Optical Studies of GaN Nanocolumns Containing InGaN Quantum Disks and the Effect of Strain Relaxation on the Carrier Distribution

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Introduction

GaN nanocolumns may find real applications in a multitude of optoelectronic device technologies such as LEDs, Lasers, Photonic Crystals, UV sensors, Biosensors and QD seeds. Some groups are even experimenting with neuron interfacing. The successful integration of III-V nanocolumns into any device architecture will require a sound understanding of the dynamic processes that exist within the columns themselves. Here we investigate GaN nanocolumns containing InGaN QDisks.

1. Sample growth and structure

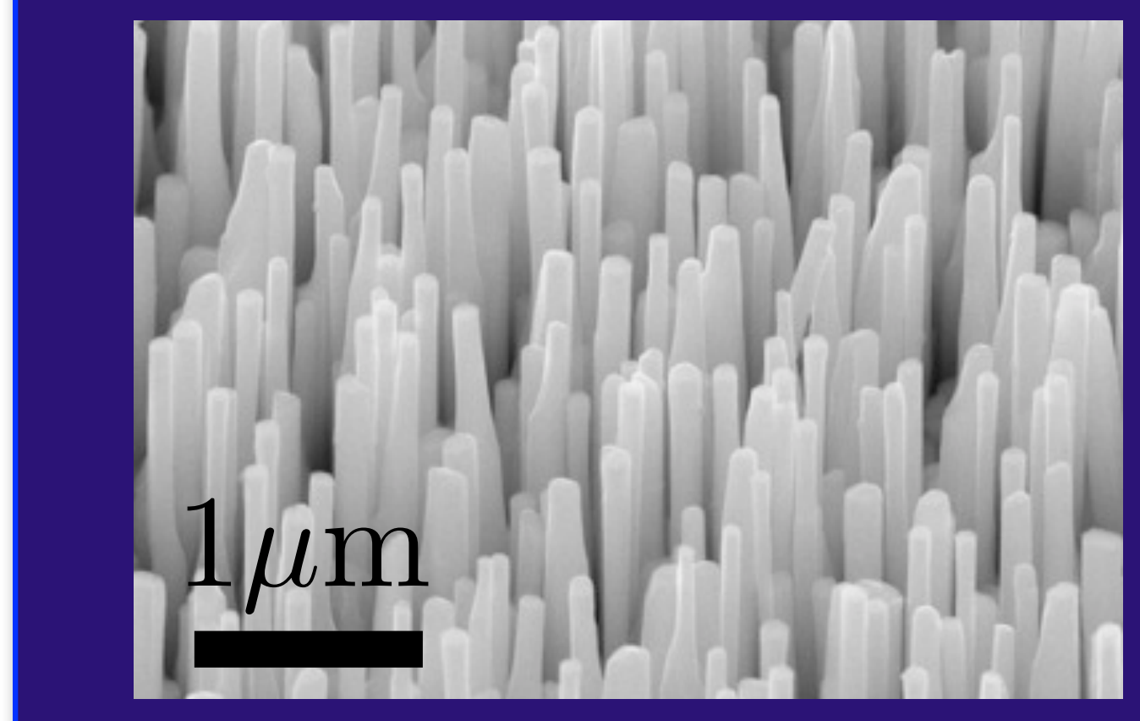
Sample grown by RF-PAMBE under nitrogen rich conditions on a Si(111) substrate, resulting in the growth of nanocolumns.

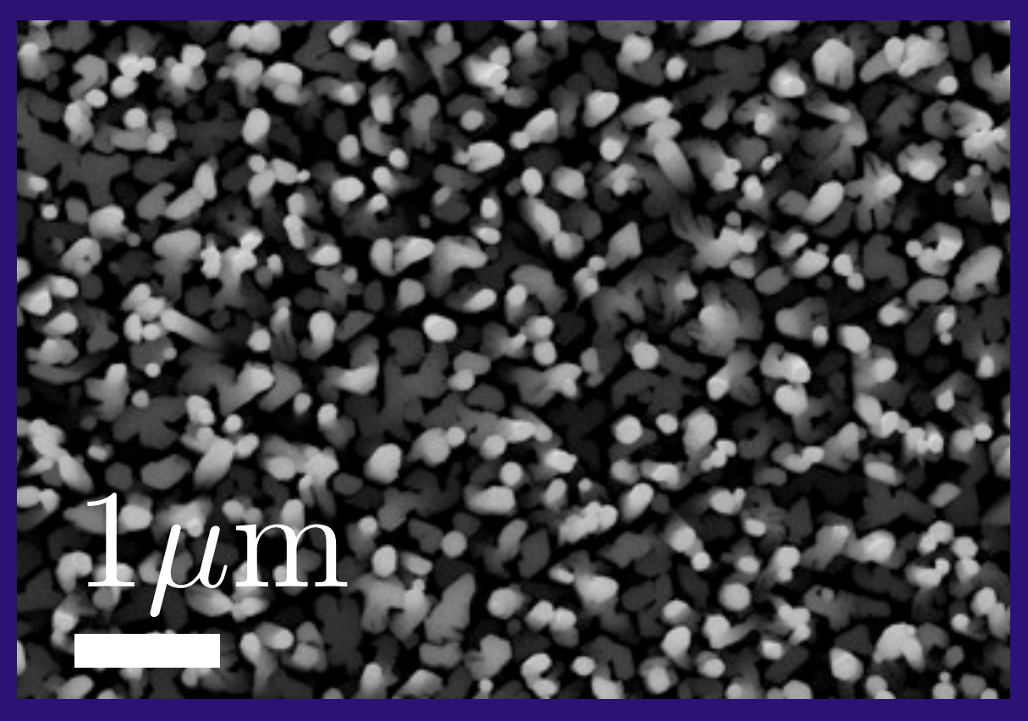
$In_xGa_{1-x}N$ quantum disk grown at the tip of each column, before being capped with GaN.

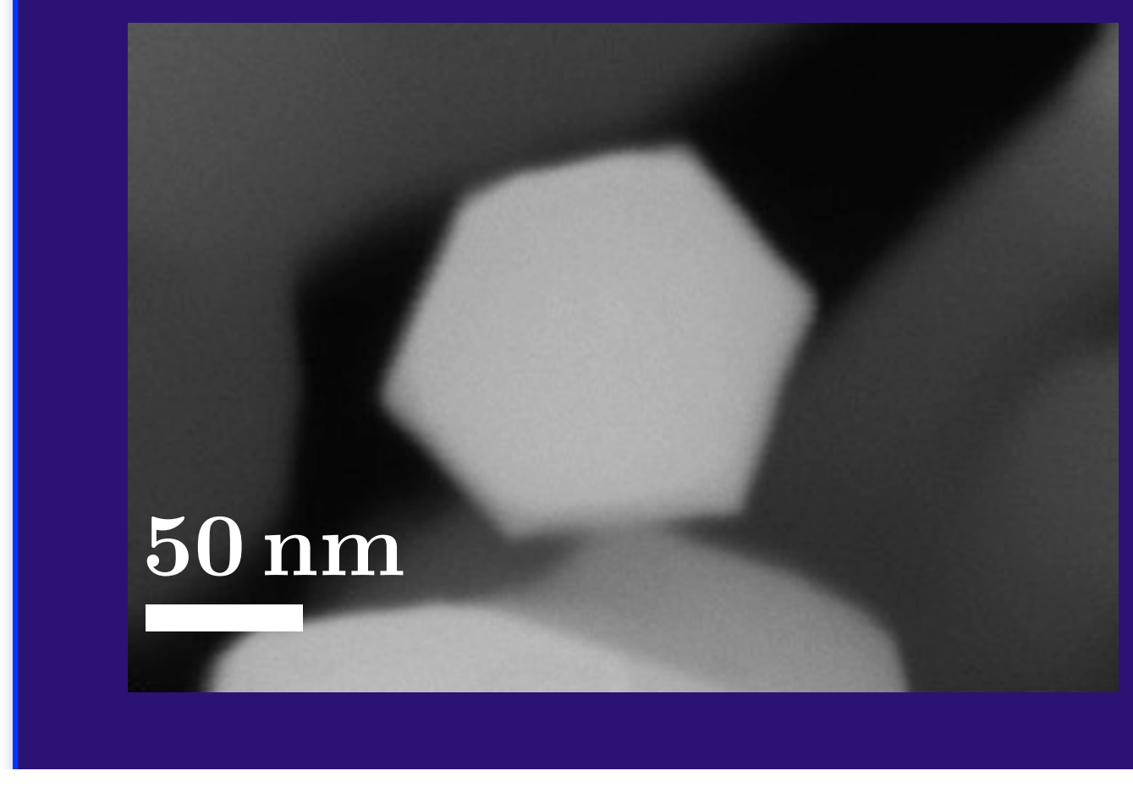
Columns are ~3μm in length and ~140nm in diameter.

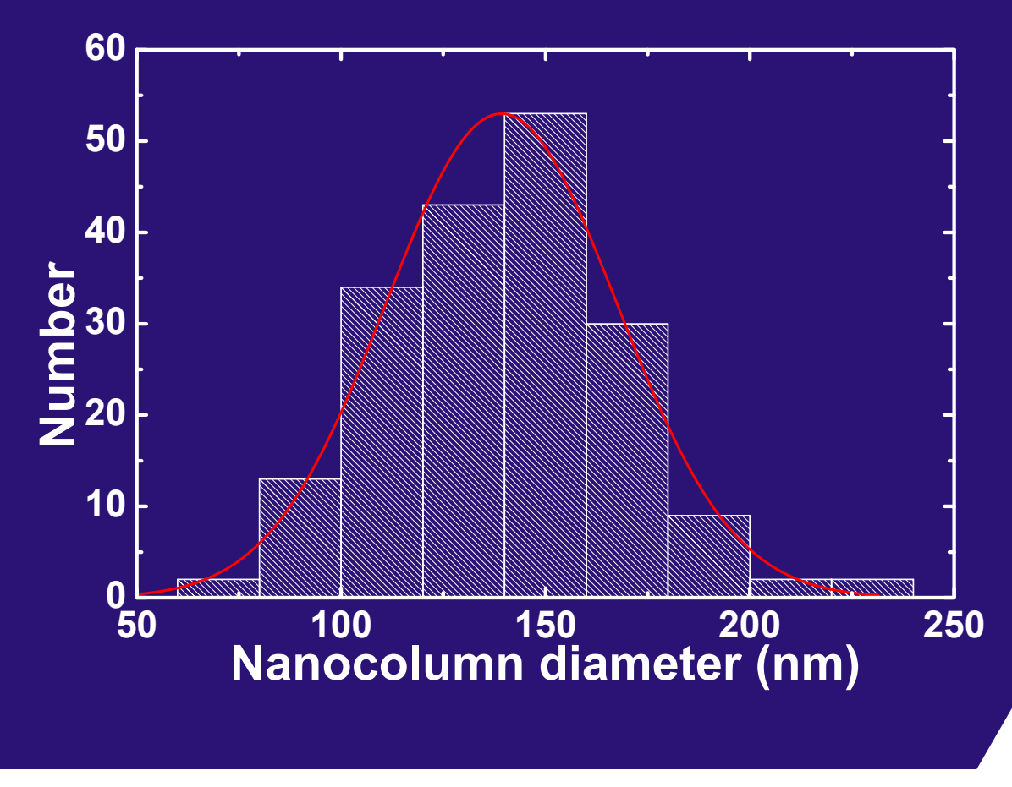
Column density is ~10^9cm^{-2}.

QDisk is nominally 3nm in hight. Indium mole fraction is estimated to be ~0.07.

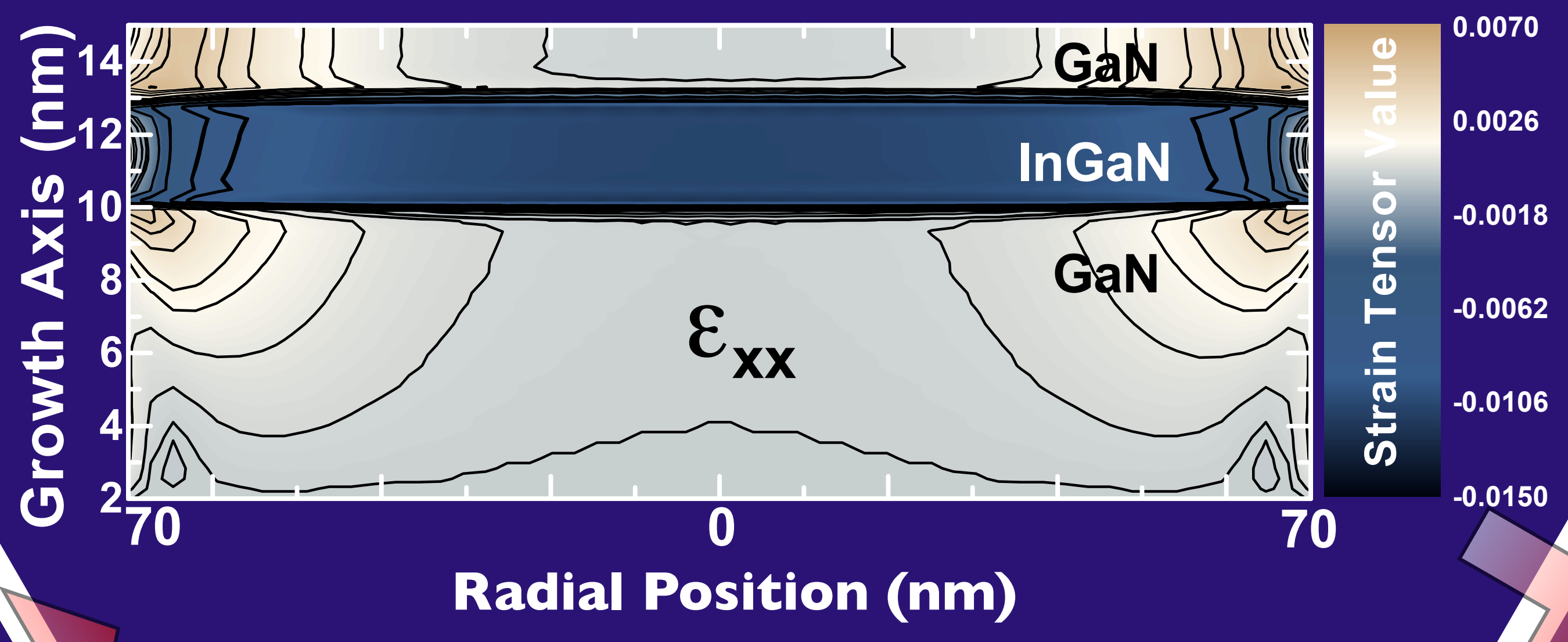








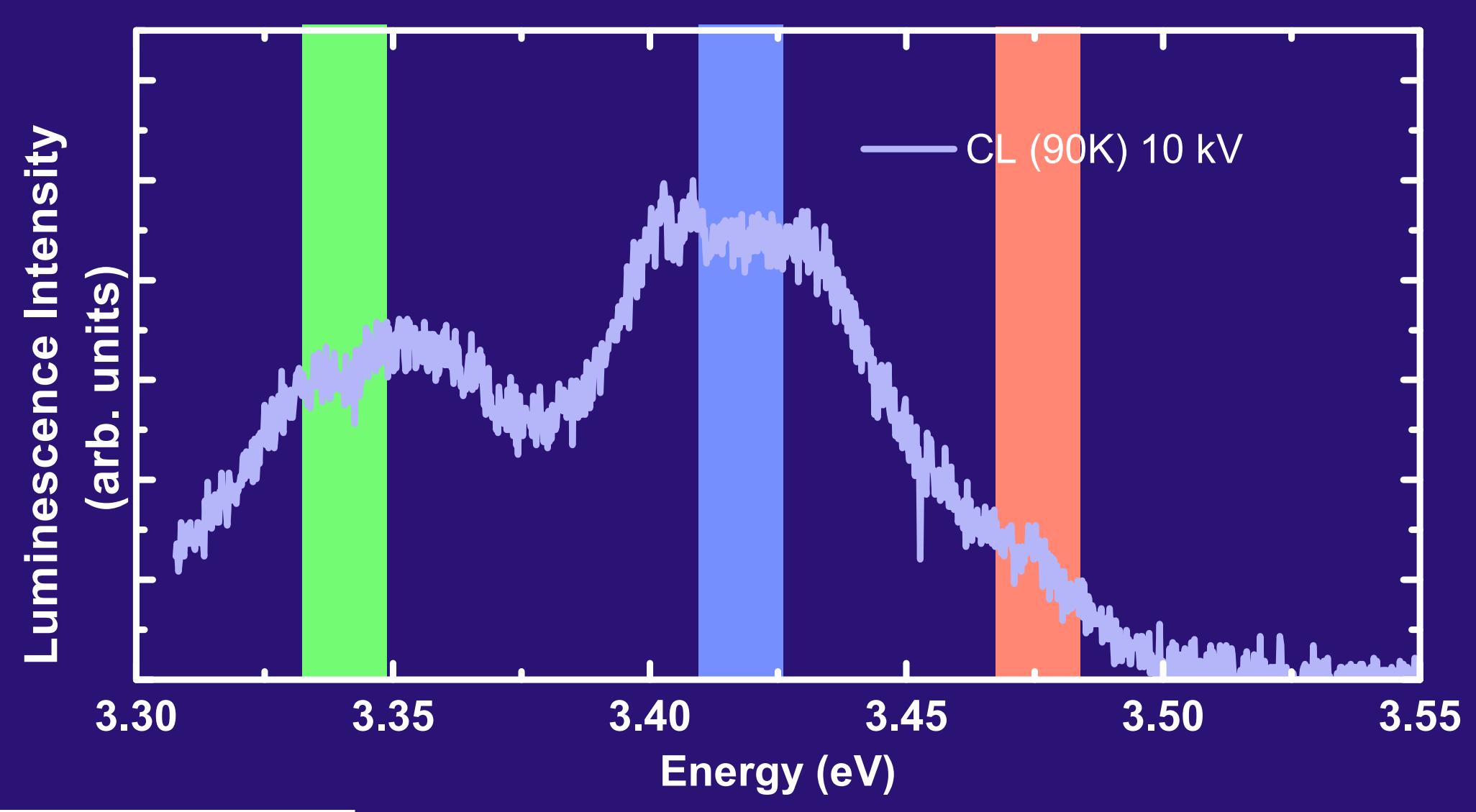
2. Strain Simulations of a QDisk/column system

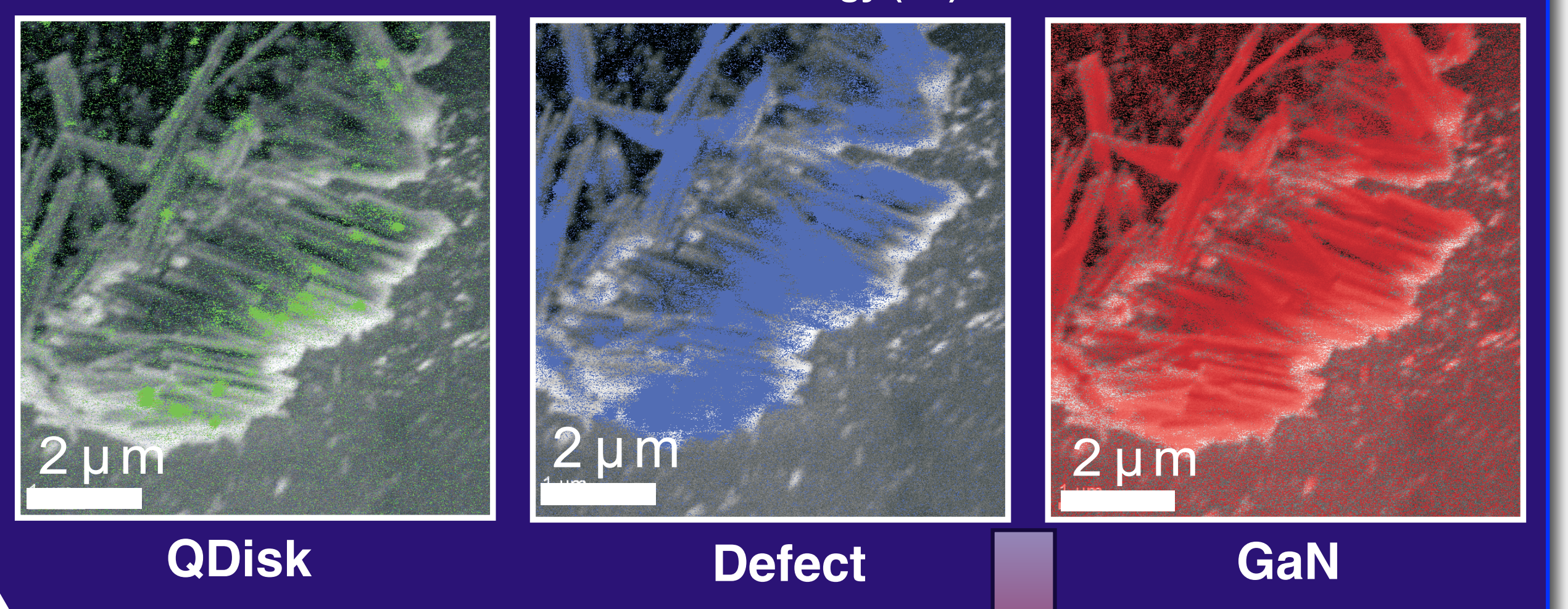


The strain distribution has been calculated for a 2.5nm QDisk of diameter 140nm using next**nano³** device simulator. An inhomogeneous distribution in strain in the QDisk **may result in a lateral separation of carriers**. The effects of deformation, piezoelectric field and fermi surface pinning play against each other.

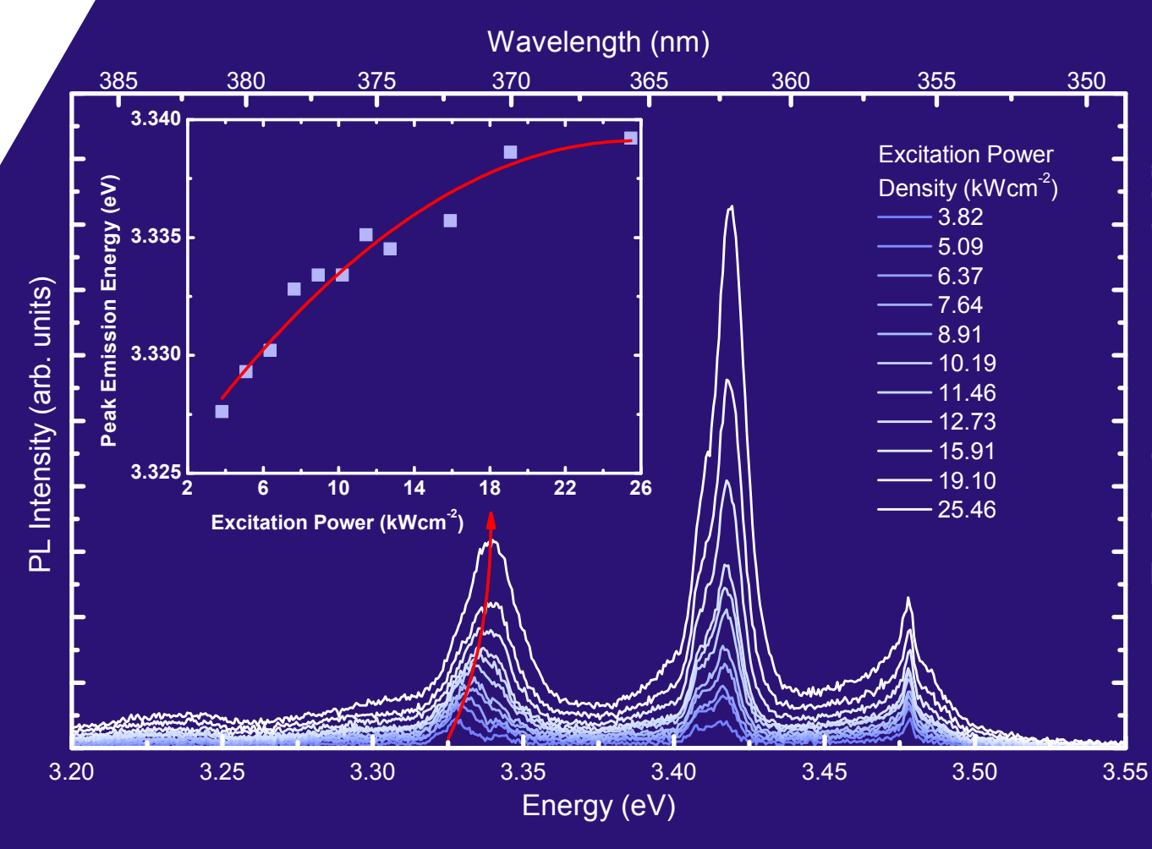
3. Initial Studies: Cathodoluminescence

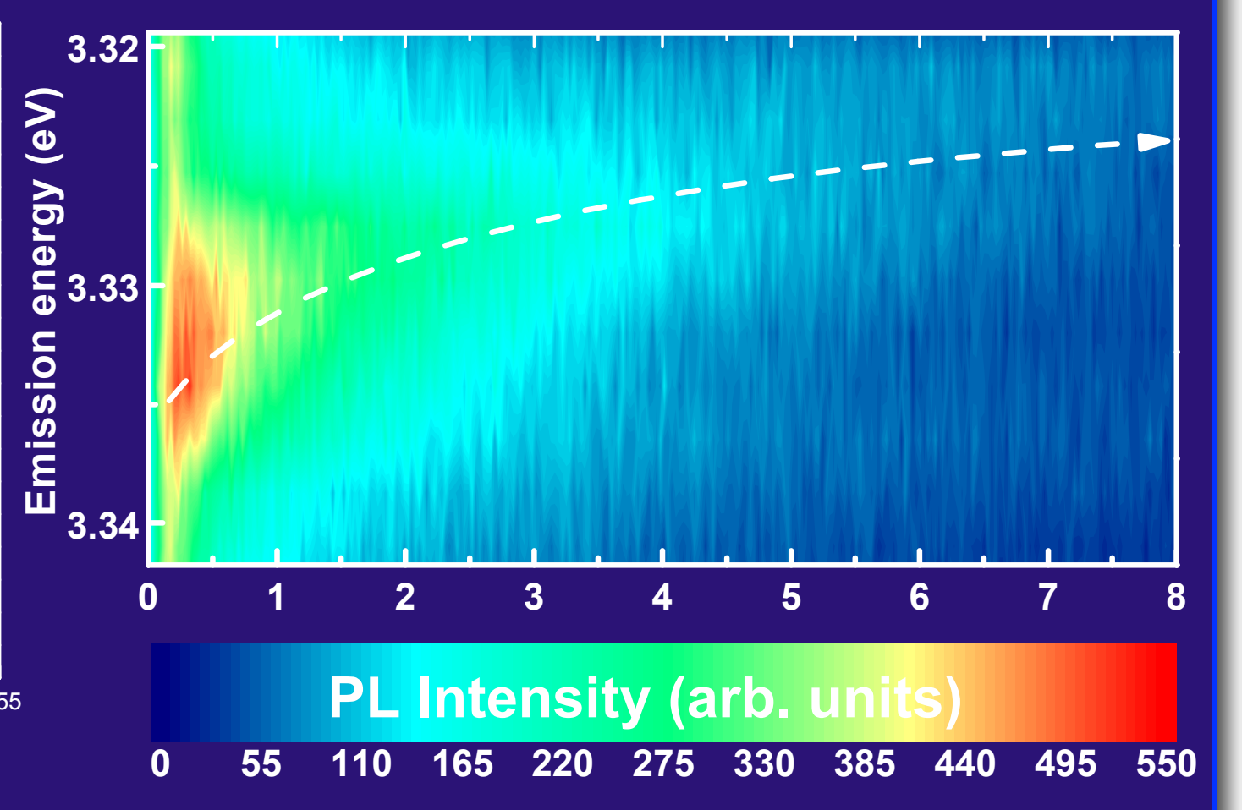
CL studies at 90K on a group of felled nanocolumns reveal the origin of 3 main emission peaks in the spectrum. The High energy GaN emission originates from the body of the column, as does the defect emission at ~3.4eV. The emission at ~3.3eV is far more spatially localised and originates from the QDisks embedded in the columns.





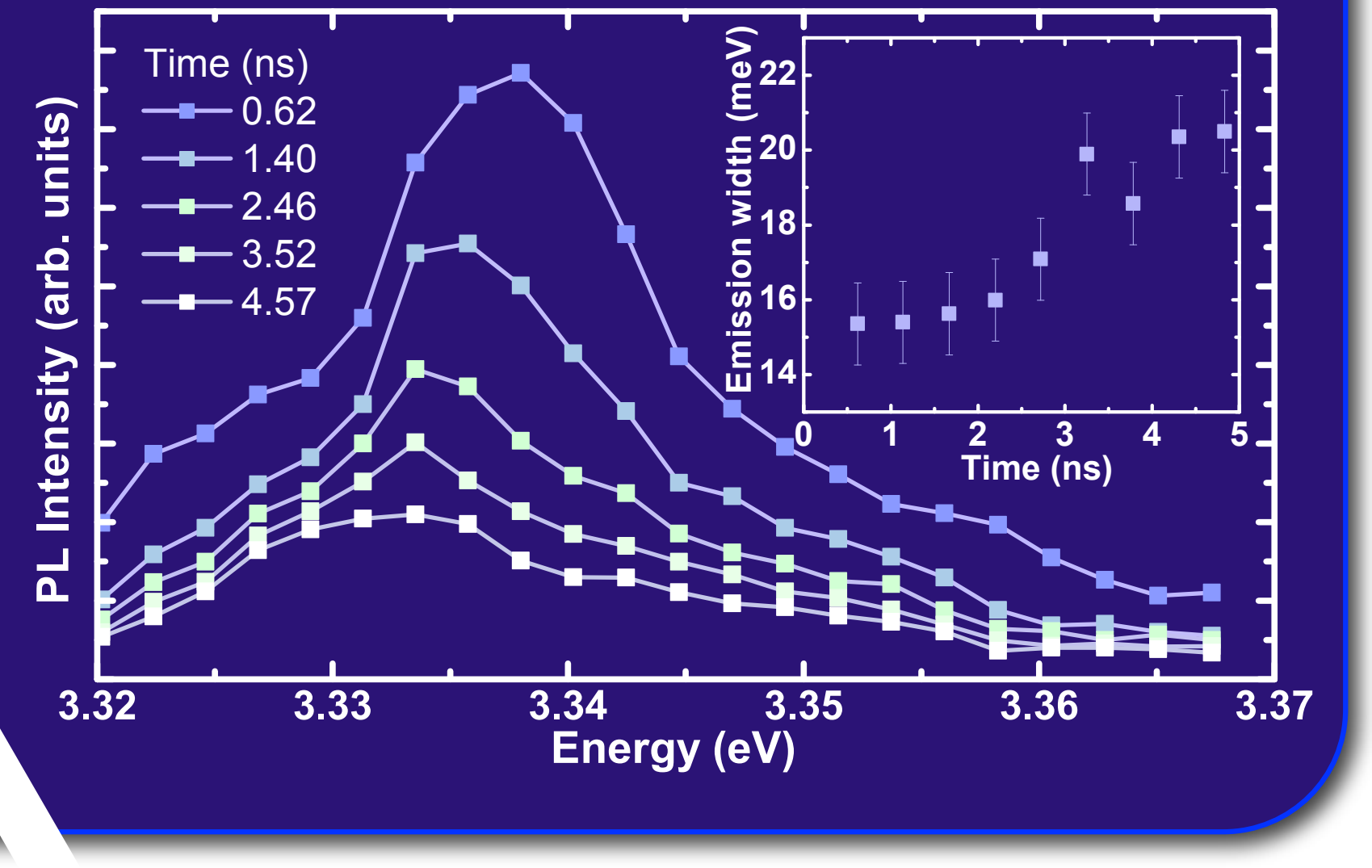
4. Photoluminescence Studies





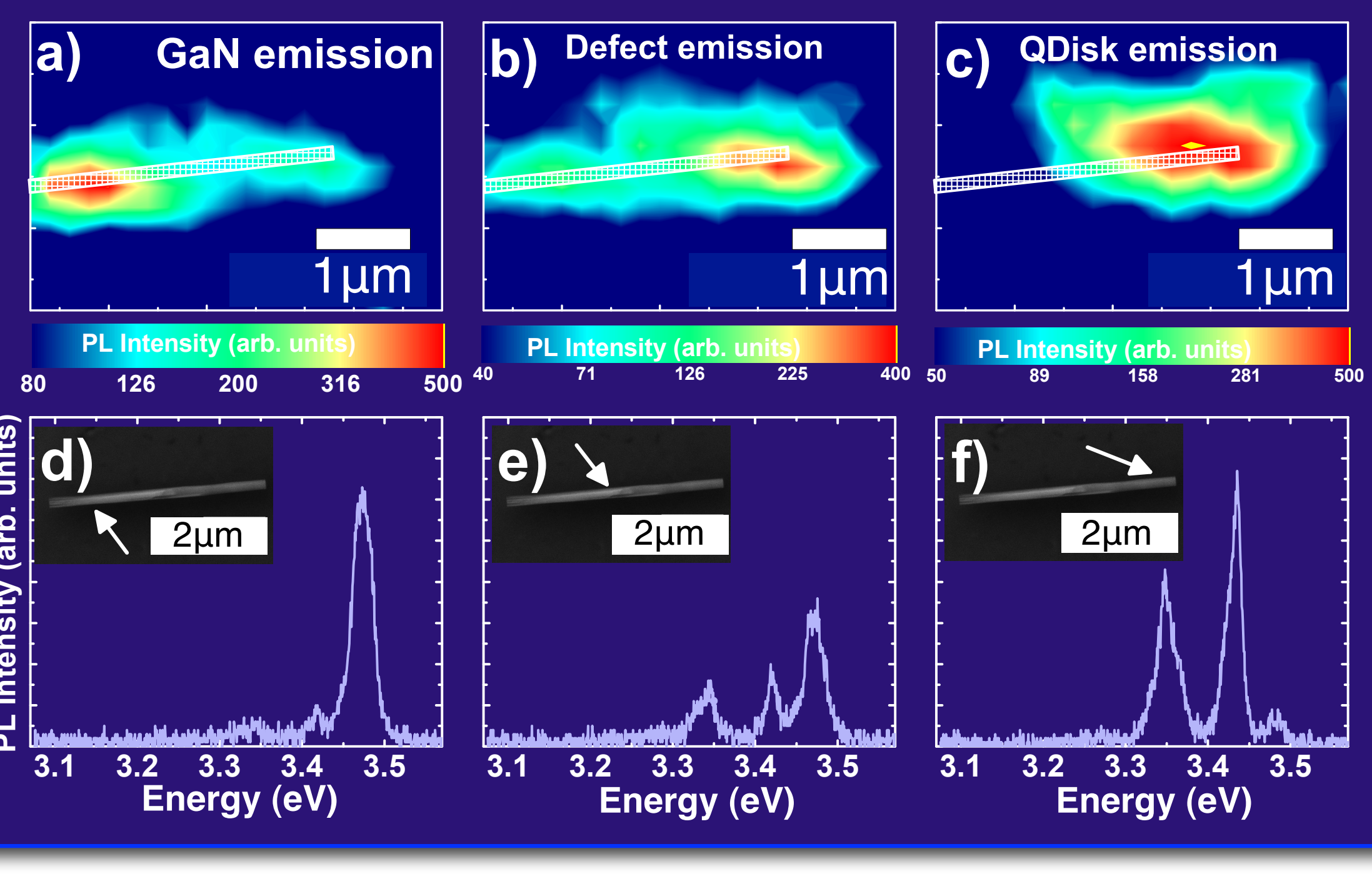
PL studies were carried out on the nanocolumns at 4K. The emission peaks become more easily identifiable and the QDisk emission blue shifts under increasing excitation power. The PL lifetime is ~4ns, which implies that there is **no large lateral separation of carriers in the QDisk**, as such a separation would invoke much longer lifetimes.

Upon collating time resolved data, it is possible to produce time resolved spectra of the QDisk emission. The dynamic shift of the peak is clear, and the broadening confirms that the shift is due to the QCSE.



5. Observing a Single Nanocolumn

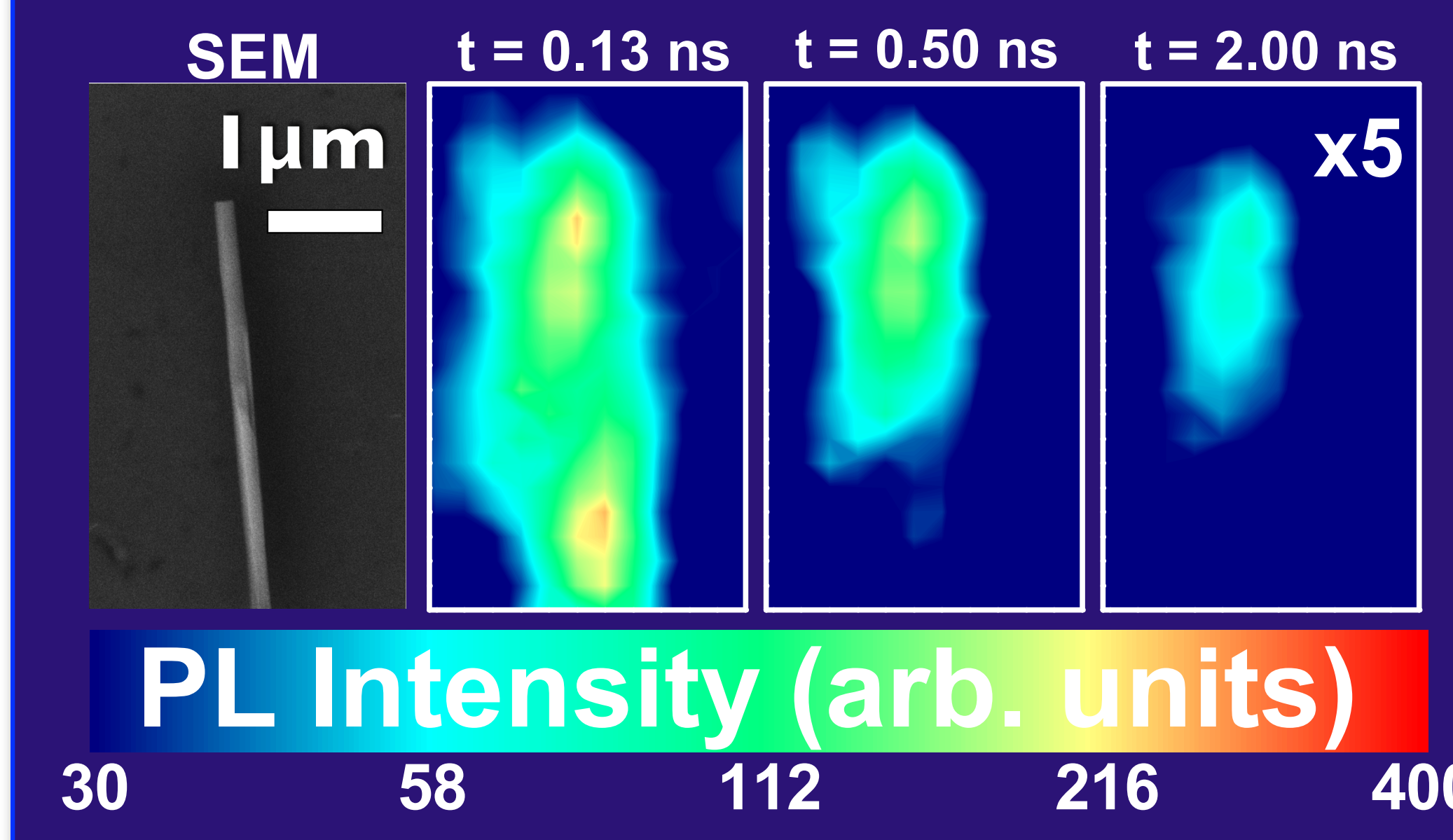
A grid was patterned in gold on quartz using e-beam lithography. Single columns were then scattered over the surface such that they could be located and investigated with μ-PL. The excitation laser could then be scanned over the single column such that spatially resolved PL could be measured to produce maps $S_E(xy)$.



6. Carrier Distribution in a Single Column

The maps, $S_E(xy)$, in 5 have been combined with time resolved data, $T_E(t)$, in order to produce temporally resolved maps of the emission intensity (and hence carrier density) from a single nanocolumn. The luminescence intensity at discrete energies was multiplied by the normalised temporal data from the same energy, and summed to produce the maps of all light from the column.

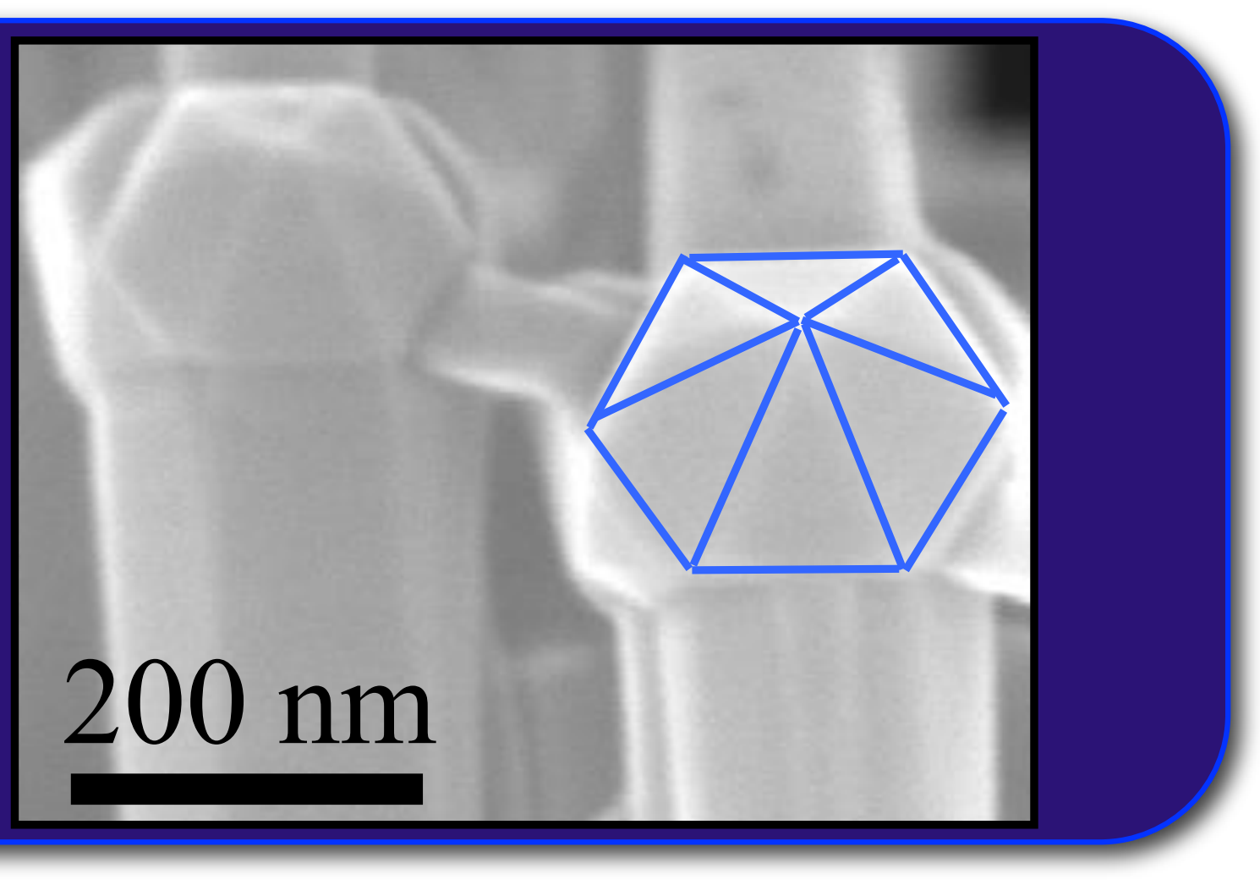
$$I(x,y,t) = \sum_{\mathrm{E}} S_{\mathrm{E}}(x,y) \times T_{\mathrm{E}}(t)$$



The maps show that at early times after excitation the carrier density in the nanocolumn is fairly uniform. As time progresses the carriers in the GaN quickly recombine and **the center of mass of the remaining carriers shifts to the region of the QDisk.** At t = 2ns, less than 7% of the initial carriers in the system remain.

Conclusions and Outlook

The optical properties of InGaN QDisks embedded in GaN nanocolumns have been investigated. No large separation of carriers in the plane of the QDisk has been observed. Fairly short lifetimes of the PL implies that a reasonable wavefunction overlap is present. This is perhaps enhanced by strain relaxation at the edges of the QDisks. As well as myriad device applications, future uses of nanocolumns may be for the seeding of **nanopyramids**, or **nanotubes**.



Further Information

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