Device Challenges with Nitride UV Emitters*

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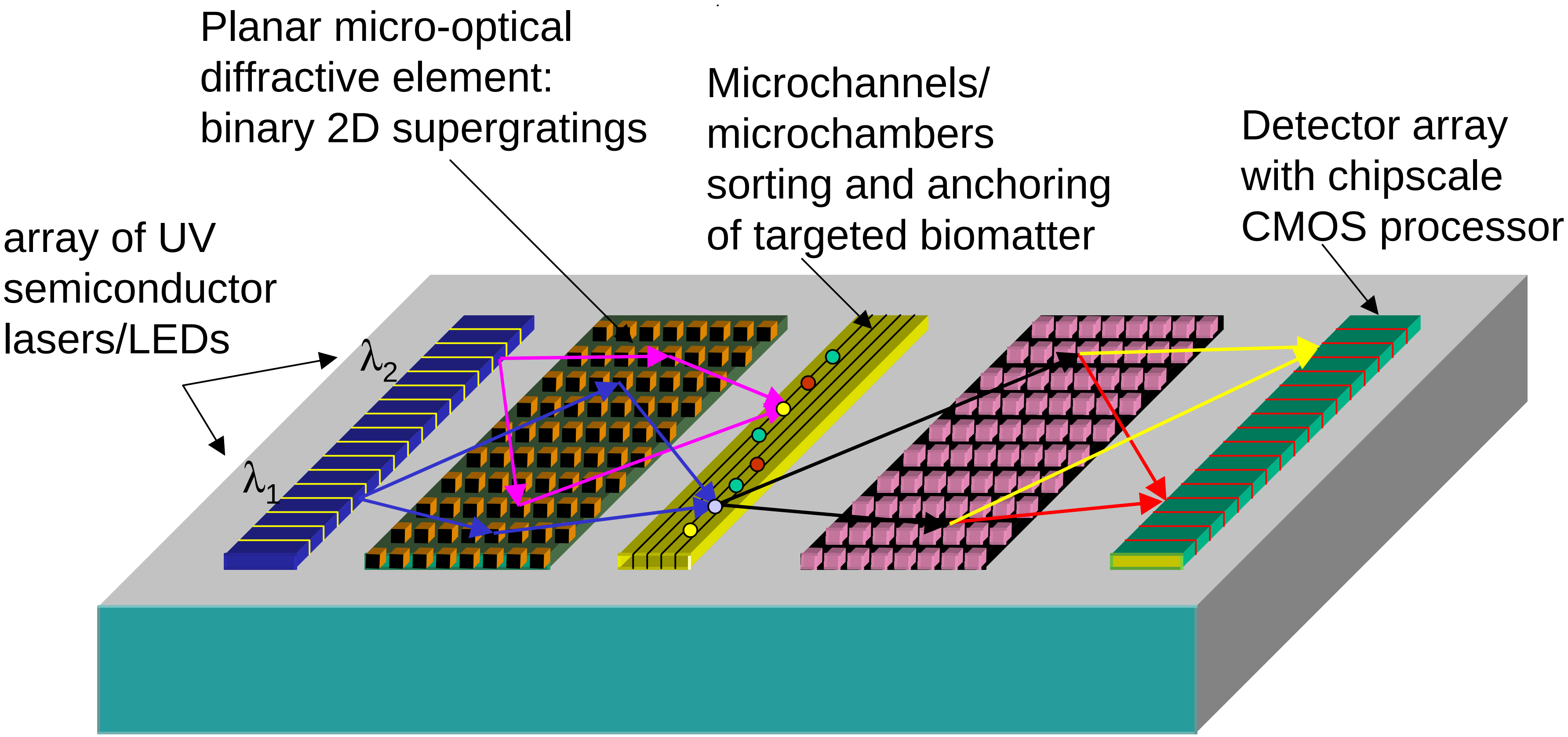
How to coax light out of e.g. AlGaN:

- a coupled materials science/device science problem: maximize **radiative** processes, minimize nonradiative traps
- need for a battery of nanoprobes: AlGaN local electronic environment (NSOM, AFM, nano-DLTS, XAFS,….)
- bandstructure (local) engineering: e.g. AlGaN:In
- LEDs vs. laser diodes: optical housing to enhance R_{rad}
- issues of light emission mechanism (including optical gain)
- example of own recent work (with J. Han Yale/Sandia; Lumileds)

* (in addition to p-doping, p-contacts, pn-heterojunction formation etc, etc)

Biospectralab-on-Chip

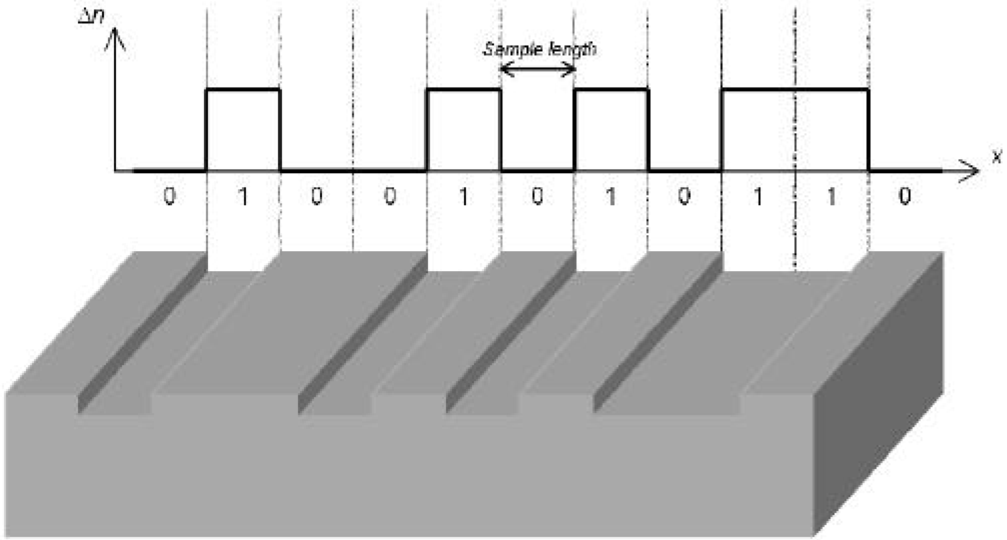
- Direct multi-λ spectroscopic fingerprinting
- UV induced photodynamical reactions

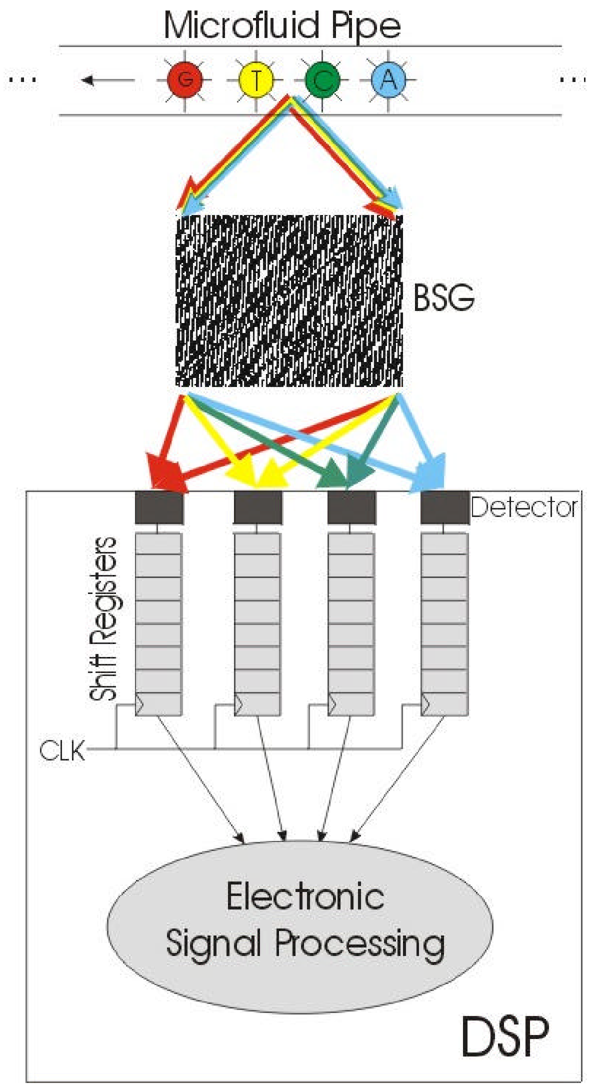


- compact chipscale spectroscopic analysis system:
  particulate and molecular level detection at the microbiology interface
- lateral vs. vertical implementation
- integration of micro-optical components
- **spectral <u>and</u> time-multiplexing**

e.g. PCR assays for B. anthracis with strand specific fluorescence

Example of subwavelength diffractive optical element: binary “supergrating”:

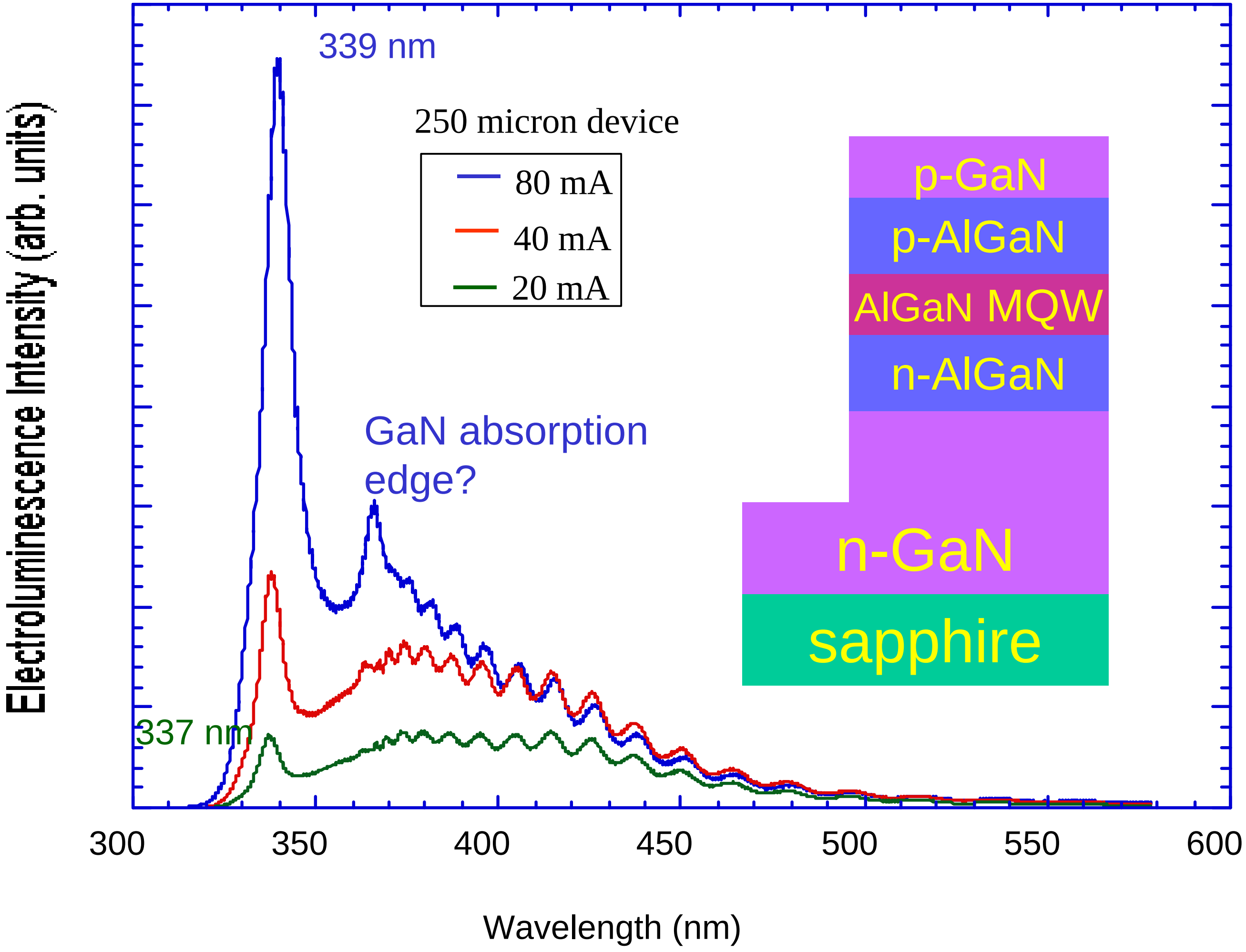




- chipscale compatible
- allows 2D implementation
- tolerant to fabrication errors

J. Xu (Brown)

Using AlGaN QWs to shift LED emission below 340 nm

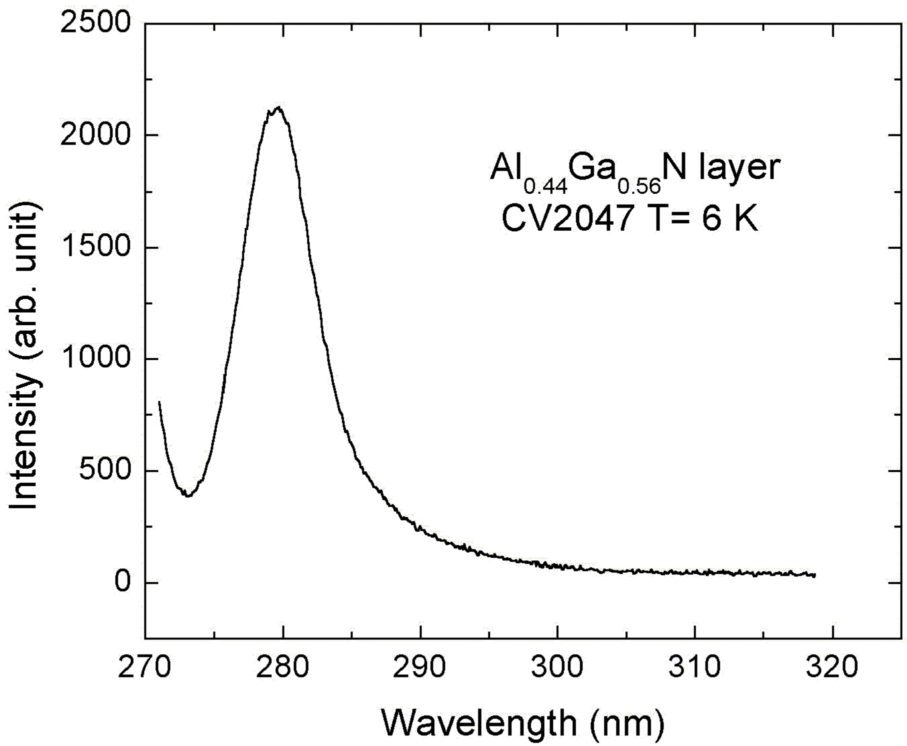


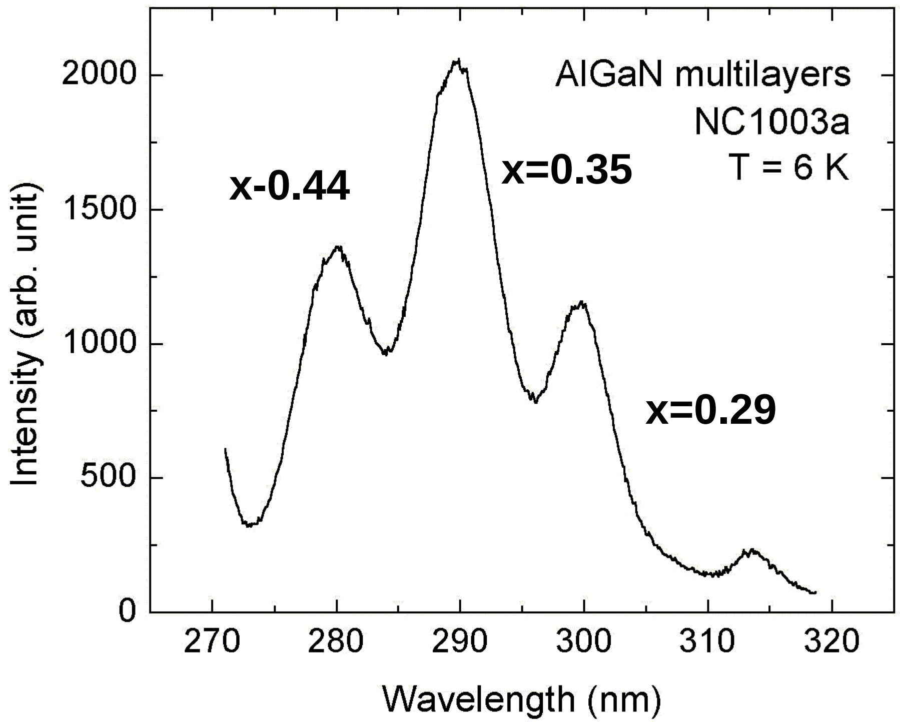
• the quantum "efficiency problem"

Crawford, Han, (1999)

Low Temperature Photoluminescence of AlGaN (x~0.4)

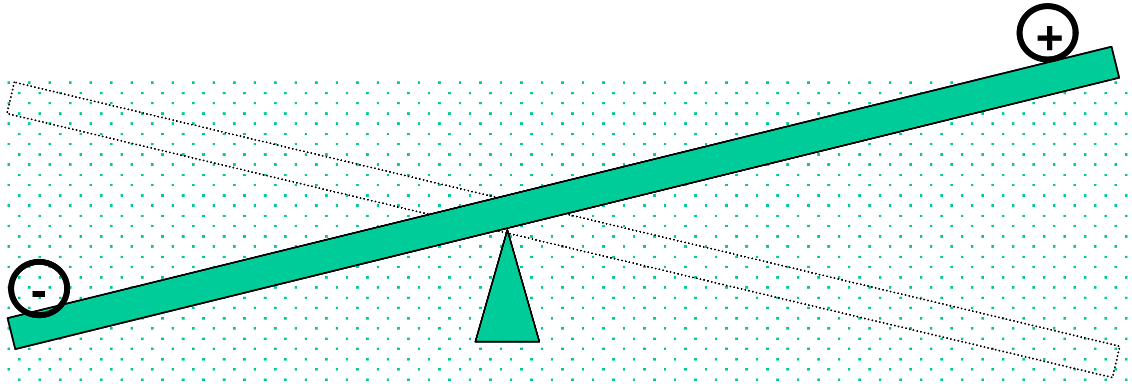
(with Jung Han, Yale University)





- emission efficiency about 100-1000x smaller than InGaN SQW (~410-450 nm range)
- unresolved issue about the nature/role of defects and e-h pair dynamics

Radiative vs. Nonradiative Processes in UV-AlGaN



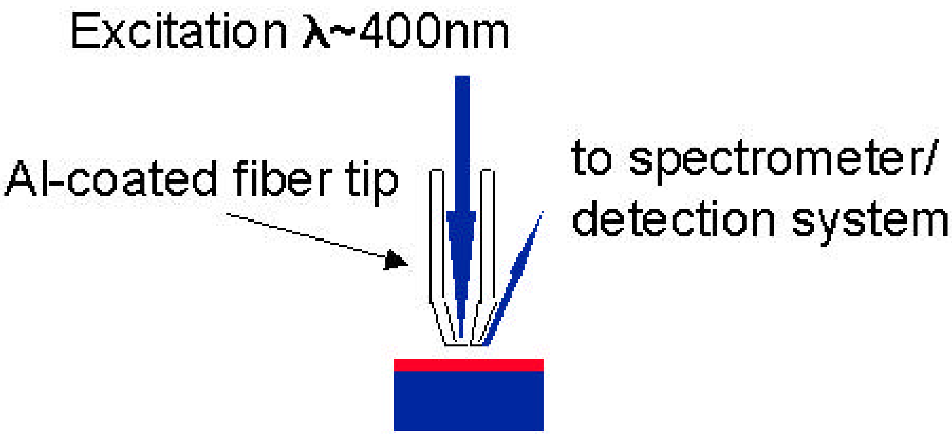
- point defects: identification and control of their chemistry and density
- extended defects: important?
- nanoscale materials: AlGaN QWs, Qdots/nanocrystals, self-assembled systems

- enhanced spontaneous emission rates in the UV (~ω^4)
- enhanced oscillator strength from e-h Coulomb (excitonic) effects

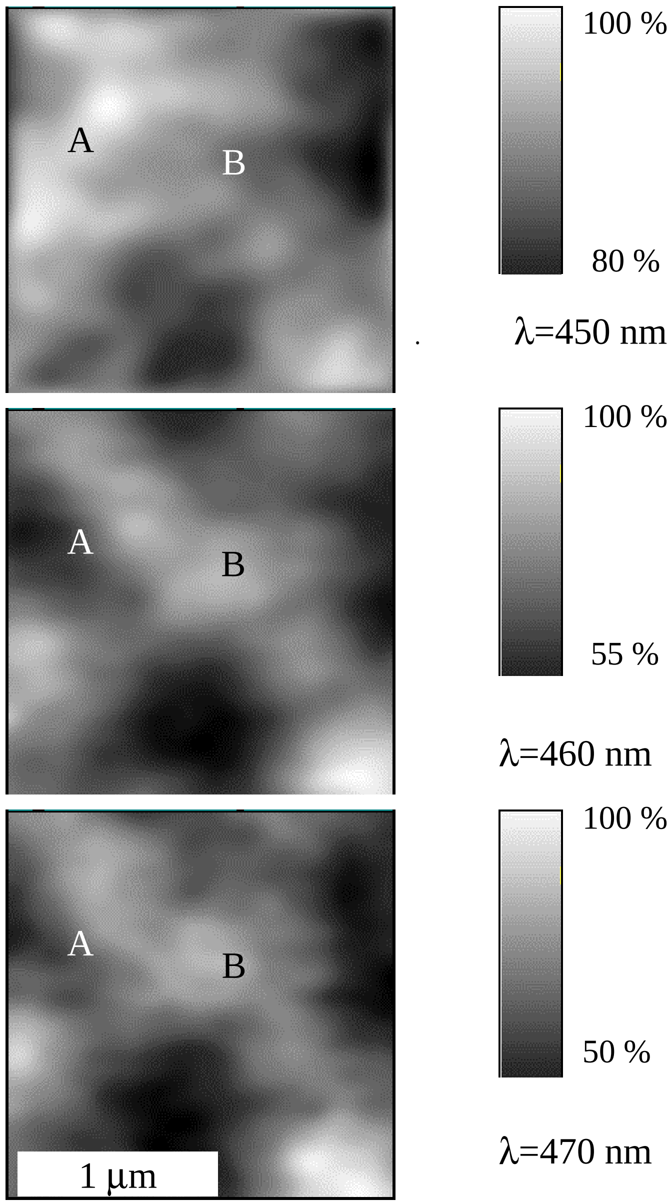
larger intrinsic gain

Example of local experimental probe: NSOM

Near Field Spectroscopic Microscopy of InGaN Compositional Fluctuations

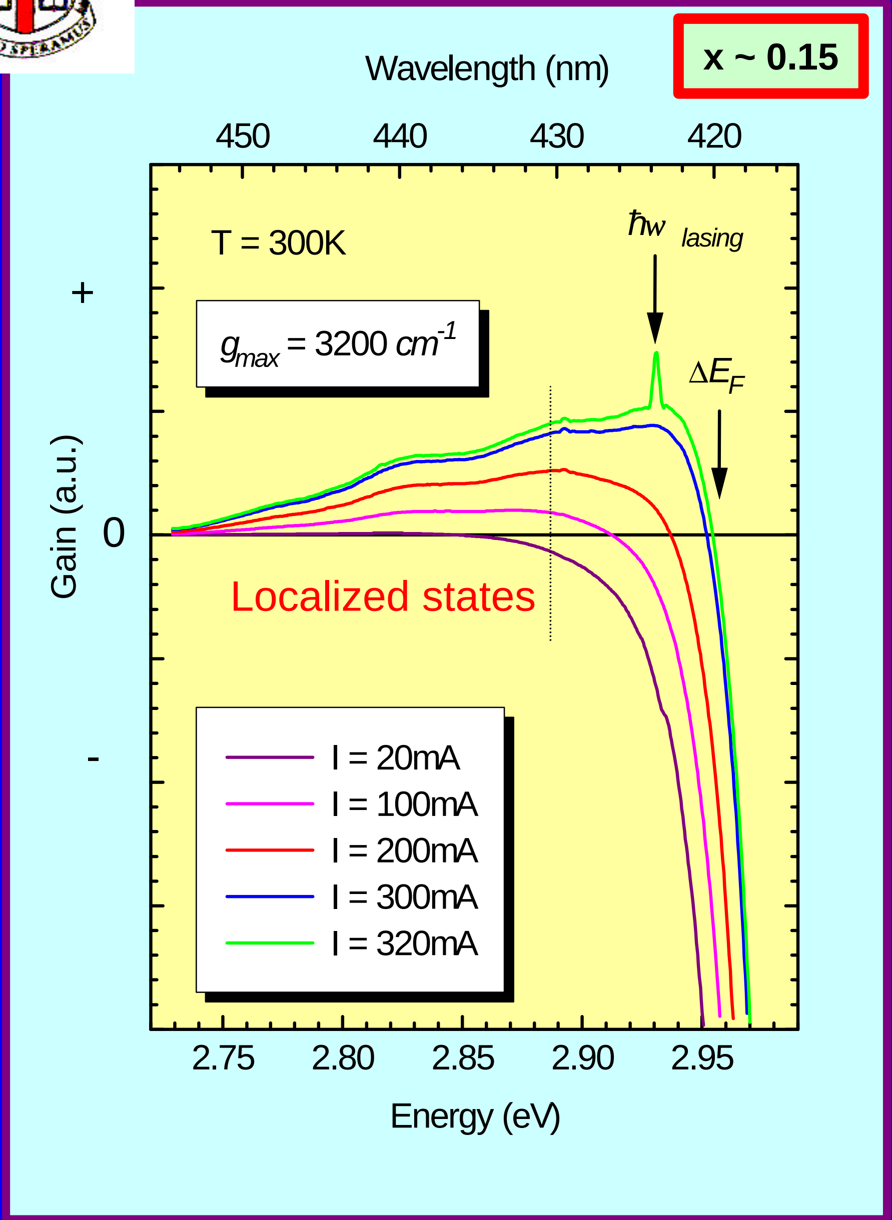


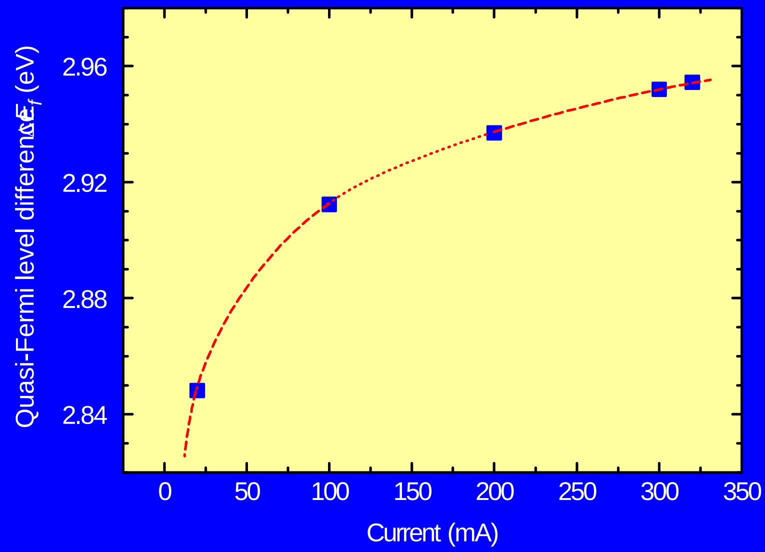
- Spatial resolution of ~ 800 Å for photoluminescence/photocurrent spectroscopy



Vertikov (1999)

GAIN SPECTROSCOPY ON EDGE EMITTING InGaN QW DIODE LASERS





- correlating spontaneous, stimulated emission, absorption
- pronounced low energy extension of gain spectra: state filling - compositional anomaly very strong for x > 0.1
- transparency achieved at modest current densities
- near saturation behavior in DE_F : Possibility of mobility edge

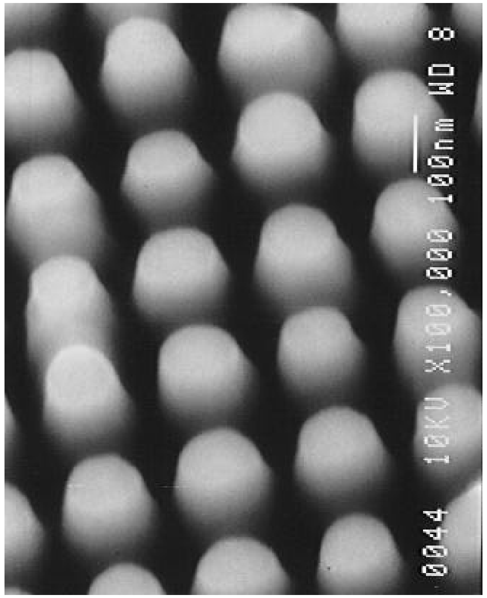
Song (1999)

Optical Resonators for Future UV Lasers/LEDs

AlGaN QWs: Optical gain very high (many-body effects); $g \sim 10^4\ cm^{-1}$

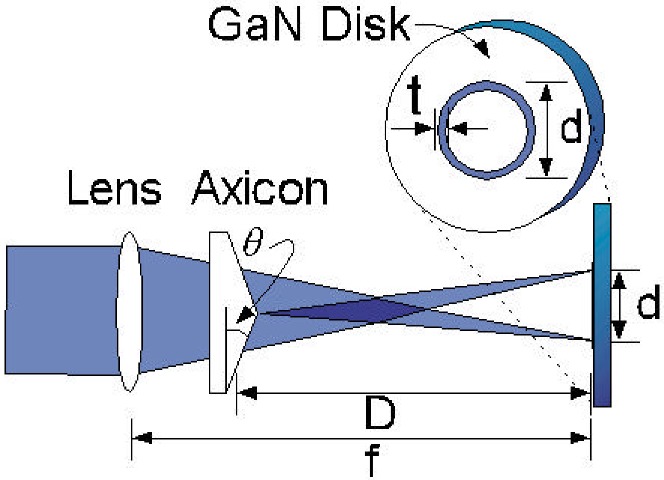
Optical resonator design (both LEDs and lasers):
enhance light-matter interaction to accelerate radiative recombination rates:

- edge emitting vs. **vertical cavity** configurations
- 3D nano-optical high-Q microcavities
- photonic bandgap structures
- distributed strong scattering media
  (high gain case)

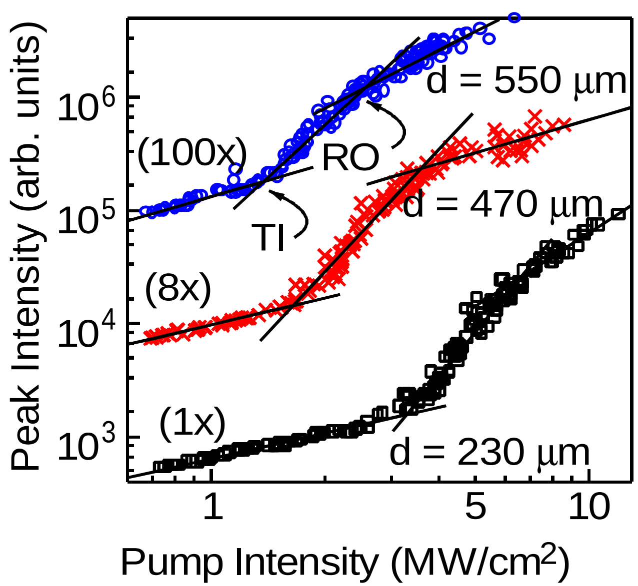


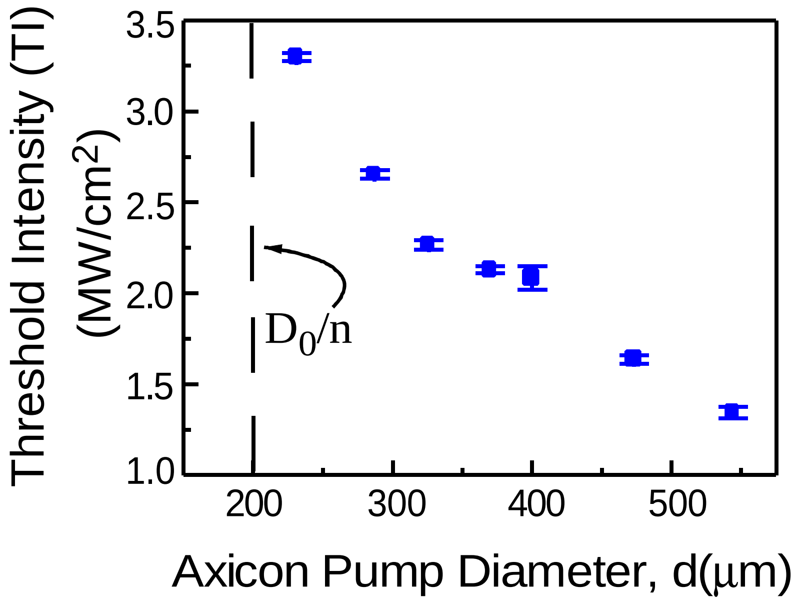
InGaN/GaN patterned
QW active matrix
(L. Chen, 2001)

Threshold Lowering Through Spatially Selective Excitation



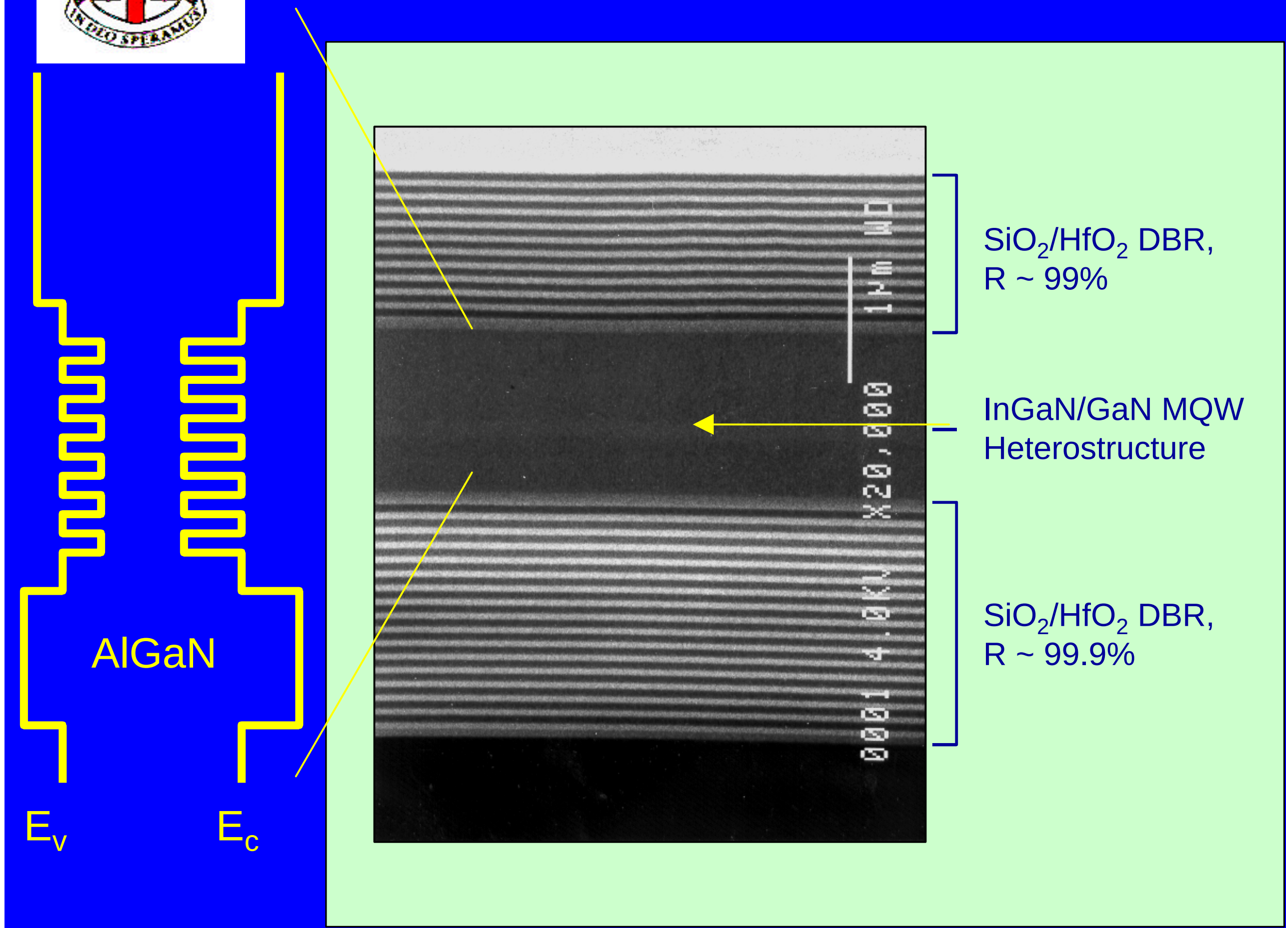
R. Chang
(Yale)

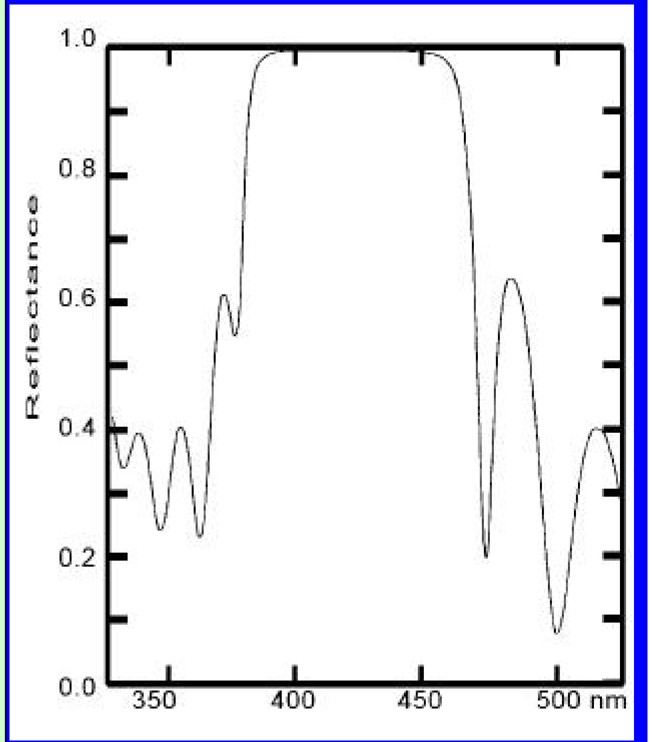




Fabrication of Optically Pumped Nitride VCSEL: All-Dielectric Mirrors

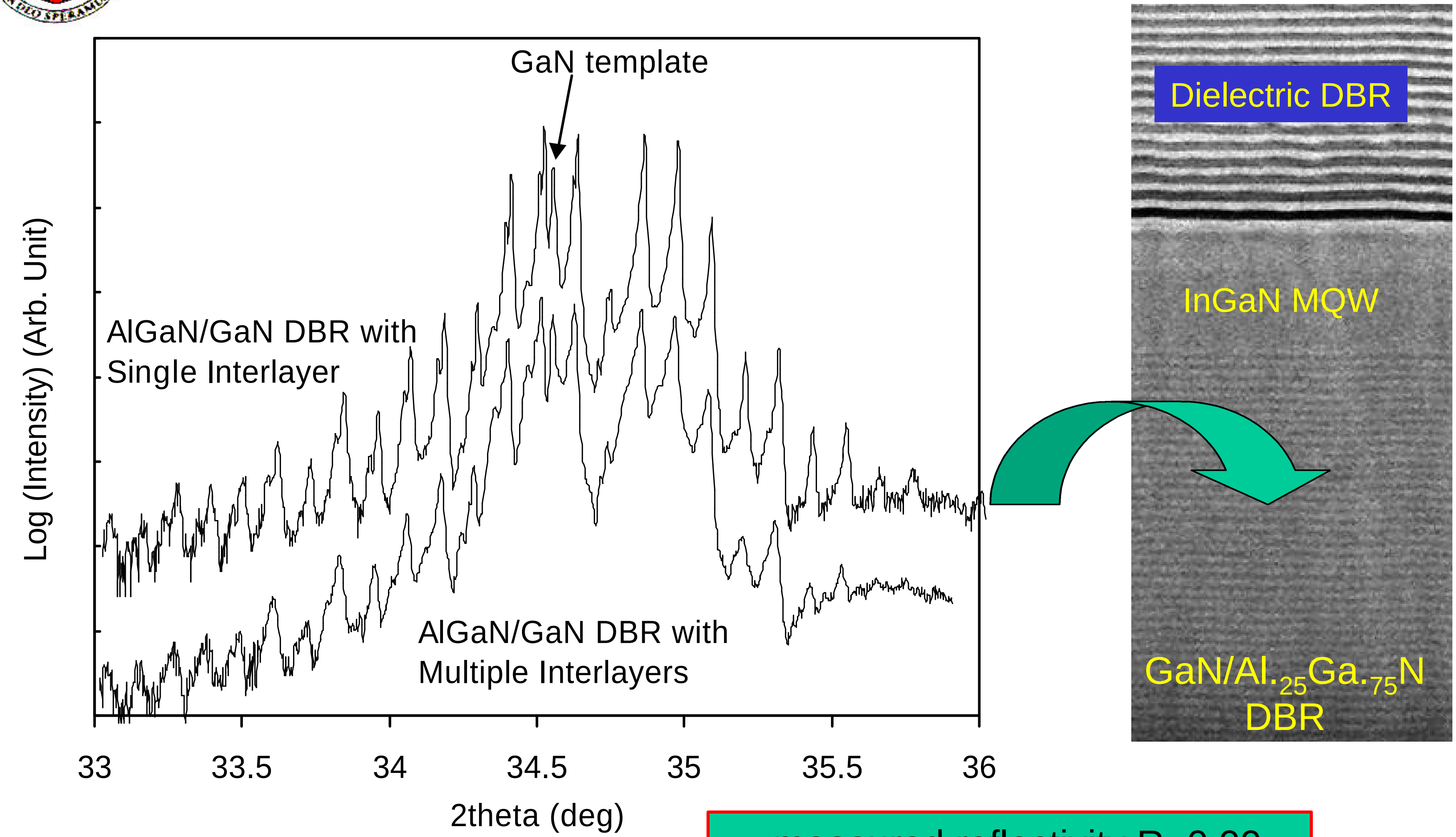
Song (2000)/Lumileds





- **12 pair SiO_2/HfO_2 (R_{FRONT}~99.5%) and 17 pair SiO_2/HfO_2 (R_{BACK}~99.9%) dielectric DBRs**
- **7λ cavity consisting of 21 $In_{0.1}Ga_{0.9}N$/GaN MQW**
- **Cl_2 ECR RIE to remove GaN buffer layer for shortening cavity length**

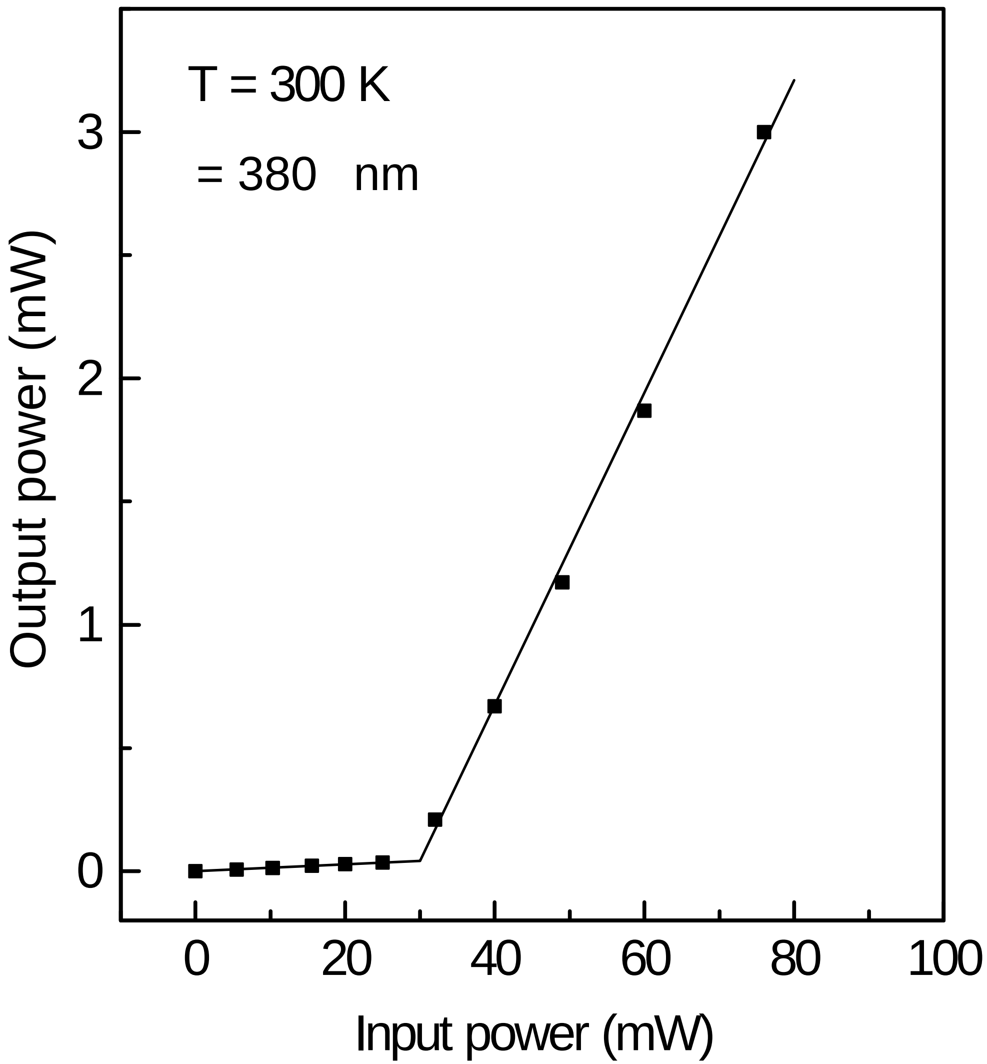
In-situ grown GaN/AlGaN DBR

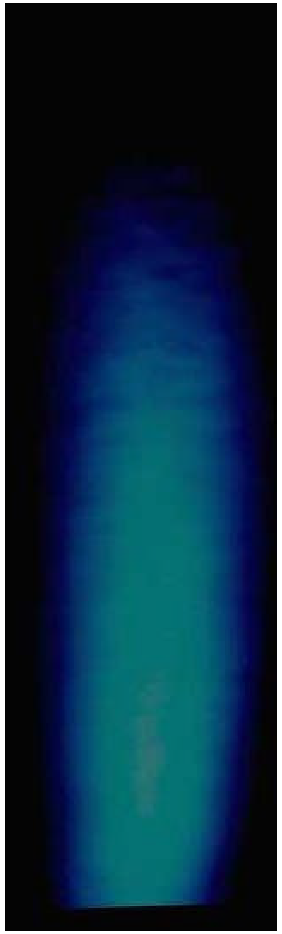


- measured reflectivity R=0.99
- 'crack-free'
- optical bandwidth ~10 nm

J. Han et al (2000)

Input-Output Characteristics of Optically Pumped 380 nm VCSEL





- <25% of incident pump radiation absorbed in QW

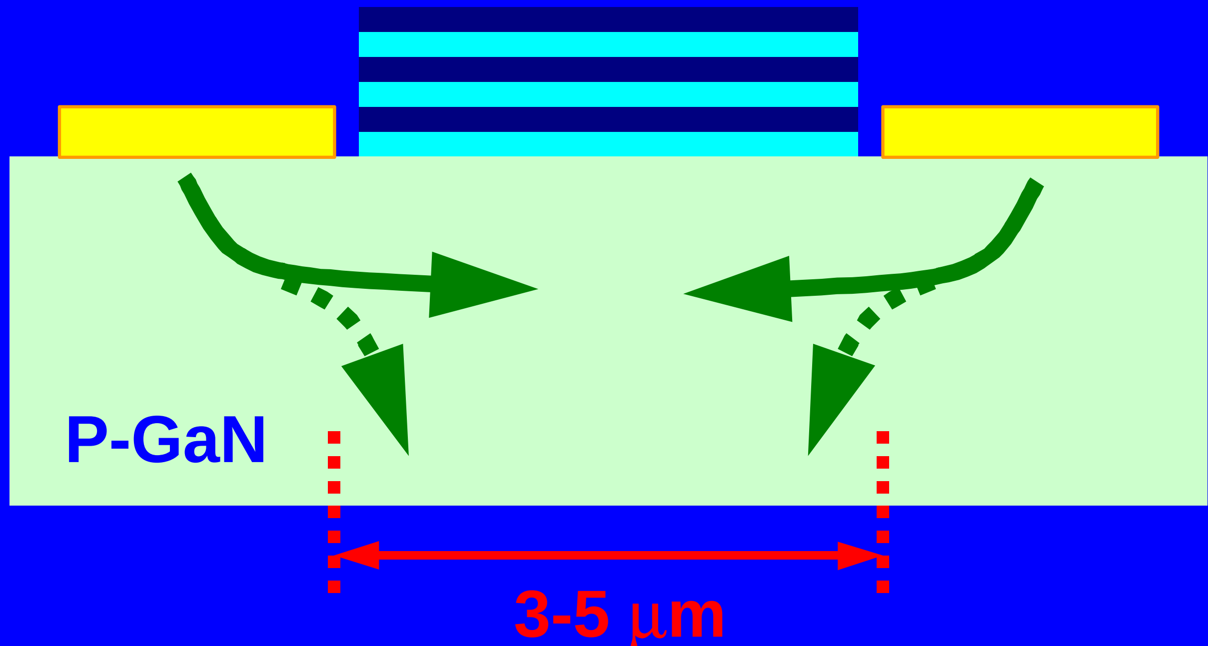
  ➡ conversion efficiency ~10%

Zhou et al (2000)

Electrical Injection for Nitride RCLEDs and VCSELs

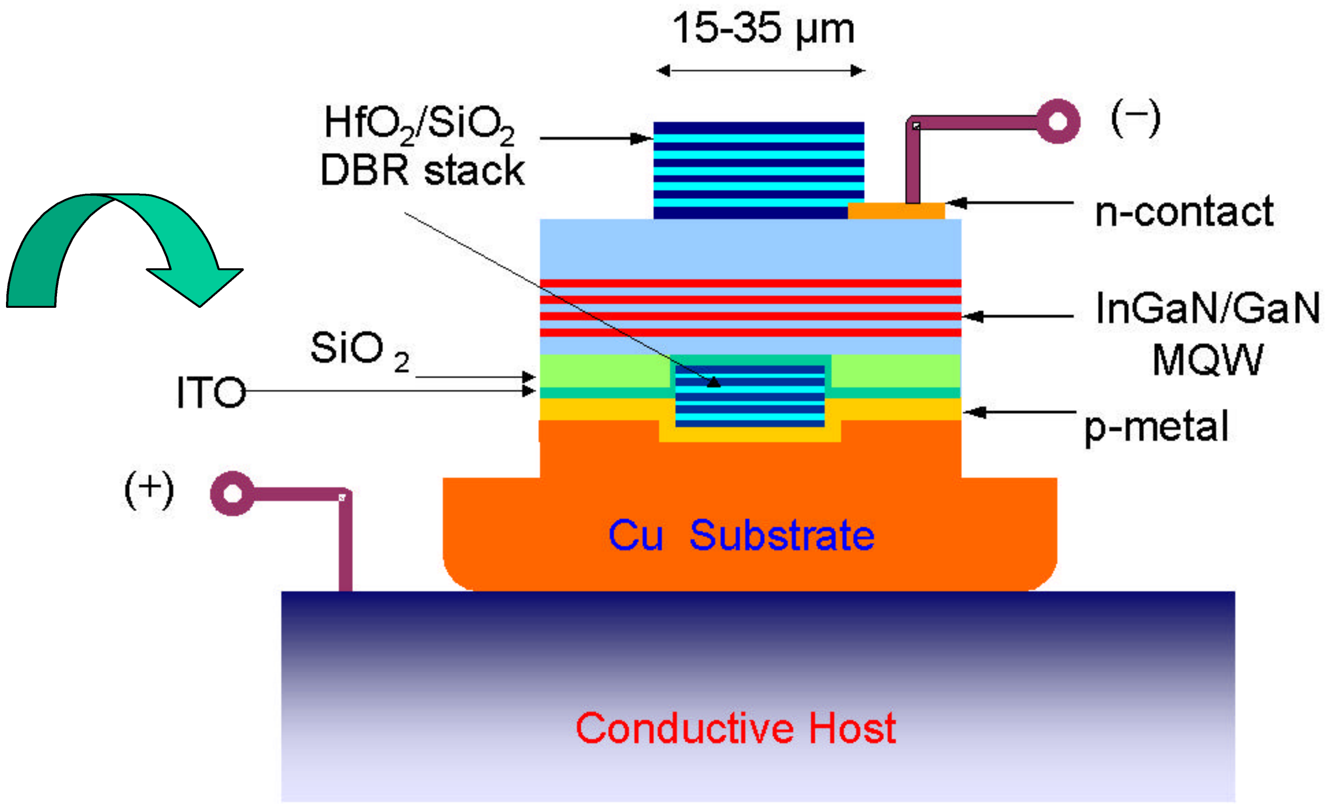
Poorly conducting/insulating DBRs: lateral injection

- low conductivity of p-GaN (~ 0.1 (cm)$^{-1}$
- weak lateral current spread (~1μm)
  piezoelectric doping?



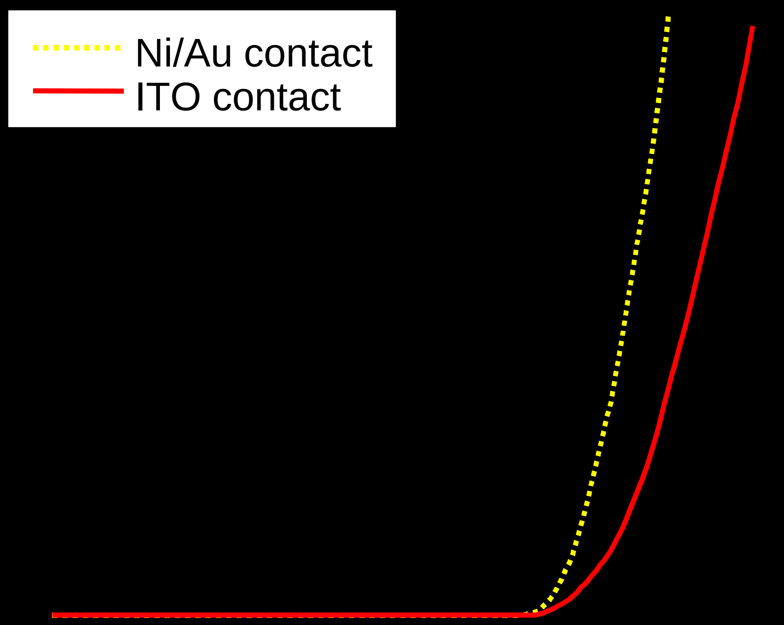
Electrical injection and a vertical cavity nitride QW light emitter

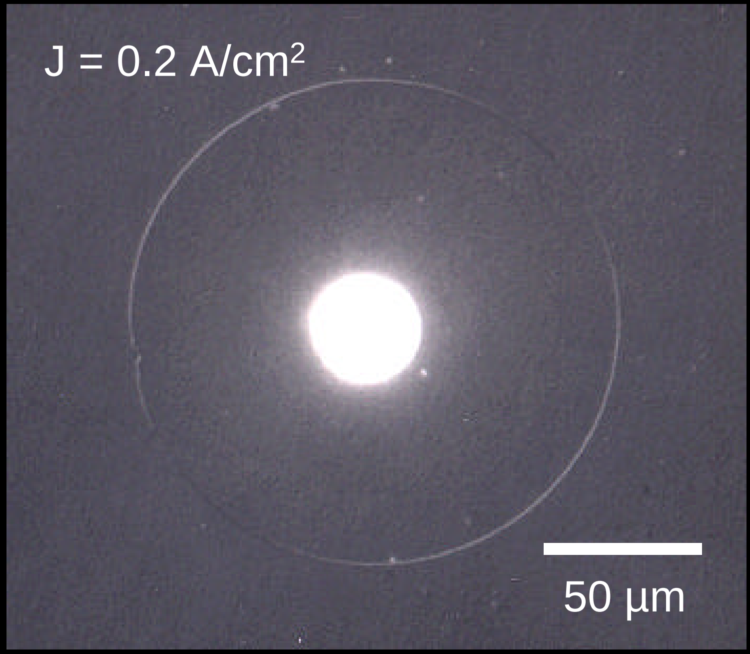
- all dielectric mirror
- use laser ablation technique for GaN liftoff
- intracavity ITO hole spreading layer



- alternative approaches to lateral hole injection: bandstructure engineering of p-GaN heterostructures

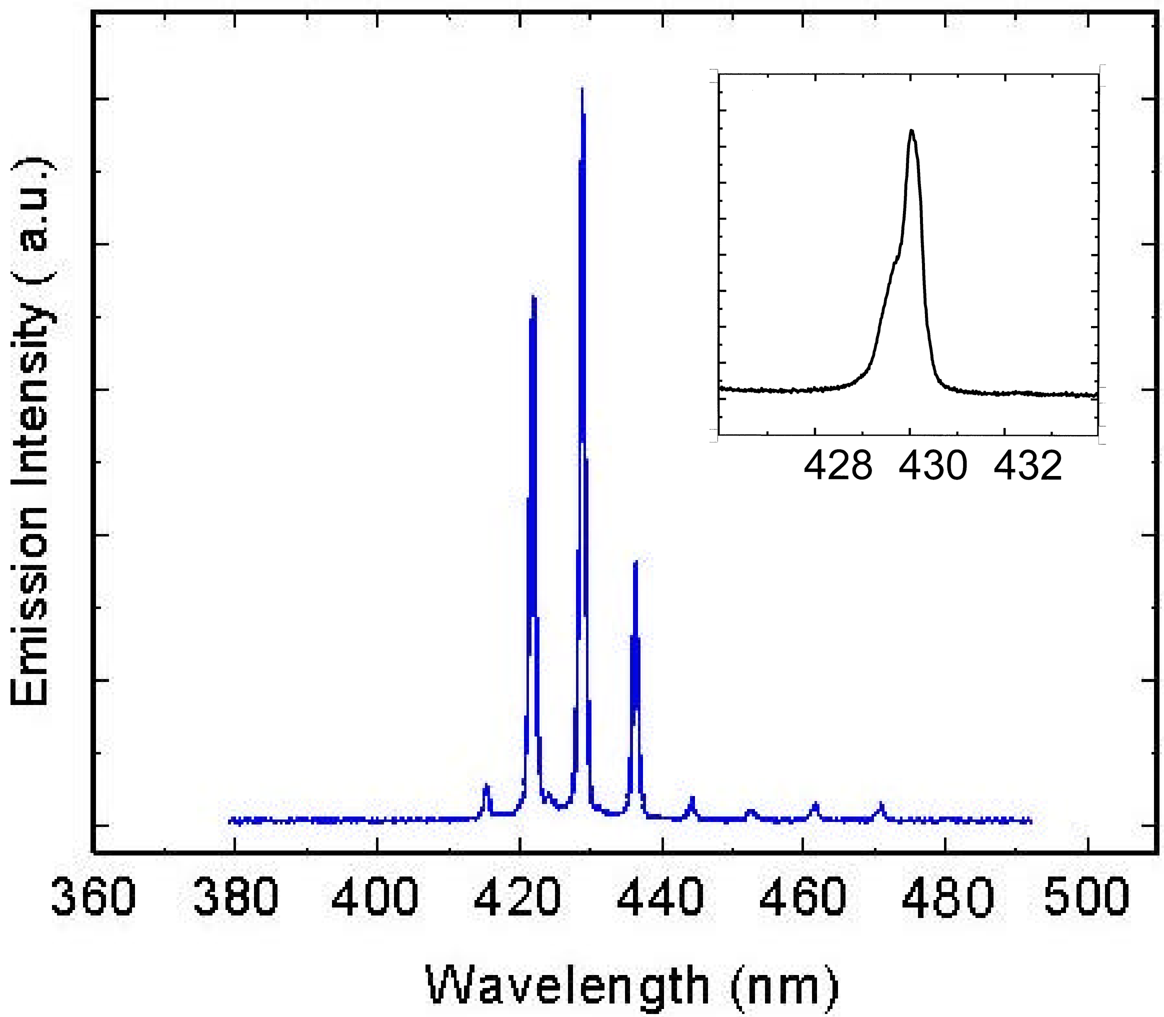
Inclusion of intracavity ITO within a GaN microcavity





- an “overhead” of ~ 1.5V (note: ITO an n-type semimetal)

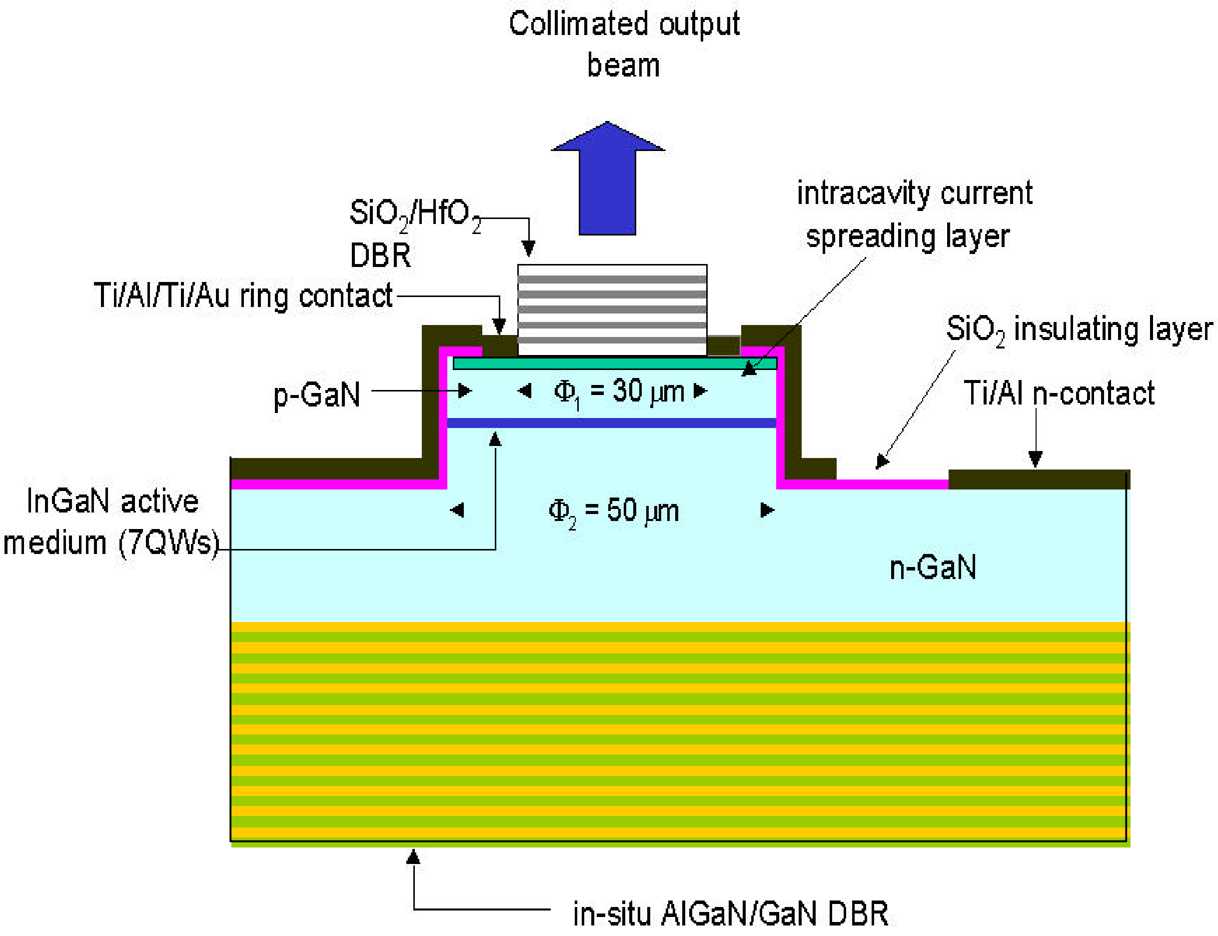
Emission spectrum of blue RCLED

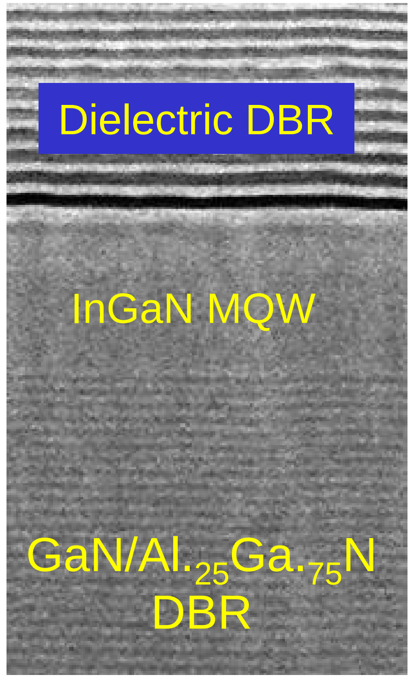


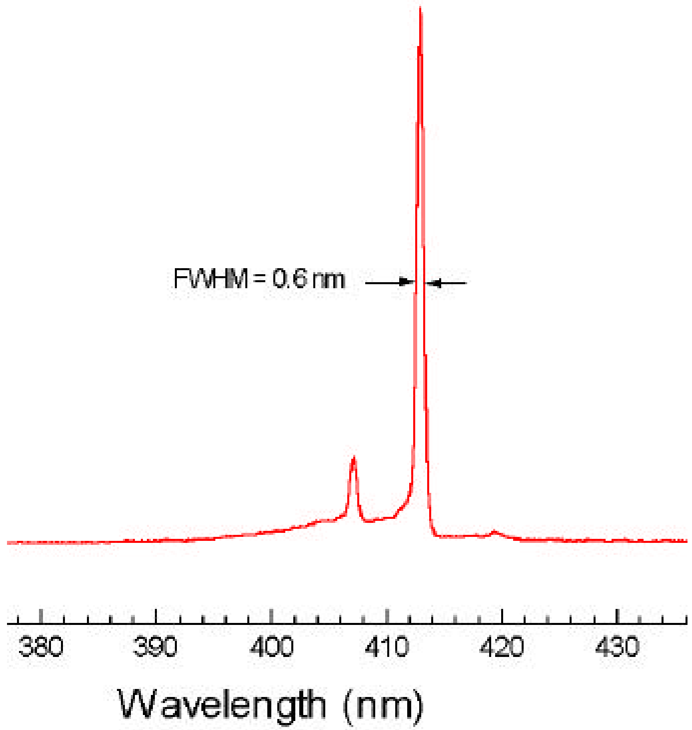
- modal linewidth ≈ 0.7 nm, Q~ 700
- shorter cavities by ECR etching
- directional emission (~10^{o} cone)

Diagne et al (2000)

Resonant Cavity Violet LED with in-situ grown AlGaN DBR







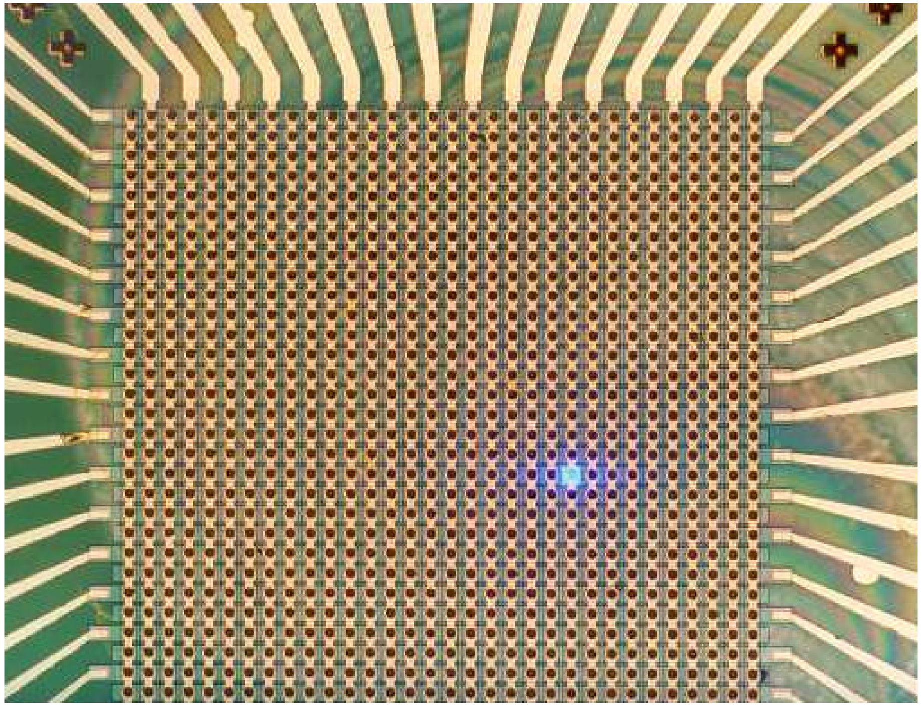
- monochromatic spectrum
- directional emission

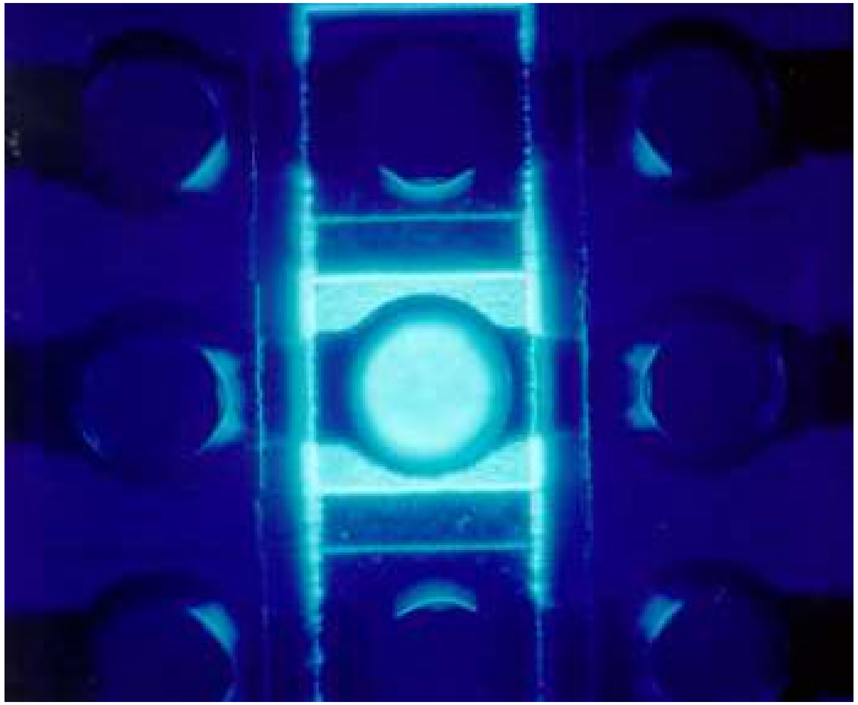
Zhou et al (2000)

A 32x32 Matrix Addressable InGaN MQW LED array

1024 elements; <100 nsec access time

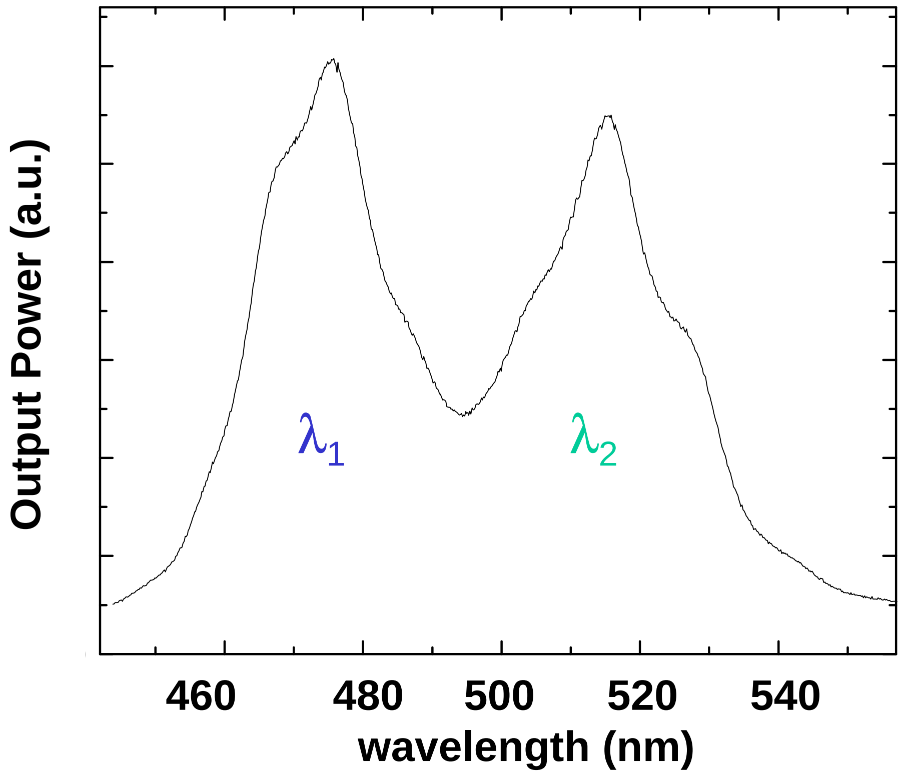
Ozden et al (2000)

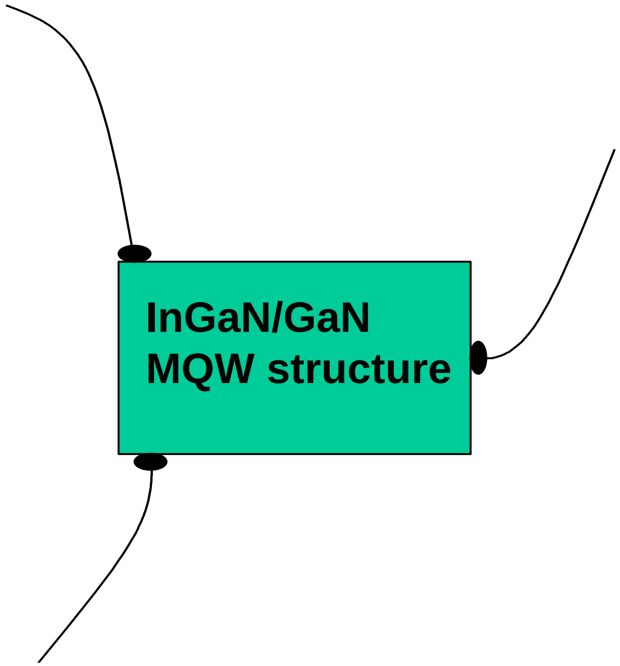




- 20 μm optical aperture
- 35 μm center-to-center separation
- integrated polymer microlens (~ 30 μm focal length)

Two-wavelength LED for time-spectral multiplexing





Ozden (2001)
with Lumileds

Summary: Towards UV VCSEL Devices

- versatile high-Q vertical cavities realized (380-450 nm)
- low threshold quasi-cw optically pumped VCSELs (380-410 nm)
- robust RCLEDs by use of intracavity current spreading layers: current densities >10 kA/cm
- prospects for blue/NUV/UV VCSELs, including fundamental aspects of light matter interaction (strong coupling regime)
- development of 2D arrays (e.g. for biochemical/microbiological analysis)