Simultaneous mapping of the cathodoluminescence and electron beam induced current from InGaN LEDs with different barrier growth temperatures

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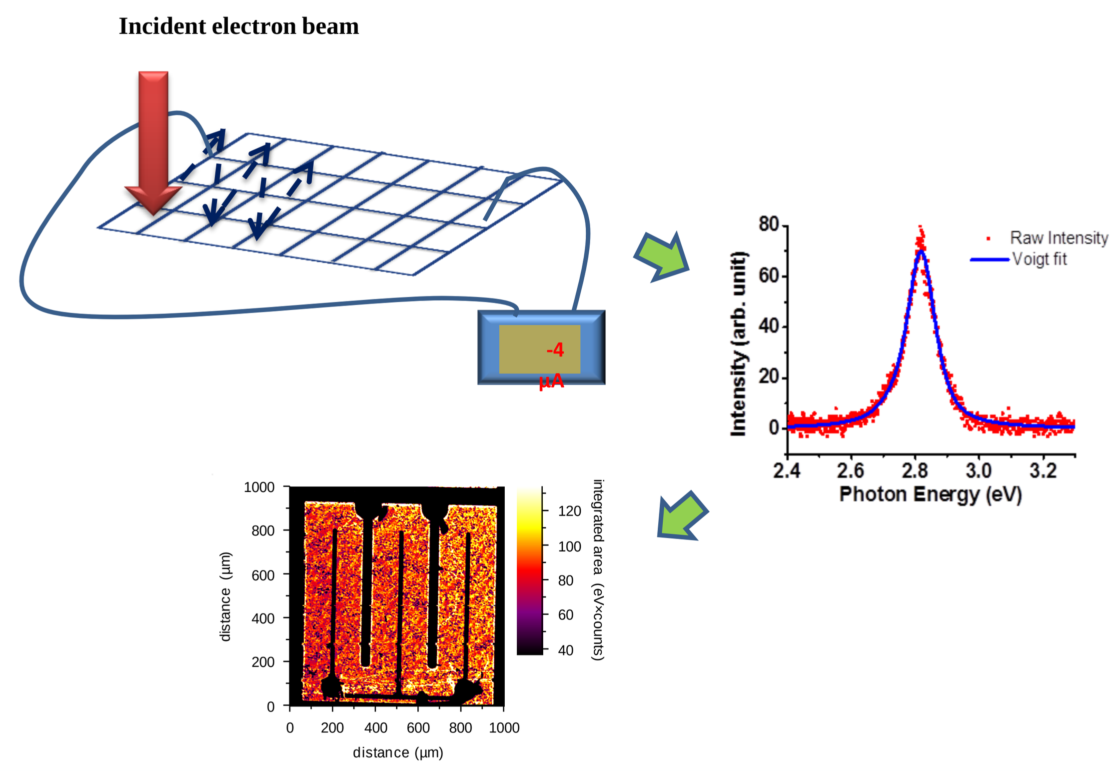
Motivation

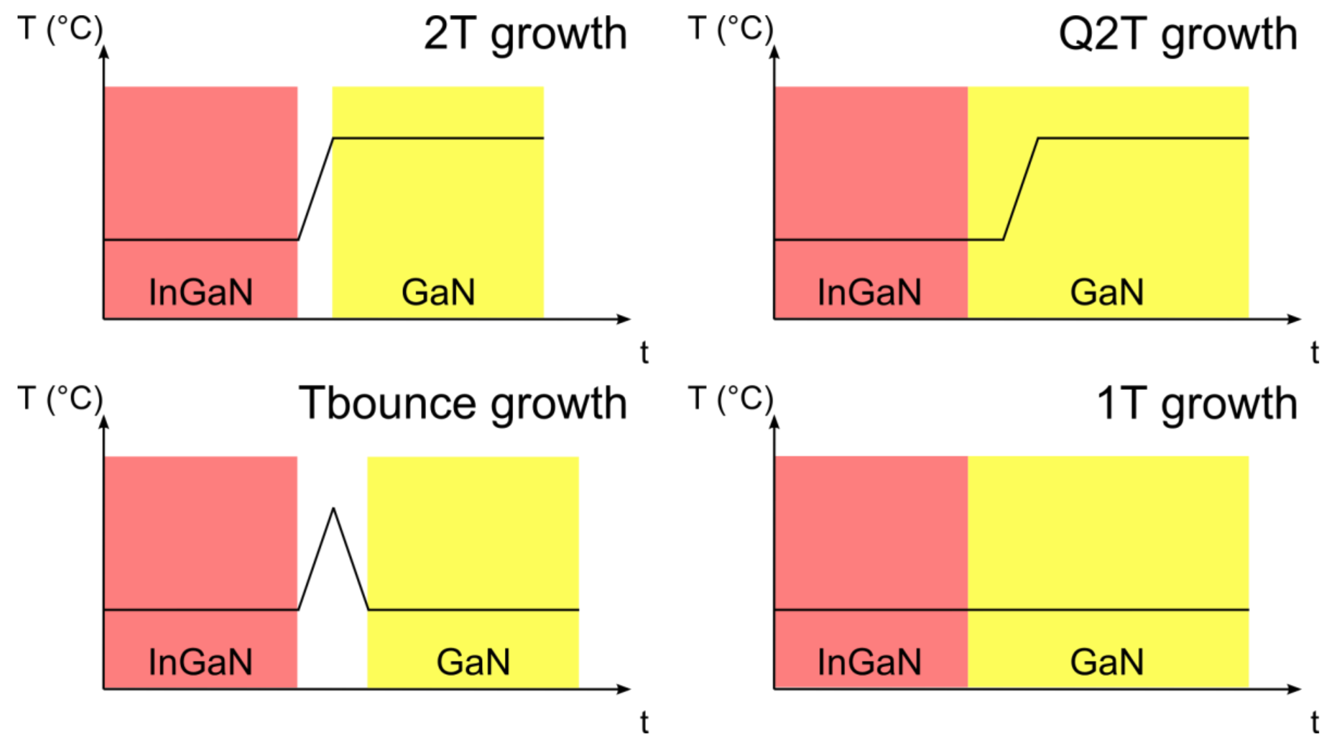
- Efficiency of of light emitting diodes (LEDs) depends on design and growth of the active region
- Growth temperature of the quantum wells and quantum barriers affects material quality, light output and flow of charge carriers.
- Spatially resolved study of luminescence and conductivity will shed light on the micron scale impact of the different growth methods
- Cathodoluminescence (CL) imaging reveals spatial variation in emission
- Electron beam induced current (EBIC) in combination with CL gives information on non radiative recombination

Simultaneous CL and EBIC

- The sample stage of an electron microscope was scanned under a static electron beam spot.
- A CL spectrum and the induced was current recorded at each point in a raster scan of the LED.
- 2D maps of spectral intensity, peak energy, peak width and induced current produced and analysed.

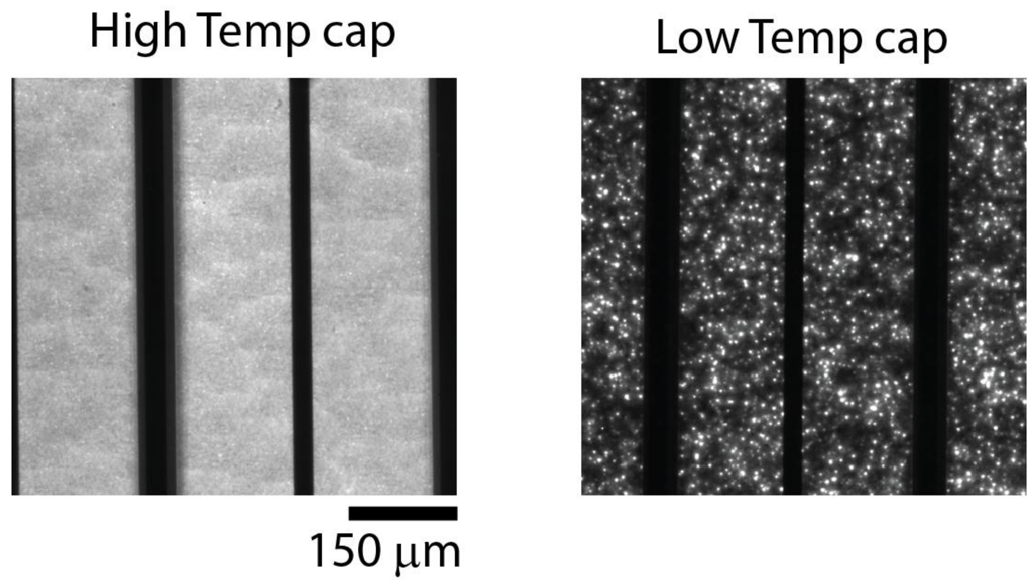


Variations in the growth of LED active regions



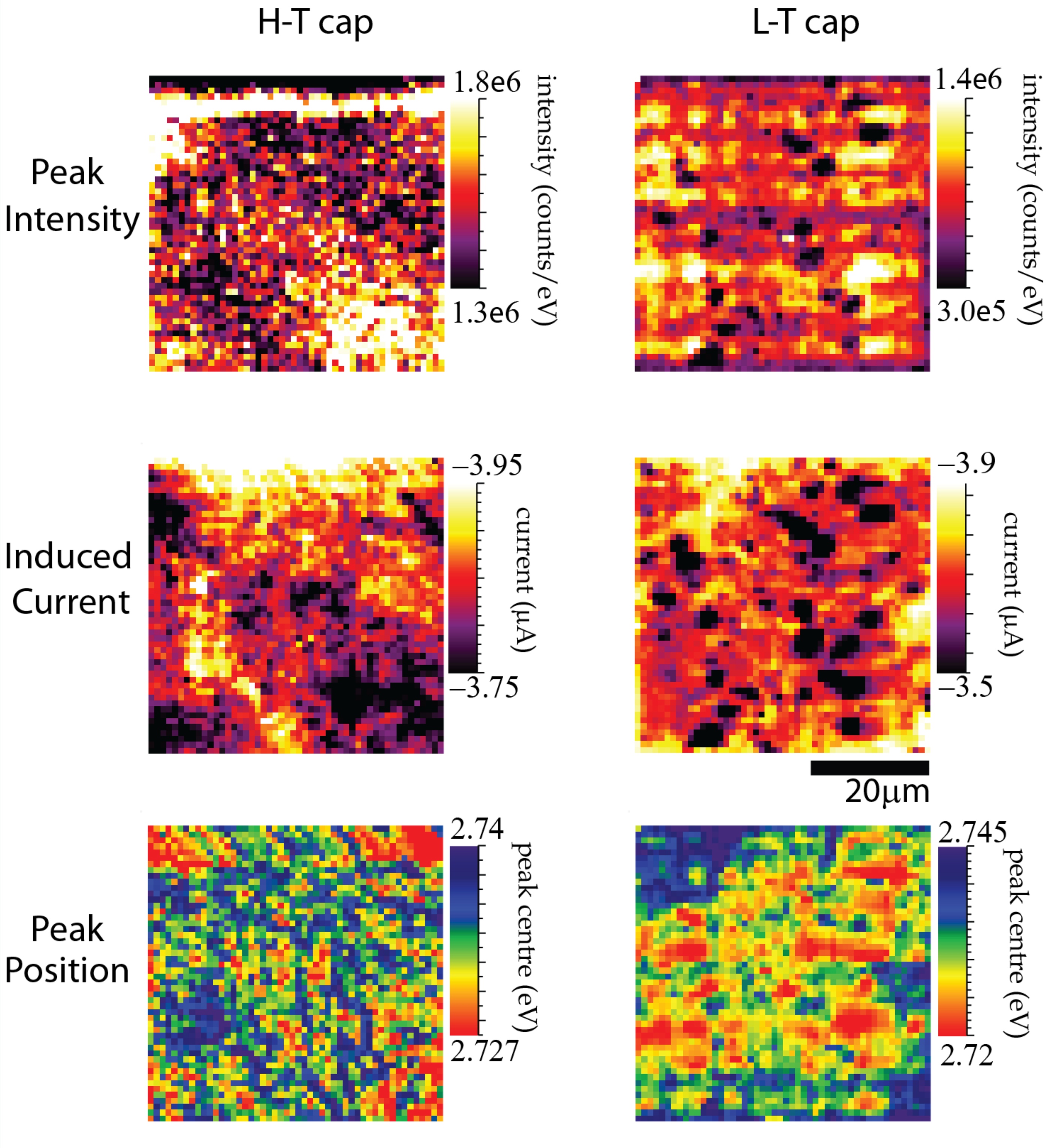
- A series of four LED samples were grown by MOCVD and processed into 1mm² chips
- The optically active regions were grown at different temperatures.
- The key difference is the temperature of the first section of the GaN barrier (cap) on each InGaN quantum well:
  - **Low T cap in Q2T and 1T**
  - **High T cap in 2T and T-Bounce**

Photos of electroluminescence



- High T cap shows smoother and brighter emission
- Low T shows many bright spots and dark patches

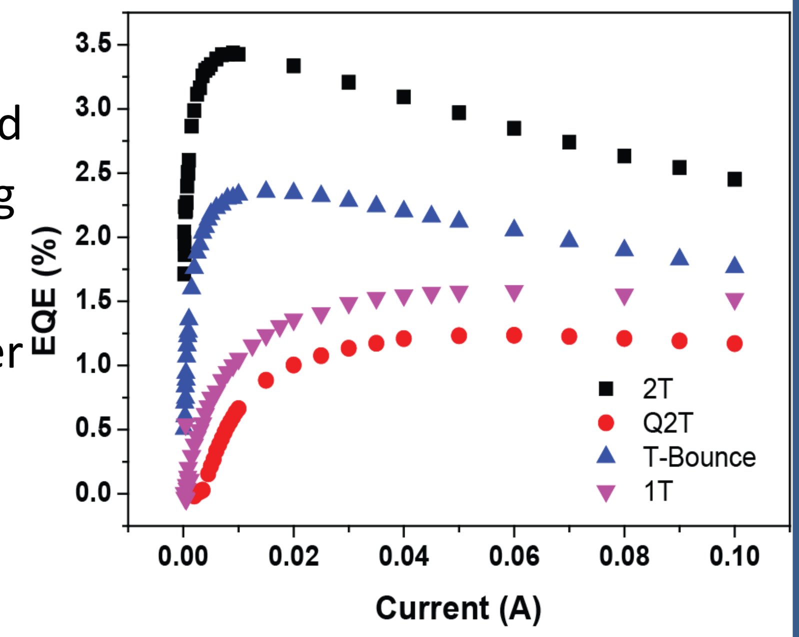
CL/EBIC mapping



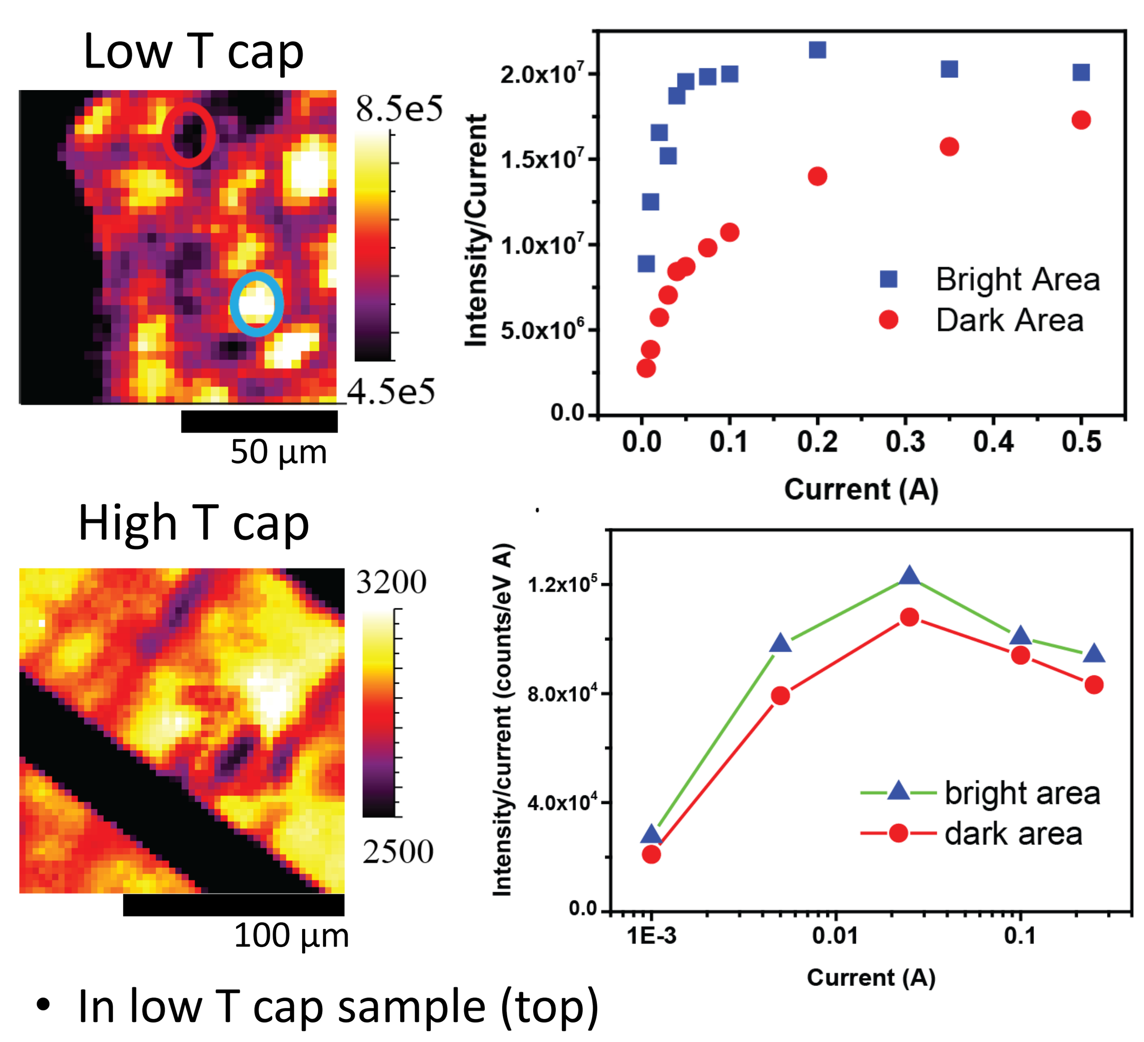
- Samples grown with high T caps:
  - Anti-correlation between CL and EBIC
  - This is due to competition between recombination and carrier escape from active region
  - Blue shift correlates with low CL and high EBIC- consistent with lower induced forward voltage.
- Samples grown with low temp caps show:
  - Spotty, patchy emission (as in the EL)
  - Black spots, 2-10 µm across, with significantly (~5x) lower emission intensity and induced current. Spectrum in dark spots blue shifted by around 10-15 meV.
  - This indicates increased non radiative recombination in these area.

Macroscopic EL efficiency

- Overall device efficiency measured using an integrating sphere
- High T shows higher peak efficiency but decays faster with increasing current



Spatially resolved efficiency



- In low T cap sample (top) electroluminescence efficiency varies across surface
- Overall efficiency curve matches that from the dark areas
- The efficiency curve from the bright areas in the low T samples are similar to those from the high T cap samples

Conclusions

- LED growth temperature affects spatial homogeneity and efficiency
- Combined CL and EBIC mapping reveals micron scale dark areas with increased carrier trapping in LEDs with low temperature quantum well caps
- Dark spots dominate EL efficiency, whereas bright patches show similar current dependence to the high T cap samples

Future Work

- The electric field dependence of the dark areas is being studied – features change size
- Further work on spatially resolved efficiency droop of various samples
- Smaller features in unprocessed LEDs to be studied with EBIC
- Study of correlations between CL and EL on same areas.

Acknowledgements

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