Spectroscopic Studies in InGaN Single-Quantum-Well Amber Light-Emitting Diodes

Akiko SETOGUCHI[*], Shigefusa F. CHICHIBU, Takashi AZUHATA[1], Takahiro DEGUCHI[2], Hisayuki NAKANISHI[2], Takayuki SOTA[3], Takashi MUKAI[4] and Shuji NAKAMURA[4,**]
Institute of Applied Physics, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8573, Tel:+81(298)53-5289, Fax:+81(298)53-5205,
[1]*Department of Materials Science and Technology, Hirosaki University, 3 Bunkyo-cho, Aomori 036-8561*
[2]*Department of Electrical Engineering, Science University of Tokyo, 2641 Yamazaki, Noda, Chiba 278-8510*
[3]*Department of Electrical, Electronics, and Computer Engineering, Waseda University, 3-4-1 Ohkubo, Shinjuku, Tokyo 169-8555*
4Department of Research and Development, Nichia Chemical Industries Ltd., 491 Oka, Kaminaka, Anan, Tokushima 774-8601
[*]*On leave from Science University of Tokyo,2641 Yamazaki, Noda, Chiba 278-8510, Japan*
[**]*Present address: Materials Department, University of California, Santa Barbara, CA 93106, USA*
Email: optoelec@bk.tsukuba.ac.jp

Optical properties of InGaN amber SQW LEDs were investigated to verify the importance of localized quantum well (QW) excitons in their spontaneous emission mechanisms. The internal piezoelectric field F_{PZ} across the QW was confirmed to point from the surface to the substrate. Transmittance and photovoltaic (PV) spectra exhibited broad band-tail states, and the emission lifetime increased with decreasing photon energy. The EL spectra did not show remarkable energy shift between 10 K and 300 K. The spectra exhibited an exponential tail and thier higher energy portion increased more rapidly than that of the lower energy one, reflecting a thermal distribution of the localized carriers within the tail states. Since the well thickness is only 2.5 nm, the device exhibited reasonable efficient emission in spite of the presence of F_{PZ} and large number of TDs.

Keywords:InGaN quantum well, QW exciton localization, Piezoelectric field, Effective bandgap inhomogeneity.

1. Introduction

$In_xGa_{1-x}N$ alloys are attracting special interest because they serve as an active region of UV and visible SQW LEDs and purplish-blue QW laser diodes.[1,2] It is known that the AlInGaP amber LED looses its output power by 50% with the increasing ambient temperature from 0°C to 40°C,[3] but the InGaN amber LED maintains 80% of the output power with increasing temperature from -40°C to 80°C.[3] However, InGaN SQW LEDs have two disadvantages. One is the blueshift of the emission peak with the increase of forward current. The other is that external quantum efficiency η_{ext} first increases with increasing emission wavelength from 350 nm to 380 nm and levels off at 20% then decreases steeply with further increase of the emission wavelength longer than 530 nm, i.e. x greater than 20 %.[4] These two factors are considered to be due to the presence of F_{PZ} normal to the QW plane,[5] i.e. quantum-confined Stark effects (QCSE). However, the reason why InGaN emits efficient emissions in spite of the large threading dislocation (TD) density up to 10^{10} cm^{-3} and the presence of huge F_{PZ} is still unclear at present. In this presentation, results of static, biased, and time-resolved spectroscopies on InGaN amber SQW LEDs will be shown to explore the answer to the above mentioned question. The importance of quantum confinement and quantum-disk (Q-disk)[6]-size band-tail states where localized QW excitons[7] recombine radiatively will be shown.

2. Experimental

The InGaN amber SQW LED[3] consisted of a 30-nm-thick GaN low temperature nucleation layer, a 0.7-μm-thick undoped GaN, a 3.3-μm-thick n-GaN:Si, a 40-nm-thick undoped GaN, a 2.5-nm-thick undoped InGaN SQW, a 30-nm-thick p-$Al_{0.2}Ga_{0.8}N$:Mg barrier layer, and a 0.2-μm-thick p-GaN:Mg layer. The InN mole fraction *x* of the well was difficult to determine since the x-ray diffraction intensity was too weak. It can be speculated to be nearly 30% judging from the growth conditions.

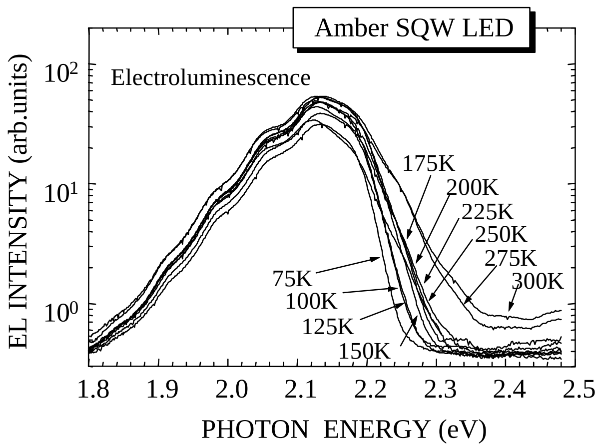

Fig. 1 EL spectra of InGaN amber SQW LED

3. Results and Discussion

The absorption structure of the amber LED is characterized by a broad absorption band extending from 2.5 to 3.3 eV. The EL peak appears its lower

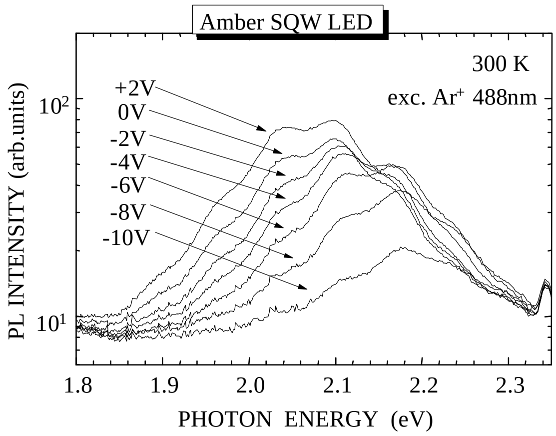

Fig.2 PL spectra of InGaN amber SQW LED as a function of external bias measured at RT.

energy at 2.1 eV, and the device exhibits large Stokes-like shift as large as 400 meV. As shown in Fig.1, the EL peak energy is nearly unchanged from 75 K to 300 K exhibiting a pronounced exponential tail. However, the EL peak shows a blueshift by up to 120 meV with increasing forward current from 0.2 mA to 20 mA. These results are explained in terms of the presence of an effective bandgap inhomogeneity and a huge F_{PZ} as follows.

To verify the direction of F_{PZ}, PL spectra of the SQW was measured as a function of external bias, as shown in Fig.2. The PL was excited with the 488.0 nm line of a cw Ar^+ laser to selectively excite the well. This method has been applied on InGaN green SQW LED.[7)] In that case, the PL peak shift was so small that we could not determine the energy shift correctly. The result meant that most of F_{PZ} was effectively screened by doped impurities and photoexcited carriers.[7)] As shown in Fig.2, the PL peak shifts to the higher energy by up to 110 meV by changing the external bias from +2V to -10V. This result suggests the presence of huge F_{PZ}, which points from the surface to the substrate. In comparison to the result for the green SQW LED,[7)] F_{PZ} in the amber SQW LED is larger than that in the green SQW LED and is not screened completely by the doped impurities. The result is consistent with the result obtained by Takeuchi *et al.*, in which they have estimated the strength of F_{PZ} in $In_{0.16}Ga_{0.84}N$ QWs to be of the order of MV/cm.[8)]

The presence of both F_{PZ} and large density of TDs is only disadvantageous for obtaining high η_{ext} from the QWs.[9)] Therefore, InGaN QWs should have another advantage to obtain sufficient η_{ext}. One is the quantum confinement, since the well thickness of 2.5 nm is smaller than the free exciton Bohr radius in InGaN QWs. The other is proposed to be a localization of QW excitons.[7,9)] As a matter of fact, the amber SQW LED shows an increasing decay time with decreasing detection photon energy in time-resolved PL measurements, as shown in Fig.3. The emission decay time at 300 K increased from shorter than 1 ns to 11 ns with decreasing detection energy from 2.5 eV to 1.7 eV, which is characteristic of a localized electronic system having an exponential density of tail states.

It is noted from Fig.1 that the higher energy portion of the EL spectra increased more rapidly than that of the lower energy one. This is considered to reflect the thermal distribution of the localized carriers within the tail states.

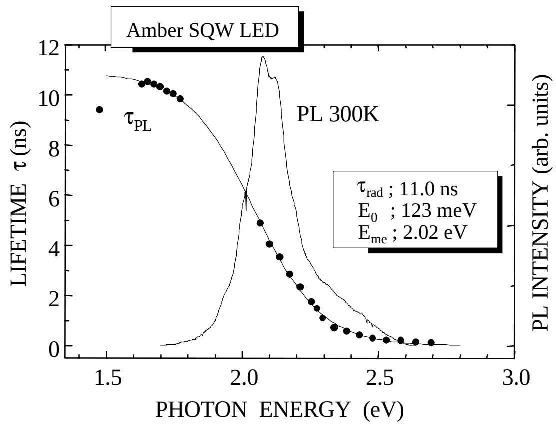

Fig.3 PL spectrum and the decay tim of InGaN amber SQW LED at 300K.

4. Conclusions

In summary, optical properties of the InGaN amber SQW LED were shown to exhibit the spontaneous emission of QW excitons localized at the band-tais states. Presence of large F_{PZ}, which points from the surface to the substrate, was confirmed by the QCSE experiments. The emission lifetime increased with decreasing the detection photon energy. Thermal distribution of the localized carriers within the tail states was suggested. The device exhibited reasonable efficient emission in spite of the presence of F_{PZ} and large number of TDs since the well thickness was only 2.5 nm, i.e. due to the strong quantum confinement.

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