Characterization of GaN-based Quantum Dots within Vertical-Cavity Surface-Emitting Lasers for realizing Green Lasers by Simulations

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The GaN-based green lasers play an important role in optoelectronic innovation. Multi quantum wells and quantum dots within a quantum well have been characterized. The polarization, effective mass, subbands and optical gain have been taken into account. The rigorous **k·p**-method with Hamiltonian (8 by 8) is applied. The electrical and optical efffect have also been compared in order to reach optimal design for green or yellow-green lasers. The piezoelectric effect is also included in simulation. Thus, it is a step ahead in optimizing such complex laser structures.

Keywords: GaN, multiphysics of semiconductor lasers, multi-quantum-well, quantum dots, green-yellow lasers and band structure.

There have been enormous progress and changes in the development of GaN-based quantum dot lasers with emission wavelength in the range from 510 nm to 620 nm during the last few years. However, it is still a challenge to produce emission in the domain of green-yellow-orange wavelength. The ultimate goal is to achieve the full coverage of visible light

There have been undesired effects while growing GaN-based lasers [8]. It is mainly due to its crystal structure, *e.g.* spontaneous polarization and internal stresses which could cause high electrostatic charges (up to $100V/\mu m$). This causes quantum confined stark effect (QCSE) [7] which increases the energy separation between the first two energy levels and causes the *blue shift, i.e.* shrinking of wavelength. However, it has been shown that 3-dimensionally confined GaN/AlGaN reduces the QCSE[9]. The quantum efficiency could drop after 550 nm due to a well-known problem, so-called 'green-yellow gap' [8].

The Crosslight Software [10] has been used and it has vast variety of examples and macros (commands) which could be modified for further development. The vertical-cavity surface-emitting lasers (VCSELs) structure (Fig.1) has $In_{0.15}Ga_{0.85}N$-GaN with compressively strained single or three quantum wells of *n*-doped InGaN (3 nm) with a barrier of GaN (12 nm). There is a blocking layer of p-AlGaN on the top of the active region. On the top and bottom of the VCSEL there are distributed feedback Bragg reflectors. The percentage (x) of In in $In_xGa_{1-x}N$-GaN and the thickness of the quantum well controls the bandgap in order to reach the longer wavelength for yellow-green or yellow emission. It has its own limitations [2, 3], whereby the plane of growth within GaN crystal plays an important role.

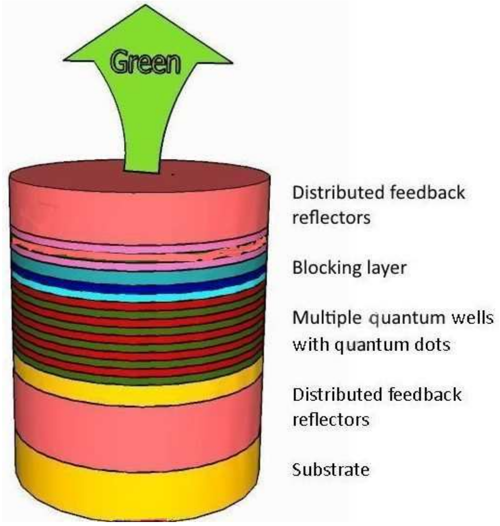

FIG. 1: Depiction of different layers configured in VCSEL

The polarization charge increases with higher number of quantum wells at the interfaces, *i.e.* the choice between single and multiple quantum well remains a matter of compromise[4]. The minimization of the strain (elasticity energy) remains a complex task [5].

The main part of the theory is based on quantum mechanical calculation of the band structure using the Crosslight software. The quantum well around a quantum dot is considered as mildly active, it is so-called wetting layer around the quantum dots. A number of quantum dots are embedded within InGaN quantum well. The quantum states (energy levels) of quantum dot are calculated microscopically and incorporated into quantum well. The polarization charge [1] effect can be set for the quantum well as well as quantum dot.

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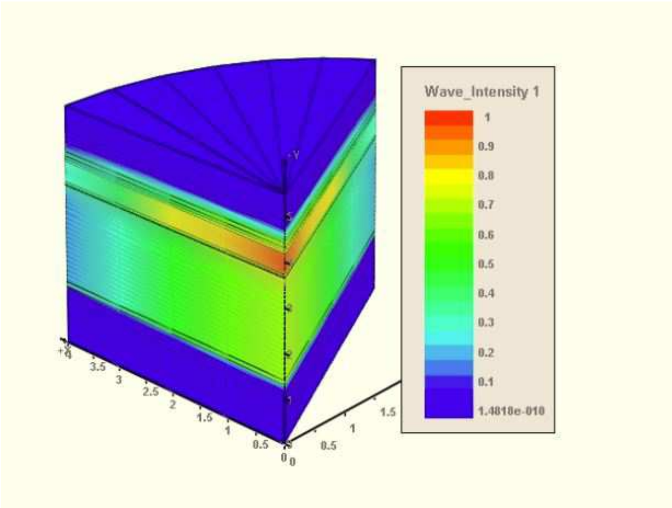

FIG. 2: Wave intensity within the VCSEL, scale is relative.

It is rather critical trade off to adjust the quantum dot in a quantum well, *e.g.* it should have the same material and background electrical field, which is imposed from quantum well. All this needs well founded repetitions of simulation in order to reach convergence (with experiments) [6]. The wave intensity of VCSEL and spectrum due to quantum dot are shown in Fig.2 and Fig.3 respectively. These numerical simulation and mathematical modeling will offer a choice for the optimization of the laser performance and a better understanding of green-yellow [3] lasers. These are expected in the near future by choosing the right material, structure and growth-plane without undesired effects. More research is required in order to continue towards even higher wavelength up to 620 nm.

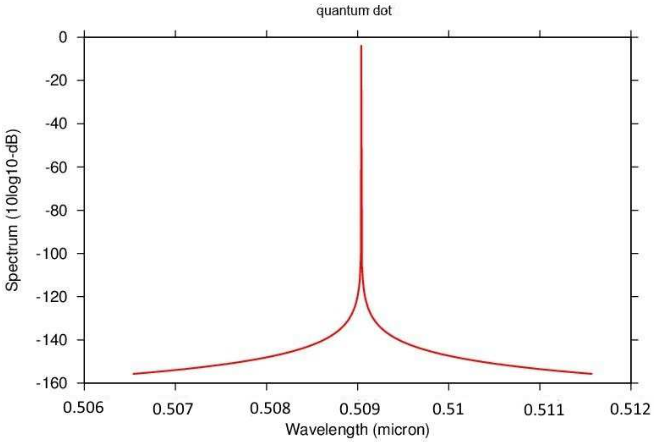

FIG. 3: The narrow spectrun due to quantum dot, the scale of y-axis is relative.

In case, these challenges are met, GaN will become the most important semiconductor next to silicon, producing devices like pico-projector and laser TV. The quantum dots as such are also stong candidates for quantum computing and for producing white light, *e.g.* quantum dots from different quantum well layers (Fig.1) could produce compound light comprising different wavelengths.

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