X-ray probes of local composition and structure near defects in InGaN multi-quantum wells

SAND2014-17428D

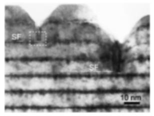
Rebecca Sichel-Tissot[1], S. O. Hruszkewycz[1], M. J. Highland[1], W. Cha[1], M. V. Holt[1], S. R. Lee[2], D.D. Koleske[2], and P. H. Fuoss[1]

[1] *Argonne National Laboratory, Argonne, USA* [2] *Sandia National Laboratories, Albuquerque, USA*

Motivation

III-N nitrides are smiconducting materials with a wide range of band gaps for high power switches (AlN) and solid state lighting (GaN, InGaN LEDS).

There are no cost-effective, lattice matched substrates to make nitride thin films, so devices are limited by large defect densities. [1]



HRTEM image of "v-defects" in InGaN/GaN MQWs. V-defects have stacking faults on (0001) planes that often originate above GaN threading dislocations. [4]

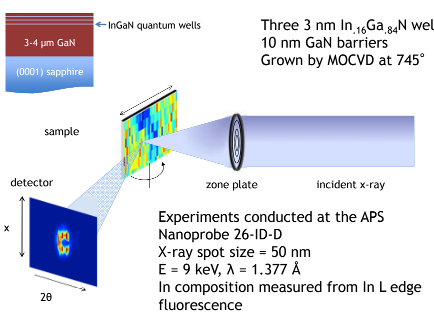
InGaN light-emitting devices (LEDs) consist of multiple thin InGaN layers separated by GaN barrier called a ***multiquantum well (MQW)*** structure.

In LEDs used in solid state lighting, high threading dislocation densities affect minority carrier concentration and recombination rates [2] within the InGaN MQW active regions of the devices, while compositional fluctuations are thought to localize carriers within the same region. [3]

Focused x-ray beams can be used to measure composition and structure at the same length scales as defects (see figure above).

How do composition and structure vary near defects in InGaN MQW films?

Experiment

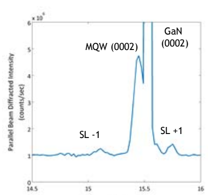


Three 3 nm $In_{.16}Ga_{.84}N$ wells
10 nm GaN barriers
Grown by MOCVD at 745° C

Experiments conducted at the APS Nanoprobe 26-ID-D
X-ray spot size = 50 nm
E = 9 keV, λ = 1.377 Å
In composition measured from In L edge fluorescence
Diffraction measurements used square grid raster scans with a step size of 33 nm

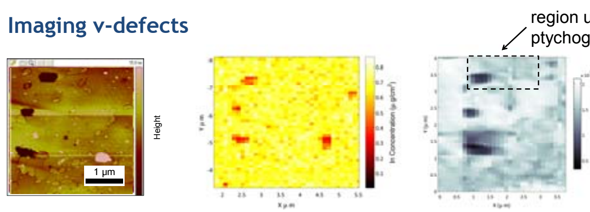
Parallel beam diffraction used to find MQW reflections.

We used the SL +1 reflection for the microdiffraction experiments because it is well separated from the GaN (0002)



Microdiffraction from defects

Imaging v-defects

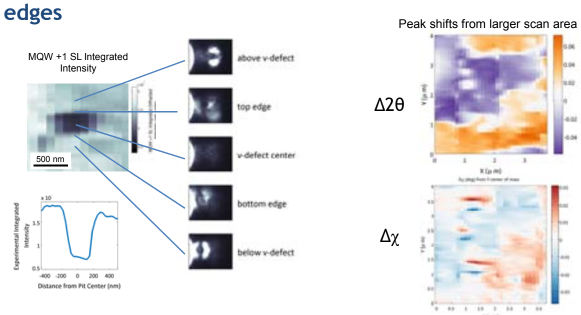


AFM: v-defects create large pits with triangluar cross sections
XRF: v-defects have less In than surrounding film
XRD: integrated intensity of MQW reflections is lower in v-defects

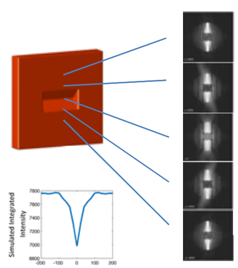
Indium content outside of defects is uniform.

Structural changes outside the defects are not related to compositional variations. Could be related to thinner MQW layers, increased roughness, strains, or rotations. To distinguish between potential causes, we quantified peak motions, simulated diffraction patterns from a pit, and used Bragg projection ptychography to reconstruct the sample.

Experimental MQW diffraction peak shifts at defect edges

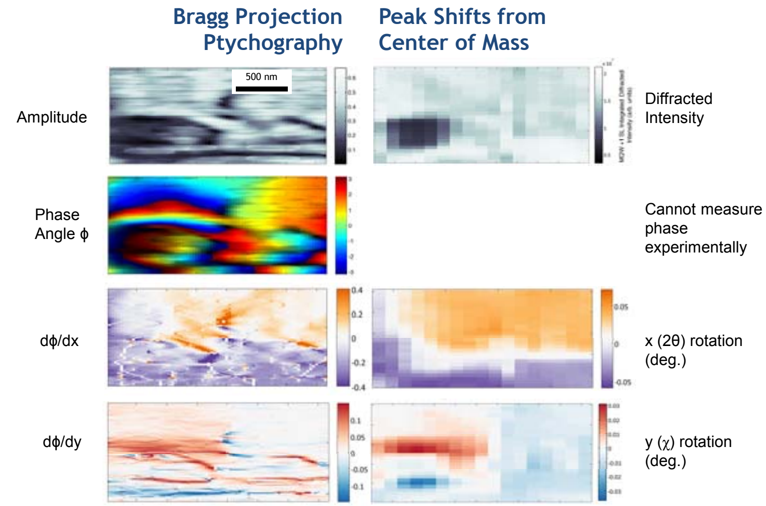


Simulated diffraction patterns from a defect



Simulation suggests that a pit in the film modifies the diffuse scattering, but does not shift the refection's center of mass.

The shifts measured from the center of mass are not caused by the shape of the defect; they come from rotations and strains in the lattice.



Bragg ptychographic reconstruction of the film was refined with the Ptychographic Iterative Engine [5-7].

Lattice rotations are related to the gradients of the phase, dϕ/dx and dϕ/dy, which closely match the centers of mass of the experimental diffraction pattern at potentially higher resolutions compaerd with traditional scanning probe diffraction.

MQW (0002) planes are rotated near the defect edges, consistent with strain relaxation near a hole in the film.

Conclusions

AFM, x-ray fluorescence, and x-ray microdiffraction were used to image v-defects in InGaN MQWs.

Diffraction peak shifts indicate significant structural variations inside and outside of pits, independent of composition.

Lattice rotations measured independently from position of Bragg peak center of mass and derivatives of the phase retrieved from Bragg projection ptychography reconstruction are well correlated.

References

[1] A. Armstrong *et al.*, *Appl. Phys. Lett.* **101**, 162102 (2012)
[2] J.S. Speck *et al.*, *Physica B* **273**, 24 (1999).
[3] M.J. Galtrey *et al.*, *Appl. Phys. Lett.* **92**, 041904 (2008).
[4] H. K. Cho, J. Y. Lee, G. M. Yang, and C. S. Kim, *Appl. Phys. Lett.*, **79**, 9 (2001).
[5] S. O. Hruszkewycz *et al.*, *Nano Lett.*, **12**, 5148 (2012).
[6] M. V. Holt *et al.*, Phys. Rev. Lett. **112**, 165502 (2014).
[7] A. M. Maiden and I. M. Rodenburg, Ultramicroscopy **109**, 1256 (2009).

Acknowledgements

This research was supported by the U.S. Department of Energy, Office of Science. Sandia National Laboratories is a multiprogram laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Sandia National Laboratories

Argonne NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY