Acerca de la elaboración y redacción de un informe científico

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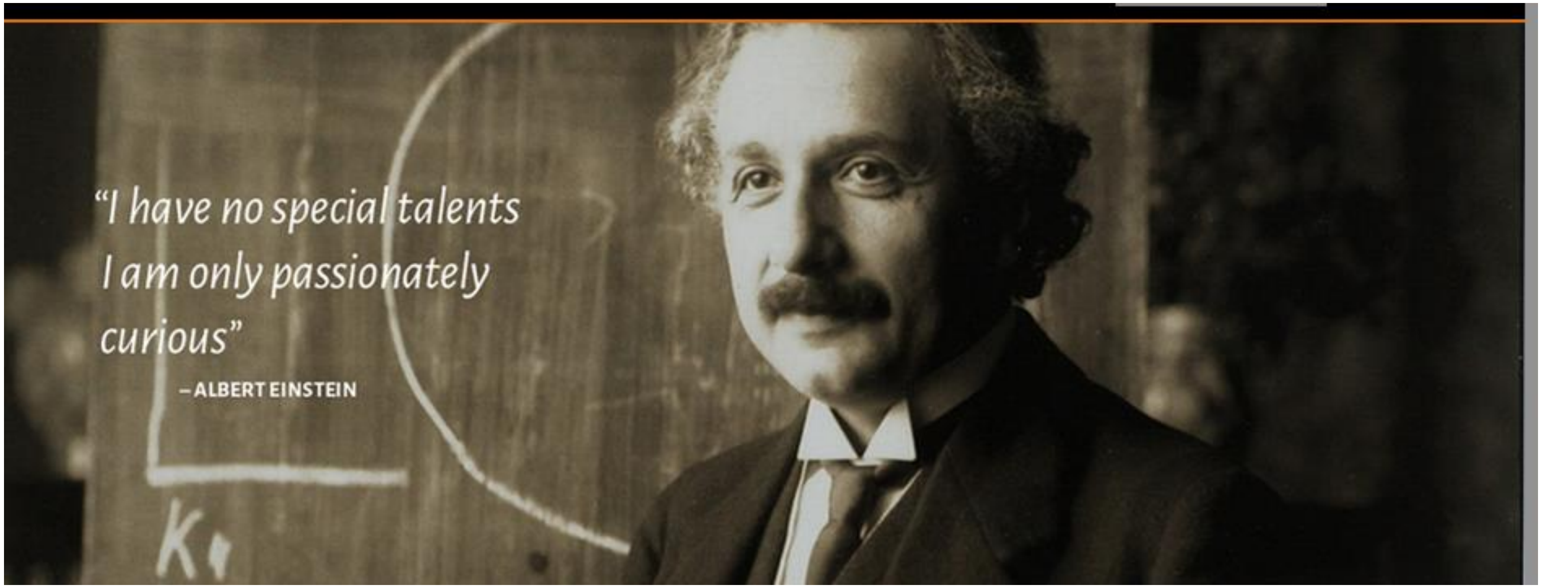
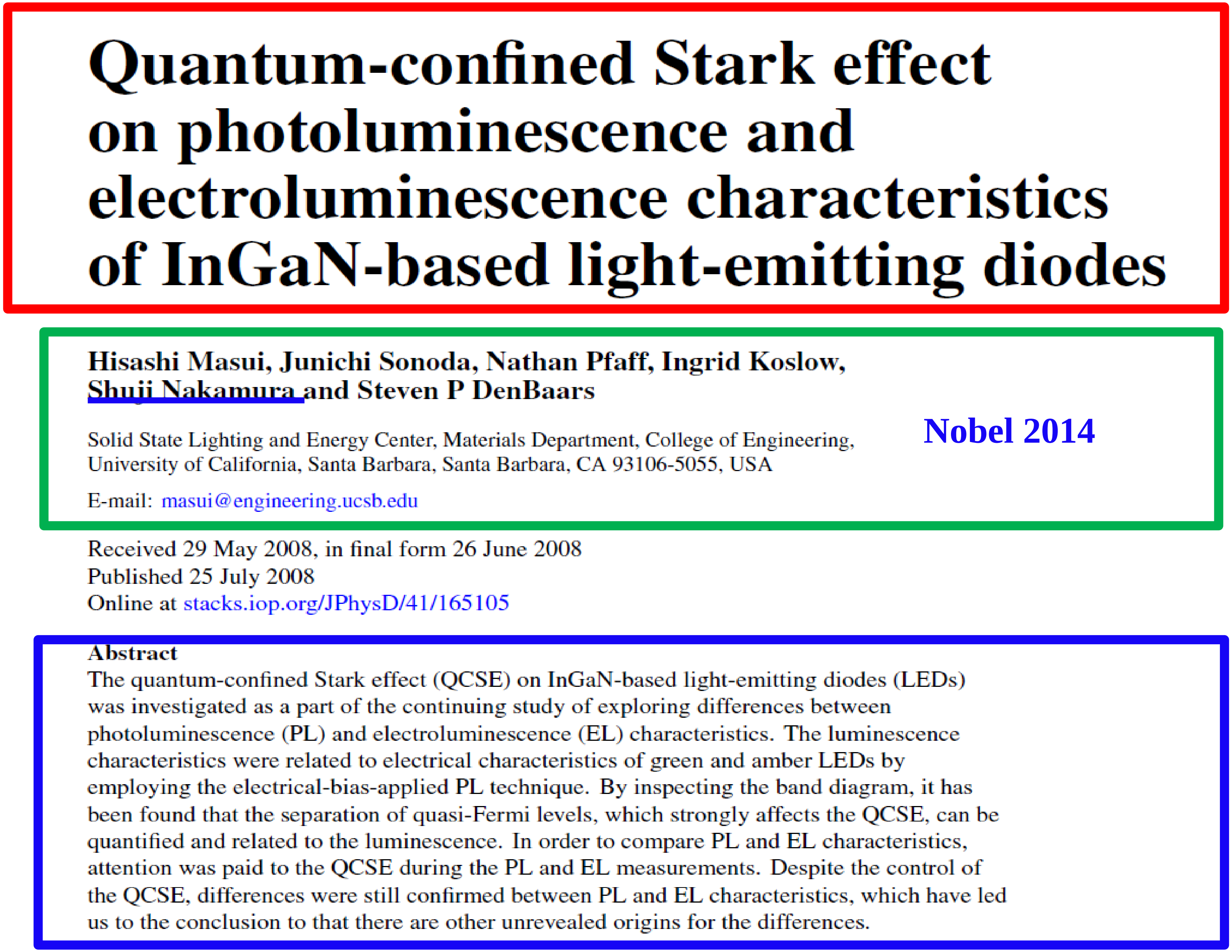
-Estructura de un artículo científico

-Elaboración de informes de laboratorio



Estructura de en artículo científico (paper)



Quantum-confined Stark effect on photoluminescence and electroluminescence characteristics of InGaN-based light-emitting diodes

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Abstract

The quantum-confined Stark effect (QCSE) on InGaN-based light-emitting diodes (LEDs) was investigated as a part of the continuing study of exploring differences between photoluminescence (PL) and electroluminescence (EL) characteristics. The luminescence characteristics were related to electrical characteristics of green and amber LEDs by employing the electrical-bias-applied PL technique. By inspecting the band diagram, it has been found that the separation of quasi-Fermi levels, which strongly affects the QCSE, can be quantified and related to the luminescence. In order to compare PL and EL characteristics, attention was paid to the QCSE during the PL and EL measurements. Despite the control of the QCSE, differences were still confirmed between PL and EL characteristics, which have led us to the conclusion to that there are other unrevealed origins for the differences.

1. Introduction

The InGaN alloy system is a candidate for solid-state green light emitters: in the green wavelength range no material systems have achieved satisfactory quantum efficiencies. Longer visible wavelengths are also goals for the InGaN system for potential monolithic multicolour/white light emitters. In addition, nitride semiconductor materials typically exhibit good stability to thermal disturbance compared with conventional AlInGaP-based red light emitters [1–3]. This advantage can be utilized for traffic lights in extreme-temperature places, for example.

Photoluminescence (PL) is a popular technique to characterize semiconductor optoelectronic materials, although apparent differences in luminescence characteristics of PL from those of electroluminescence (EL) are commonly shown [4]. The present authors are interested in exploring the differences and in organizing the cause and effect to achieve a thorough understanding of how EL is represented by PL.

We proposed an experimental technique to correlate excitation intensities between PL and EL [4], where differences were confirmed in luminescence characteristics of InGaN green light-emitting diodes (LEDs) between the two excitation methods. The origin of the differences is presumably multi-fold: luminescence depends on carrier generation and transport mechanisms [5], generated heat [6], alloy compositional fluctuations [7–9], carrier distribution in energy and in real space [10, 11], and so on. In InGaN quantum-well (QW) structures prepared on the *c* orientation in particular, the quantum-confined Stark effect (QCSE) strongly affects the luminescence characteristics [12].

This paper focuses on the QCSE. The strength of the QCSE depends on the externally applied voltage to the device structure. The pn junction, however, receives only a part of the applied voltage, so that the true reduction in the built-in voltage is usually unknown. While EL always requires an externally applied voltage, PL does not necessarily. When a PL measurement is performed on a pn-junction device, a potential

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2. Experimental details

Two types of InGaN-based LED samples were prepared via the metal organic chemical vapour deposition technique on *c*-plane sapphire substrates. They had a common multiple QW structure (six 2.3 nm thick wells). The InGaN alloy in the active layers was intended to be as homogeneous as the growth parameters could control. The In contents in the active layers corresponded to green (EL at 20 mA typically peaking at 2.43 eV with a full width at half maximum 0.134 eV) and amber (2.12 eV, 0.158 eV) light emissions. The barrier layers were binary GaN (10 nm thick) and no other InGaN layers were present in the device structures. The common etched mesa and metal contact formation techniques were applied to fabricate individual devices. The active area was 0.121 mm^2.

For the electrical-bias-applied PL measurements, a commercial fluorescence microscope was employed with a 20× objective lens [13]. Energy-selected (380–420 nm) optical excitation [14] was achieved by emission from a metal-halide lamp filtered through a V-2A standard filter cube. The LED active area was illuminated evenly. The excitation intensity was approximately 4 $\mathrm{W\,cm^{-2}}$ [4]. Luminescence was collected by an optical fibre placed at the conjugated focal point and introduced to a spectrometer where the spectra were recorded [13]. The electrical bias was applied by a commercial SourceMeter®.

The measurement sequence was as follows. Luminescence spectra were measured at selected bias voltages while

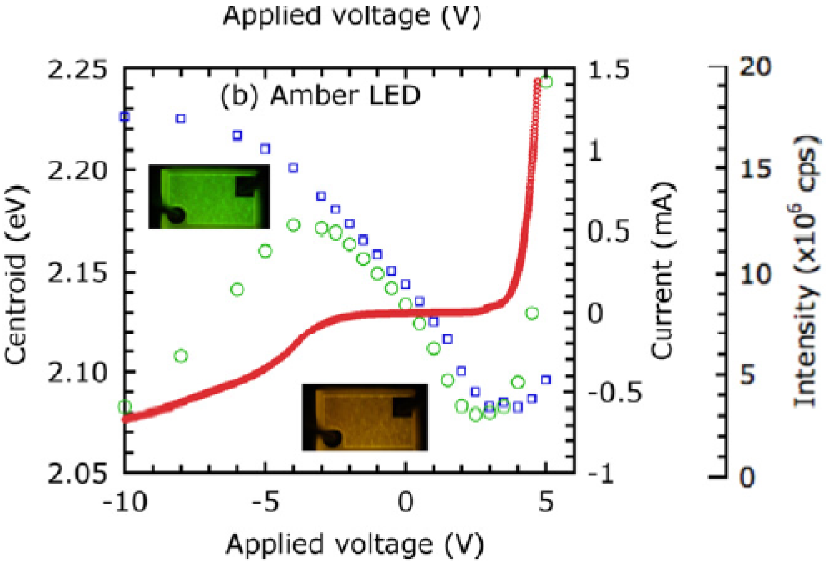

Figure 1. Luminescence and electrical characteristics of the two LEDs under illumination: (*a*) green LED and (*b*) amber LED. The inserted photomicrographs in (*b*) show the luminescence change visually: the 'amber' LED biased at −4 V (top left) and +2 V (bottom right).

reverse current), between −3 and +3 V (a plateau, constant reverse current) and above +3 V (forward current).

In the first part, it was noticed that the luminescence intensity was decreased as the voltage became more negative, as a result of increased reverse current (losing carriers from the QW). Photocarriers escaped from the QW via field emission as the apparent potential barrier became sufficiently thin [17]. It was also noticed that the plateau was extended slightly towards more negative voltages in the amber LED than in the present in the device structures. The common etched mesa and metal contact formation techniques were applied to fabricate individual devices. The active area was 0.121 mm^2.

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The measurement sequence was as follows. Luminescence spectra were measured at selected bias voltages while maintaining constant illumination. Luminescence peak shifts were evaluated by the centroid of the spectral curves by calculating the normalized first moment [15] of each spectral curve, in order to suppress external disturbances, e.g. Fabry–Pérot fringes. Luminescence intensity was determined by the spectral integration of each spectral curve. Current–voltage (I–V) characteristics [16] were measured under the same illumination, in addition to the background environment.

3. Results

The luminescence spectra were dominated by a single peak under all examined conditions. Figure 1 shows the peak shift (as the centroid) and luminescence intensity as a function of applied voltage along with the I–V characteristics.

To interpret figure 1, the voltage axis is split into three parts in terms of the I–V characteristics: below -3 V (increased reverse current), between -3 and $+3$ V (a plateau, constant reverse current) and above $+3$ V (forward current).

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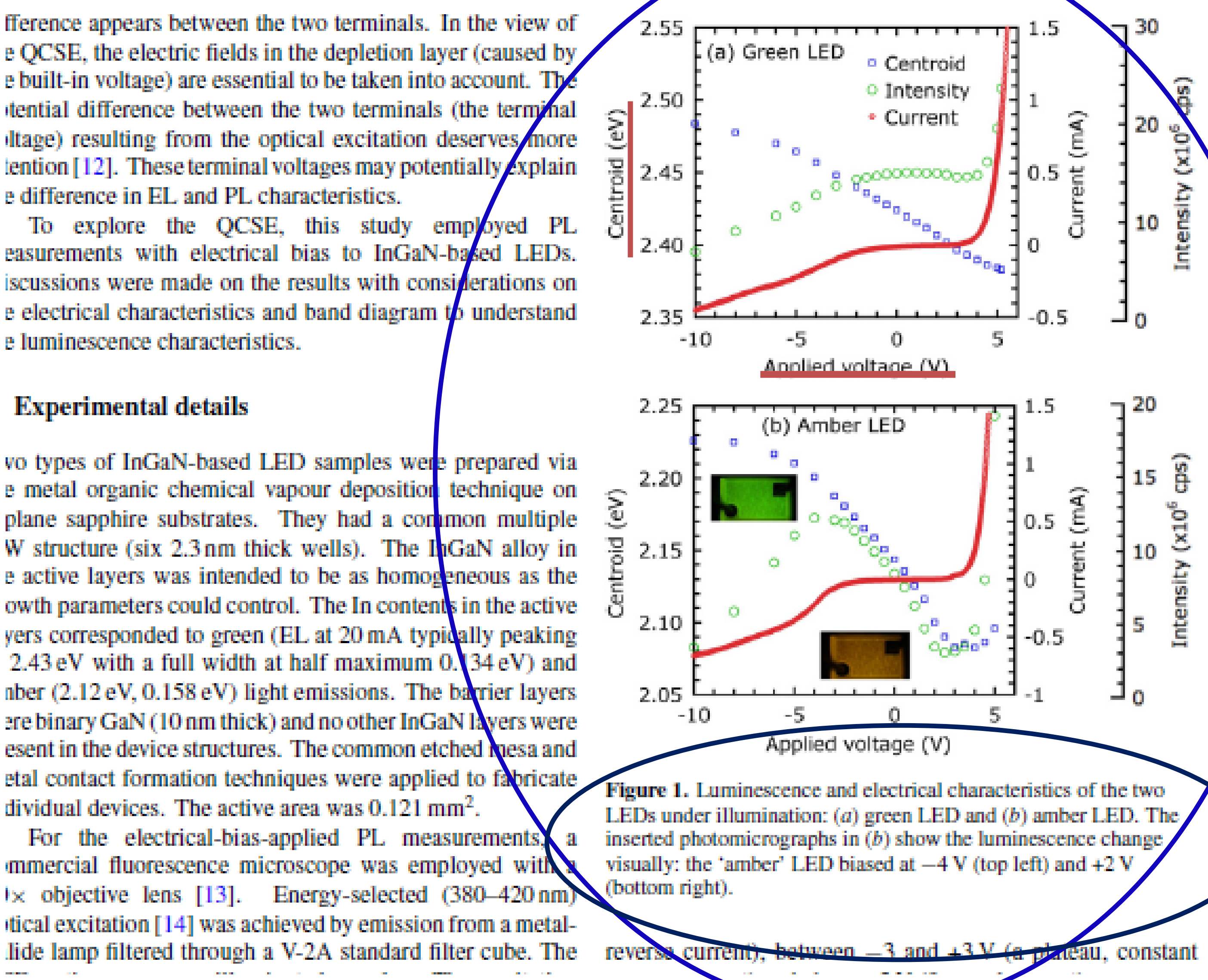
In the first part, it was noticed that the luminescence intensity was decreased as the voltage became more negative, as a result of increased reverse current (losing carriers from the QW). Photocarriers escaped from the QW via field emission as the apparent potential barrier became sufficiently thin [17]. It was also noticed that the plateau was extended slightly towards more negative voltages in the amber LED than in the green LED; this is believed to be due to the deeper QW (hence, more reverse voltages were needed to make the potential barriers sufficiently thin).

In the second part, photocarriers were mostly confined in the QW, and the current plateau appeared until the forward current started flowing at positive voltages. It was remarkable that the emission peak constantly shifted towards the lower energy in both samples. This was because of the QCSE: as the voltage became less negative (towards positive voltages), the electronic transition energy between the two ground quantum states became smaller [14]. This constant red shift signaled that the QW internal fields were strengthened, indicating their opposing direction to the depletion-layer field. Accompanied by this red shift, the luminescence intensity was reduced in the amber LED. This is believed to be due to the reduced overlap between the electron and hole wavefunctions (i.e. increased radiative recombination lifetimes). The intensity reduction

Figuras y fotos



fference appears between the two terminals. In the view of e QCSE, the electric fields in the depletion layer (caused by e built-in voltage) are essential to be taken into account. The tential difference between the two terminals (the terminal ltage) resulting from the optical excitation deserves more tention [12]. These terminal voltages may potentially explain e difference in EL and PL characteristics.

To explore the QCSE, this study employed PL easurements with electrical bias to InGaN-based LEDs. iscussions were made on the results with considerations on e electrical characteristics and band diagram to understand e luminescence characteristics.

Experimental details

vo types of InGaN-based LED samples were prepared via e metal organic chemical vapour deposition technique on plane sapphire substrates. They had a common multiple W structure (six 2.3 nm thick wells). The InGaN alloy in e active layers was intended to be as homogeneous as the owth parameters could control. The In contents in the active yers corresponded to green (EL at 20 mA typically peaking 2.43 eV with a full width at half maximum 0.134 eV) and nber (2.12 eV, 0.158 eV) light emissions. The barrier layers ere binary GaN (10 nm thick) and no other InGaN layers were esent in the device structures. The common etched mesa and etal contact formation techniques were applied to fabricate dividual devices. The active area was 0.121 mm^2.

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reverse current), between −3 and +3 V (a plateau, constant in the second part cannot be explained predominantly by the localized state model while the luminescence intensity is decreased.

4. Discussion

4.1. The band diagram

Two enlarged I–V curves (with and without illumination) of the green LED are shown in figure 2. Note that the two curves intersect near zero current. Photocarriers were responsible for the increased forward current for the illuminated I–V curve above 2.50 V. The increase in the reverse current (as the applied voltage became more negative than +2.50 V) was exponential-like; this was understood as the tunnelling of carriers being dependent on the field strength in the potential barriers approximately exponentially.

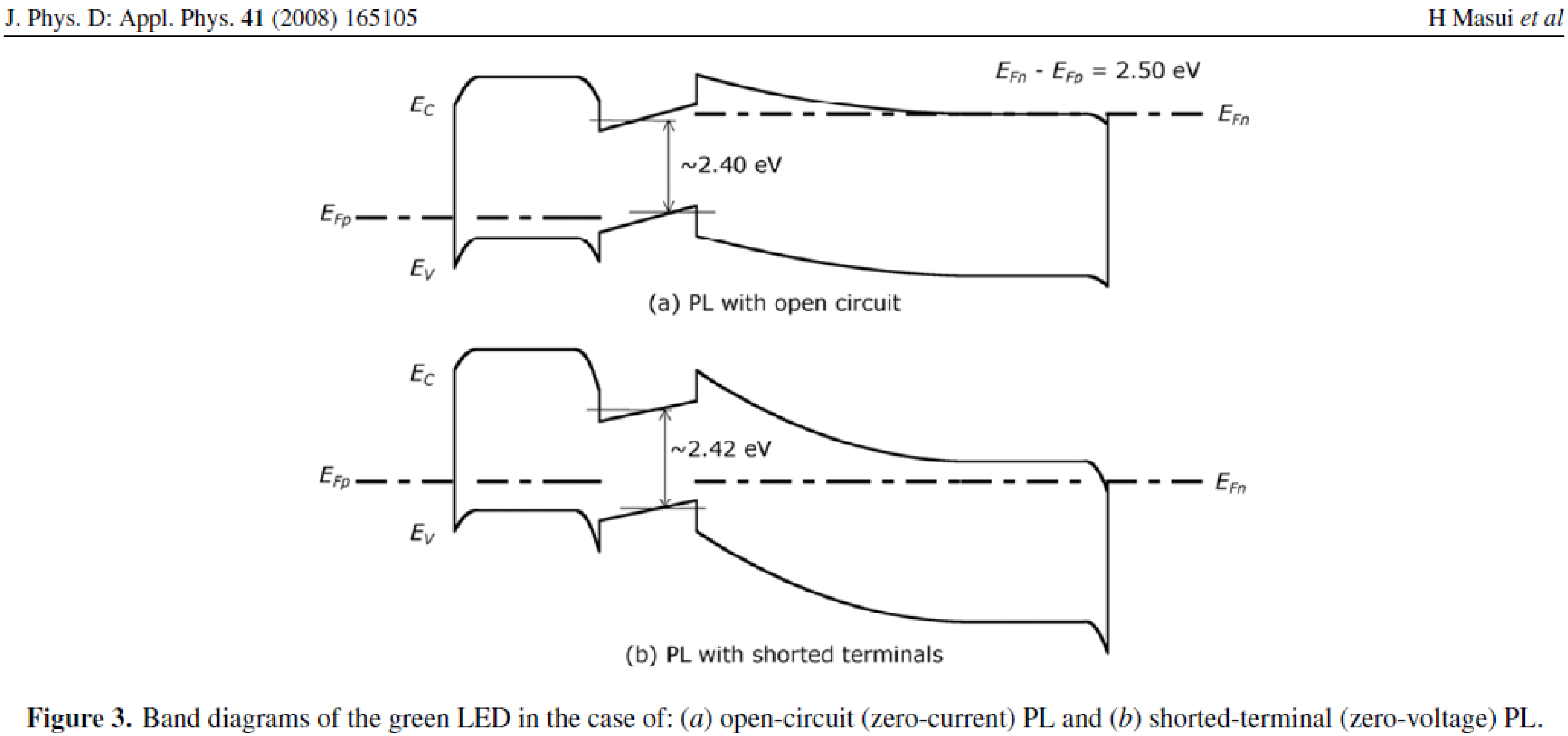
PL measurements are commonly performed on pn devices with open electrical circuits. A voltage appears between the two terminals as a result, which can be easily measured. The open-circuit PL condition corresponds to a voltage in figure 2 where the current is exactly zero, which was 2.50 V in this case. The band diagram at this terminal voltage is presented in figure 3(*a*); the band diagram has been drawn for a primitive single QW device structure to emphasize the essential point of view. Note that there are no voltage drops at the contacts or in the n- and p-type layers because no current is

PL at zero voltage (i.e. short circuit) can also be inspected. The band diagram is presented in figure 3(b). This band diagram is very similar to that at thermal equilibrium, except the fact that quasi-Fermi levels are unknown in the active region. Under conditions where optical excitation is weak enough not to raise a significant quasi-Fermi level separation in the active layer (i.e. not to screen the internal fields), the resulting luminescence contains information on the band diagram at thermal equilibrium. This short-circuit PL technique can be used to probe the QW structure at thermal equilibrium. In the present green LED case, the transition energy was represented to be 2.42 eV; the 2.50 V terminal voltage reduced the transition energy by 0.02 eV.

The amber LED is now analysed in the same way. The open-circuit PL terminal voltage was obtained to be 1.96 V. The centroid at 1.96 V was 2.10 eV. The band diagram is presented in figure 4. The centroid was 2.14 eV at zero voltage. The change in the centroid from zero voltage to zero-current voltage was 0.04 eV, which is greater than that of the green LED in spite of the smaller voltage change, because of the stronger QCSE.

The terminal voltage (1.96 V) was smaller than the centroid divided by the unit electrical charge, 2.10 V. It can be said that the electronic transition energy partially relied on thermal energy. This was, nonetheless, somewhat an inconsistent observation with what was observed on the green LED. The effects of illumination on the terminal voltage are under investigation.

Figuras esquemáticas para apoyar la discusión



J. Phys. D: Appl. Phys. **41** (2008) 165105 H Masui *et al*

Figure 3. Band diagrams of the green LED in the case of: (*a*) open-circuit (zero-current) PL and (*b*) shorted-terminal (zero-voltage) PL.

There is a depletion layer near the surface of the PL samples, where QWs may have been embedded. When PL measurements are performed on these samples, the depletion-layer fields are weakened by the photocarriers: electrons partially neutralize the space charges and holes partially neutralize the negative polarization charges at the surface. In contrast, when QWs are embedded deep in the n-type layer with a reasonably thick (compared with the depletion-layer thickness) capping layer on top, there are zero background electric fields around the QWs. Hence, these QWs do not experience the background field changes. The internal field screening may occur, nevertheless.

These two types of PL samples will exhibited different luminescence characteristics when optically excited. This may cause misinterpretations of PL characteristics when they are compared with EL characteristics of pn-device samples with 'nominally' the same QW structure; therefore, care must be paid during the experiments.

5. Conclusions

The QCSE in InGaN-based QW LEDs was the focus of this study to investigate PL and EL characteristics. The electrical-bias-applied PL technique was performed on green and amber LEDs. The results were inspected with I–V characteristic and band diagram considerations to evaluate the impact of the QCSE on the luminescence. With the knowledge of the impact, PL and EL were compared on the LEDs.

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Agradecimientos y Referencias

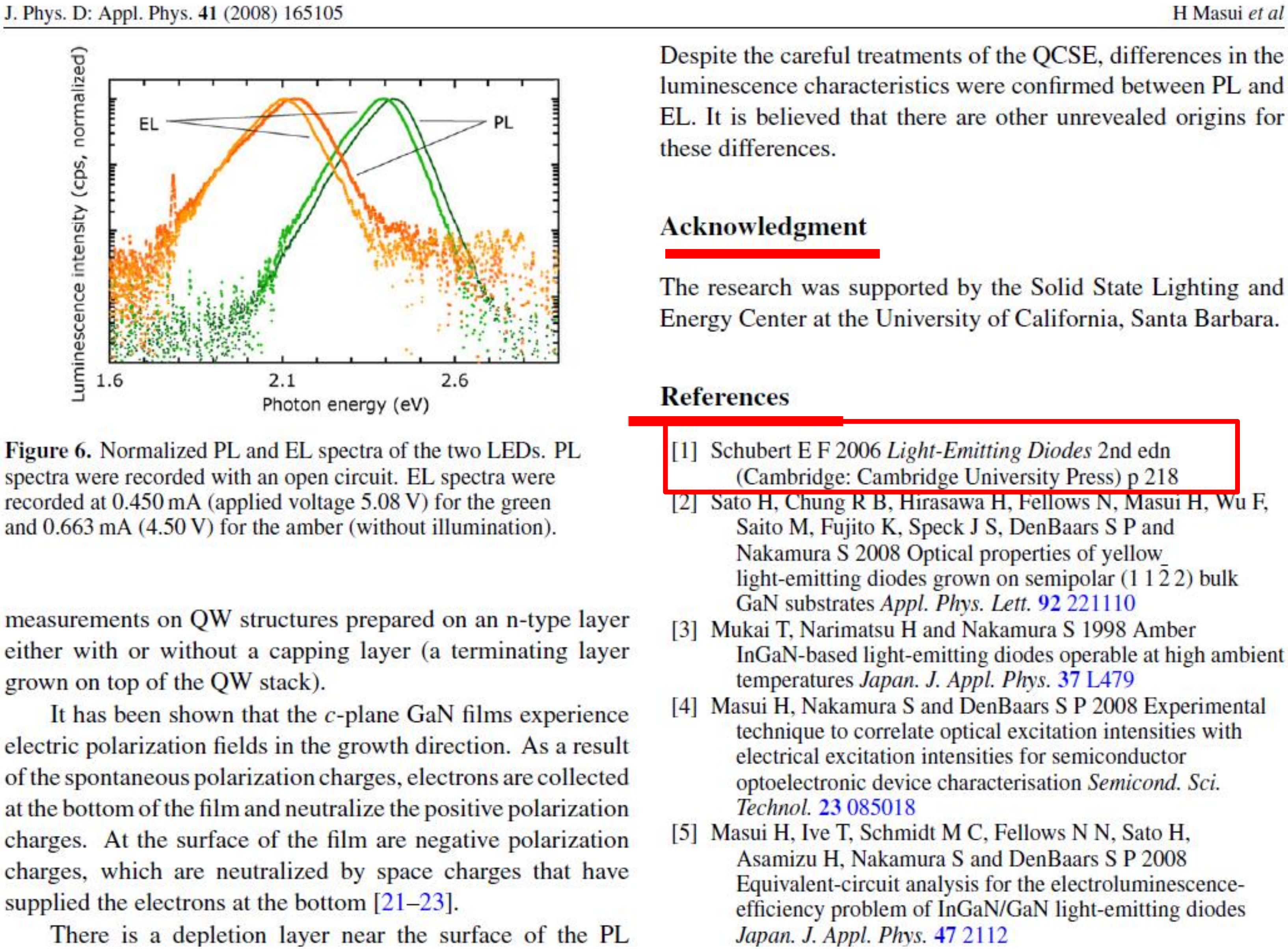

Figure 6. Normalized PL and EL spectra of the two LEDs. PL spectra were recorded with an open circuit. EL spectra were recorded at 0.450 mA (applied voltage 5.08 V) for the green and 0.663 mA (4.50 V) for the amber (without illumination).

measurements on QW structures prepared on an n-type layer either with or without a capping layer (a terminating layer grown on top of the QW stack).

It has been shown that the *c*-plane GaN films experience electric polarization fields in the growth direction. As a result of the spontaneous polarization charges, electrons are collected at the bottom of the film and neutralize the positive polarization charges. At the surface of the film are negative polarization charges, which are neutralized by space charges that have supplied the electrons at the bottom [21–23].

There is a depletion layer near the surface of the PL

Despite the careful treatments of the QCSE, differences in the luminescence characteristics were confirmed between PL and EL. It is believed that there are other unrevealed origins for these differences.

Acknowledgment

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Elaboración de informes de laboratorio

-Título

-Resumen

-Introducción

-Instrumentación (Técnicas Experimentales)

- Teoría

-Resultados experimentales y discusión

- Discusión

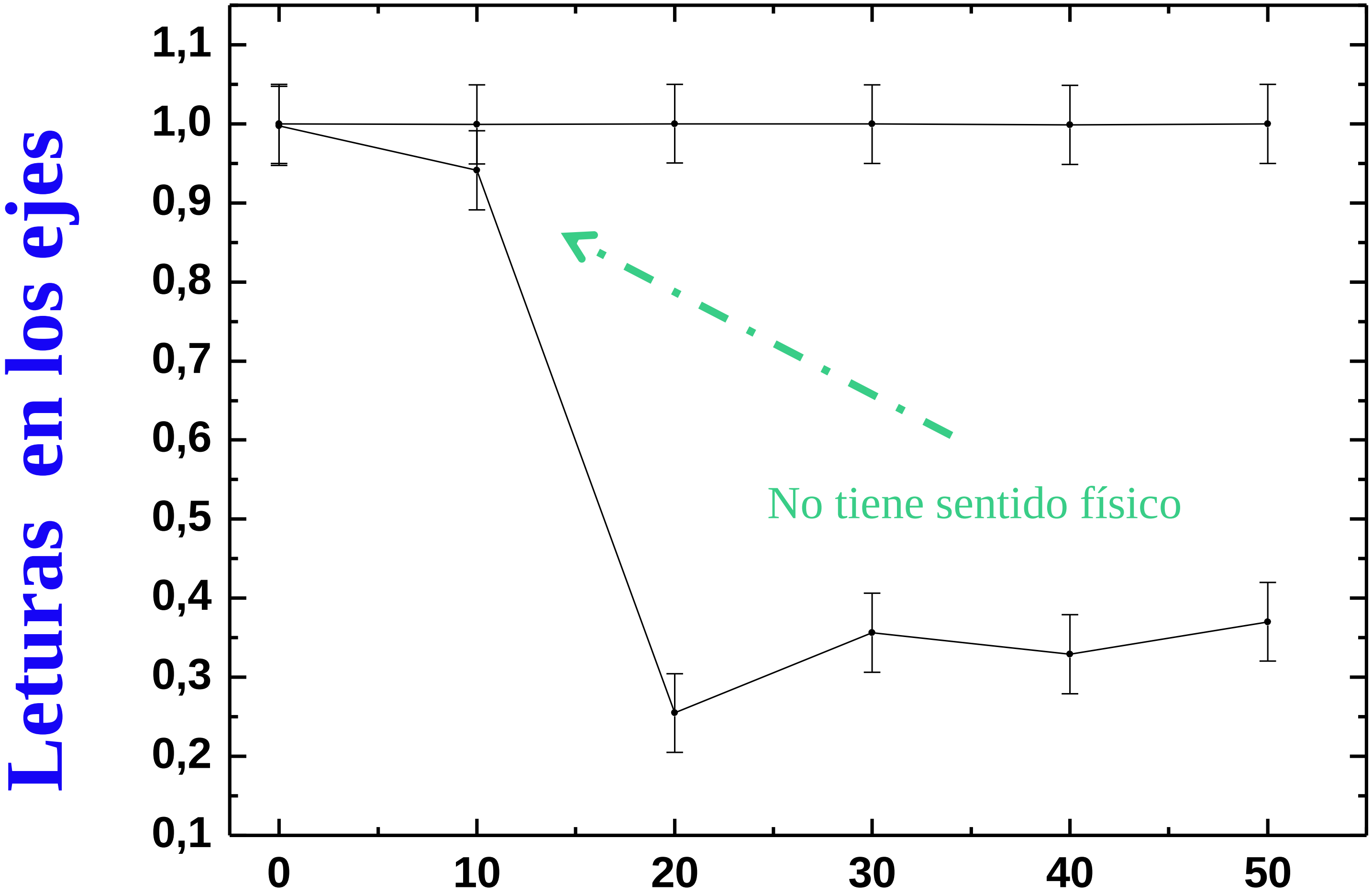
¡¡¿¿Por donde empezar??!!

-Conclusiones

-Referencias

-Tablas de datos numéricos (Gráficas)

Gráficas



No tiene sentido físico

¡¡¡Hay que hacerlas estéticas!!!

Pie de Figura. Hay 2 gráficos (a) y (b)

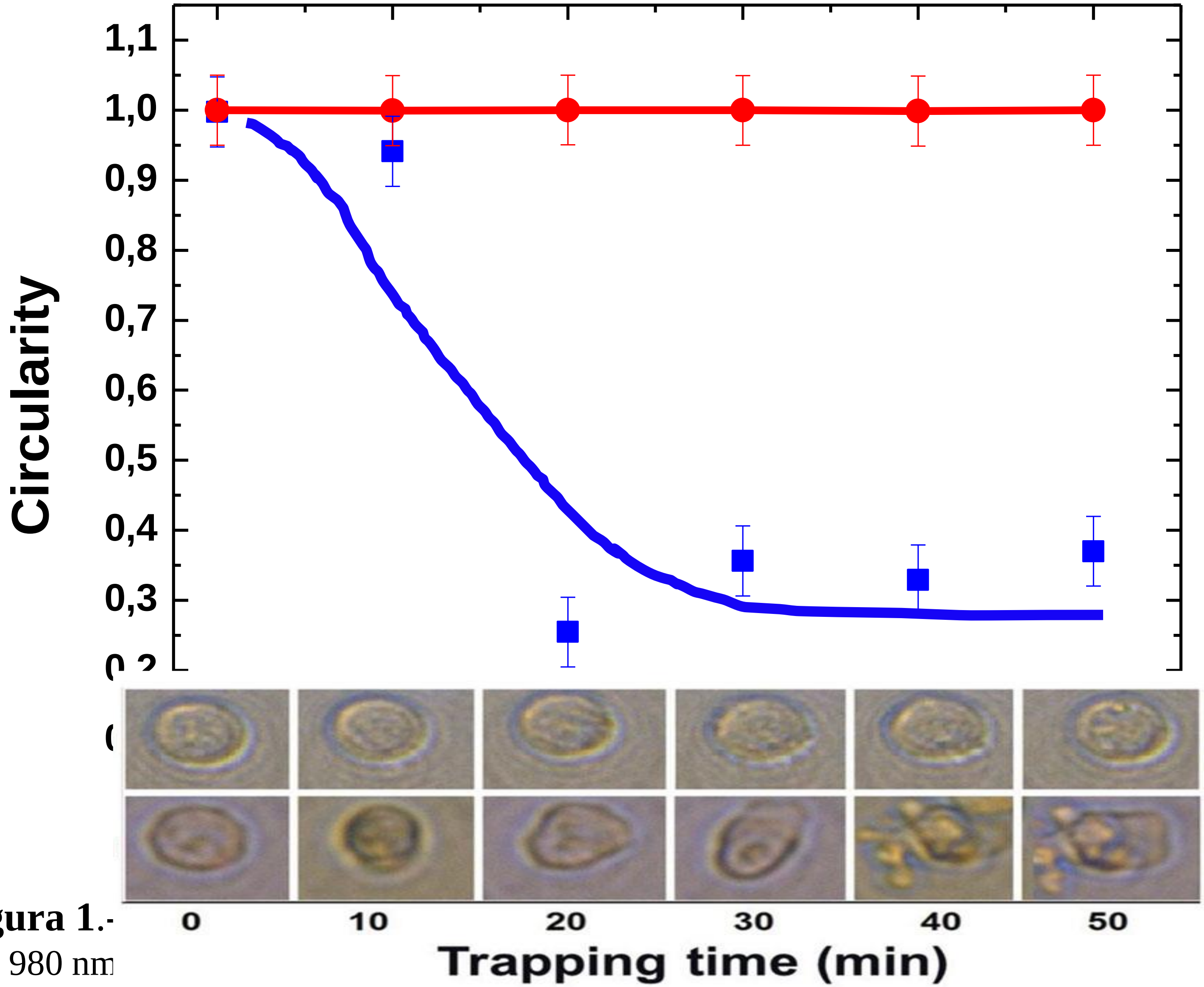


Figura 1.- nm (red)
and 980 nm

Descripción de los resultados experimentales (Inserción de tablas)

Discusión

Conclusiones

Referencias

Introducción

↓

Resumen

↓

Título y autor

↓

Lectura detallada

↓

Presentación

Presentación

Con la misma estructura y formato que un artículo científico (“paper”)