Optical properties of type-II InGaN/GaAsN/GaN quantum wells light-emitting diodes

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Abstract -- ***Spontaneous emission spectra of type-II InGaN/GaNAs QW light-emitting diodes are investigated using the multiband effective mass theory. These results are compared with those of conventional InGaN/GaN QW structures. In the case of a low carrier density, a type-II InGaN/InGaN/GaN QW structure shows much larger matrix element than a conventional InGaN/GaN QW structure. On the other hand, in the case of high carrier density, a type-II QW structure shows slightly smaller matrix element than a conventional QW structure. The type-II InGaN/InGaN/GaN QW structure shows much larger spontaneous emission peak than that of a conventional QW structure. This is mainly due to the fact thate, in the case of the type-II QW structure, the effective well width is greatly reduced.***

I. INTRODUCTION

III-V gallium nitride (GaN) and related compounds have great potential for applications in high-power electronic devices, such as field-effect transistors, and in optical devices, such as laser diodes and light-emitting diodes in the blue and the ultraviolet regions. The (0001) wurtzite (WZ) GaN-based quantum well (QW) structures are found to have a large internal field due to the strain-induced piezoelectric (PZ) and spontaneous (SP) polarizations.[1,2] The radiative recombination rate and the optical gain of these QW structures hence are largely reduced due to the larger spatial separation between electron and hole wavefunctions. This leads to high threshold current densities (J_{th} ~ 1.5-6 kA/cm^2 , λ =425-482 nm) even in current state-of-the-art InGaN/GaN QW lasers.[3] Several methods such as using non-polar planes[4-6], inserting δ layer into InGaN well[7], using the ultrathin In-rich InGaN layer[8], and using a quarternary AlInGaN[9] have been proposed in an effort to reduce the effect of the internal field due to polarizations.

On the other hand, recently, a type-II InGaN/GaNAs QW structure has been proposed to reduce the internal field effect.[10] It was demonstrated that the use of type-II QW leads to significant improvement in the optical gain and spontaneous recombination rate. The type-II structure offers an extra degree of freedom which may be employed to tune the emission wavelength.

In this paper, we investigate spontaneous emission spectra of type-II InGaN/GaNAs QW light-emitting diodes. These results are compared with those of conventional InGaN/GaN QW light-emitting diodes. The self-consistent (SC) band structures and wave functions are obtained by solving the Schrodinger equation for electrons, the 3x3 Hamiltonian for holes, and Poisson's equation iteratively.[11,12] We also take into account the many-body effects on the spontaneous emission spectrum.

II. RESULT AND DISCUSSIONS

Figure 1 shows the potential profiles and the wave functions of the first conduction subband (C1) and the first valence subband (HH1) at zone center for the ground state of (a) conventional InGaN/GaN and (b) type-II InGaN/GaNAs/GaN QW structures. The thickness and As composition of the GaNAs well (L_{w1}) in a type-II QW structure are set to be 1.0 nm and 0.03, respectively. The thickness and the In composition of the left and right side barriers (L_{w2}) in a type-II QW structure is selected to give a transition wavelength of 530 nm. Potential profile of a conventional InGaN/GaN QW structure shows that there exists a large internal field in the well due to the difference of piezoelectric and spontaneous polarizations between well and barrier. That is, a large spatial separation between electron and hole wavefunctions is observed in the single QW structure due to the large internal field. However, the type-II InGaN/GaNAs/GaN QW structure shows that a spatial separation between electron and hole wavefunctions is greatly reduced, compared to that of the conventional QW structure.

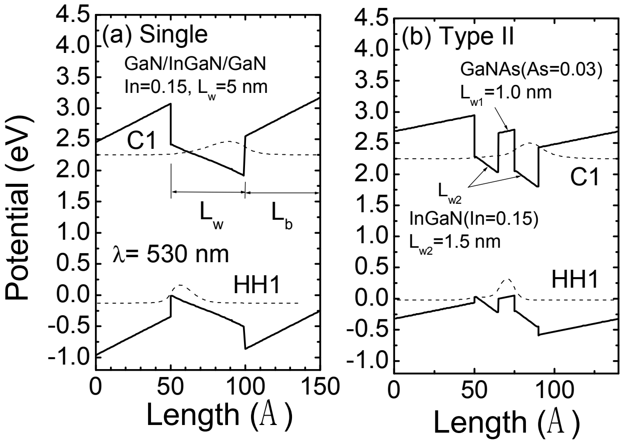

FIG. 1 potential profiles and the wave functions of the first conduction subband (C1) and the first valence subband (HH1) at zone center for the ground state of (a) conventional InGaN/GaN and (b) type-II InGaN/GaNAs/GaN QW structures.

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Figure 2 shows (a) optical matrix elements and (b) spontaneous emission spectra 530 nm (a) conventional InGaN/GaN and (b) type-II InGaN/GaNAs/GaN QW structures. The SC solutions are obtained at a sheet carrier density of N_{2D} = 10×10^{12} cm $^{-2}$. In the case of the low carrier density, we know that a spatial separation between electron and hole wavefunctions is largely reduced for a type-II InGaN/GaNAs/GaN QW structure. This is mainly attributed to the fact that the hole wavefunction is shifted toward the right side while the electron wavefunction is nearly invariant. As a result, a type-II InGaN/InGaN/GaN QW structure shows much larger matrix element than a conventional InGaN/GaN QW structure. However, in the case of high carrier density, a type-II InGaN/GaNAs/GaN QW structure shows slightly smaller matrix element than a conventional InGaN/GaN QW structure. This means that the screening effect at higher carrier density is dominant for a conventional InGaN/GaN QW structure. In the case of a conventional QW structure, the peak position of spontaneous emission spectrum is blueshifted at a high carrier density of N_{2D} = 20×10^{12} cm $^{-2}$, compared to that of a type-II InGaN/GaNAs/GaN QW structure. On the other hand, in the case of a type-II QW structure, the peak position at a high carrier density is shown to be similar to that (530 nm) at a non-injection level. This can be explained by the fact that the internal field effect is reduced for a type-II QW structure.

The spontaneous emission peak of a type-II QW structure is shown to be much larger than that of a conventional QW structure in an investigated range of carrier densities. This is because, in the case of the type-II QW structure, the factor $k_{\|} / \pi L_{weff}$ corresponding to the 2-D density of state in an optical gain formula increases due to the reduction of the effective well width.

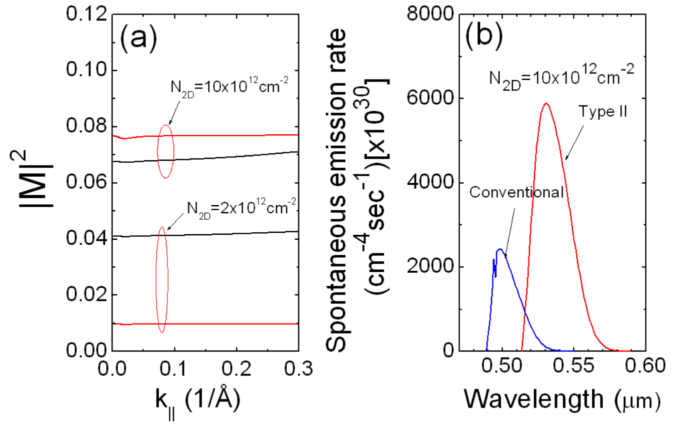

FIG.2 (a) optical matrix elements and (b) spontaneous emission spectra 530 nm (a) conventional InGaN/GaN and (b) type-II InGaN/GaNAs/GaN QW structures. The SC solutions are obtained at a sheet carrier density of N_{2D} = 10×10^{12} cm $^{-2}$.

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