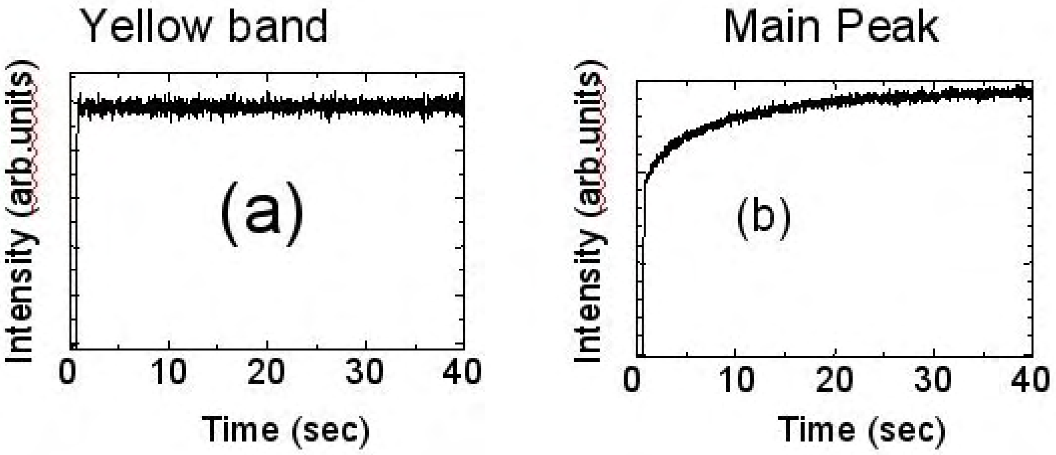


Figure 9.4: After starting to illuminate the sample with 365 nm UV light the intensity of the main peak and the yellow band showed different behavior. The yellow band reaches a maximal intensity immediately, whereas the intensity of the main emission peak rises slowly.

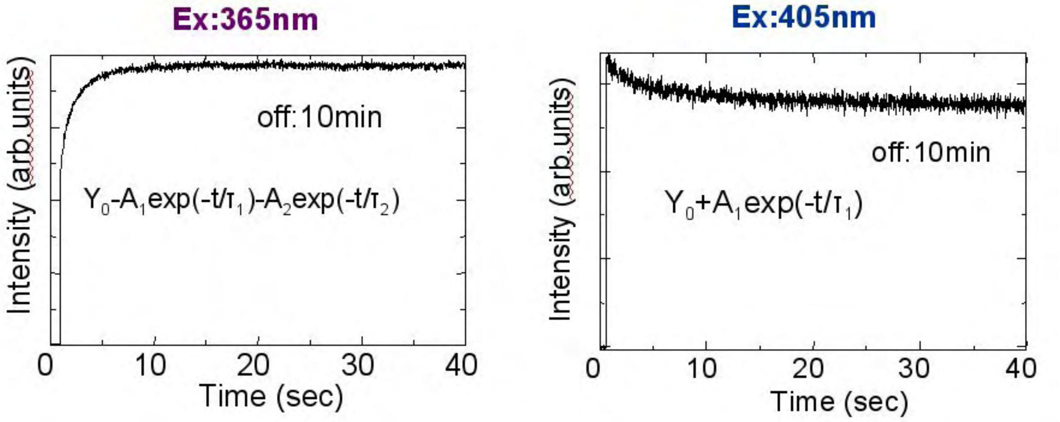


Figure 9.5: The temporal behavior of the main emission peak intensity after starting the illumination depends on the exciting wavelength. Excited with 405 nm light the intensity reaches a maximal value and then falls exponentially, excited with 365 nm light the intensity doesn't reach its maximal value immediately but rises exponentially

and the 405 nm excited ones with

$$I = Y_0 + A_1 exp(-t/\tau_1) \tag{9.2}$$

9.3 Systematic illumination interval sequence

To examine if the timeconstants depend on previous illumination and dark times a systematic illumination interval sequence was applied. Measurements of 40 s illumination periods were taken after different darktimes. A initializing darktime of 1 hour was followed by darktimes increasing in 5 min steps starting from 5 min up to 60 min. Fig. 9.6 illustrates this darktime illumination sequence. The 40 s time intensity profiles were recorded subsequent to each darktime and fitted with equation 9.2. The resulting time constants τ_1 and τ_2 were plotted in dependence of the previous darktime. Another series of measurements was done in reverse time order, starting with a darktime of 60 min down to 5 min in 5 min steps.

Fig. 9.7 reveals that the time constants of the photoluminescence rise depend on the previous darktimes. Moreover a comparison to the time inverted illumination interval sequence demonstrated that the time constants not only depend on the previous darktime but on the whole previous illumination history. The time constants in the second graph are almost double than in the first graph after corresponding darktimes. This shows a clear memory of the previous illumination history.

We think that the behavior observed in these experiments is due to carriers trapped in the quantum well that act like Coulomb barriers and inhibit recombination.

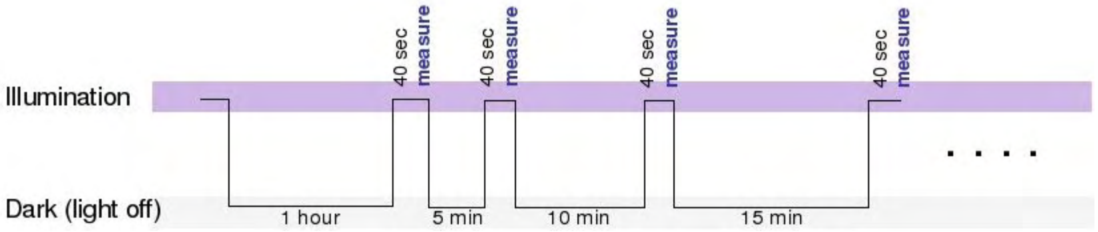


Figure 9.6: The scheme shows the systematic illumination interval sequence. After a darktime of one hour the sample was illuminated for 40 s and the temporal behavior of the intensity recorded. After that the darktime was varied from 5 min up to 60 min (5 min steps), each darktime followed by a 40 seconds measurement when the sample was illuminated. Another measurement was done in reverse time order.

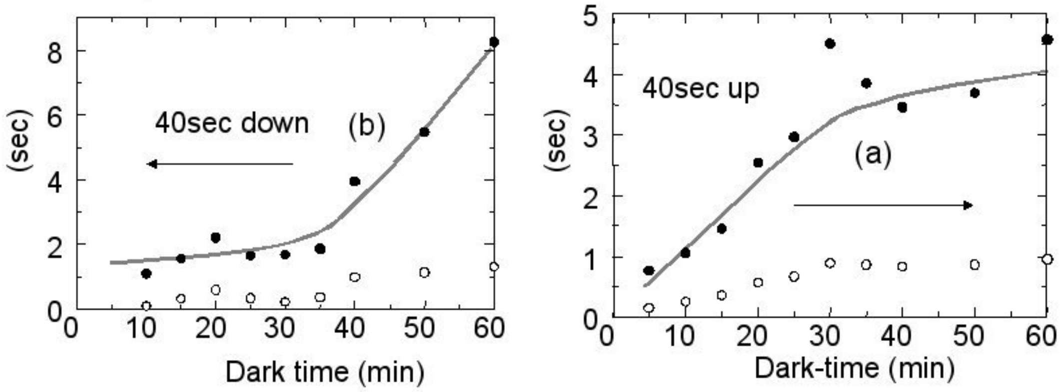


Figure 9.7: The time constants of the main emission peak excited with 365 nm light. The illumination interval sequence was conducted for darktimes from 60 min down to 5 min (left) and form 5 min up to 60 min (right). The time constants depend on the previous dark time and the whole previous illumination history.

This doesn't act within one single illumination event. It cumulates over multiple on-off sequences and thus remembers previous illumination events.

Summary

In the work presented for this thesis, we investigated on a blinking phenomenon observed in InGaN/GaN single quantum wells. The photoluminescence of quantum wells with high indium content showed strong luminescent centers. Some of these bright points were optically not stable, they blinked.

To investigate on this phenomenon we characterized the blinking behavior of different points. A small amount of points showed random telegraphic behavior switching between clear on and off states. Statistics on the time intervals spent in the on or off state revealed two different probability distributions. One distribution was exponential which could be explained by a simple quantum jump model in a three-level system, the other distribution obeyed a power law which indicated a more complex underlying mechanism. Most points however did not show telegraphic behavior but a more chaotic one without observable discreate intensity levels. There is evidence to suggest that the intensity changes are caused by the local electric field of a carrier in a deep trap in vicinity to a bright point, deforming the quantum well and thus reducing or increasing the radiative recombination rate when charged or discharged. Such an interaction of a bright spot with a single switching center results in exponentially distributed times in on and off states. The other kinds of blinking points can be caused by more complex situations like the coupling of a bright spot to several deep traps. Simulating such a situation resulted in blinking behavior without obvious intensity levels similar to the measurements.

Experiments on the temperature dependence of the blinking points showed that with increasing temperatures the switching gets faster, the off times shorter and, applying the model of the charged traps, the delocalization probability higher. At low temperatures all blinking points disappeared. The average intensity of blinking points switching between more than two levels decreased with lower temperatures, the switching occurred between less distant intensity levels.

In another experiment gold nanoparticles were put on the quantum well. The motivation for this experiment were former observations of a strong emission enhancement caused by the resonant coupling of quantum wells to surface plasmons in metal-semiconductor interfaces. Strong emission enhancement was observed and moving the gold on the sample resulted in significantly changed emission patterns. This way new intense emitting centers and blinking points could be created by means of gold nanoparticles or small dots of atomic gold on the quantum well. The quantum well resonantly couples to surface plasmons in the gold-GaN interface,

the inherent curvature of the nanoparticles and the roughness of the gold film can scatter the surface plasmons making them loose momentum and enabling them to couple to light.

In the last part of the thesis the temporal behavior of the overall photoluminescence of the main emission peak of a InGaN/GaN single quantum well was studied. The photoluminescence intensity turned out to rise or fall after starting the illumination depending on the exciting wavelength. A systematic illumination interval sequence revealed an optical memory effect. The photoluminescence temporal behavior turned out to be dependent on previous dark times and the whole previous illumination history.

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Erklärung

Hiermit erkläre ich, dass ich die Diplomarbeit selbstständig angefertigt und keine Hilfsmittel außer den in der Arbeit angegebenen benutzt habe.

Regensburg, den 20. November 2009