Improvement of current injection efficiency in AlGaN-based deep-ultraviolet light-emitting diodes via strains

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AlGaN-based deep ultraviolet (DUV) light-emitting diodes (LEDs) offer a compact, environment-friendly alternative to traditional mercury vapor lamps and bulbs as light sources. However, the power conversion efficiency of DUV-LEDs decreases rapidly as the emission wavelength decreases. The low current injection efficiency (CIE) is one factor that limits the efficiency of electrically-injected AlGaN-based DUV-LEDs.[1] It is well known that the performance of the DUV-LEDs is sensitive to the strains in the epilayers. A number of researchers focused on strain effects on the radiative recombination efficiency due to the quantum-confined Stark effect (QCSE) of the quantum wells (QWs). The strain effects on the light extraction efficiency via the modulation of the photon polarization have also been investigated extensively. In this talk, we report the discovery of strain effects on the CIE in AlGaN-based DUV-LEDs.

The dependence of the CIE on strain relaxations was studied both theoretically and experimentally. A one-dimensional drift diffusion model was used for the carrier transport simulations when taking the strain-induced piezoelectric effects into account. It is shown that an unrelaxed strain in p-AlGaN cladding layer can significantly improve the hole injection efficiency, as shown in Fig. 1. Deeper analysis indicates that the strain-induced piezoelectric field can generate a high hole concentration layer, which can provide abundant holes for injection into the active region and can also suppress the spillover of electrons into the p-region. As a result, the number of holes injected into the MQWs was greatly enhanced, resulting in a high CIE. Two types of sub-280 nm DUV-LEDs wafer were grown with special designs for different strain relaxations in their lattice-mismatched p-AlGaN layers. The strain difference was identified via Raman scattering spectroscopy. The wafers were then fabricated for the DUV-LEDs using a standard fabrication process. The light output power was measured from the on-wafer devices. The measured external quantum efficiency (EQE) was much higher in the DUV-LEDs with residual strain in the p-AlGaN than in the devices in which the strains in the p-AlGaN was relaxed. By separating the injection and recombination efficiencies from the EQE, we found that the high EQE can mainly be attributed to the high CIE, which showed good agreement with the simulation results.

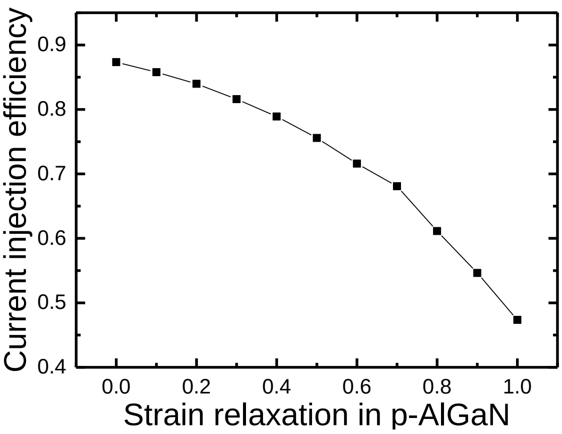

Fig. 1 Current injection efficiency as a function of strain relaxation in p-AlGaN cladding layer.

1. G. D. Hao, N. Tamari, T. Obata, T. Kinoshita, and S. Inoue, Opt. Express **25,** A639 (2017).