Philosophical Magazine,
Vol. 87, No. 13, 1 May 2007, 1967–1969

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Preface

Intentional and unintentional localization in InGaN

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It is now more than 10 years since Nakamura *et al*. [1] announced the fabrication of the first GaN-based light-emitting diodes (LEDs) with luminous intensities in excess of 1 cd. These early devices were based on an InGaN/AlGaN double heterostructure, but were swiftly followed by structures employing quantum wells (QWs) in the active region to achieve higher external quantum efficiencies [2]. In the intervening years, an enormous number of innovations and adaptations have been employed to enhance the performance of LEDs and laser diodes (LDs); nevertheless, basic questions on the mechanisms of light emission in these devices remain unanswered.

In those early devices, the density of threading dislocations (TDs) [3] intersecting the active region was well in excess of $10^{10}\,\mathrm{cm}^{-2}$ and even today's lower TD densities would cause immediate failure in LEDs made using other III–V semiconductors. Since TDs in GaN have been shown in cathodoluminescence studies to act as non-radiative recombination centres [4], their limited impact on LED performance led various authors to suggest that the excitons are localized at potential minima caused by indium composition fluctuations in the QWs, preventing diffusion to TD cores [5]. This concept was supported by transmission electron microscopy (TEM) images showing significant inhomogeneous strain contrast in InGaN QWs, which both energy-dispersive X-ray spectroscopy (EDX) and electron energy loss spectroscopy (EELS) showed was due to the presence of nanometre-scale indium-rich regions that could act as localization centres [6].

In this Special Issue, Humphreys [7] reviews the discovery that led many scientists to challenge these data, namely, that these apparent indium-content fluctuations may form in the TEM upon exposure of the sample to the electron beam. His contention, that no TEM images may be treated as a faithful representation of the as-grown InGaN QW, is contested by Bartel *et al*. [8] who, using TEM, compare thick InGaN epilayers with layers of other semiconductors and conclude that there *is* evidence for nanoscale phase separation in the nitride system, leading to the formation of localization centres. Humphreys [8] raises doubts about the relevance of studies of relaxed epilayers to our understanding of strained QWs, a query which Bartel *et al*. also attempt to answer.

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Philosophical Magazine
ISSN 1478–6435 print/ISSN 1478–6443 online © 2007 Taylor & Francis
http://www.tandf.co.uk/journals
DOI: 10.1080/14786430701359663

In the context of this continuing controversy concerning TEM data, other measurement techniques are examined to help understand the microstructure of InGaN alloys. In term of microscopy, Humphreys [7] illustrates the application of a laser-assisted atom probe to InGaN QWs, presenting data which suggest that compositional fluctuations in InGaN are only those expected in a random alloy. Other authors in this issue take an alternative approach, using techniques which assess the sample's average properties rather than imaging particular regions. This methodology is exemplified by Kachkanov *et al.* [9] who use extended X-ray absorption fine structure (EXAFS) measurements. This technique looks at the average environment of a chose atomic species in a sample. Their studies have yielded some surprising results, suggesting that, while weak phase separation does occur in InGaN, this effect is more pronounced in samples with lower indium content. From the thermodynamics of spinodal decomposition, one would expect the opposite to be true.

Supposing for a moment that indium compositional fluctuations are not the main source of localization in InGaN QWs, one must consider other possible explanations, such as quantum well thickness fluctuations [7]. Chichibu *et al.* [10] have used positron annihilation techniques as a probe of the diffusion length for holes in nitride materials and discovered that, for In-containing alloys, this distance is extremely short. Hence, they suggest that holes (and hence excitons) may be localized by randomly occurring In–N–In–N zigzag chains, rather than by 2–3 nm In-rich clusters. Hangleiter *et al.* [11], on the other hand, contend that the most efficient emitters do not exhibit nanoscale localization. Instead, they point to changes in QW thickness around the TDs, which provide a local barrier to exciton diffusion. In fact, in this issue, two papers make the case for the involvement of the broad microstructure around TDs causing 'dislocation self-screening': Grandjean *et al.* [12] describe a similar effect for a rather different microstructure. The fact that both groups describe emitters with high efficiencies, but with very different microstructure, may suggest that neither can provide a general explanation for the operation of all InGaN-based LEDs. However, the engineering of the broad QW microstructure may provide a useful route towards improved devices in the future.

Lastly, we include in this Special Issue one example of how the structure of InGaN might be further engineered for other applications, in addition to its current role in LEDs and LDs. Jarjour *et al.* [13] describe their optical studies on deliberately grown InGaN quantum dots (as opposed to the possible unintentionally formed In-rich clusters in InGaN QWs, which should be dot-like – if they exist). They raise the possibility of devices based on single InGaN quantum dots with potential in fields such as quantum cryptography and quantum information processing.

Altogether, we in no way expect this Special Issue to end the discussion and controversy on the subject of localization in InGaN. It should, instead, be viewed as a snapshot of the debate at a given moment in time. Some of the ideas advanced here may appear controversial and even add to the confusion surrounding these questions. If this is the case, we may, in fact, have reached one of our aims, which is to stimulate the imagination of the scientific community and to encourage further progress in the development of new ideas and experiments.

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