Bandgap engineering of III-nitride quantum wells for efficient green light emitting diodes (GreenLight)

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UA

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Summary

Electric lighting accounts for 19% of the total electricity consumed in Europe and forms a significant part of all domestic and industrial energy budgets throughout the world. The development of efficient, energy-saving solid-state lighting (SSL) devices is therefore a task of the highest priority for materials scientists in the 21st century.

Semiconductor light emitting diodes (LEDs) are already considered the most efficient of all light sources. Group-III-nitrides (III-N) (GaN, InN, AlN and their alloys) have shown impressive potential as material for LEDs [1]. However, the technology is relatively new and there is still great potential for improvements. In particular, green LEDs, necessary for lighting devices based on the mixing of light from red, green and blue (RGB) LEDs, still suffer from low efficiencies – the so called “green gap”.

As one of the major issues limiting the efficiency, we point out the strong polarisation effects in quantum wells (QWs) grown along the c-axis of the wurtzite lattice which constitute the active region of an LED. The polarization induced electric fields cause a spatial separation of the electron and hole wave functions in the QW reducing strongly the radiative recombination rate (the quantum confined Stark effect, QCSE) [2]. Another issue is the “efficiency droop”, the strong drop of LED efficiency at high current densities. Its origin is still under debate and both QCSE as well as Auger losses are investigated [2]. Both effects are especially strong in green LEDs containing InGaN QWs with high InN contents.

In a novel approach this project aims to develop a *bandgap engineering strategy* to address and overcome both QCSE and Auger losses. Compositional grading of QWs will be used to tune the potential profile and strain distribution in a multi QW (MQW) in order to control the electron-hole recombination. The goal is to increase the overlap of electron and hole wave functions within the QWs resulting in increased internal quantum efficiency. In addition, the softening of heterostructure interfaces in the active region has been shown to eliminate Auger losses in quantum dots [3].

Bandgap engineering will be performed by compositional grading of QWs realized by post-growth interdiffusion of QW and barrier materials. QW intermixing (QWI) is achieved either by simple thermal annealing or enhanced by ion implantation followed by annealing. In the latter case the introduction of point defects and breaking of the bonds facilitate diffusion during post-implant annealing. QWI will affect both the composition and strain distributions within the QW. In this way, the overlap of electron and hole wave function can be increased by changing the form of the potential, leading to a higher internal quantum efficiency. Simulation studies which we performed in collaboration with the University of Rome reveal a high potential for the proposed QWI approach [4, 5]. This project serves to provide an experimental proof of concept and to develop efficient QWI techniques.

The project is subdivided into three interrelated tasks.

1. QWs will be characterized by structural and optical techniques. The compositional analysis of ternary and quaternary alloys will also play an important role here since this is the main factor influencing both band gap and strain state and therefore the emission properties of the materials.

2. QWI during post-growth thermal annealing and its effect on structural and optical properties will be investigated.

3. Ion-beam assisted QWI techniques will be developed.

The main objectives of the present proposal are the following:

- Feed-back to crystal growers for the optimization of growth conditions of III-N based QWs;
- Understanding the effect of thermal annealing on as-grown heterostructures;
- Understanding implantation damage build-up and its recovery in III-N QWs;
- Development of efficient QWI recipes for LED production.

References

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