Lithographic Processing of Photonic Crystal Structures on GaN Epilayers for LED Applications

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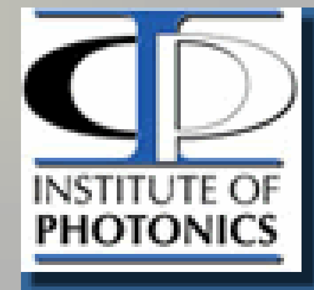


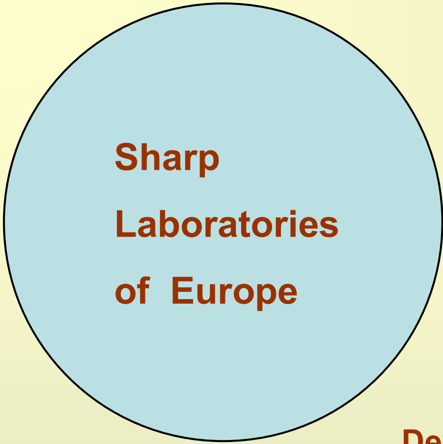
Photonic Quasicrystal LEDs for Display Illumination (PQLDI)

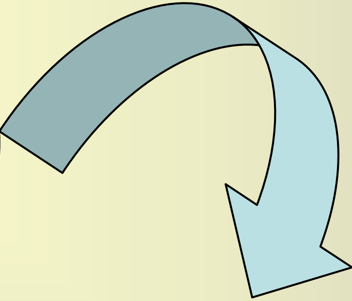
Project Objective:

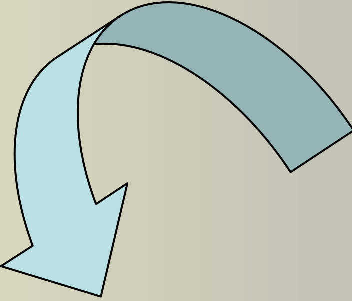
Demonstrate High Brightness LEDs Suitable for Backlighting Large Screen LCD Televisions.

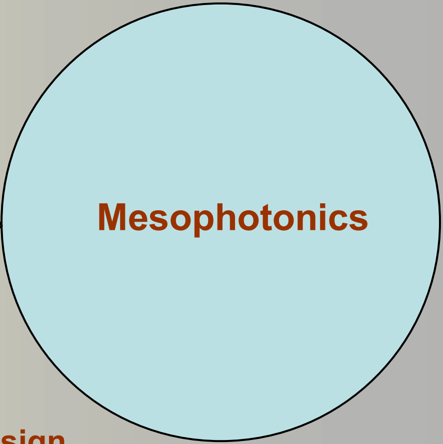
Devices must satisfy the following criteria:

1) Sufficient brightness in a small form factor
2) Appropriate radial intensity distribution
3) Provision of the right colour point









Device Simulation

Material

System Integration

Photonic Quasicrystal Design

Material

Device Fabrication:

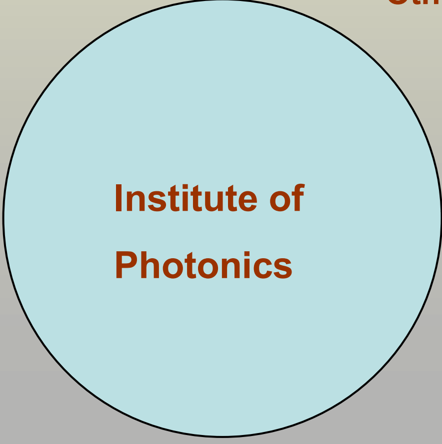
Dry Etching

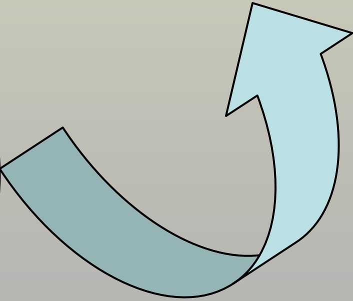
Other Steps

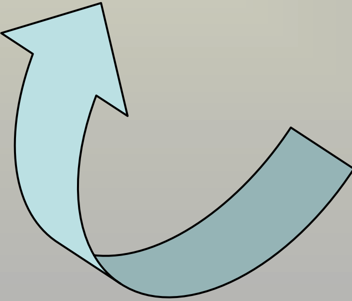
Device Fabrication:

E-beam Lithography

Nano-imprint Lithography



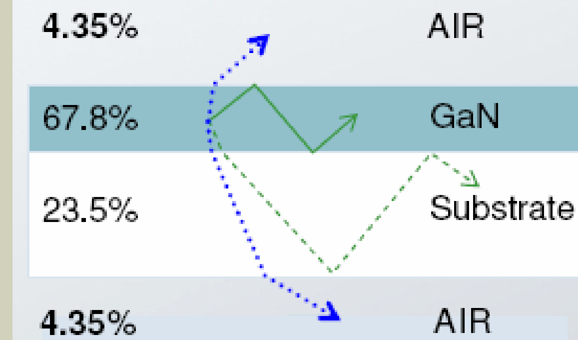


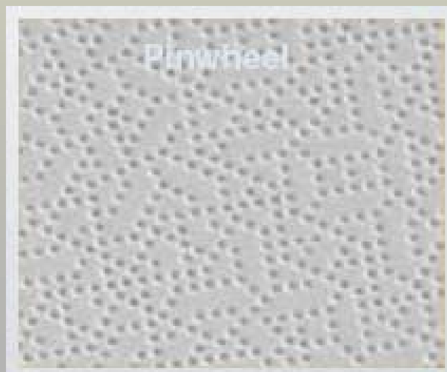


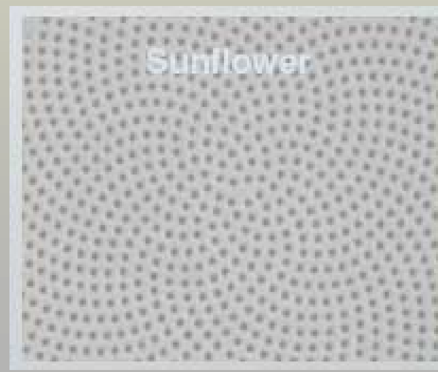
Photonic Quasicrystal-based Light Extraction

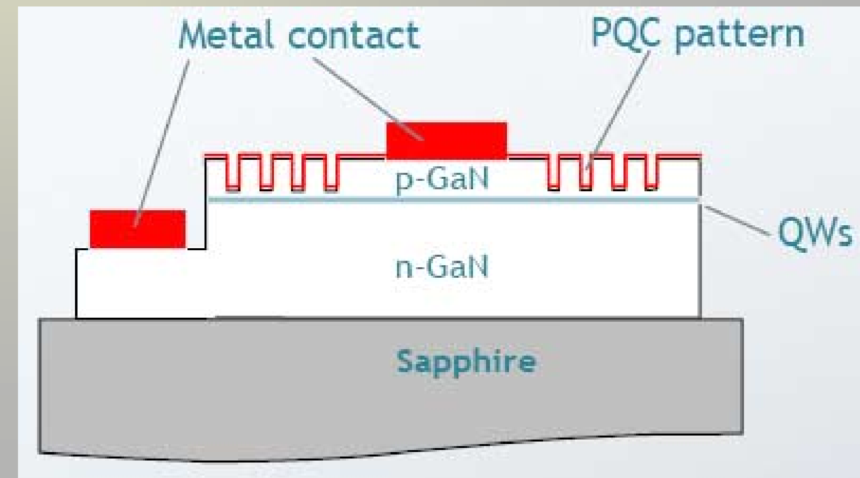
Courtesy: Mesophotonics Ltd.

- 2 Fundamental problems of LEDs
  - Limited conversion of electrical to optical energy
  - Large % of Emitted light trapped inside high index GaN layer.
- Photonic crystals
  - Provide optimal leakage mechanism for light trapped in high index layers.
  - Improves extraction efficiency.
  - Increase efficiency of light emission
  - Potentially $\eta_{rad} \cdot \eta_{extr} > 75\%$







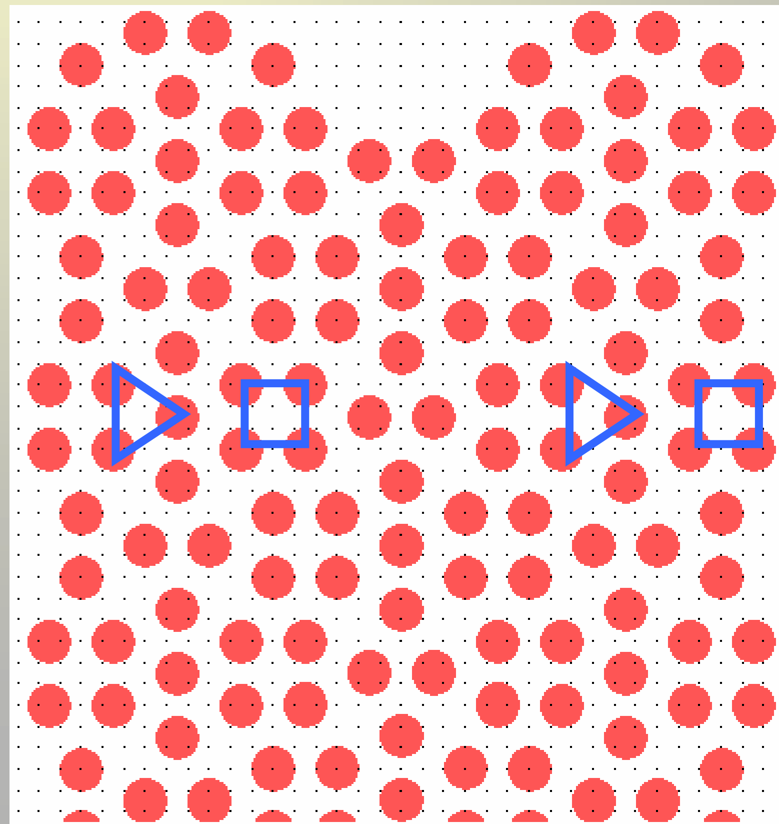


Fabrication of Photonic Quasicrystals through E-beam Lithography Techniques

- VB6 machine
  - *High resolution e-beam lithography tool: spot size 3 nm*
  - *Capable of writing 10 nm lines*
- Resists tested
  - *HSQ, PMMA, ZEP, UV-III*
- Dose tests
  - *100 KV at 350 – 1600 μC/cm^2*
- Different substrates
  - Si
    - *for process and tool calibration*
  - Quartz
    - *Stamp for nano-imprinting via UV curing polymer*
  - GaN
    - *final substrate for LEDs*

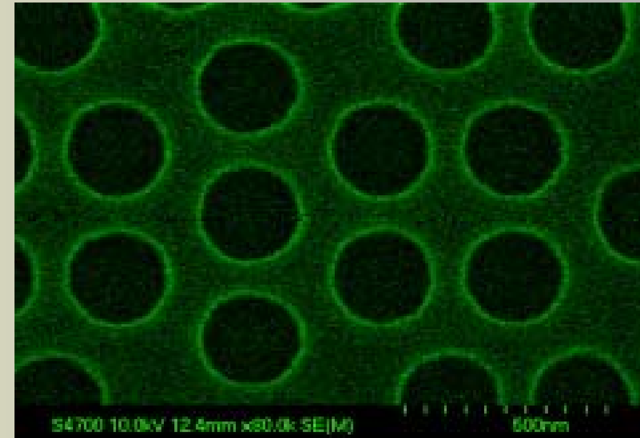
12-fold PhQC pattern (University of Glasgow)

- Square + Triangular lattice
- Hole diameter 200 nm
- Pattern 300 x 300 μm

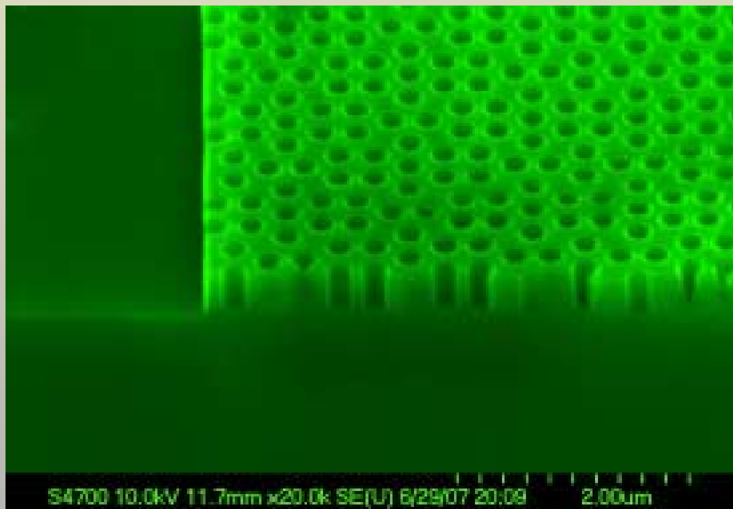


Pattern Transfer to Si Substrate

- 12-fold Quasi PhC
  - *Square + Triangular lattice*
- Mask
  - *Hydrogen SilsesQuioxane (HSQ)*
    - *High resolution negative tone e-beam resist*
  - *@ 3000 RPM : thickness 200 nm*



Pattern transfer to HSQ

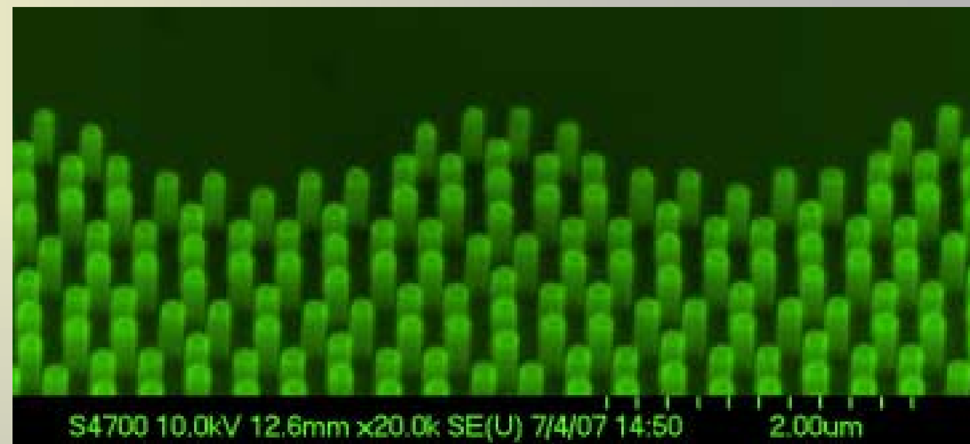


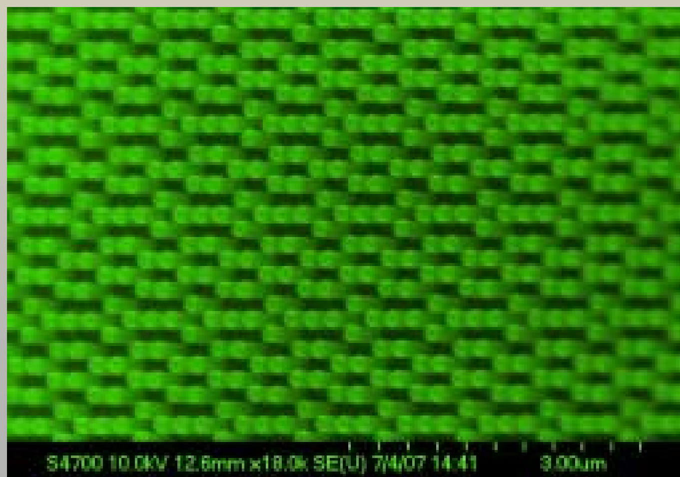
Pattern transfer to Si after dry-etching

- **Dry-etching recipe:**
- **ICP ; SF_6 / C_4F_8**
- ***220 nm etch depth***

Inverse Pattern on Si substrate

- **Could act as a stamp for nano-imprinting**
- **Inverse pattern of Quasi PhC**



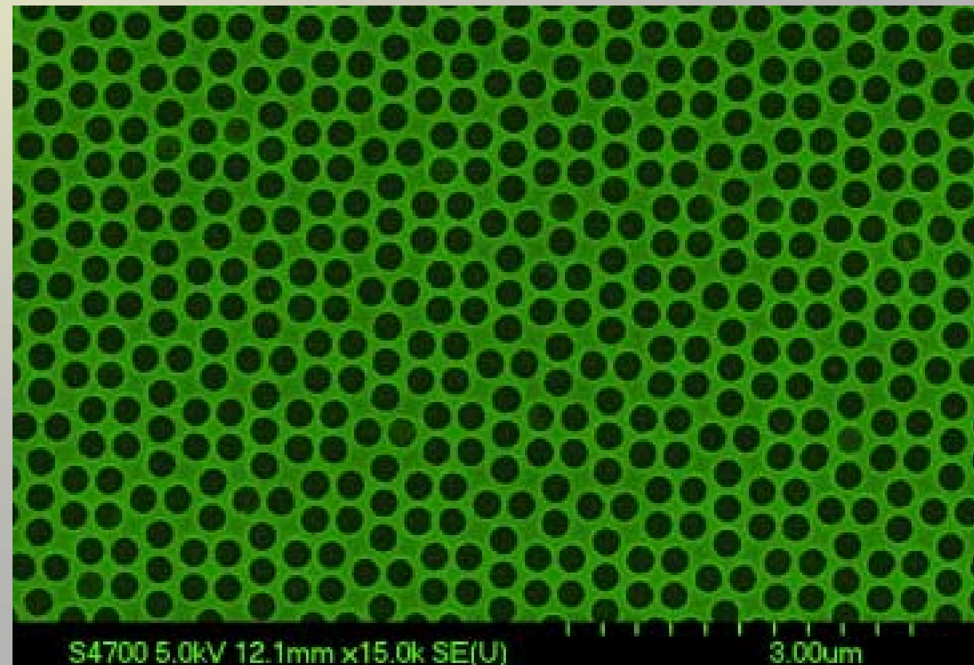


- **Dry-etching recipe:**
- **ICP ; SF_6 / C_4F_8**
- ***220 nm etching depth***

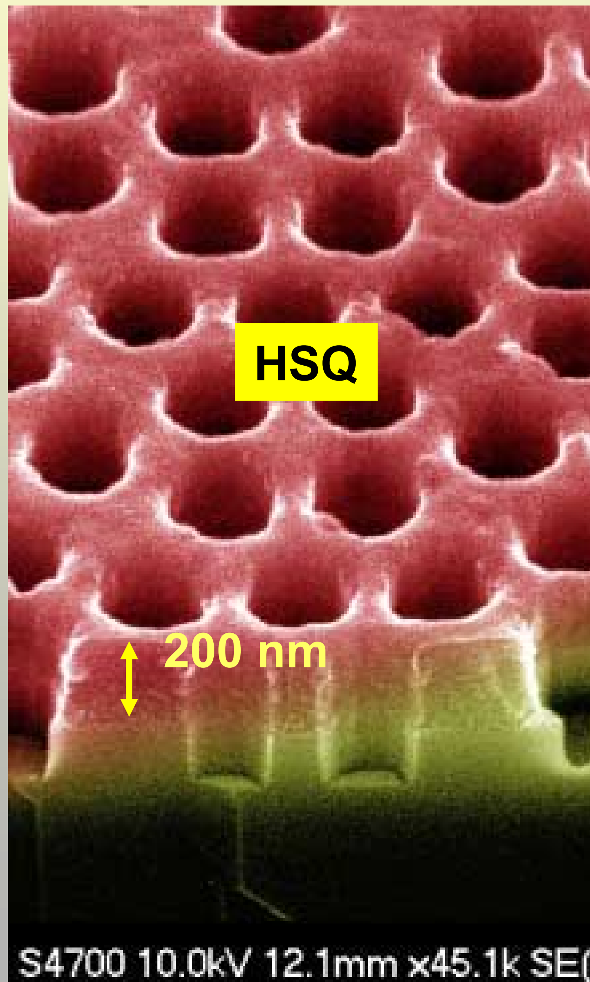
Patterning on PMMA resist

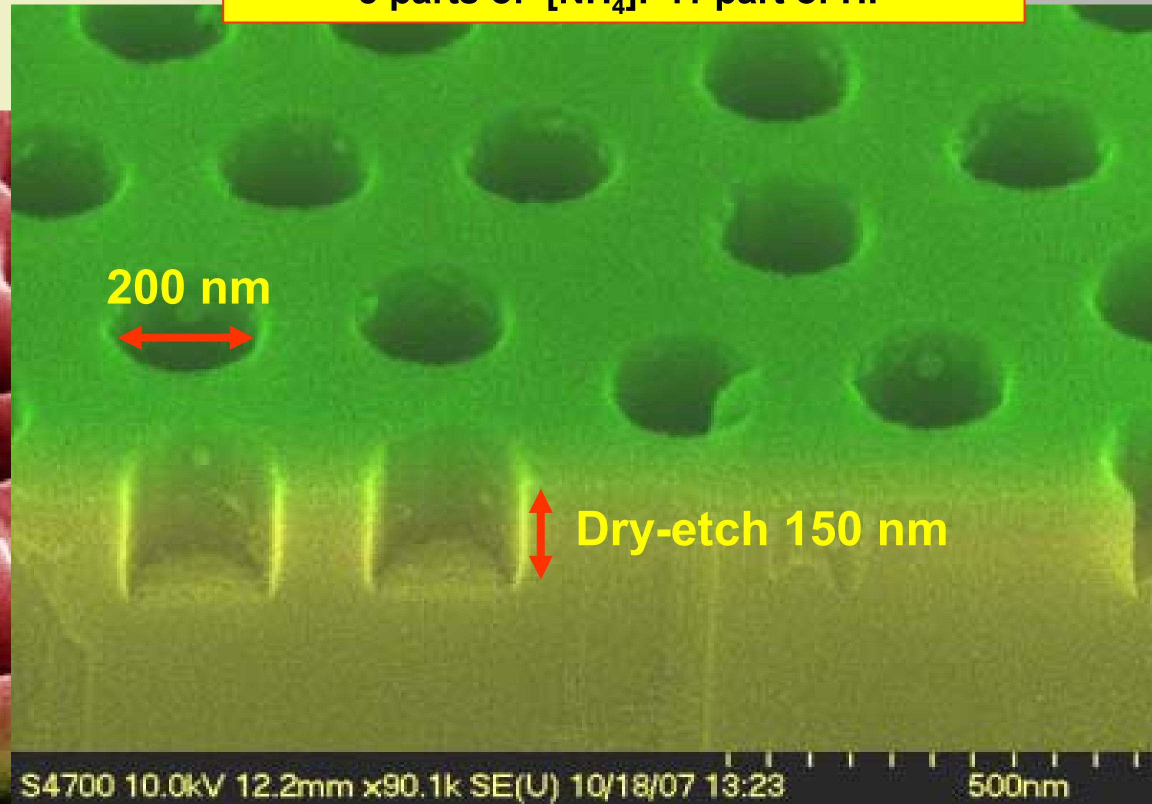
- **Quartz substrate**
- **For nano-imprinting via UV curing polymer**
- **PMMA (Polymethyl Methacrylate)**
    - ***Postive tone e-beam resist***
    - ***double layer PMMA @ 5000 RPM***
    - ***Final thickness 200 nm***

Pattern transfer to PMMA



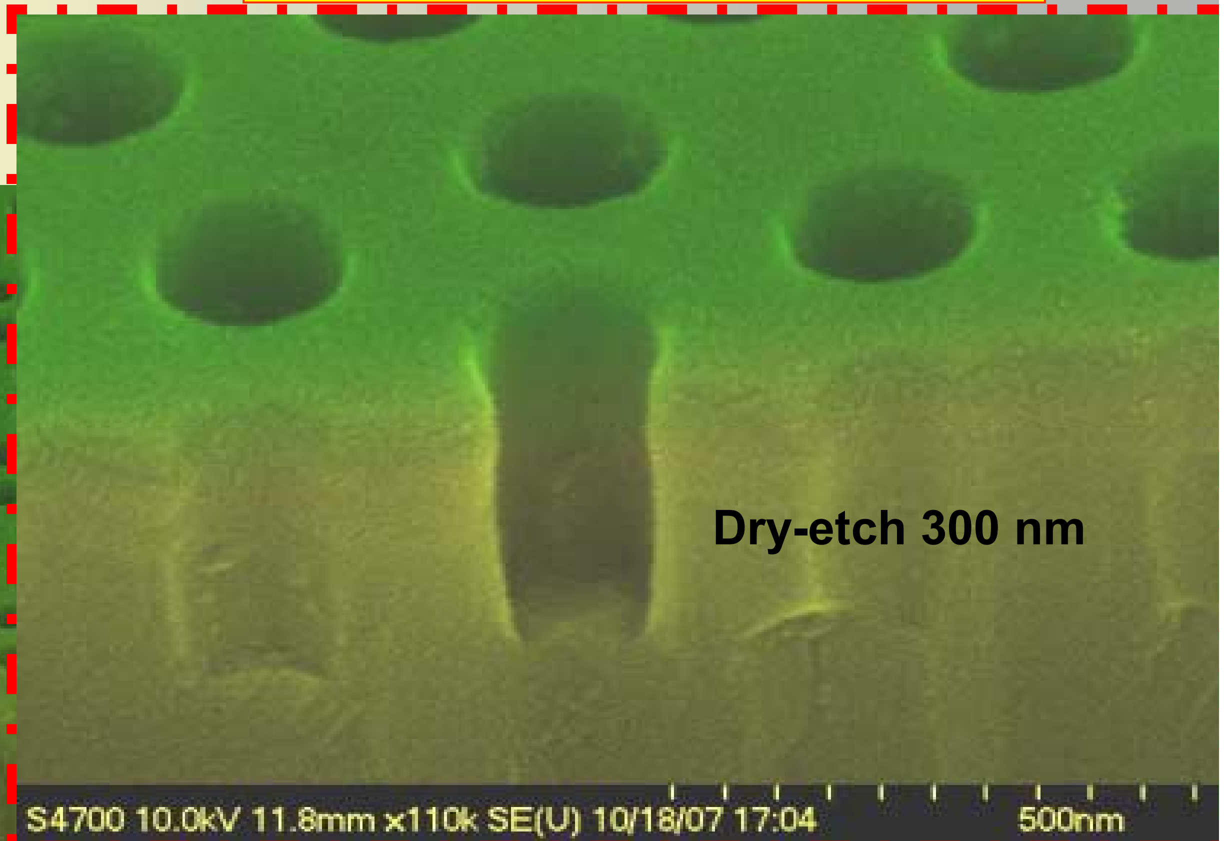
Before and After Stripping HSQ Mask





Before and After Stripping HSQ Mask

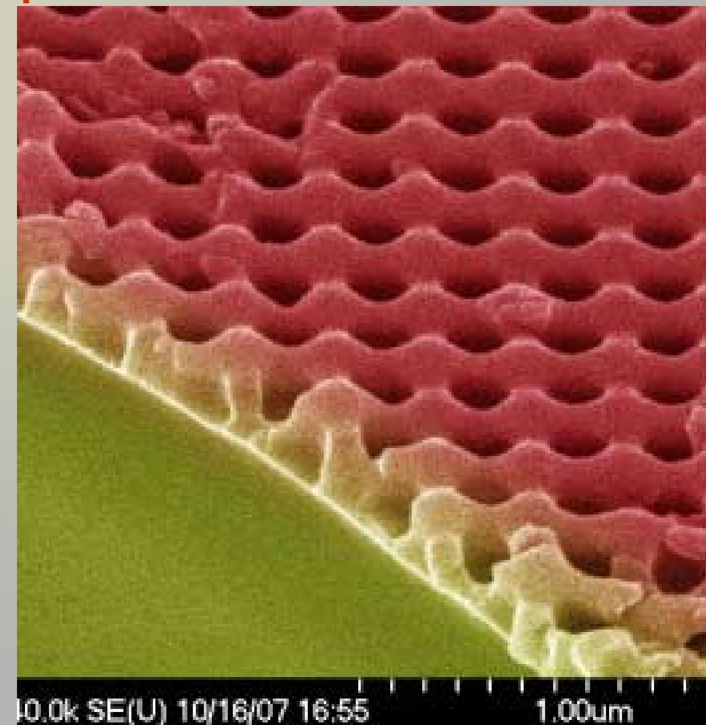
After (5:1) HF
5 parts of $[NH_4]F$:1 part of HF



S4700 10.0kV 11.8mm x20.0k SE(U) 10/18/07 17:11 2.00um

Nano-imprinting on GaN

- Ormoclear
  - Hybrid inorganic polymer
  - (4:1) 4 parts of thinner : 1 part of ormoclear
    - **Spin @ 4000 RPM**
    - **Pre-baked at 80 °C for 2 minutes**
    - **Pressure upto 1 Tonne by using hydraulic press on area of 64 mm^2 (153 MPa)**
    - **Thickness ~ 200 – 250 nm**
    - **UV curing for 3 minute**
      - **By using Mask Aligner λ = 365 nm**
    - **Post-baked at 180 °C for 1 – 2 hours.**
  - Residual layer < 20 nm



SUMMARY

The PQLDI project has demonstrated high quality, largely defect-free patterning of PhQC light extraction structures on GaN

Similar results have been obtained with both direct write E-beam lithography and with flat stamp nano-imprint lithography

Next we shall work on fabricating complete diodes, their electrical and optical characterisation and on demonstrating roll nano-imprinting of PhQC structures