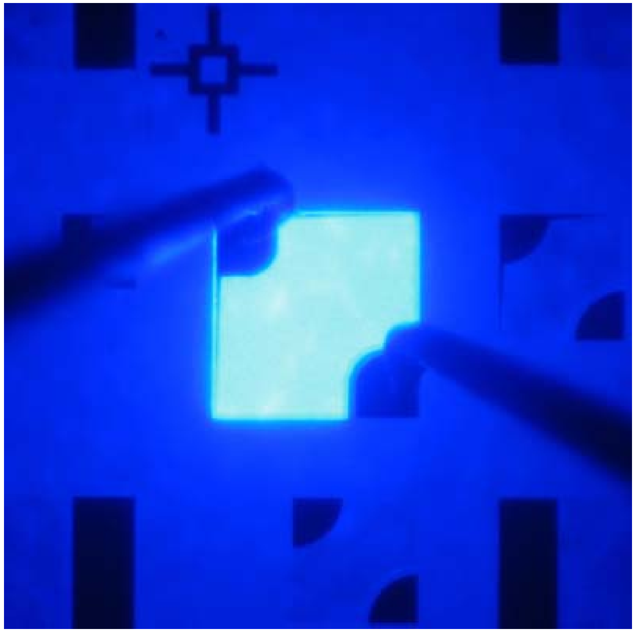
Blue GaN LEDs by MOVPE Technology

Optoelectronics Laboratory

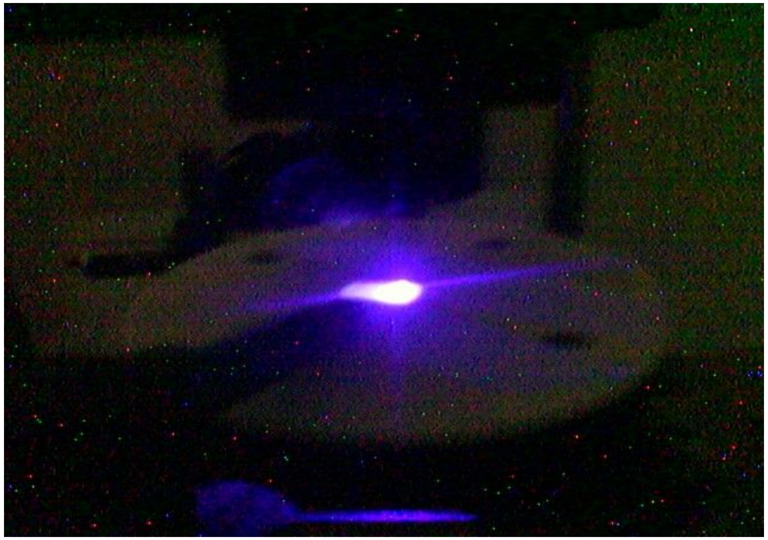
Helsinki University of Technology

OPTOGAN



GaN Technology for Blue Lasers (2004 -)

- Joint project of Optoelectronics Laboratory, OptoGaN Oy and Lumilaser Oy
- Funding by Tekes
- 4 PhD students, 1 diploma worker

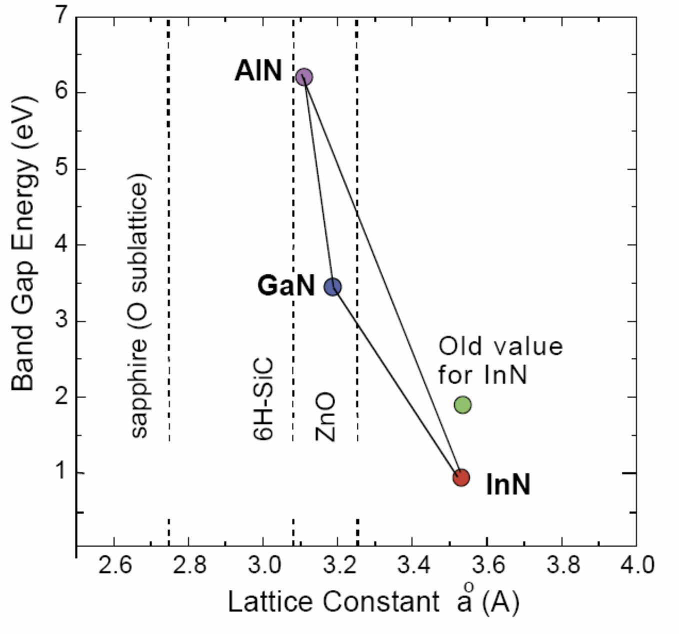


Achievements

- Low dislocation density GaN, May 2005
- Optically pumped GaN laser, July 2005
- High brightness GaN LED, October 2005
- Electrically pumped GaN laser diode, ?? 2006
- Scientific papers in 2005, 1 published, 4 pending

III-N semiconductors (Al Ga In - N)

- **Strong N bonds**
- **Chemically inert**
- **Devices suitable for high temperature applications**
- **Large and direct band gap**
- **Emission can be tuned from UV to green**

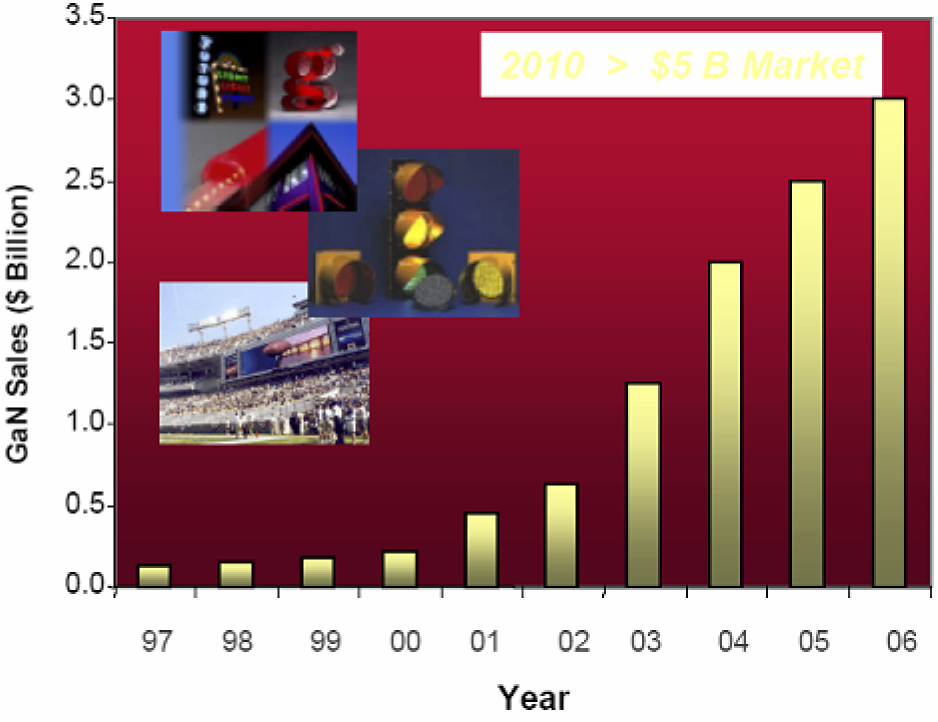


Problems

- **No cheap lattice matched substrate available**
- **Processing difficult**

Commercial Opportunities for GaN

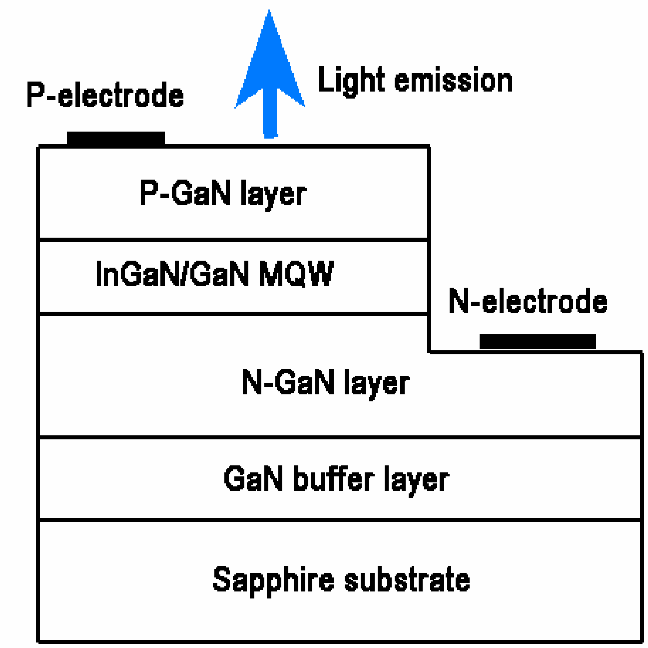
- Traffic lights
- Illumination
- Automotive
- Medicine
- Outdoor displays
- Mass data storage
- Wireless communications



Data Source: Strategies Unlimited

Blue GaN LED

- Sapphire substrate
- ICP etching of mesa structure
- Both electrical contacts on top side
- Emission from $In_{15}Ga_{85}N$ / GaN quantum wells

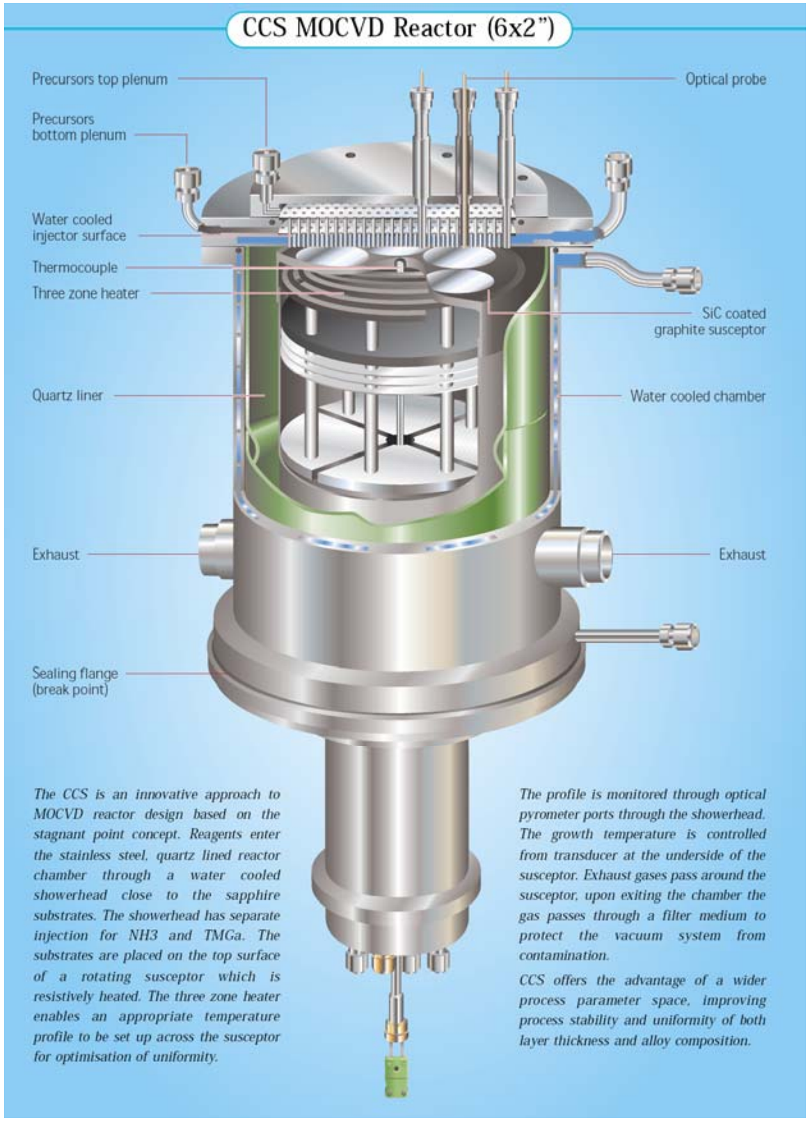


Problems

- High dislocation density due to sapphire / GaN lattice mismatch
- Different growth regimes for InGaN and GaN
- P-type doping
- Non uniform current spreading

Thomas Swan CCS 3 x 2” MOVPE reactor

- Optimised for the growth of III – N materials
- Real-time optical monitoring of growth (layer thickness, surface temperature...)
- Excellent uniformity of thickness and alloy composition
- Suitable for both research and small scale production

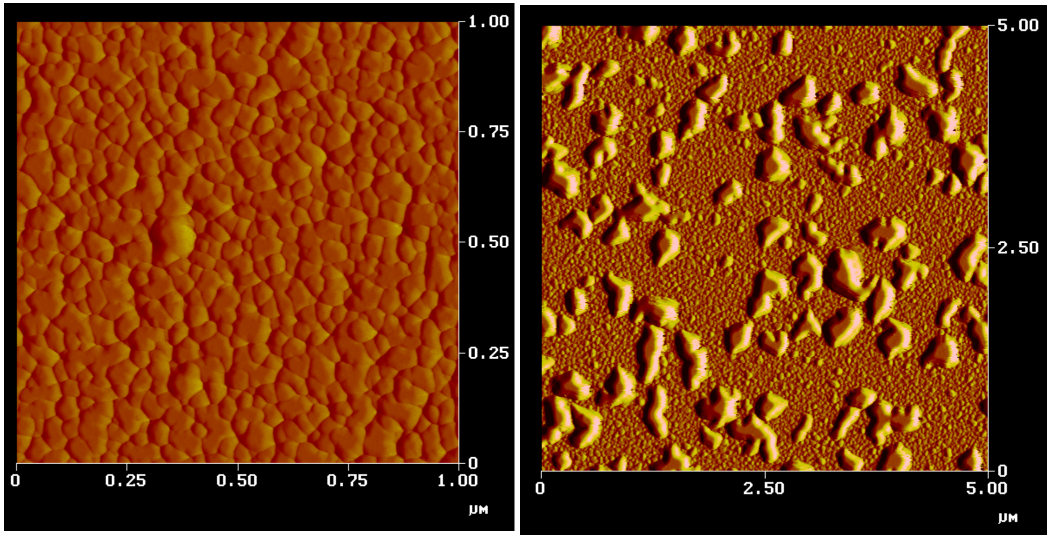


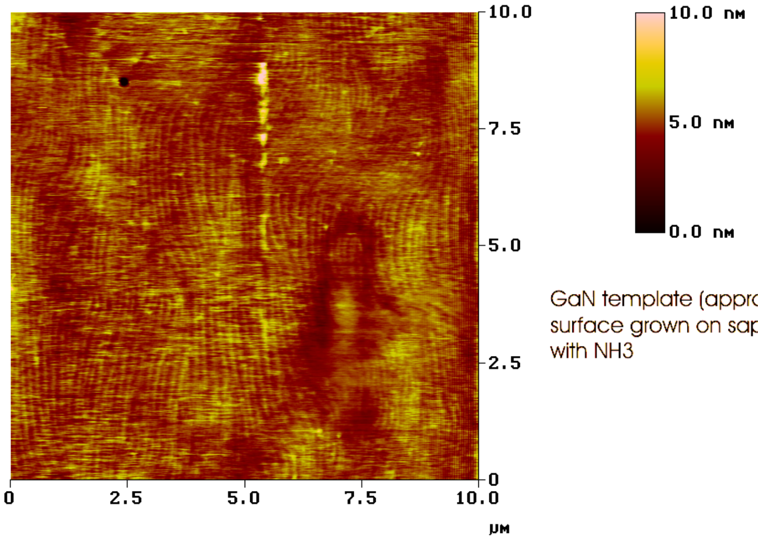
The CCS is an innovative approach to MOCVD reactor design based on the stagnant point concept. Reagents enter the stainless steel, quartz lined reactor chamber through a water cooled showerhead close to the sapphire substrates. The showerhead has separate injection for NH3 and TMGa. The substrates are placed on the top surface of a rotating susceptor which is resistively heated. The three zone heater enables an appropriate temperature profile to be set up across the susceptor for optimisation of uniformity.

The profile is monitored through optical pyrometer ports through the showerhead. The growth temperature is controlled from transducer at the underside of the susceptor. Exhaust gases pass around the susceptor, upon exiting the chamber the gas passes through a filter medium to protect the vacuum system from contamination.

CCS offers the advantage of a wider process parameter space, improving process stability and uniformity of both layer thickness and alloy composition.

MOVPE of GaN on sapphire





GaN template (approx. 3 um)
surface grown on sapphire wafer
with NH3

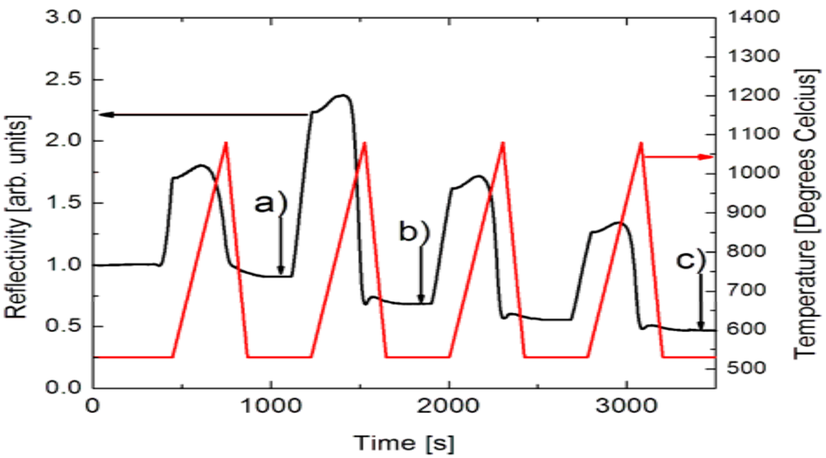
1. Low temperature (530C) growth of GaN creates multi-phase nucleation layer
2. Subsequent annealing (1080C) leaves only islands with hexagonal crystalline structure on sapphire surface
3. During high temperature (1080C) growth islands coalesce and 2D growth starts

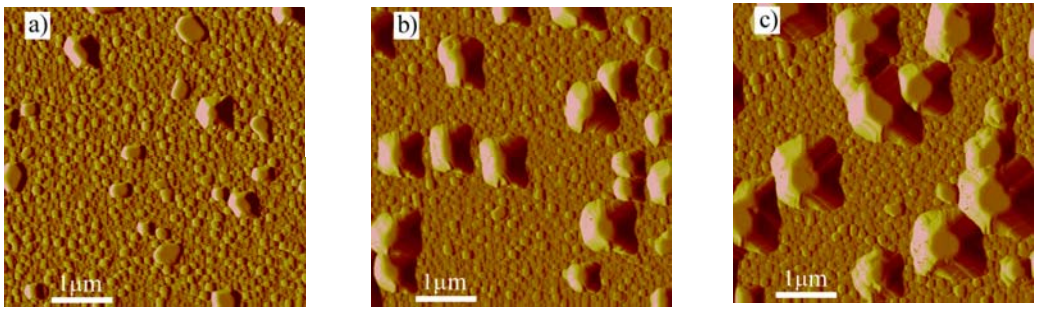
Dislocations are generated in island boundaries

Reducing dislocation density by multi step growth method

[T. Lang *et al., Journal of Crystal Growth 277 (2005) 64-71*]

- **Island size and density can be controlled by the number of low temperature growth and annealing cycles**

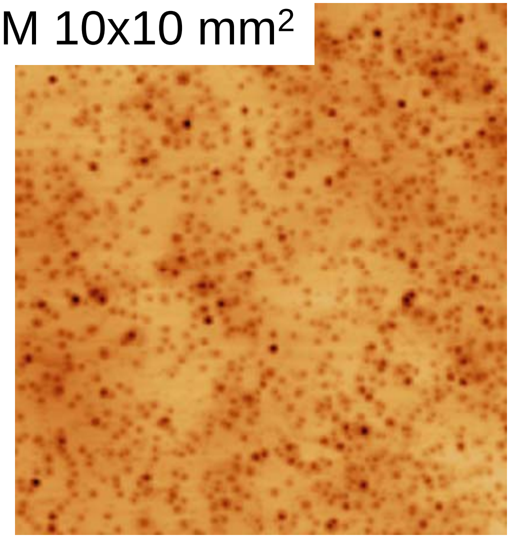




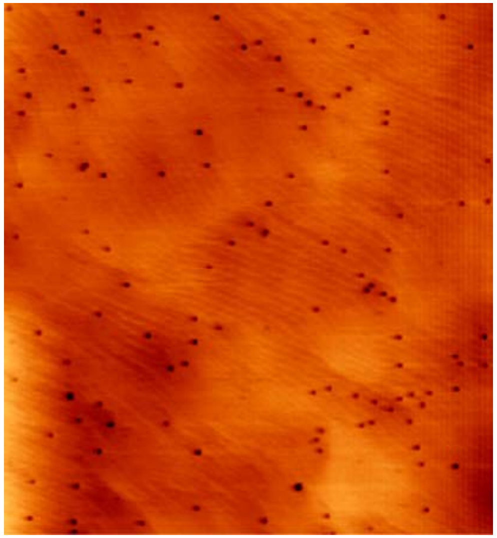
Number of cycles 1 2 4

Reducing dislocation density by multi step growth method

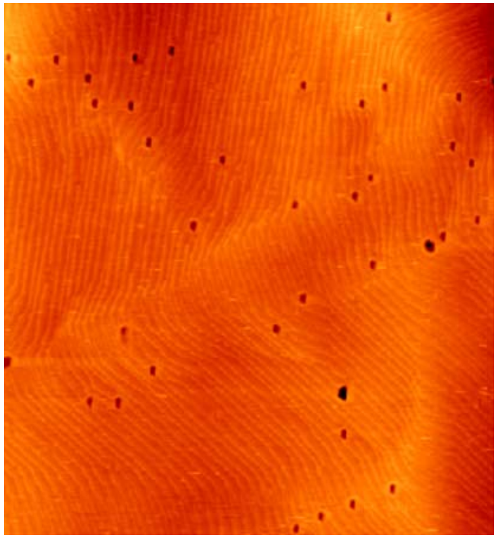
AFM 10x10 mm^2



commercial wafer
TDD ~ 1x10^9 cm^{-2}



our regular optimized wafer
TDD ~ 2x10^8 cm^{-2}

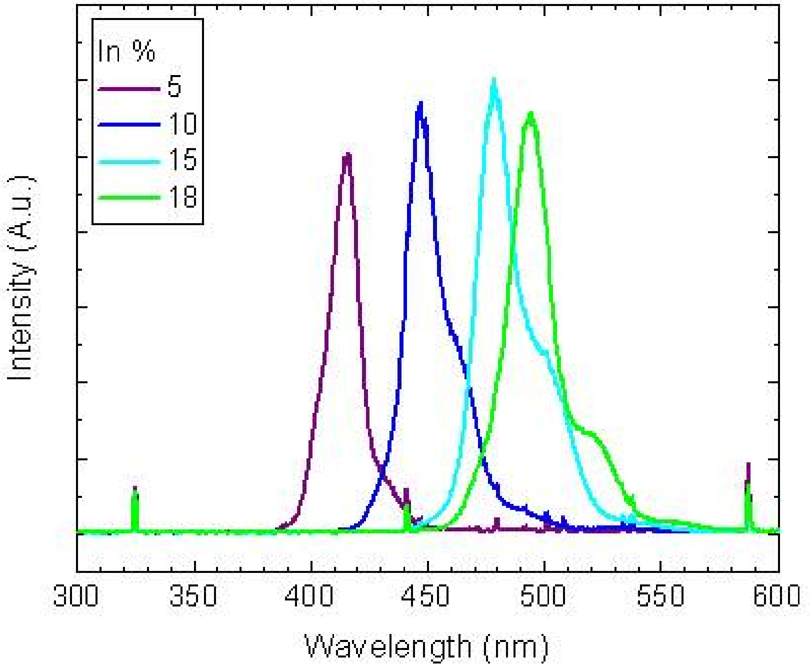


with multistep nucleation layer
TDD ~ 6x10^7 cm^{-2}

Improvement in device performance and lifetime

InGaN / GaN quantum wells

- **QW emission can be tuned with In content**
- **High radiative efficiency of QWs is due to efficient self screening of dislocations**

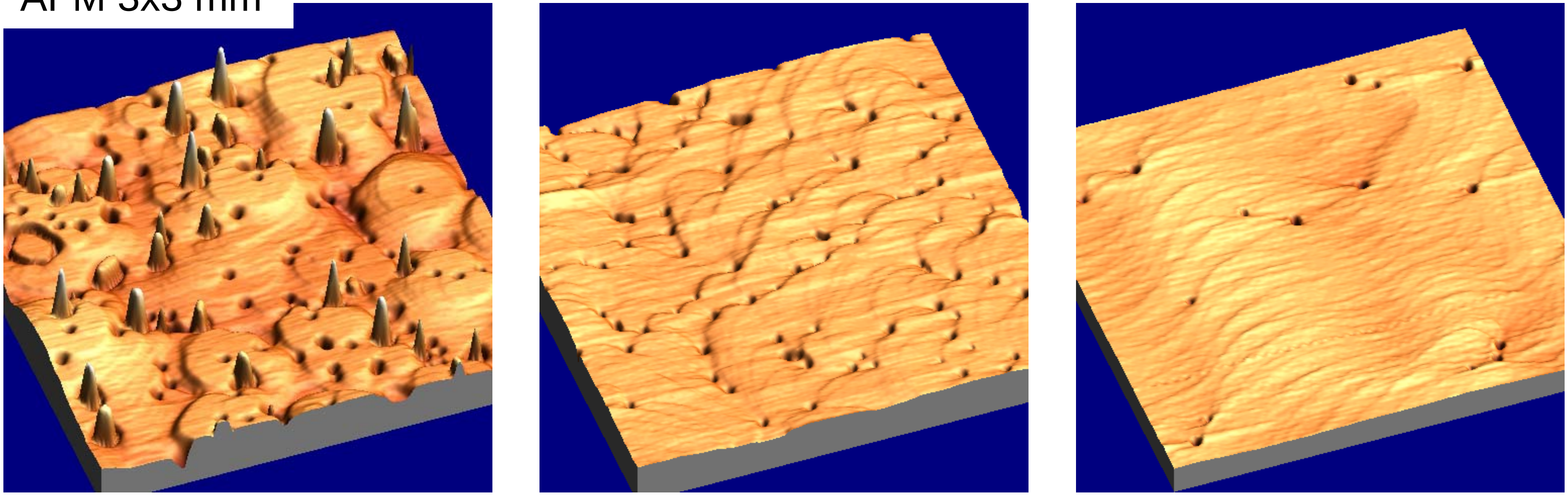


Problems

- **Desorption of In at high temperatures**
- **Bad surface morphology of GaN barriers grown at low temperatures**

InGaN / GaN quantum well optimization

AFM 3x3 mm^2



InGaN MQW surface with standard growth method

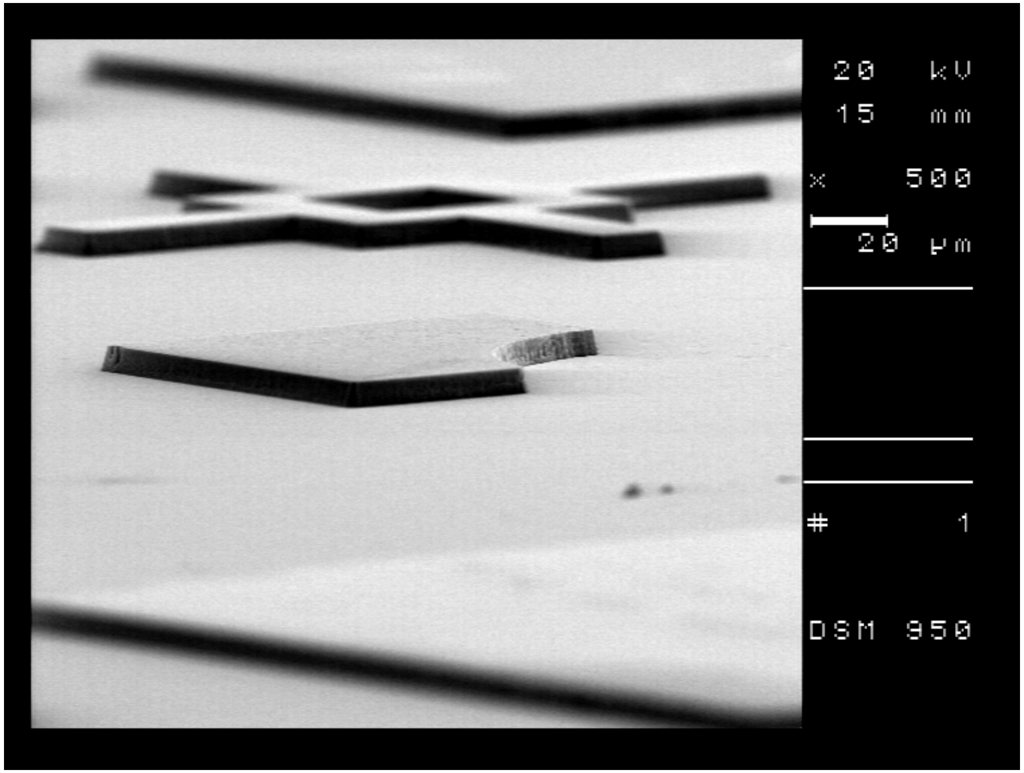
InGaN MQW surface with *in-situ* H$_2$-treatment

InGaN MQW surface with *in-situ* H$_2$-treatment & low TD buffer

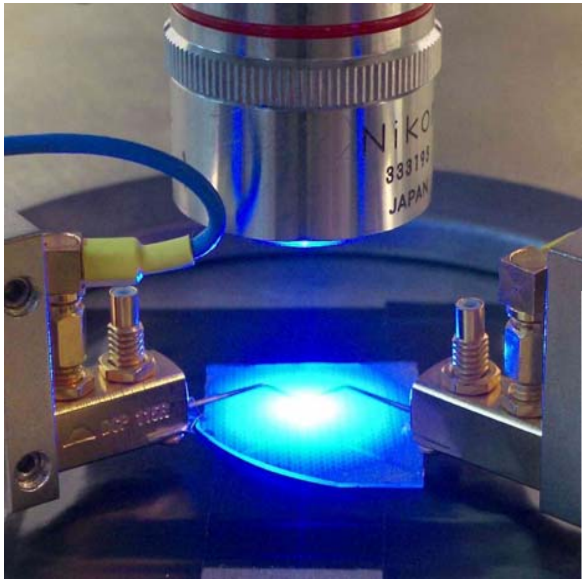
InGaN MQW thermal stability and LED lifetime is expected to improve

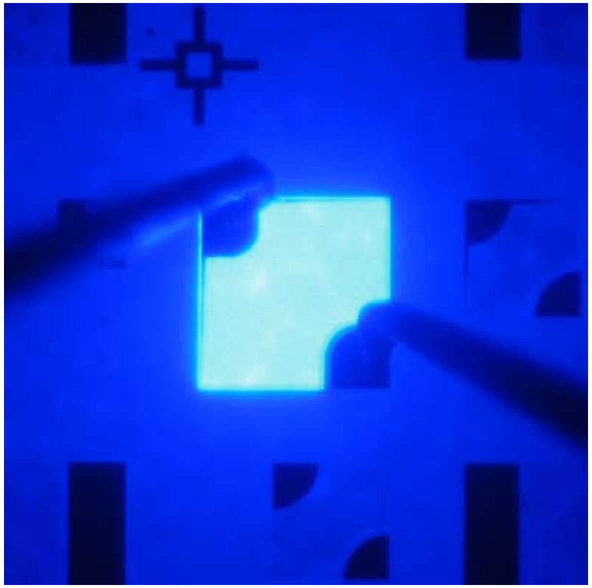
ICP-RIE etching of LED sidewalls

- **High ion energy and plasma density are needed due to strong Ga – N bonds**
- **Nickel or SiO_2 used as mask**
- **Cl_2 and Ar based plasma**
- **Etch depth of 10 µm achieved**



GaN LED manufactured at Optoelectronics Laboratory





3mW@20 mA output power was measured on wafer-level
This corresponds to 7mW on packaged-chip-level.
Wall-plug efficiency ~11%

Research plans

LED

- Optimization of p-type doping of GaN and AlGaN
- Contacting technology
- Application of the multistep technique to low TDD AlGaN epilayers
- Fabrication GaN/AlGaN modulation-doped superlattices
- UV emitters on AlGaN

Laser

- Electrically pumped laser diode operating at room temperature

Acknowledgements

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Thank you for your attention