The effect of temperature on the recombination rate of AlGaN/GaN light emitting diodes

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***Abstract-* Nitride semiconductors and their alloys recently have versatile applications as high-power and high-efficiency electro optical devices duo to their high thermal stability, direct transition and wide bang-gap. Nanostructure light emitting diodes of these materials have an emission spectrum from infrared to ultraviolet. In this paper, besides simulating a nanostructure nitride semiconductor LED, such as multi quantum well nitride LEDs, the effect of temperature on the recombination rate has been investigated.**

I.INTRODUCTION

Group III nitride semiconductors have recently attracted much attention for their tensile applications as high-brightness and high-efficiency light emitting diode (LEDs) especially in the visible-ultraviolet spectral region. Specifically, for the purpose of energy saving, in which, they can be used in full-color indicators and light sources for lamps [1, 2].

The fabrication technology and engineering of these semiconductor devices, however, have currently leaved far behind a detailed understanding of mechanisms involved in their operation. This is mainly because of non-ordinary properties of nitride semiconductors, like a spontaneous polarization, a strong piezoeffect and an extremely low acceptor activation efficiency [3].

II.MODEL DERIVATION

In this paper, the LED active region structure consists of a two-period $Al_{0.2}Ga_{0.8}N$/GaN double quantum well. Each AlGaN/GaN quantum well consists of a 4-nm-thick doped AlGaN barrier layer and a 6-nm-thick doped GaN well.

The electric fields in the well and the barrier due to the spontaneous and piezoelectric polarization for a wurtzite structure can be estimated from the periodic boundary condition for a superlattice structure as follows:

$$F_z^w = \frac{(P_{SP}^b + P_{PZ}^b - P_{SP}^w - P_{PZ}^w)}{\varepsilon^w + \varepsilon^b (\frac{L_w}{L_b})} \quad (1),$$

$$F_z^b = -\frac{L_w}{L_b} F_z^w \quad (2).$$

Where superscripts w and b represent the well and the barrier, and L and ε are the layer thickness and static dielectric constant, respectively [4].

In a junction LED, photons of near-bandgap energy are generated by the process of injection luminescence, in which, a large population of electrons, injected into a normally empty conduction band by forward bias, recombine with holes in the valence band [5].

A complete self consistent numerical solution should be performed, solving Poisson's equation, and the electron and hole continuity equations, to obtain information about current spreading, leakage current, electric field distribution, and recombination rates at different locations in the device [6].

In the case of III nitride LED, the Drift-Diffusion model consist of the Poisson equation for the electrostatic potential φ and P^{tot} accounting for both spontaneous and piezopolarization, and the continuity equations for electrons and holes are as follows[3] :

$$\nabla.(P^{tot} - \varepsilon_0 \hat{\varepsilon} \nabla \varphi) = q(N_D^+ - N_A^- + p - n) \quad (3),$$

$$\nabla.J_n = -R \quad , \quad J_n = -\frac{\mu_n n}{q} \nabla \varphi_n \quad (4),$$

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$$\nabla . J_p = -R \quad , \quad J_p = \frac{\mu_p p}{q} \nabla \varphi_p \qquad (5).$$

Where, φ_n and φ_p are electron and hole quasi Fermi levels respectively.

The recombination rate R accounts for both non-radiative and radiative channels: $R=R^{nr}+R^{rad}$. The non-radiative recombination which is assumed to proceed on the threading dislocation cores is:

$$R^{nr} = \frac{np}{\tau_p(n+n_d)+\tau_n(p+p_d)}[1-\exp(-\frac{\varphi_n-\varphi_p}{KT})] \quad (6),$$

$$n_d = n \cdot \exp(\frac{E_d-\varphi_n}{KT}) \quad , \quad p_d = p \cdot \exp(\frac{\varphi_p-E_d}{KT}) \quad (7).$$

The bimolecular radiative recombination rate is defined by the expression:

$$R^{rad} = Bnp[1-\exp(-\frac{\varphi_n-\varphi_p}{KT})] \qquad (8)$$

Where B is the radiative recombination rate constant.

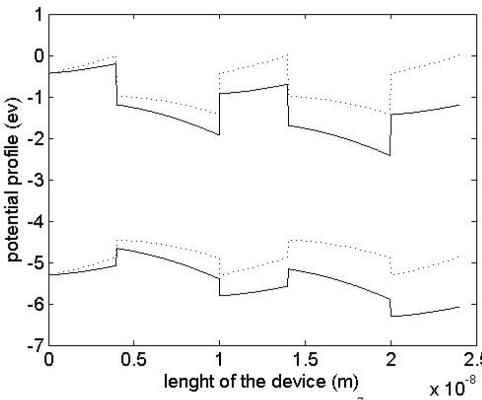

Fig1: potential profile with applying $5*10^7$V/m electric field (solid lines) and potential profile without applying electric field (dashed lines) for AlGaN/GaN LED active region.

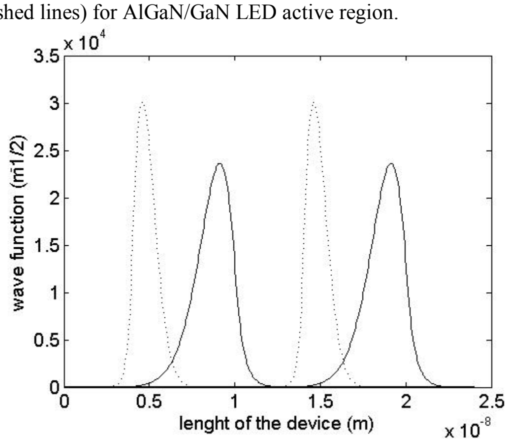

Fig2: wave functions for electrons (solid lines) and for holes (dashed lines) with applying $5*10^7$V/m electric field for AlGaN/GaN LED active region.

The effects of temperature variation on the characteristics of LEDs inherently lead to the deterioration in the light output power constancy. Thermal effects on LED performances are a very important technical issue. Nevertheless, there has been little investigation of the Nitride-based LED characterization in the above-room-temperature region up to about 100 °C [7].

With solving the Schrodinger, Poisson and continuity equations self consistently, one can achieve the characteristics of the device. These equations have been solved using finite difference method. The effects of temperature on carrier dispersion and also recombination rate have been analyzed. Knowing the temperature dependant recombination rate, one can investigate the LED characteristics at different temperatures.

SUMMERY

The Schrodinger equation, Poisson equation and continuity equations for electrons and holes have been solved numerically to find the temperature dependant recombination rate in AlGaN/GaN LED. Finally the effect of temperature on the recombination rate has been used to characterize the AlGaN/GaN LED.

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