

Simulating the Effects of Crystal Orientation and Polarization in InGaN-GaN based Lasers

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Towards producing stable green semiconductor lasers, it is useful to compare c-plane and m-plane grown GaN-based quantum wells by simulations. The Hamiltonian, upto 8 by 8 $\mathbf{k}\cdot\mathbf{p}$ -method, is used to estimate dipole moments and to calculate subbands. It is evident that piezoelectric effects due to crystal orientation and effective mass are reduced while optical gain is enhanced in (nonpolar) m-plane grown lasers. These comparisons and effects have been shown by simulations.

Keywords: semiconductor lasers, green lasers, c-plane and m-plane grown devices, piezoelectric effects, multiphysics of semiconductor lasers

- For decades it has been wishful thinking to produce green laser straight away without doubling the frequency which is a complicated and inefficient process [1]. Due to internal stresses and electrostatic charges, a strong field is created perpendicular to the crystal's c-plane in between the active thin layers. It can be as big as 100 volts per micron. This is known as Stark effect [4] which mainly increases energy separation between the first two energy levels and causes *blue shift*. These problems are less dominant if the crystalline GaN is sliced along m-plane (Fig.1) at the start of growth, i.e. polarization charge [2] and internal stresses are much less and give more stable green emission in InGaN-GaN based lasers[1].

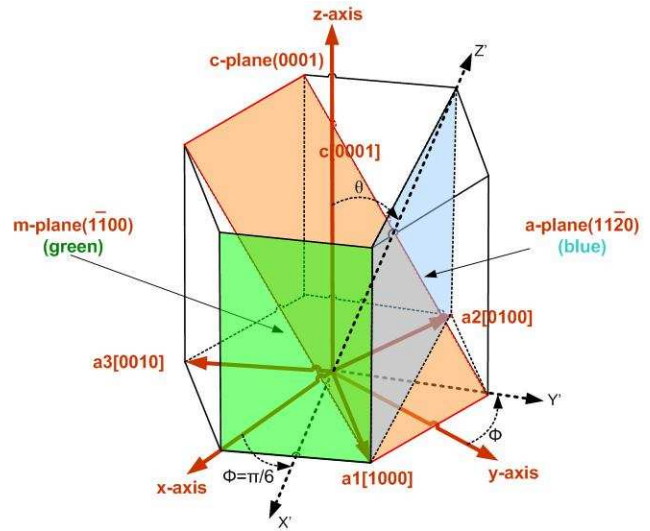


FIG. 1: Showing m-plane(nonpolar), c-plane(polar) and a-plane (semipolar) in wurtzite crystal structure of GaN.

- A self-consistent software (Crosslight Inc.[7]) has been exploited in order to simulate and make predictive estimation of a wide spectrum of outcomes. It has a vast range of updating possibilities with respect to emerging new technologies, structures and algorithms.
- The structure comprises a wurtzite $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}/\text{GaN}$ with compressively strained three quantum wells of *n*-doped InGaN (30 Å) with a barrier of GaN (120 Å), and there is a cladding layer on both sides and it is grown on a thick GaN substrate layer.

Main part of the theory is based on quantum mechanical calculation of band structure using the Hamiltonian based on $\mathbf{k}\cdot\mathbf{p}$ -method for a-plane, c-plane and m-plane grown crystal orientations. This remains a new approach for

band structure engineering in order to achieve better optical properties. The interband optical momentum matrix elements are also calculated for TE or TM polarization in m-plane and c-plane grown orientations. For example, optical matrix elements for m-plane grown devices are polarization dependent. The optical gain is related to optical matrix element, *i.e.* optical gain increases in a particular polarization direction (orientation) if the optical matrix element decreases in that particular direction. There is possibility to calculate the Hamiltonian for an arbitrary rotation by choosing the angles ϕ and θ , see Fig. 1.

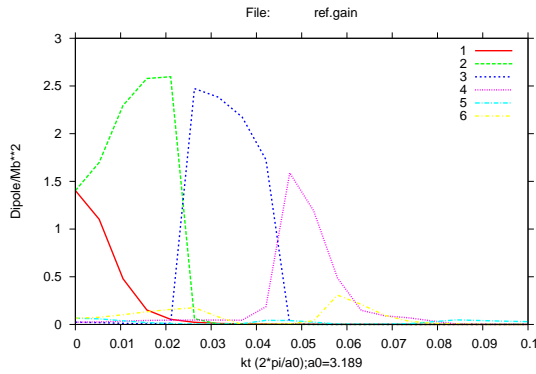


FIG. 2: Showing dipole transitions from valence subbands to the conduction band for c-plane growth.

This work is based on publications by Park and Chuang [3, 6].

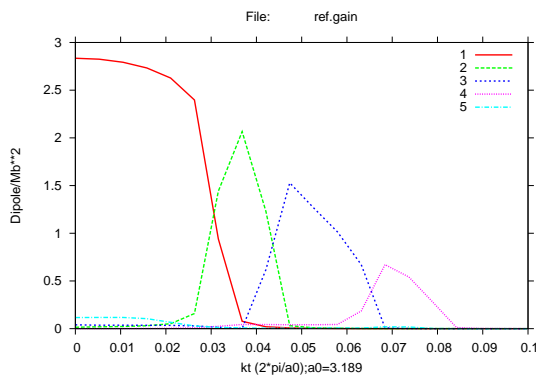


FIG. 3: Showing dipole transitions from valence subbands to the conduction band for m-plane growth.

When comparing the results of Fig.2 and Fig.3, it can be clearly observed that transitions from first three valence subbands to the lowest conduction band are stronger in m-plane transitions (Fig.3) than in c-plane transitions (Fig.2). These transitions have more significant effect near $\mathbf{K}_t = \mathbf{0}$ causing direct transitions.

- These results will contribute to the *optimization* of laser performance and better understanding of green lasers which are expected in near future by increasing the amount of In in the $\text{In}_x\text{Ga}_{1-x}\text{N}/\text{GaN}$ based blue laser. It will play a significant role in novel applications *e.g.* pico-projectors cf. [1]. Such calculations are an alternative method towards investigating device cost-efficiency as a designing tool. However, the availability of material parameters is an important and ongoing development for better modelling by numerical simulations.

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