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# The Characteristics of Optical Pumped GaN-based Vertical Cavity Surface Emitting Laser Structures

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**Abstract.** Time-resolved photoluminescence spectra of vertical cavity surface emitting laser (VCSEL) structures under different excitation intensity are investigated. The effect of the distributed Bragg reflectors (DBR) on the laser emission and the mechanism of multi-longitudinal-mode are analysed. A broad peak around 2.80eV is observed from the structure without DBR cavity when pumped under low excitation intensity. At higher excitation density up to 21.4kW/cm$^2$, a lasing peak appears at 2.86eV, and exhibits a rapid growth and red shift with the increase of the excitation density. The decay time of the peak is about 66ps. When the spectrum is measured after the deposition of DBR on the top side of the grown nitride structure, the number of peaks increases to 7, and the free spectral range $0.21\times10^{14}$ Hz is close to the value that calculated by the Fabry-Perot cavity length. After depositing the second DBR, multi PL peaks around 2.87eV are observed. The relationship of laser emission intensity and angle of the polarizer shows nearly a cosine square variation. However, the polarization characteristics of the four main peaks are different, which indicates that these peaks occurr by the oscillation of different optical cavities.

## Introduction

Vertical cavity surface emitting laser (VCSEL), which has features of low threshold current, good dynamic single mode, wide modulation bandwidth and high electro-optical conversion efficiency (>50%), is widely applied in optical communication, high speed optical Ethernet, CD, laser printer and other devices in optoelectronic field.

The concept of VCSEL was proposed by Professor Kenichi IGA in 1977[1], then he built the first surface emitting laser with GaInAsP material[2] and the first room temperature continuously operating GaAs series VCSEL devices in 1988 successfully.[3]. In the past 30 years, the market of VCSEL is growing rapidly, and 980, 850, and 780 nm VCSEL have been commercialized [1]. Yu Higuchi *et al* reported that room temperature electric injection VCSEL in 2008 [4]. At present most VCSEL research are focus on the device, not the physical properties of the VCSEL. In this paper, time-resolved fluorescence spectrum method is employed to study the related factors influencing the performances of vertical cavity surface laser emitting, in order to improve the VCSEL device performance.

## Experiment

A Nd:YAG mode-locked laser, after the frequency doubling to 355nm, was employed as exciting source, with pulse width of 25 ps and repetition frequency of 10 Hz. Steady-state spectra was collected and recorded by a JOBIN YVON Trax550 spectrometer, with the resolution of 0.02 nm. Transient spectrum was collected and recorded by streak camera and CCD records. When the polarizer was measured, a Glan prism was put in front of the spectrometer. Time-resolved photoluminescence spectrums of three samples are observed under different excitation intensity. Sample 1 (marked as S1) was not deposited with DBR cavity, while sample 2 (marked as S2) was the one that with DBR on the top side of the grown nitride structure and sample 3 (marked as S3) was with DBR on both side of the GaN structure.

## Results & Discussion

From Fig. 1 (a), the PL spectra of S1 under different exciting power, we can see that when the exciting power is less than 21.40 kW/cm$^2$, the broad emission peak is observed near 2.80 eV and its linewidth is 187 meV. As the exciting power increasing to 21.40 kW/cm$^2$, a peak with linewidth of 20meV shows up near 2.862eV. And this peak enhances, when the exciting power increases to 56.66 kW/cm$^2$. Look closer, its position shifts down to 2.857 eV and its linewidth increases to 48 meV. This phenomenon fits the characteristics of electron-hole pair (EHP)'s recombination. The redshift is due to the energy band's contraction [5].

Fig. 1 (b) shows S1's decay curves of the two peaks at 2.78 eV and 2.86 eV, the exciting power is 1.05uJ. Each decay curve can be fitted with two exponentials, such as $I \sim A_1\exp(-t/\tau_1) + A_2\exp(-t/\tau_2)$, with two decay times of $\tau_1$ and$\tau_2$. The fast decay time of the peak near 2.86eV is about 66 ps, shorter than 155 ps of the peak near 2.78 eV.

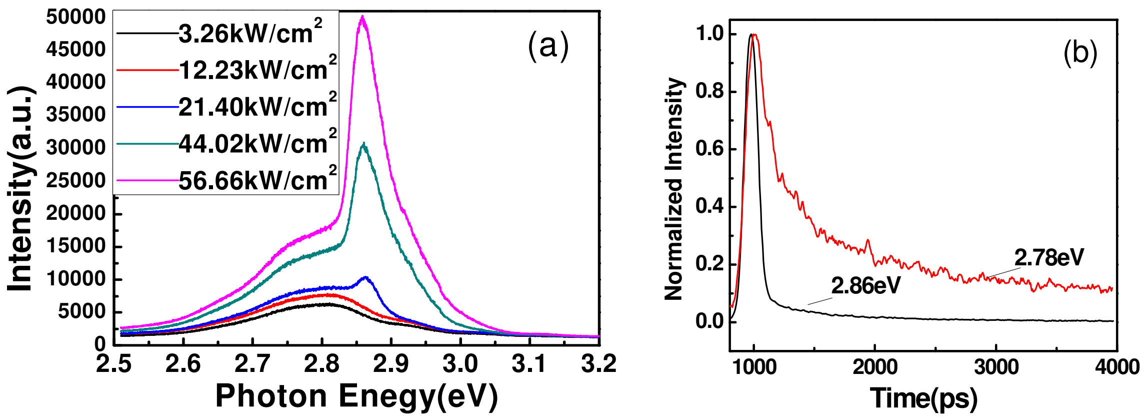


Fig. 1 (a)PL spectra of the sample without DBR cavity in different exciting power (b) the decay time of different peaks

For S2 the sample that the DBR was deposited on the top side of the grown nitride structure, when the exciting power is 50.54kW/cm$^2$, seven peaks show up at 2.61 eV, 2.69 eV, 2.78 eV, 2.86 eV, 2.94 eV, 2.99 eV and 3.03 eV, and the peak near 2.78 eV is the big peak. The emission intensity increases as the exciting power increases. When the exciting power increases to 129.6 kW/cm$^2$, the peak near 2.86 eV enhances quickly that replaces the peak near 2.78 eV and it becomes the big peak.

With the frequency equation $\upsilon = c/\lambda$, frequency spacing between these peaks is obtained: $\Delta\upsilon = 0.21\times10^{14}$ Hz.

And there is such a formula:

$$\Delta\upsilon_q = \upsilon_{q+1} - \upsilon_q = \frac{c}{2nL}. \tag{1}$$

where n is the refractivity and L is the cavity length. For the refractivity of GaN is 2.67 and the cavity length is 2332nm (the length between the DBR and substrate), the frequency spacing of the longitudinal mode in the cavity can be obtained: $\Delta\upsilon = 0.23\times10^{14}$ Hz, which is close to the experimental result. This reflects that the DBR near surface and the substrate amounted to a Fabry–Perot cavity, and the peaks show up in S2's photoluminescence spectra are the modes in the cavity. The fast decay time of the peak near 2.86 eV is about 25 ps reaching to the resolution limit, while that of the two peaks near 2.77 eV and 2.68 eV are over 100 ps.

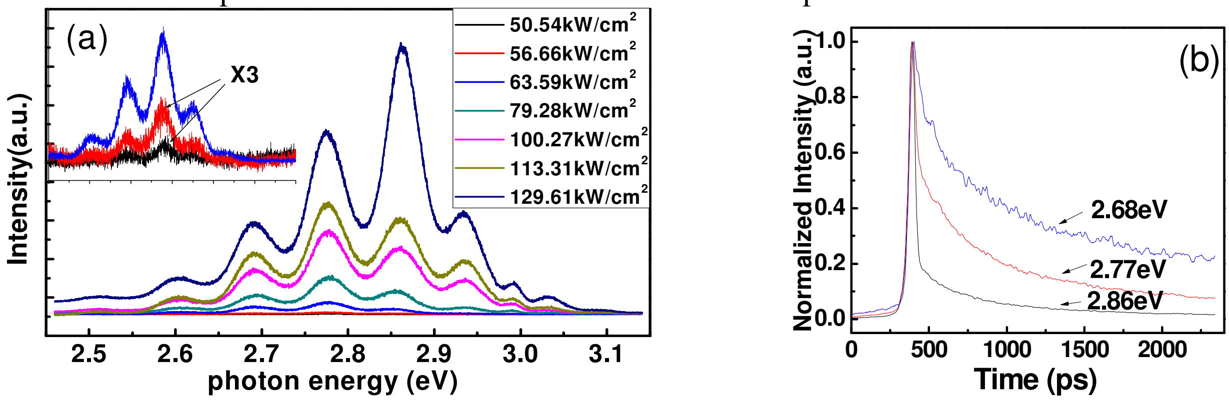


Fig. 2 (a)PL spectra of the sample with a DBR on one side in different exciting power (b) the decay time of different peaks

S3 is the sample that with DBR on both sides of the structure. Fig. 3 (a) is S3's photoluminescence spectra under different exciting power. When the exciting power is 280.86 kW/cm$^2$, four peaks, which their linewidth are all the same as 2.2meV (0.4nm), show up at 2.860 eV, 2.869 eV, 2.877 eV and 2.885 eV. As the exciting power increases, the emission intensity increases. When the exciting power increases to 354.61 kW/cm$^2$, four more peaks, with linewidth of 2.2 meV, show up at 2.8927 eV, 2.8983 eV, 2.9043 eV and 2.9085 eV. And the decay time is so short that reaches to the resolution limit 25 ps.

When calculate with formula (1), the frequency spacing of the longitudinal mode in the cavity can be obtained: $\Delta\upsilon = 0.23\times10^{14}$ Hz, not close to the frequency spacing between these peaks obtained from Fig. 3 (a): $\Delta\upsilon = 0.02\times10^{14}$ Hz. So the peaks show up in S3's photoluminescence spectra are not the modes in the Fabry–Perot cavity.

It's known that birefrigent effect could happen because the epitaxial layer based on GaN would be anisotropic due to stress [6]. To the material with birefrigent effect, there is different refractivity for the light with orthogonal polarization direction. So there are two different resonant frequencies in the cavity. When the exciting conditions is greater than the threshold value, the anisotropy in the cavity will reduce the monochromaticity of the spectra. And S3 is made of several GaN epitaxial layers, so there are several optical cavities and there can be several modes.

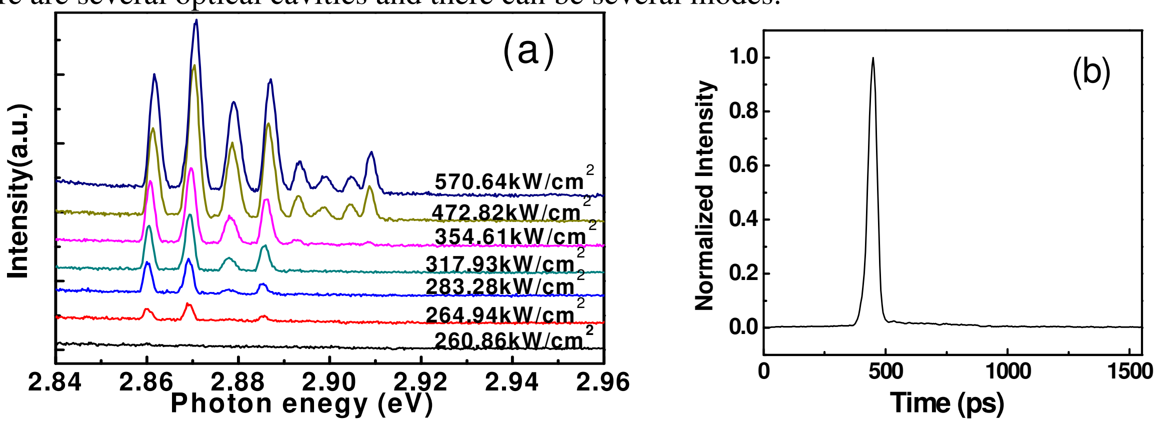


Fig. 3 (a) PL spectra of the sample with DBR cavity in different exciting power (b) the decay time of the spectra

Fig. 4 shows the relationship of laser emission intensity and angle of the polarizer of the four peaks at 2.860 eV, 2.869 eV, 2.877 eV and 2.885 eV, respectively. These curves fit cosine square variation well. The angle that versus the maximum of these peaks vary as 140°, 145°,155° and 150°. Calculating the degree of polarization of these four peaks though formula: $P=(I_{\max}-I_{\min})/(I_{\max}+I_{\min})$ , the results we obtained are 79%, 60%, 75% and 79% respectively. The polarization characteristics of these four main peaks are different, which confirm that these peaks occur by the oscillation of different optical cavities.

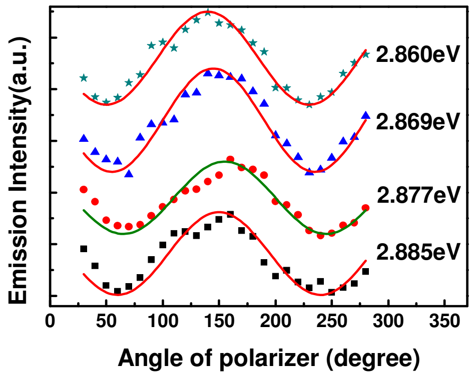


Fig. 4 The polarizer curve of S3's four peaks.

## Summary

The effect of the distributed Bragg reflectors (DBR) on the laser emission and the mechanism of multi-longitudinal-mode are analyzed. For the sample that the DBR is deposited on the top side of the grown nitride structure, several modes occur by the optical cavity. For the sample with DBR on both sides, modes occur by the oscillation of different optical cavities because of birefrigent effect induced by stress. After being coated with DBR, the decay time of the peaks becomes shorter.

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