Simulations of light emission at reverse voltage of wide-well InGaN light-emitting diodes

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GaN-based heterostructures are typically grown in the polar direction. Due to differences in polarization constants between layers of varying composition and the built-in strain, significant interfacial charges emerge. This phenomenon is particularly important for quantum wells (QWs), where the resulting built-in electric fields lead to the quantum-confined Stark effect (QCSE) and a spatial separation of electrons and holes. This separation significantly reduces the radiative recombination efficiency, especially in wider quantum wells where the increased distance between carriers is more detrimental to recombination.

Moreover, these interface polarization charges attract mobile carriers, which can partially screen these charges. While such mobile carriers are present in quantum wells, they do not significantly contribute to radiative recombination due to the spatial separation of electrons and holes, which tend to accumulate on opposite sides of the QWs.

Using drift-diffusion simulations of an InGaN LED, we have shown that this screening charge, or *dark charge*, can slowly accumulate under low forward voltages. These voltages, while insufficient to generate electroluminescence, allow to charge the quantum well by inducing an electron-hole buildup on opposite sides of the QW. We demonstrated that for a given forward bias, a sufficient time is required to charge the device with this screening dark charge and reach a stable concentration. This stable concentration, as well as the charging time, depends on the applied voltage; the dark charge concentration increases with the voltage, while the charging time decreases.

The presence of this dark charge was confirmed through both numerical simulations and physical experiments. The experimental confirmation relies on the application of short reverse-bias negative voltage pulses. These pulses alter the electric field distribution within the quantum well, affecting the distribution of charge carriers. Subsequently, some of the excess carriers recombine radiatively, leading to short pulses of light. The intensity of these light pulses depends on both the charging time and the applied forward voltage. The numerical simulations show qualitative agreement with the experimental results.

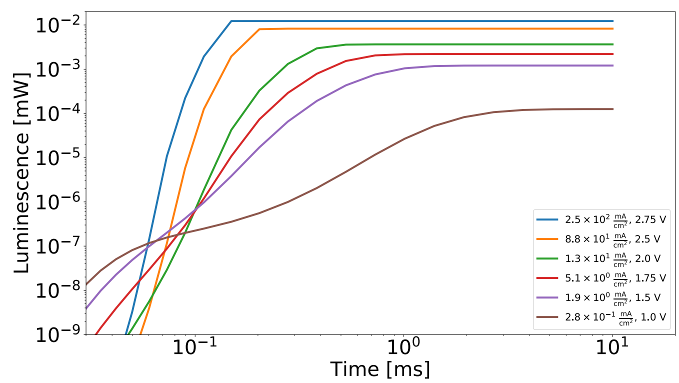

Fig. 1. Simulated intensity of the short pulses of light as a function of charging time for various forward biases and corresponding currents for an InGaN LED with 25 nm $In_{17\%}Ga_{83\%}N$ quantum well.

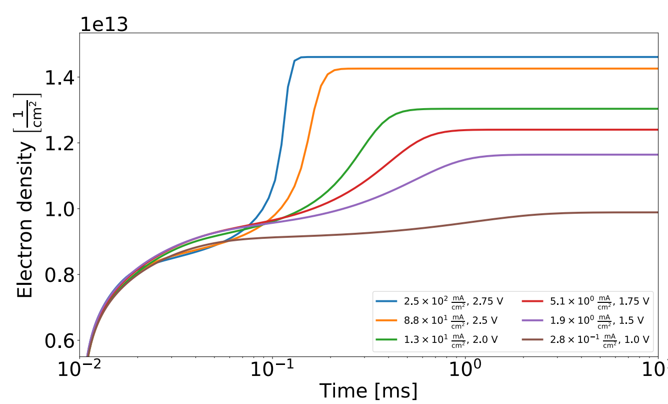

Fig. 2. Electron density in the quantum well vs charging time.

References

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