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Carrier localisation mechanisms and efficiency droop in nitride quantum wells

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A variety of experimental evidence indicates that the carriers in InGaN quantum wells (QWs) in InGaN/GaN QW structures are localised at room temperature, for example the S-shape temperature dependence of the peak photoluminescence (PL) energy with increasing excitation power density, a key fingerprint of carrier localisation. This localisation is believed to be responsible for the high efficiency of light emission from InGaN QWs since it prevents the carriers from moving to non-radiative recombination centers such as dislocations. In-rich clusters in the InGaN QWs were widely believed to be responsible for the localisation of the carriers. However, careful electron microscopy (EM) and atom probe tomography (APT) have shown that such clusters do not exist in InGaN QWs, at least for In contents less than 25%, and hence such clusters cannot be responsible for the localisation of the carriers. So what mechanisms are localising the carriers? APT and EM have shown that the InGaN in the QWs is a random alloy, with the In atoms distributed at random on the Ga sites. They have also shown that the InGaN QWs have monolayer and bilayer thickness fluctuations. Quantum mechanical calculations show that the holes in the InGaN QWs are localised on a scale of 1-2nm by the random indium fluctuations, and the electrons are localised on a scale of about 5nm by the QW thickness fluctuations. This localisation prevents the carrier from diffusing to dislocations and hence results in a high efficiency of light emission at room temperature. At high carrier densities the localised states saturate with carriers and the additional non-localised carriers can then diffuse to defects and recombine non-radiatively. It is suggested that this is a significant contributory factor to the efficiency droop observed in InGaN/GaN QW structures at higher current densities.