High Efficiency Nitride-Based Photonic Crystal Light Sources

PIs

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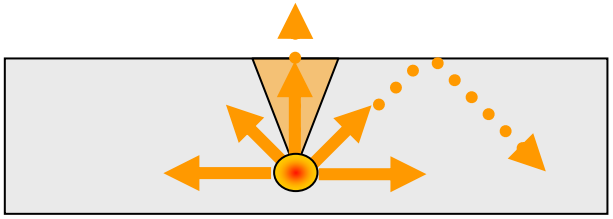
Objectives

Achieve high extraction efficiency in LEDs
Achieve controlled directionality of emitted light
- ***Integrated design of vertical device structure***
- ***Nanoscale patterning of lateral structure***

Develop a planar, high throughput, low cost photonic crystal technology

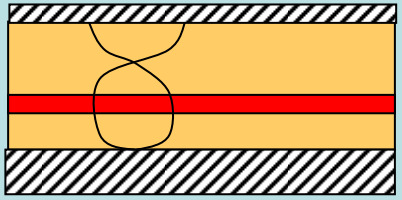


~ 6 % of light extracted per facet
- remainder trapped in high-index material

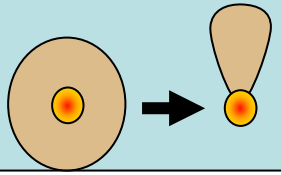
Using Wave Nature of Light

Microcavity (MCLEDs)

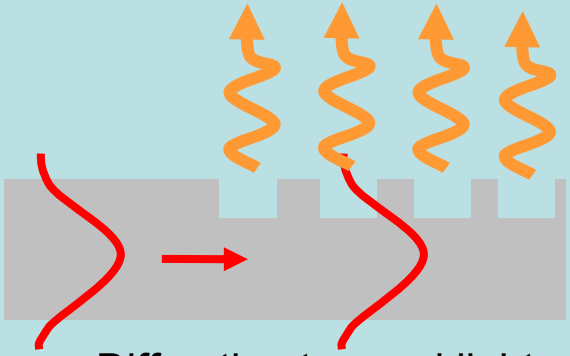
Cavity-emission tuning



Modified emission pattern



Photonic Crystal (PhCLED)



Diffracting trapped light

Engineering the Vertical Dimension: Photonic Crystal LEDs

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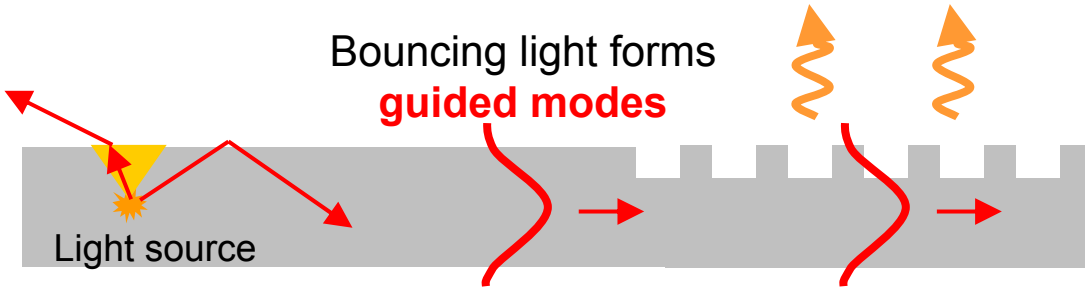
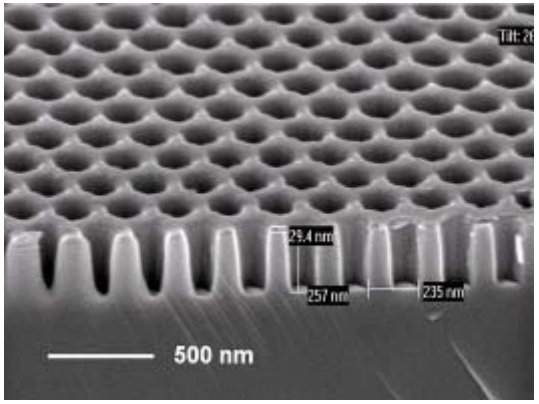
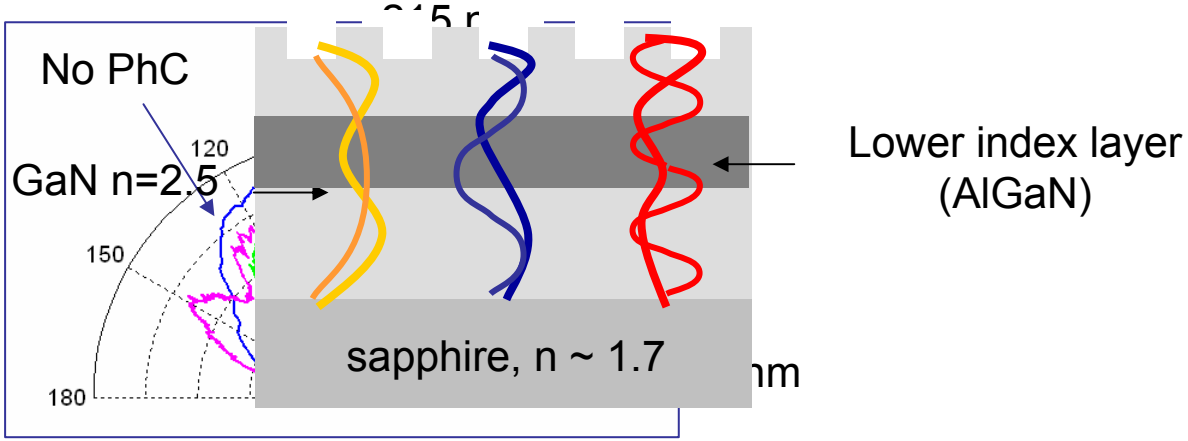
Goal : **extraction** of guided light by a 2D PhC acting as **diffraction** grating







Emission for different PhC lattice constants

Challenge: to engineer large overlap (interaction) between modes and photonic crystal

Technical Approach: Engineering Optical Confinement Layers

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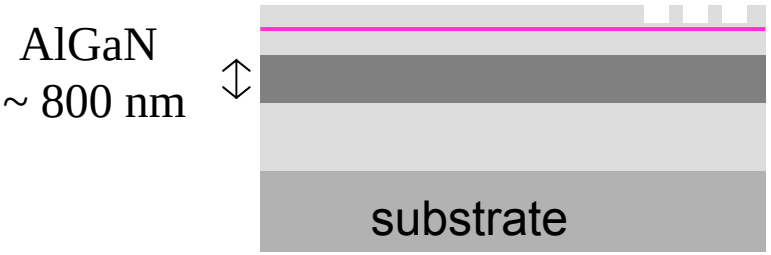
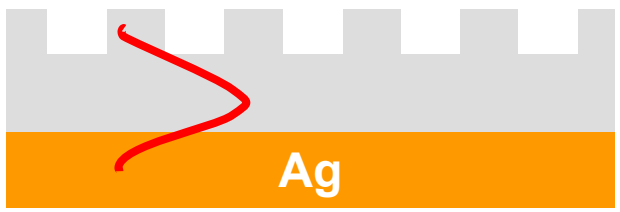
Needed: *low loss* vertical confinement of the guided modes to interact Strongly with PhC: 3 approaches



AlGaN layer for vertical mode control
- Relatively easy to fabricate
- Performance is moderate (up to 75%?)



Substrate lift-off and layer thinning
- Challenging to fabricate
- Metal absorption losses
- Fabrication damage?
- Performance could be excellent (90%+?)

Lateral epitaxial overgrowth
- Challenging to fabricate (thin active layer)
- But no fabrication damage!
- Performance is intermediate (80%+?)

Vertical mode control by AlGaN
Required: growth of high quality AlGaN

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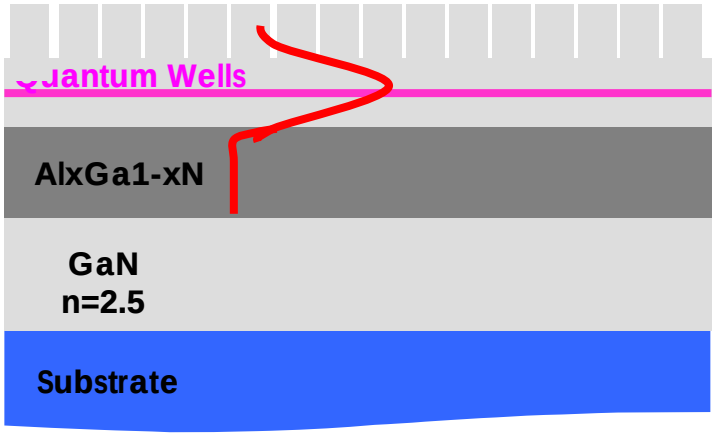
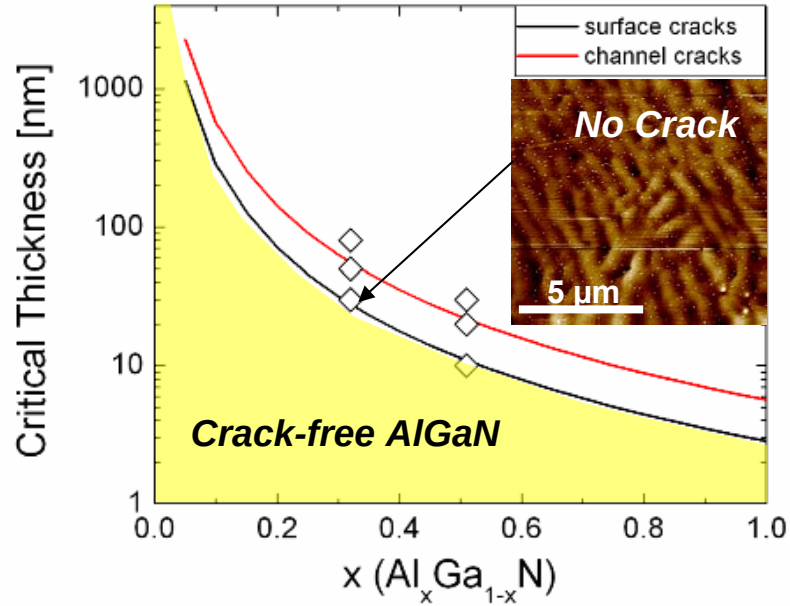
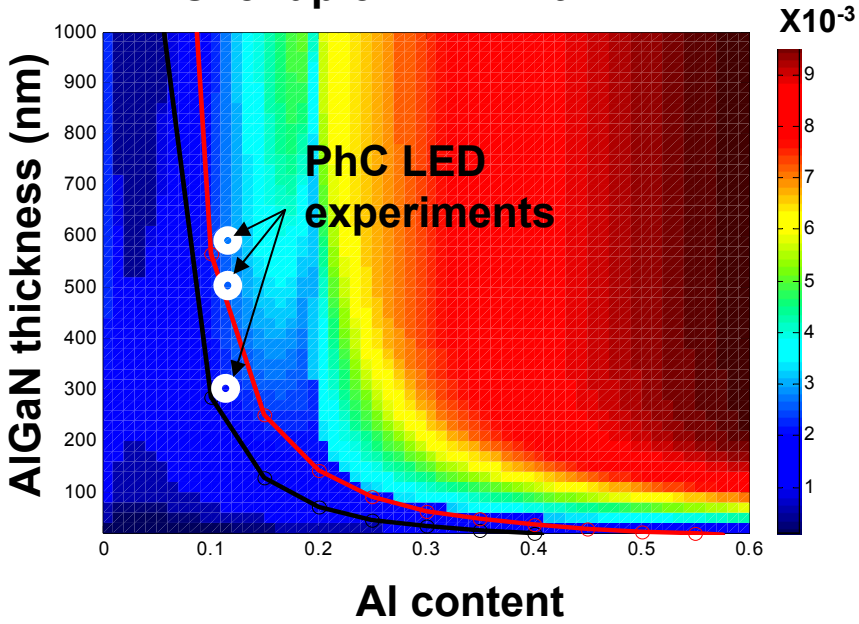
Cap layer mode (CLM)



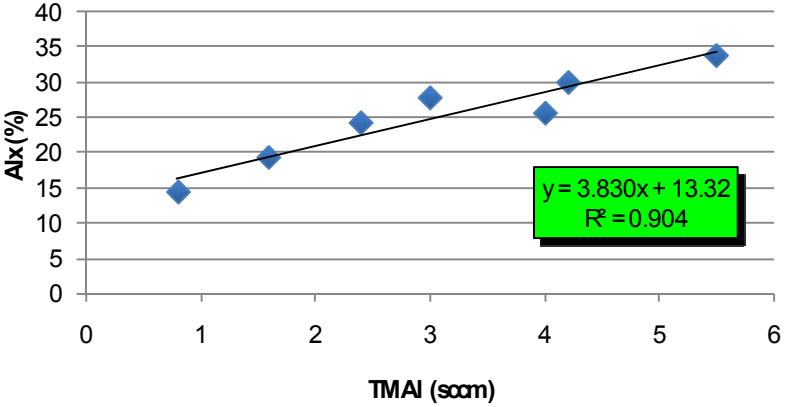
Plasma assisted MBE: AlGaN cracking



Overlap of CLM with PhC



MOCVD: Growth of LED wafers w/ AlGaN



AlGaN PhC LED: present state of the art

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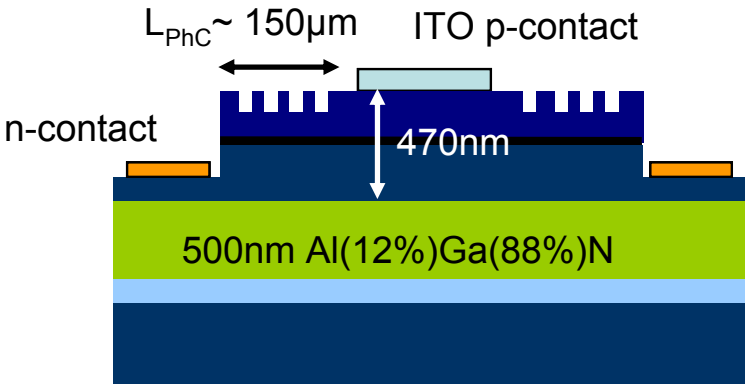
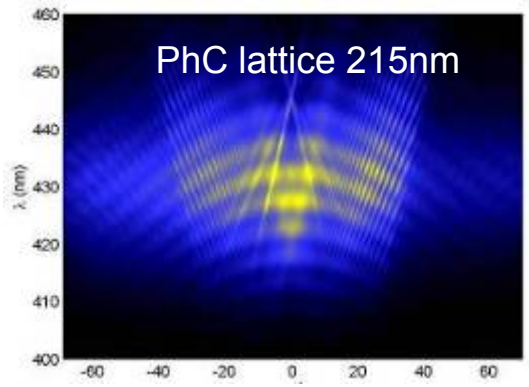
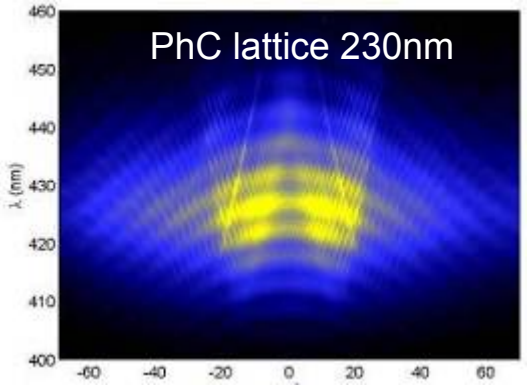
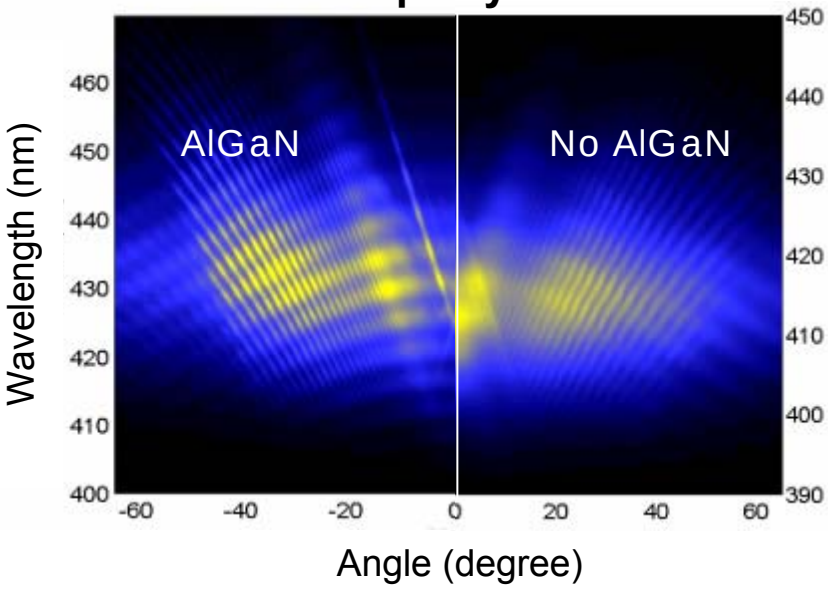
Schematic of AlGaN PhC LED





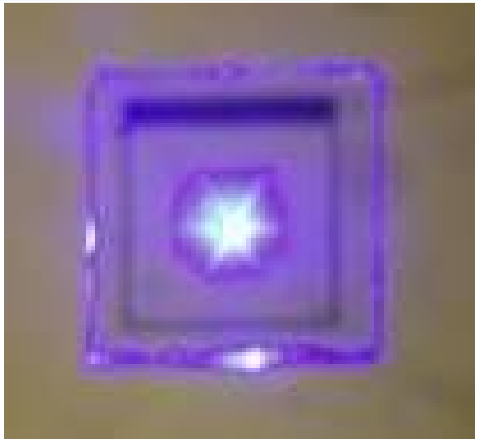


Effect of Cap Layer Mode

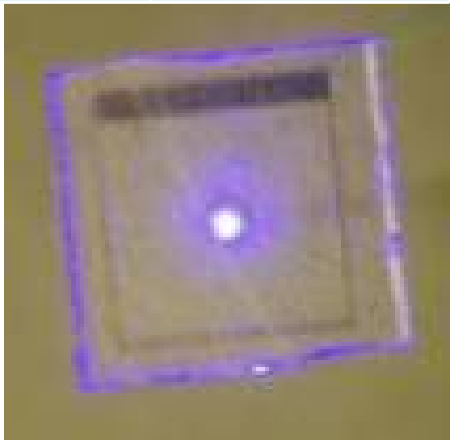


PhC LED vs. Non-PhC LED

	350nm AlGaN	600nm AlGaN
Total increase	1.5x	2.1x



PhC lattice = 200 nm



Non-PhC

Needed: thicker, higher Al content AlGaN layer

Optimizing Device Performance: Microcavity LEDs

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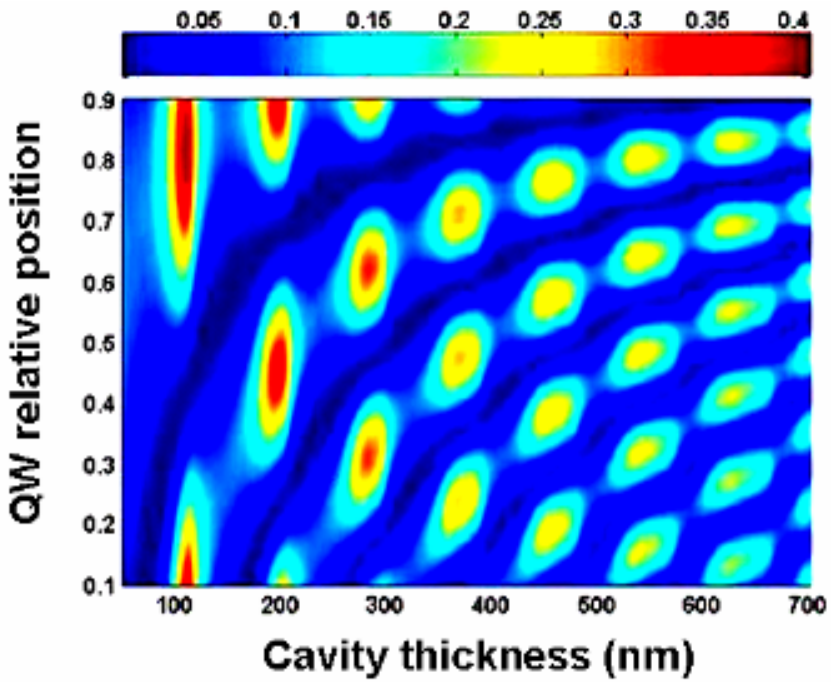
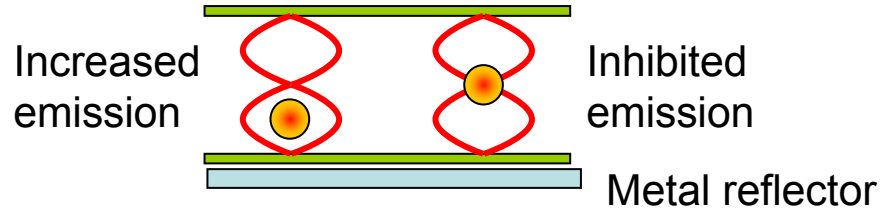
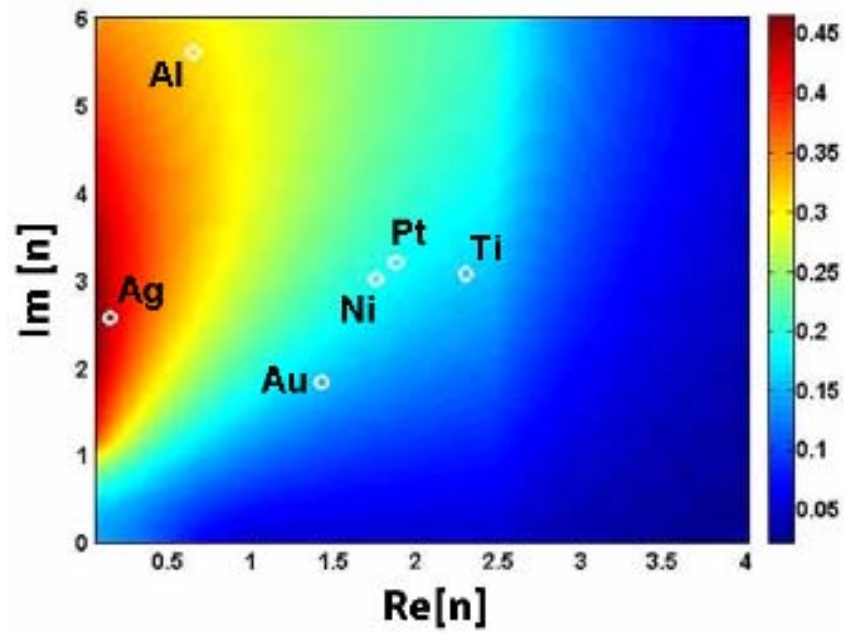
Extraction Efficiency





- Relative placement of quantum well and cavity critical (20 nm accuracy)
- Thin cavities (< 1 micron) critical



Choice of metal reflector

Metal optical constant essential to performance

Initial Results on MCLED

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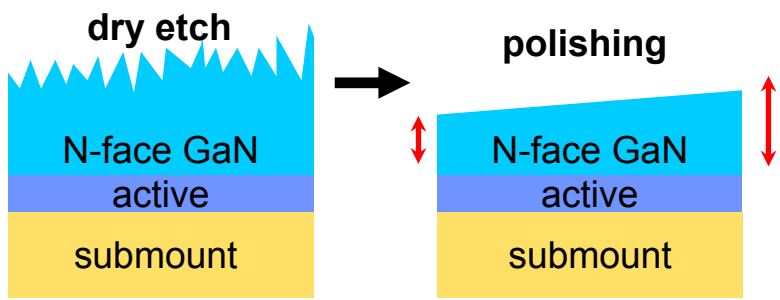
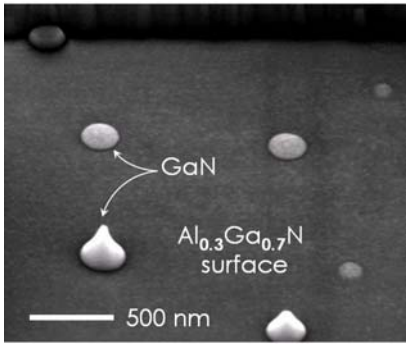
High-precision thinning process by using selective ICP dry etching

Non-selective thinning

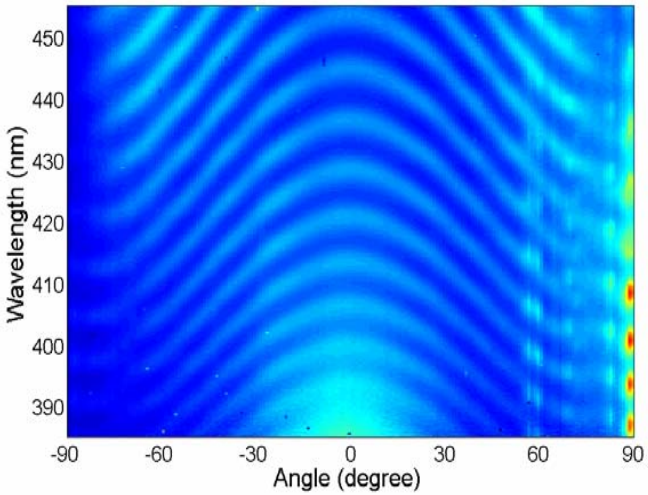


Selective ICP thinning

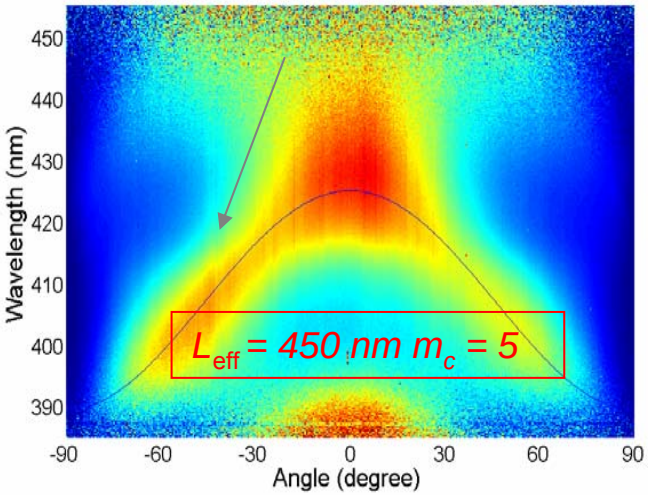


Demonstration of 2.5λ-thick MCLED with a single Fabry-Perót Mode

Thick LED



MCLED



Lifted-off MCLED and PhC LED: present state of the art

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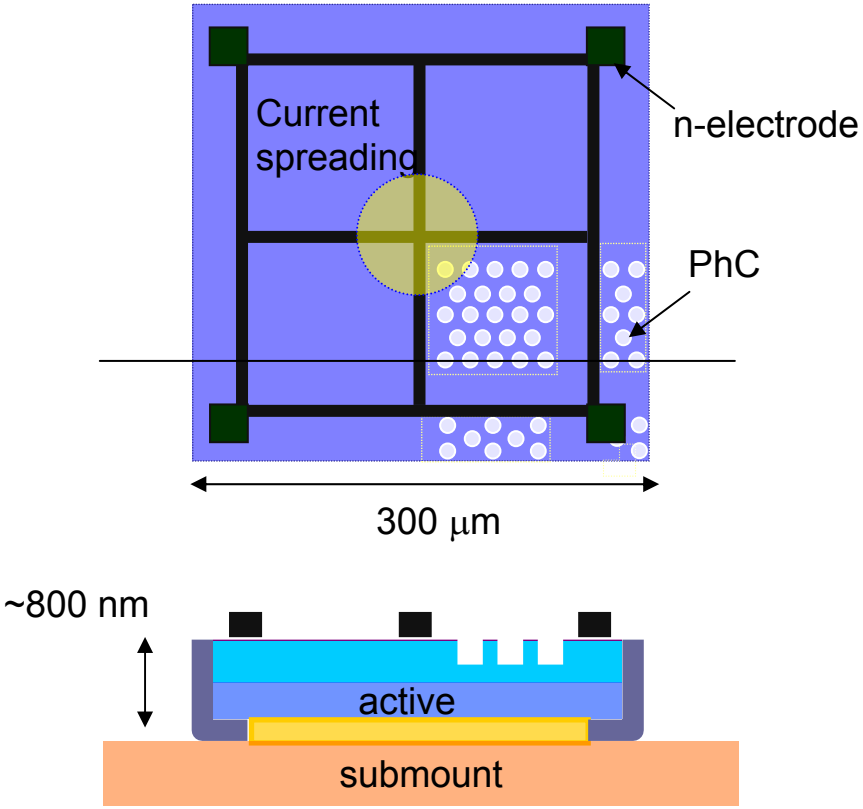
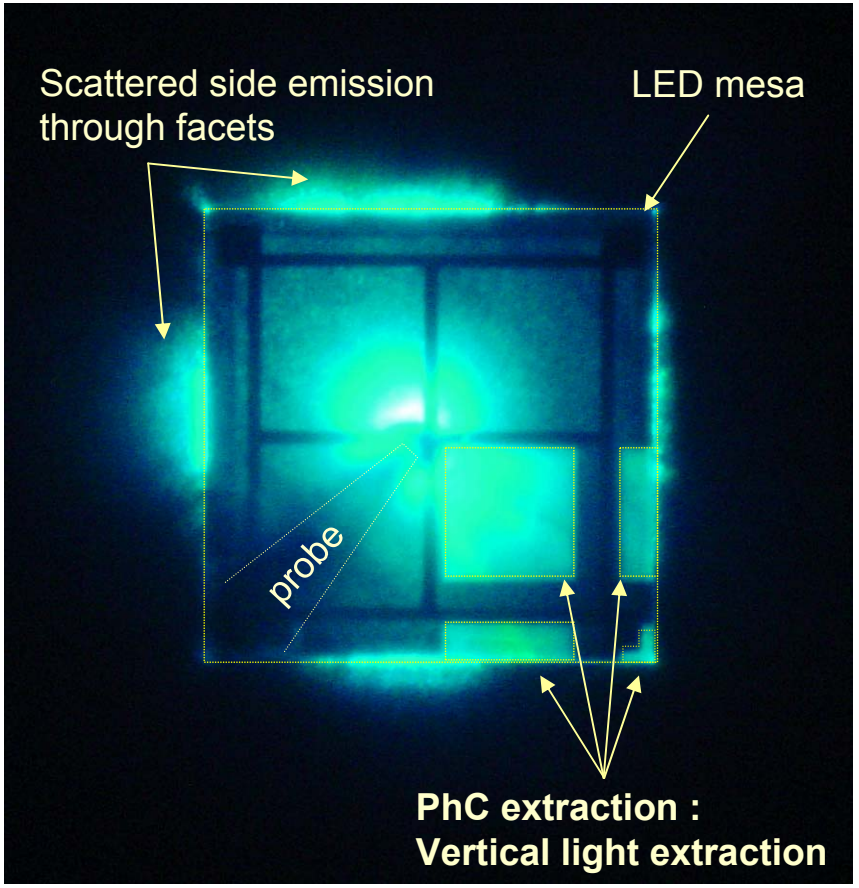
PhC LED; Extraction of "all" guided modes from MCLED

Schematic diagram of a test structure





Interplay between LLO MCLED and LLO PhCLED

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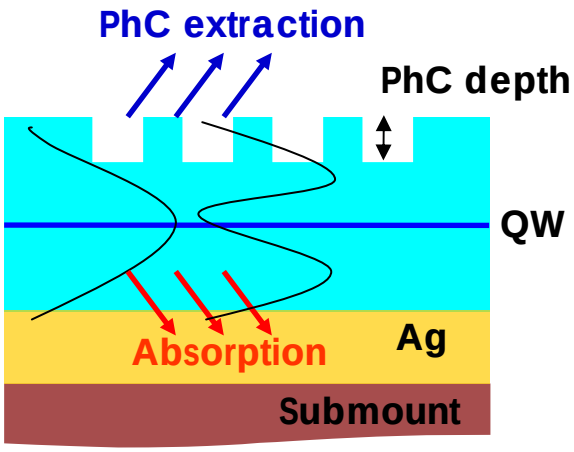
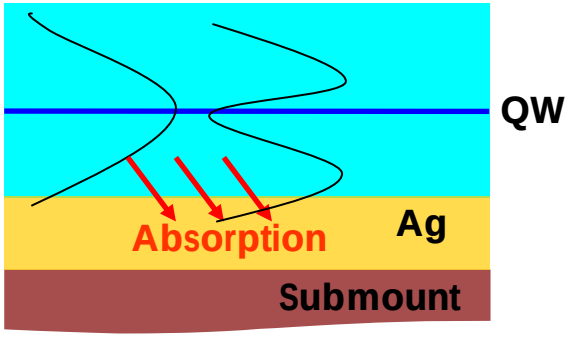
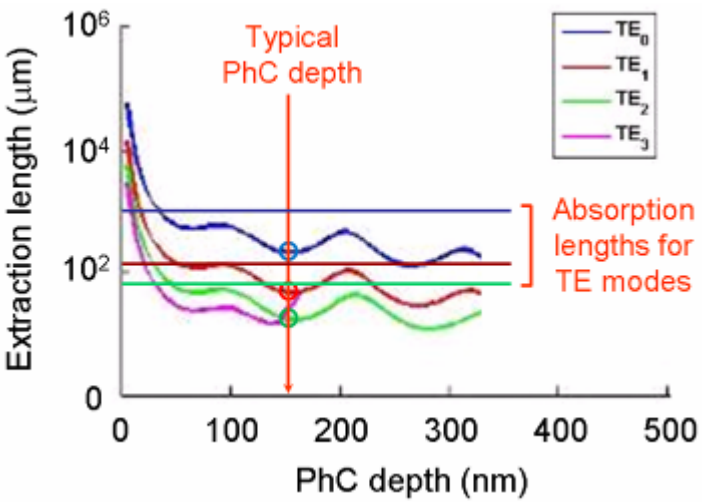
LLO PhCLED
To recover guided modes by PhC

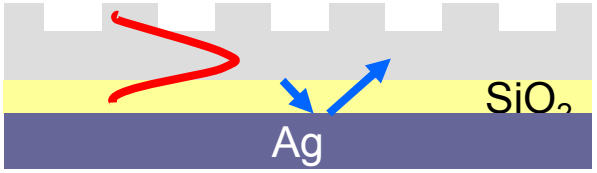


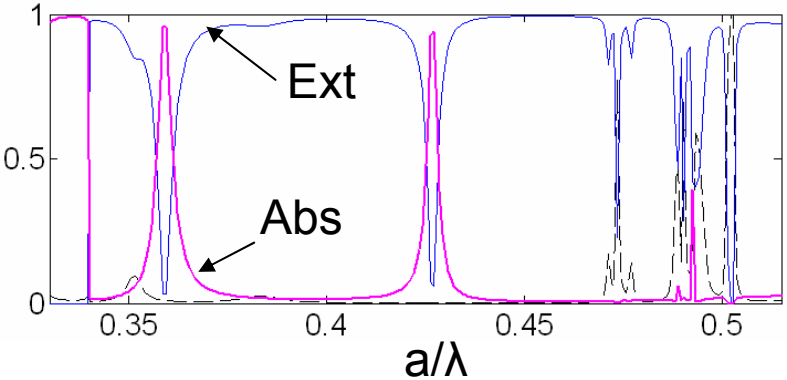
Limitation of LLO MCLED
Metal loss for guided mode



Competition between PhC and metal loss







Lateral epitaxy overgrowth (LEO) PhC LED

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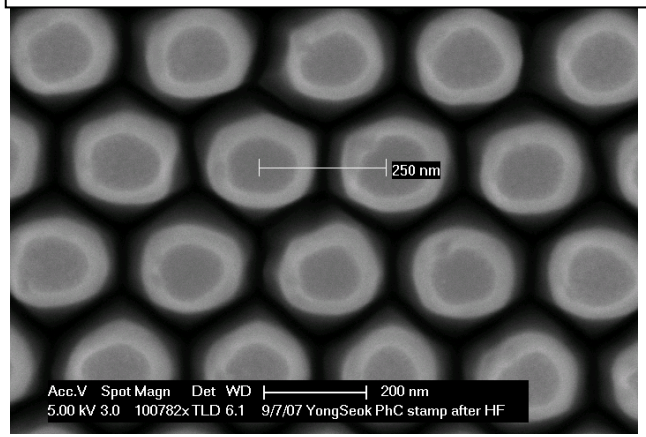
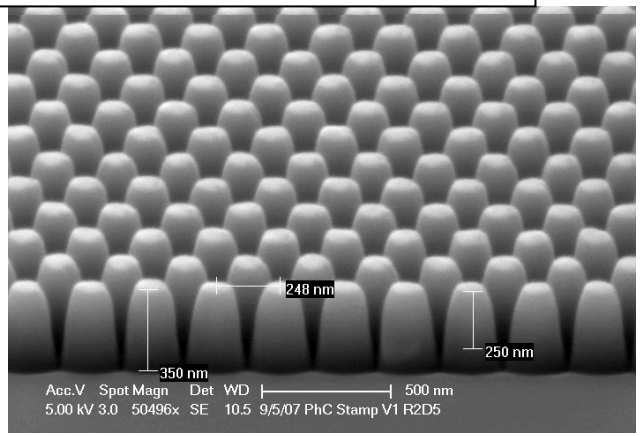
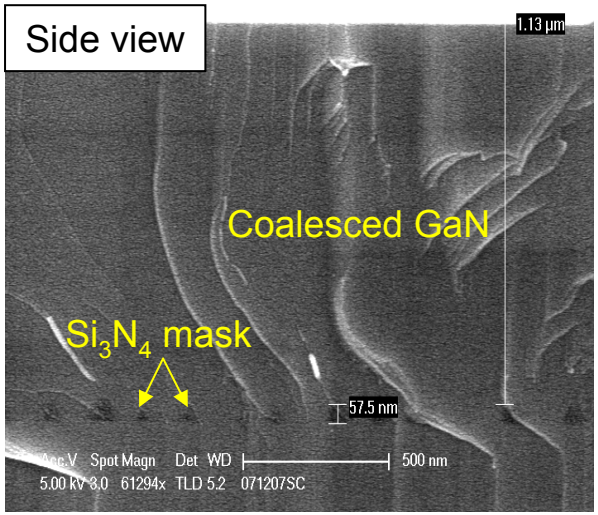
Demonstration of 2-D LEO with triangular photonic crystals

Initial photonic crystal pattern for nano imprint lithography

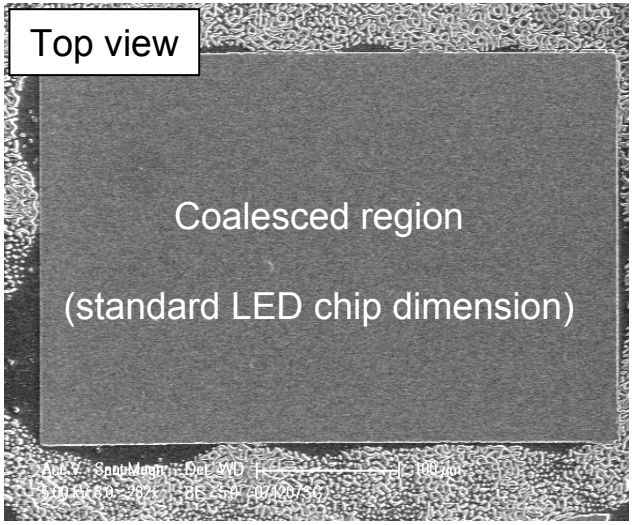




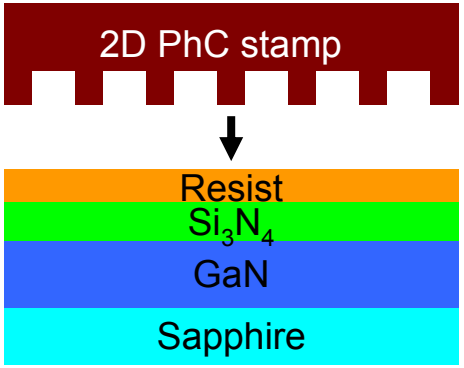
Side view



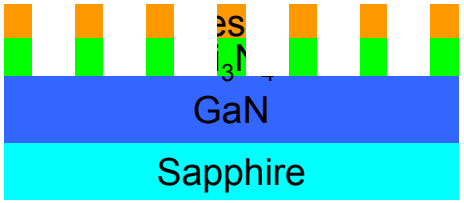
Top view



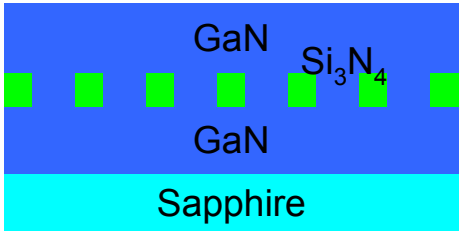
molding



pattern transfer



overgrowth



High Efficiency Nitride-Based Photonic Crystal Light Sources : conclusions & outlook

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- Advances in large area patterning and fabrication of devices – pathway to manufacturable processes
- Microcavity and photonic crystal LEDs both require vertical confinement of light & low loss metal mirrors
- Confinement by AlGaN layer is a major growth challenge; Try other materials?
- Thinned LLO layers by selective etching looks promising; requires better metal contacts to give high performance
- LEO approach puts a major challenge on 2D thin LEO coalescence & growth; otherwise, maybe the ultimate solution?