Structures of non-polar (11-20) InGaN nanostructures grown by modified droplet epitaxy

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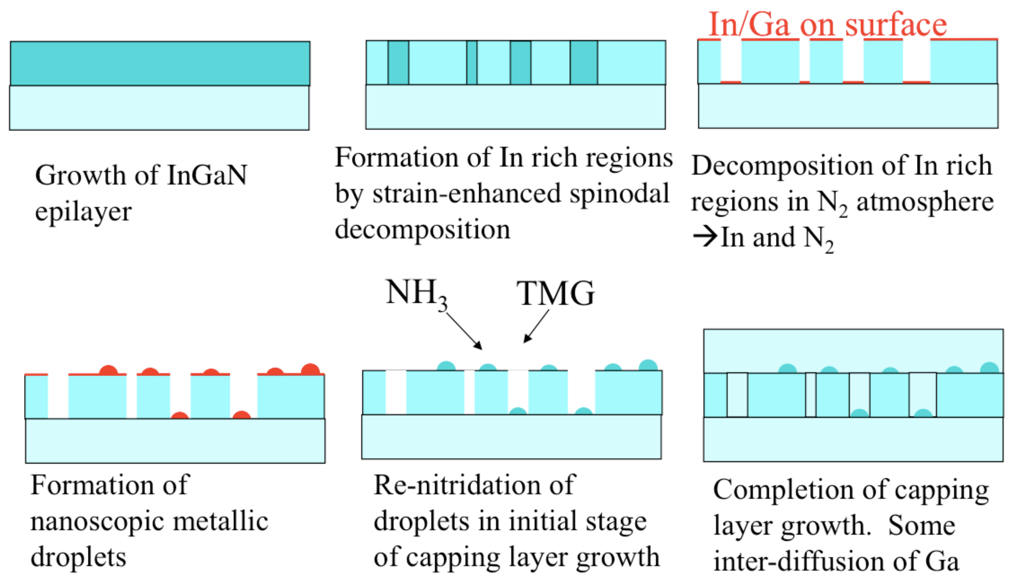
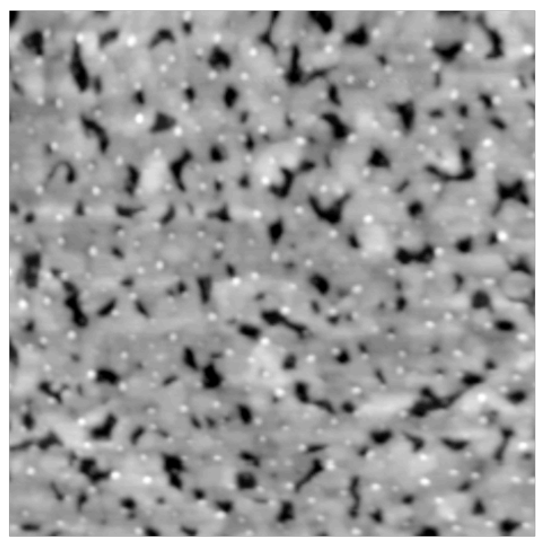
Introduction

- Semiconductor quantum dots (QDs) show promise as sources for single photon emission, enabling comparably high temperature emission and access to the blue and green spectral regions.
- The wurtzite structure of gallium nitride (GaN) results in significant electric fields across strained structures grown in the c-plane orientation due to spontaneous polarization and a large piezoelectric constant.
- This reduces the radiative recombination efficiency due to the spatial separation of the electron and hole via the quantum confined Stark effect (QCSE).
- Non-polar structures are therefore of interest; reduced exciton lifetimes have already been observed [1].

Quantum dot growth- modified droplet epitaxy

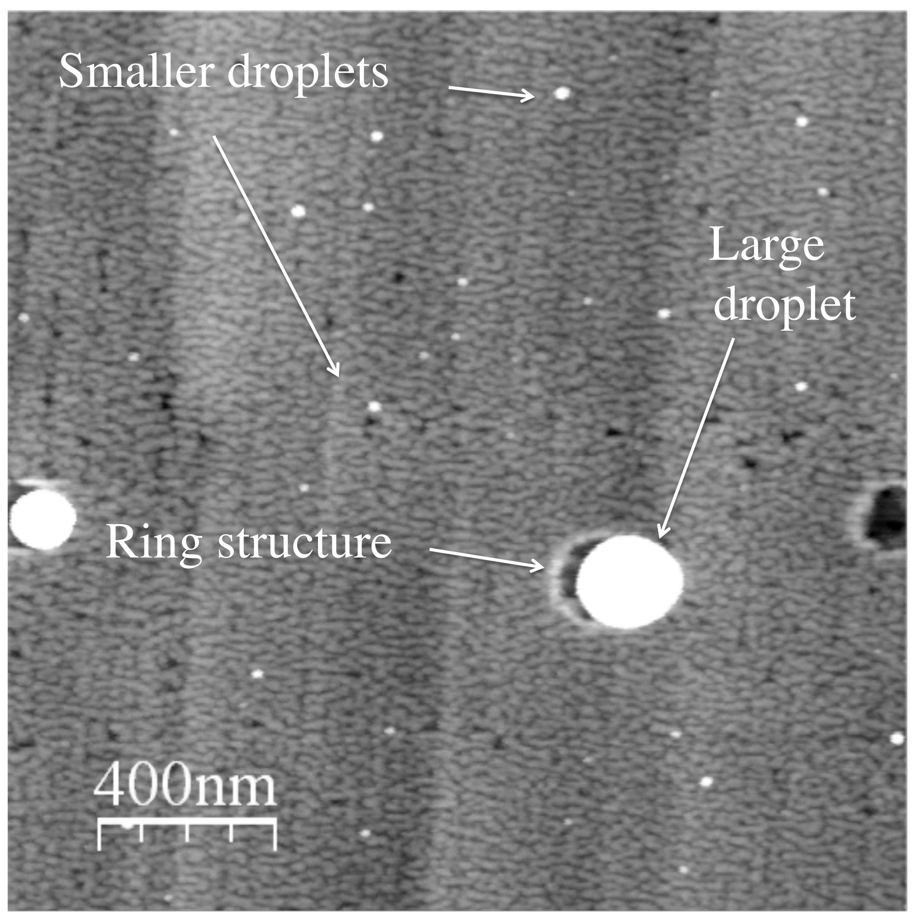


Schematic of the mechanism of 'modified droplet epitaxy'.

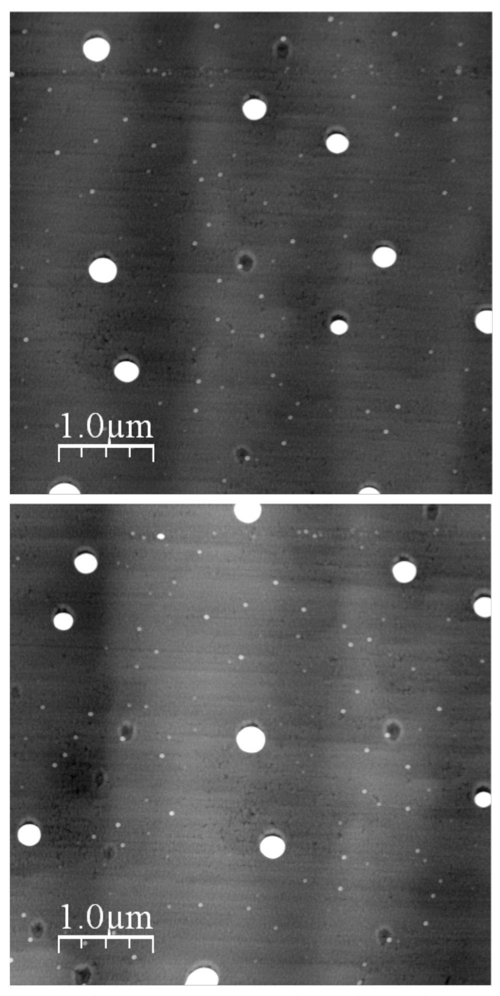


AFM image of an InGaN/GaN c-plan. e epilayer 2 x 2 µm scan, image height h= 5.82 nm.

AFM of as-grown non-polar epilayers

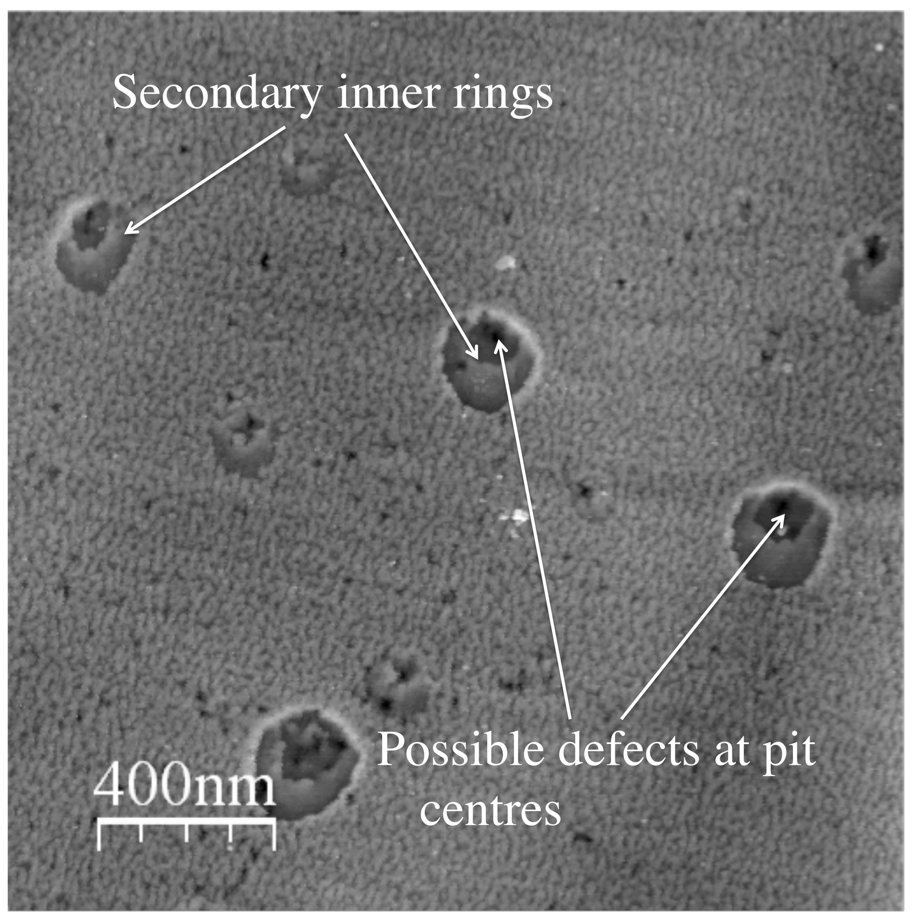


AFM image of InGaN epilayer after 15 s anneal in N_2. Image height, h = 15 nm. The large droplet sits to one side of the ring; this is a consistent feature. Smaller droplets more similar to those seen on c-plane are also observed.

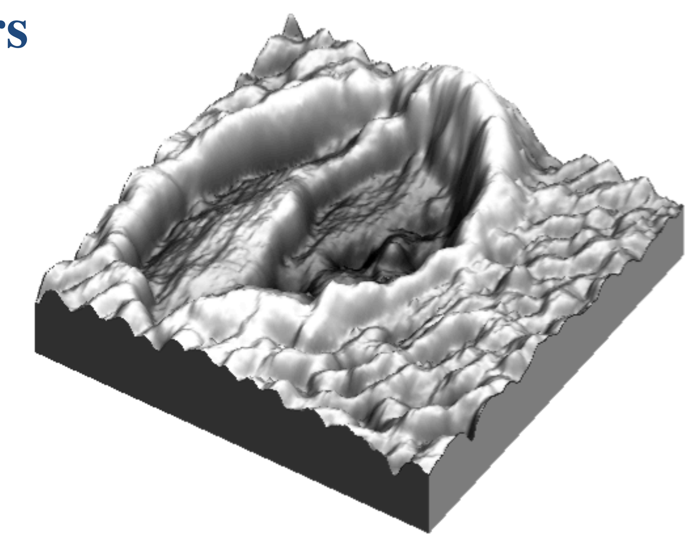


AFM images scan direction a) down and b) up, x offset 2 µm. This shows that the droplets are not being moved by the tip during the scan. h = 20 nm.

AFM of HCl-etched non-polar epilayers



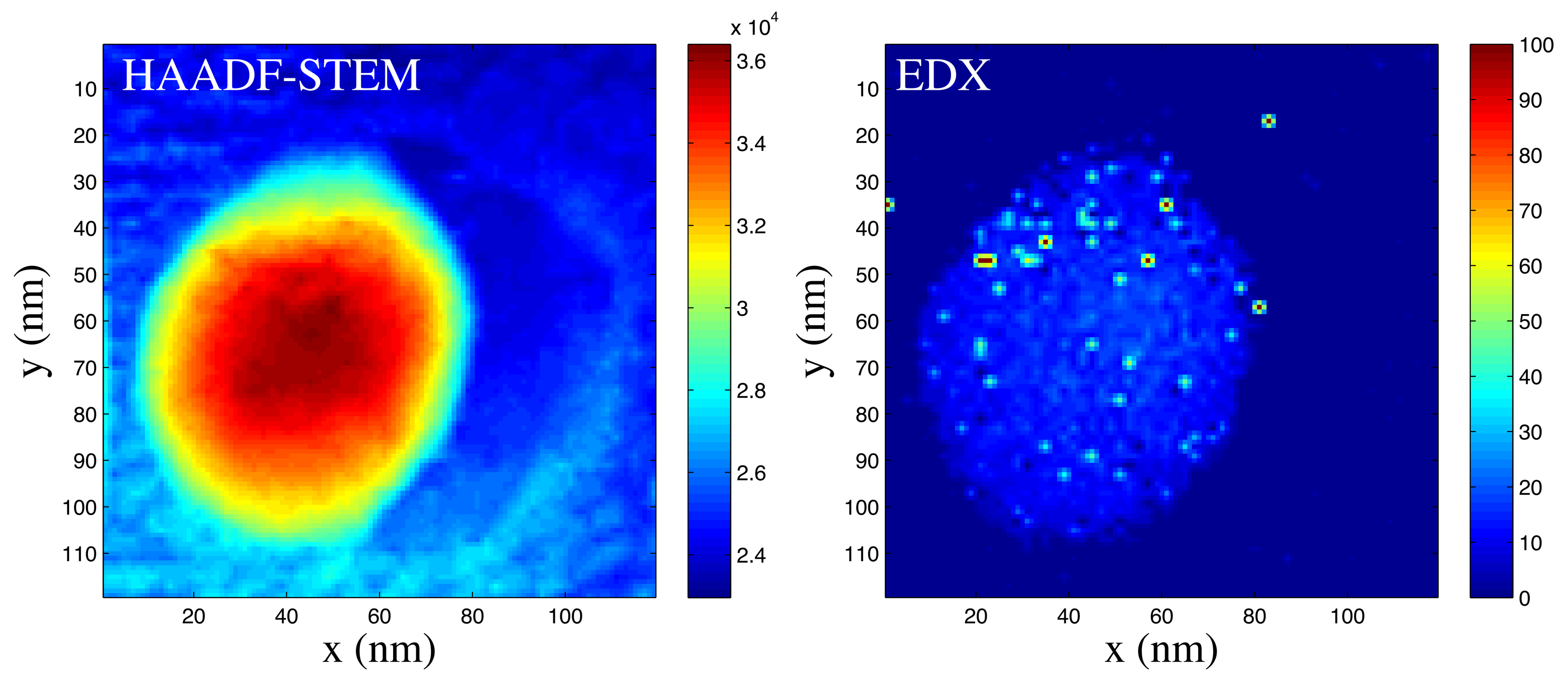
AFM image of etched epilayer. h = 16 nm.



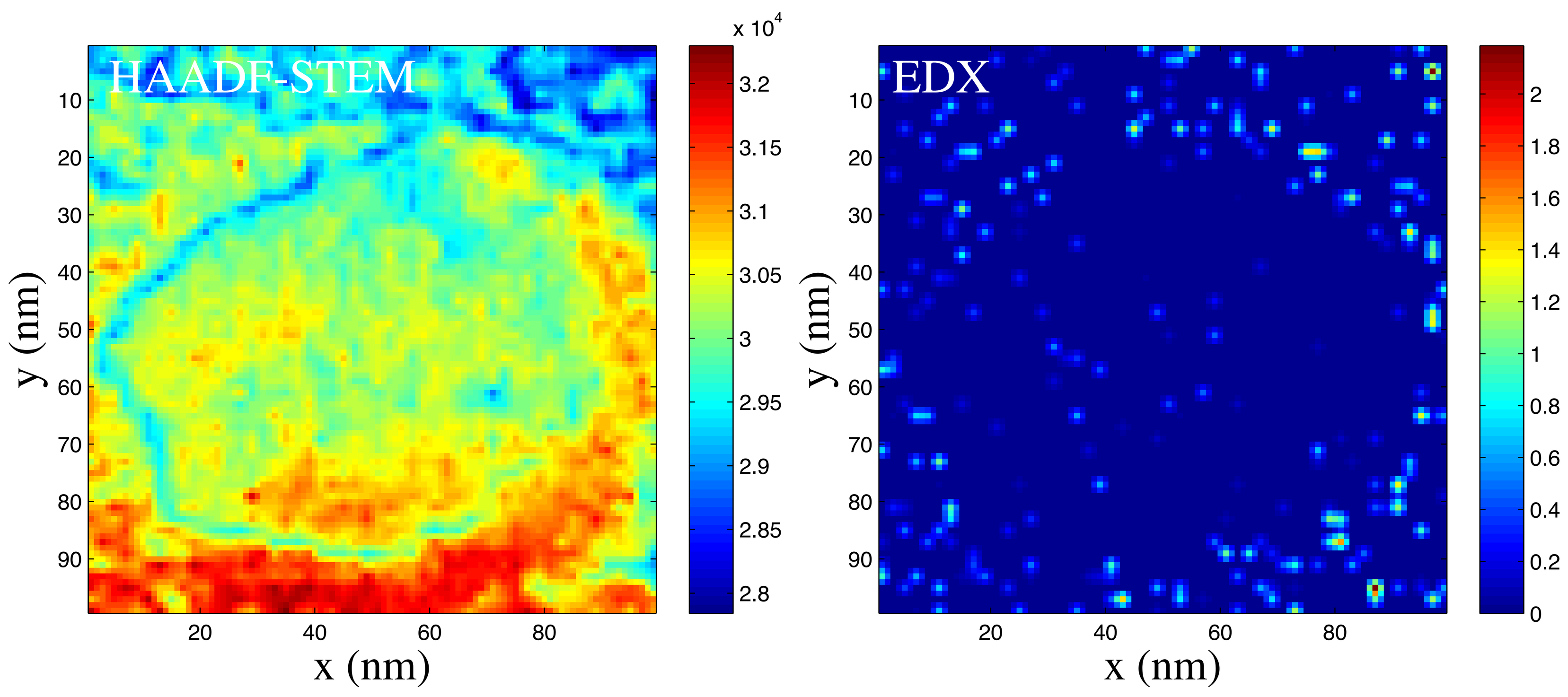
3D AFM image of 'double-ring' structure. 350 x 350 nm scan size, height, h= 8.2 nm.

- Upon etching, a 'double-ring' structure is observed
- It is possible that a defect may lie at the bottom of the pits
- The inner ring appears to lie in an anti-parallel direction to the droplet

Electron dispersive x-ray analysis scanning transmission electron microscopy (EDX-STEM)

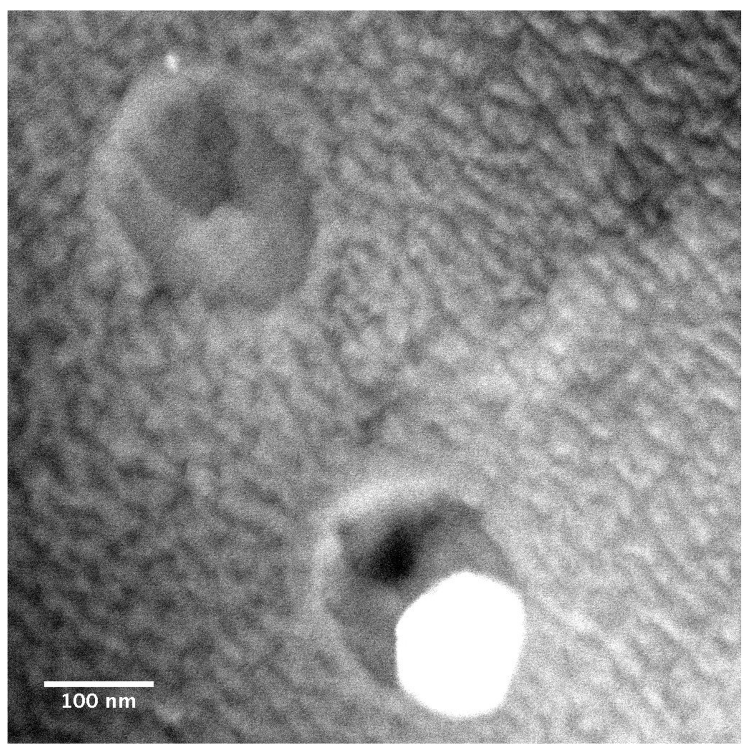


HAADF-STEM and EDX data for the droplet. As expected, increased In content is observed in the droplet.



HAADF-STEM and EDX data for the ring structure. A decrease in In content can be observed within the pit.

HAADF-STEM



HAADF-STEM image, showing the and secondary ring to be on opposite sides of the main ring.

Summary

- Droplets are shown to be metallic, as expected, as they can be removed by etching in HCl. It is believed to be metallic indium.
- The ring structure is hypothesized to form via a local droplet etching mechanism analogous to that proposed by Li et al for GaAs [2]; beneath a Ga droplet, GaAs is decomposed into Ga and As; the As from here and the surface diffuses to the edge of the droplet where it crystallizes with Ga to form a GaAs ring. The remaining pit is deeper than the epilayer deposited, as is the case for the pits observed in this study.
- The droplet and inner ring appear to lie in anti-parallel directions- as of yet, it is unclear why this occurs.
- It is unknown which structure leads to the formation of quantum dots; it believed that the In droplets react with NH_3 upon capping, but it is not certain whether the large droplets disintegrate or the dots are formed by the small droplets.
- Some rings are observed to consist of discrete hillocks adjoining one another in a ring-like formation, rather than a single continuous toroid. Further investigation is required to determine how this affects their behaviour.
- It is possible that the ring structure observed may act as a 'quantum-ring'.

References

[1] Zhu, T. *et al*. Non-polar (11-20) InGaN quantum dots with short exciton lifetimes grown by metal-organic vapor phase epitaxy. *Appl. Phys. Lett*. **102,** 251905 (2013).

[2] Li, X. *et al*. Origin of nanohole formation by etching based on droplet epitaxy. *Nanoscale* **6,** 2675–81 (2014).

Acknowledgments

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