

Optical investigation of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ alloys and GaN/AlGaN UV LEDs



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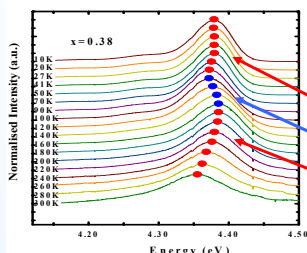


Introduction: The $\text{Al}_x\text{Ga}_{1-x}\text{N}$ bandgap can be varied between 3.4 eV and 6.2 eV which makes $\text{Al}_x\text{Ga}_{1-x}\text{N}$ an ideal semiconductor material for ultraviolet (UV) applications especially light emitting devices. However, due to lack of a lattice-matched substrate, a high dislocation density is observed in $\text{Al}_x\text{Ga}_{1-x}\text{N}$ alloys. These dislocations act as non-radiative recombination centres and greatly reduce the luminescence efficiency. On the other hand, exciton localisation may help to reduce the sensitivity of the optical efficiency to the dislocation density.[1] The excitons trapped in localised sites and hence may be prevented from reaching dislocation centres. In this work, we studied the exciton localisation in $\text{Al}_x\text{Ga}_{1-x}\text{N}$ alloys and 340 nm GaN/AlGaN UV light emitting diodes by photoluminescence (PL) and electroluminescence (EL).

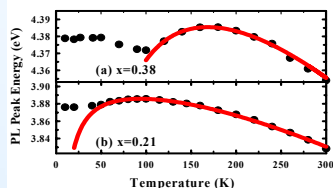
AlGaIn alloys:

- PL emission energy of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ shows a decrease-increase-decrease shift (S-shape)
- This S-shape behaviour is a signature of exciton localisation:

- Red shift: distribution of excitons to deeper localised states through hopping
- Blue shift: the excitons de-localise from the localised states to the extended states
- Red shift: temperature induced bandgap shrinkage



Temperature dependent PL spectra of $\text{Al}_x\text{Ga}_{1-x}\text{N}$.



PL energy of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ as a function of temperature. The solid lines were fitted using expression (1).

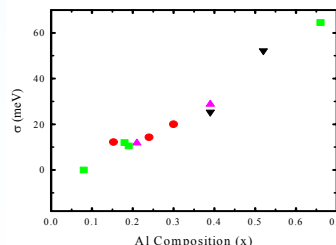
- Exciton localisation in $\text{Al}_x\text{Ga}_{1-x}\text{N}$ is attributed to random alloy compositional fluctuations

The S-shape PL energy is modelled using a band-tail model:[2]

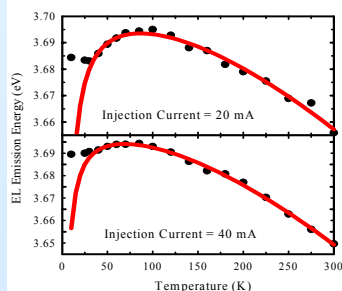
$$E(T) = E(0) - \alpha T^2 / (T + \beta) - \sigma^2 / (K_B T) \quad (1)$$

$E(0)$ is bandgap energy at 0 K. α and β are Varshni fitting parameters and σ is indicative of degree of exciton localisation

- The degree of localisation is found to increase with Al composition, x across range studied



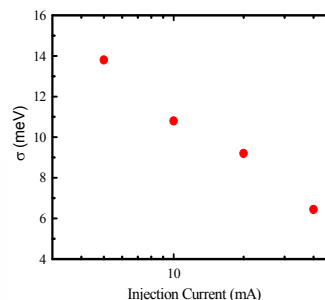
The localisation parameter, σ of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ as a function of x . Different symbols represent $\text{Al}_x\text{Ga}_{1-x}\text{N}$ grown at different conditions.



EL energy of UV LEDs as a function of temperature. The solid lines were fitted using expression (1).

340 nm GaN/AlGaIn SQW LEDs:

- Temperature dependence EL shows the S-shape behaviour
- Localisation behaviour in the UV LEDs is attributed to GaN quantum well (QW) thickness fluctuations
- Exciton localisation is sensitive to injection current
- Exciton localisation is expected to be enhanced by adding Al into QW for emission wavelengths shorter than 340 nm



The localisation parameter, σ of UV LEDs as a function of injection current.

Conclusions: In summary, the exciton localisation in $\text{Al}_x\text{Ga}_{1-x}\text{N}$ alloys with x ranging from 0.08 to 0.66 and GaN/AlGaIn UV LEDs has been studied. The exciton localisation in $\text{Al}_x\text{Ga}_{1-x}\text{N}$ increases with Al composition and is attributed to compositional fluctuations. On the other hand, an S-shape behaviour observed in the UV LEDs is due to QW thickness fluctuation and is injection current dependent. It is expected that the localisation will be enhanced by adding Al for shorter emission wavelengths.

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[1] S. Chichibu et al, Appl. Phys. Lett. 71, 2346 (1997)

[2] P. G. Eliseev et al, Appl. Phys. Lett. 71, 569 (1997)