Innovative Photon Management for Smart Control of Light

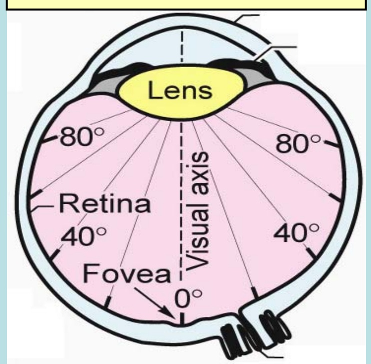
Shawn-Yu Lin
Device Thrust Leader
RPI Constellation Professor (The Future-Chips)

Light, Visual Experience & Innovation

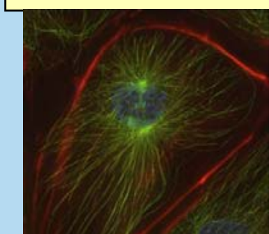
Sun light

Vacuum-tube technology

Human eye



Bio-imaging (Nucleus)



Semiconductor-chip technology

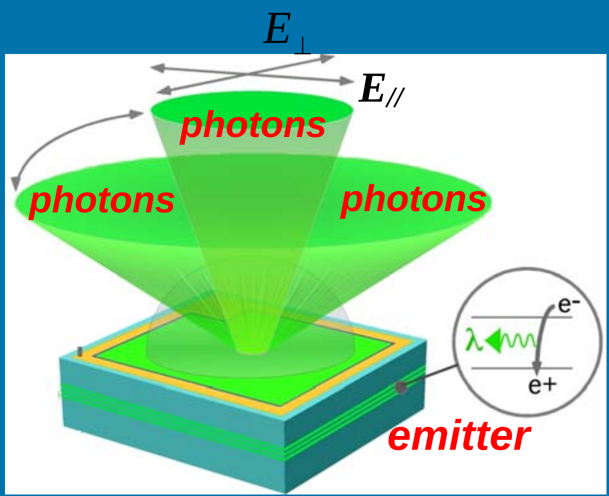
Lighting & health

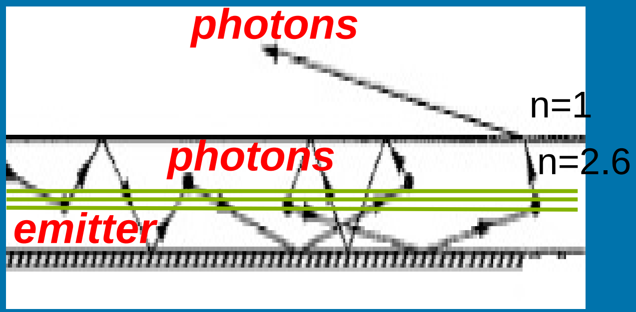
Display-"Polarization"

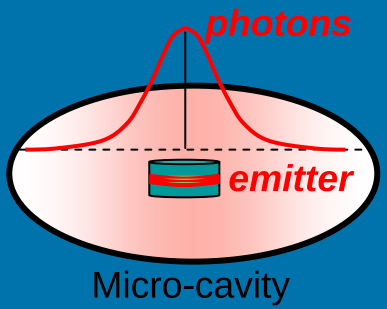
"Color"

(Summer Davos 09, photonic revolution, opening remark-1/2, Dr. SY Lin-RPI, USA)

What are the most innovative contributions?
the New Science of LED
- tailoring the emitter-photon interaction -







C_{ex}>80-100%**

η_{int}>90%***

- ***Guided modes*** –eliminate
- Rad. pattern- (Δθ<10º)

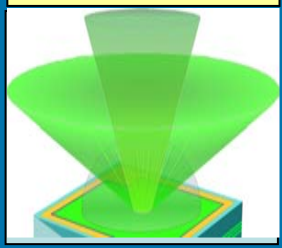
- ***Guided/ trapped light*** (4%)
- Rad. pattern- Lambertian
- Un-polarized- θ~0º

- ***Cavity modes***
- Emitter-photon- coupled

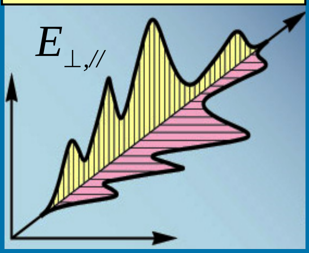
(source: Laser & Photonics Rev. 1, 307-333, 2007, ***Nature 425, 268, 2003)**

On-Chip Control of the Nature of Light

Pattern

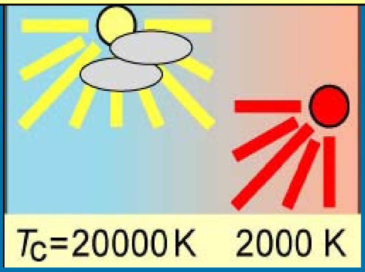


Polarization

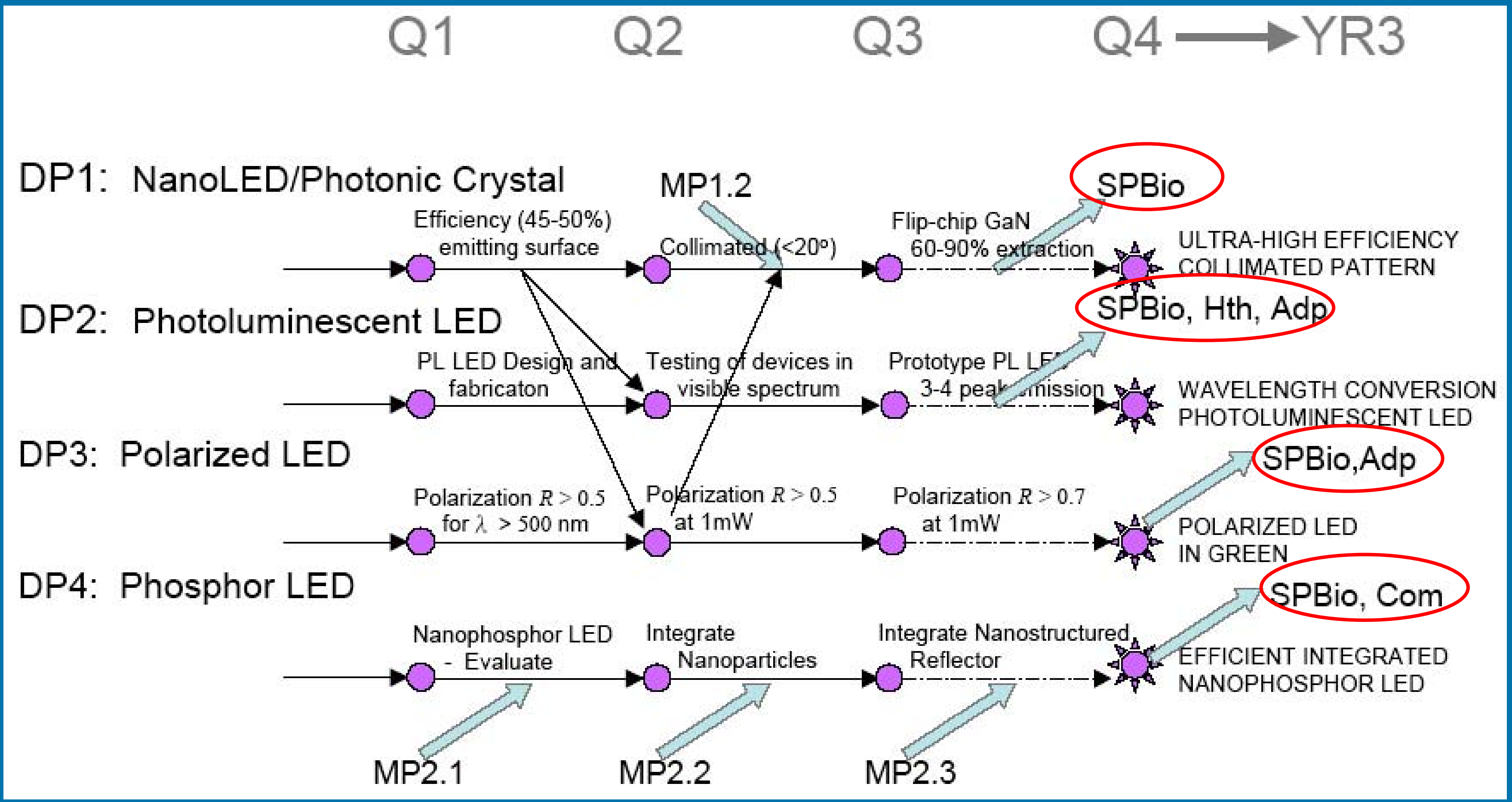


color

Color temperature



Under This ERC, We Have Identified 4 Areas as our Device Focus for Year 2-3.



(from Art Sanderson Nov. 09)

DP: Device Project
SP: System Project

We Have Formulated a Preliminary List of Device Performance Matrix As our Near-Term Objectives.

1. Wavelength bandwidth	(variable/tunable/$\Delta\lambda$ 30/10nm)
2. Brightness	(C_{ex}, η, droop effect)
3. Uniformity	(0.25mm^2, 5mm^2, 50mm^2)
4. Directionality /emission θ	(30/20/10^0)
5. Polarization selectivity	(2:1/10:1/50:1)
6. Phosphor lifetime new device design	(100ns/10ns/1nsec) Broadband green Narrowband red
7. Color mixing	(spectral uniformity)
8. Thermal management	
9. Fabrication technology	(70nm over 625mm^2)

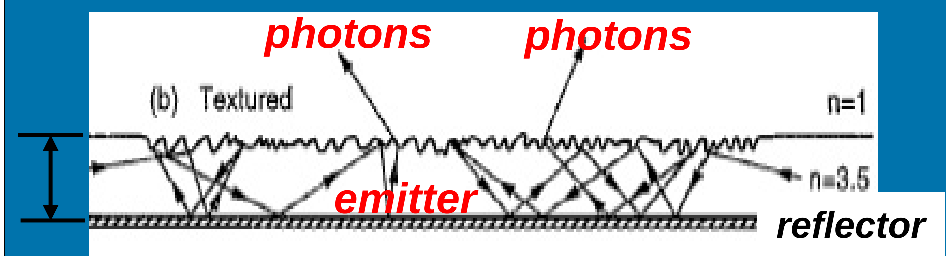
What are the trade-offs in optimizing for system performance?

The key performance attributes and characteristics-
(I) extraction and radiation pattern

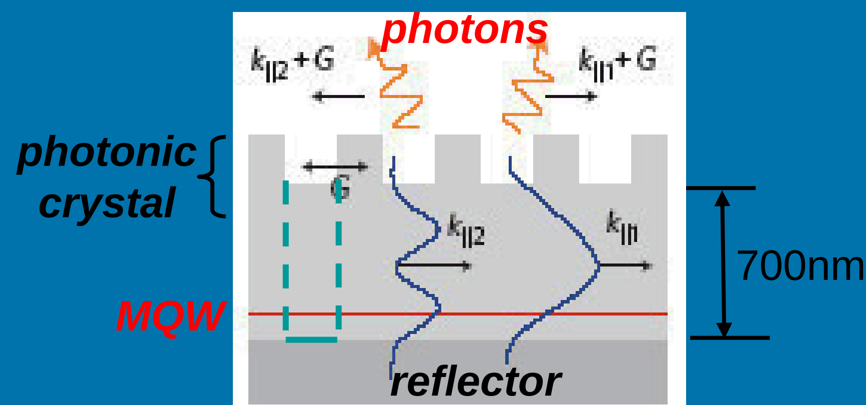
Device Grand Challenge

Approach	Principle	C (extraction)	Source
a. Surface texture +thin film-reflector	Optical scattering; FP cavity	External efficiency: 46%	APL 63, 2174, '93 APL 79, 2315, '01
b. Photonic crystal +thin film-reflector	Bloch scattering; FP cavity	**68-78% (total)** - 1mA	Nature Photonics 3, 163, 2009
c. Nano LED* **	Single-mode or few modes	**50-70% (one-side)**	
d. Nano LED* +thin film-reflector**	Single-mode; FP cavity	**Expect: >80-90% (total)**	

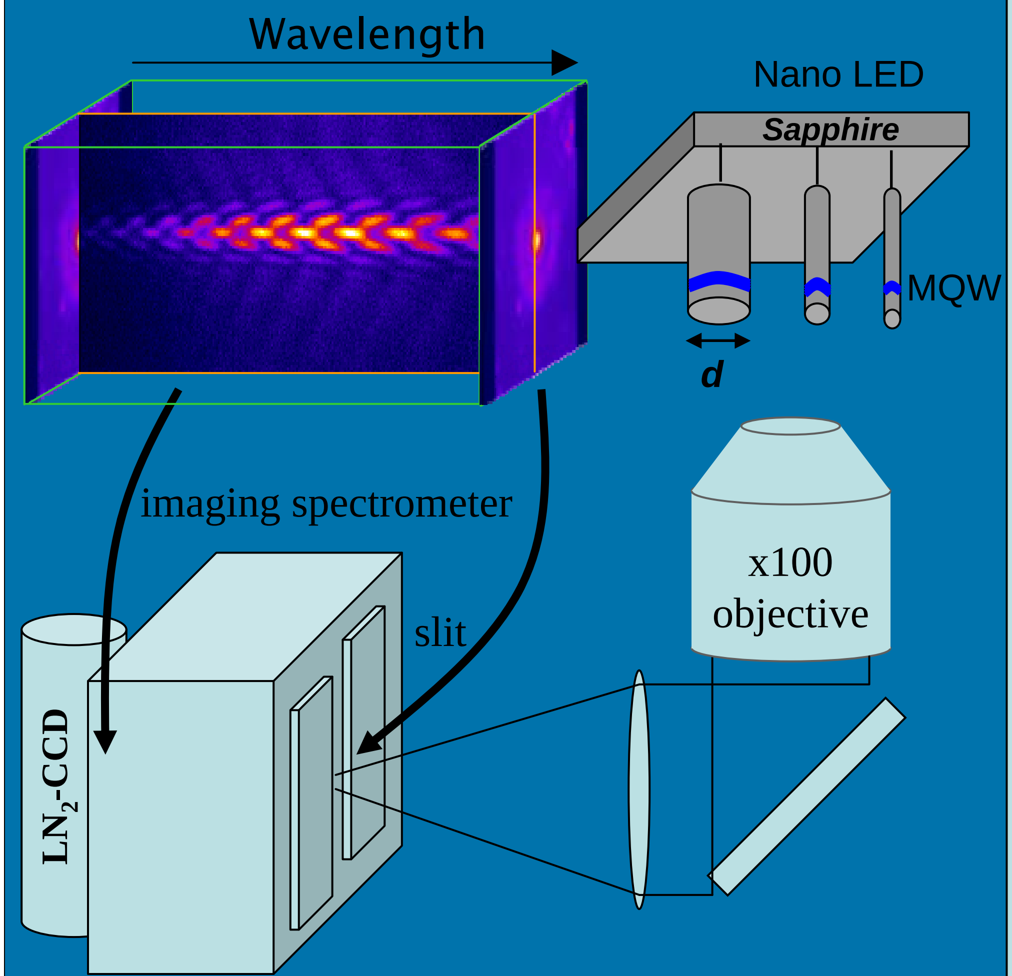
a

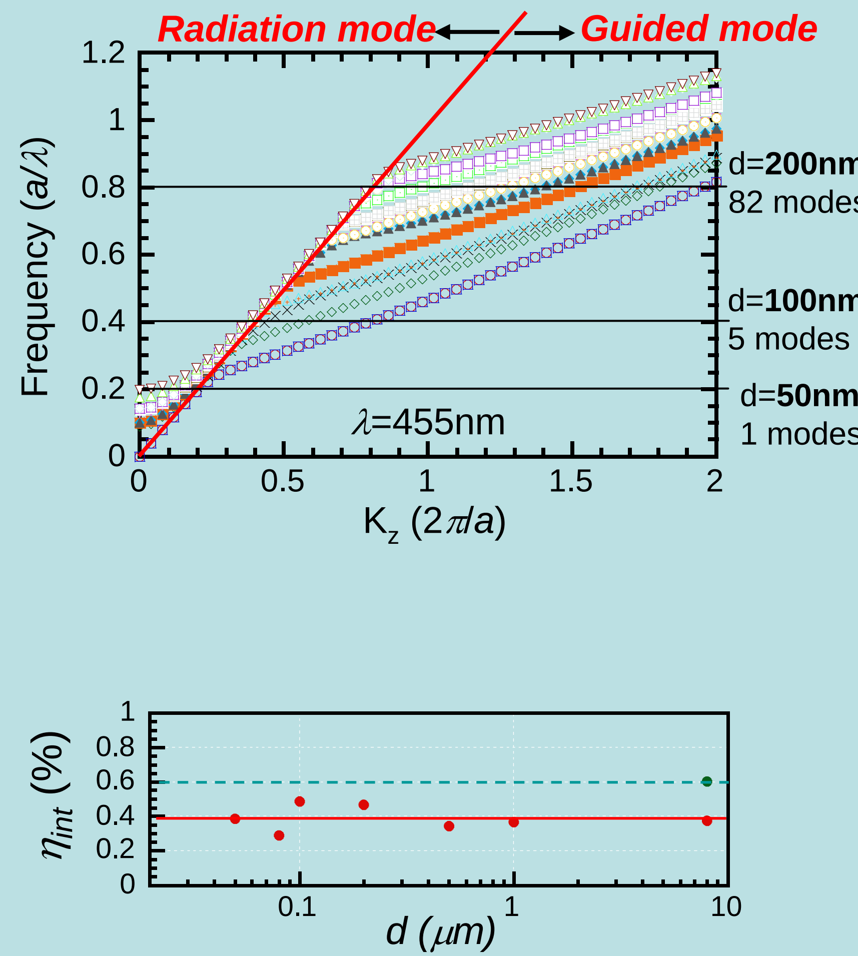


b



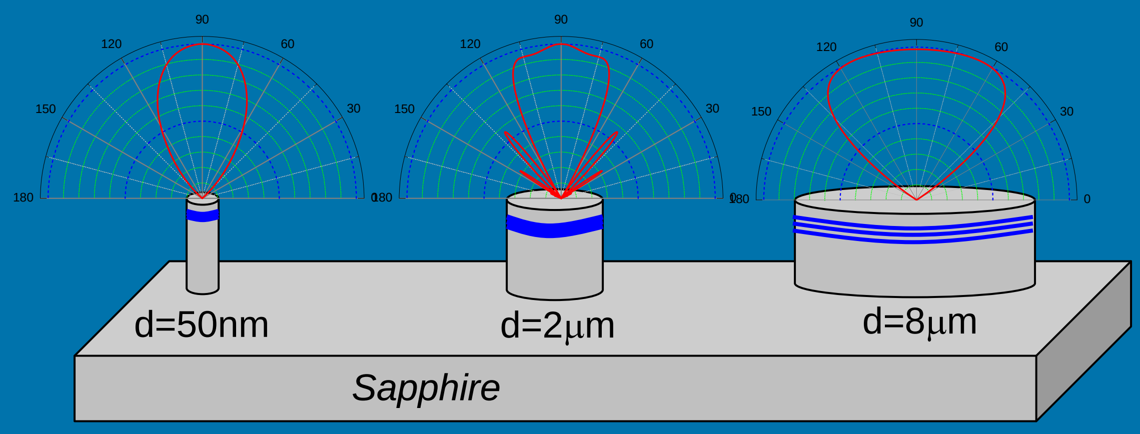
Engineering the Basic Optical Mode
: LED Light Extraction and Pattern Control

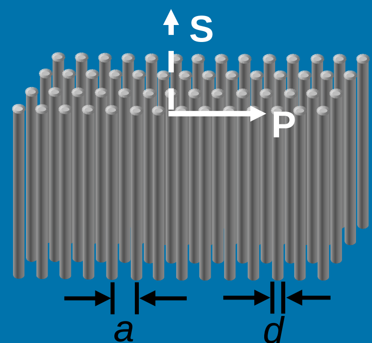




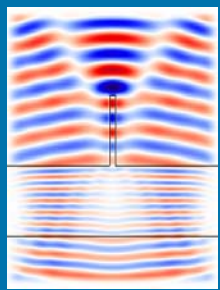
(data to be published)

Nano Engineering of the Basic Mode Also Allows Us to Tailor an LED's Radiation Pattern.

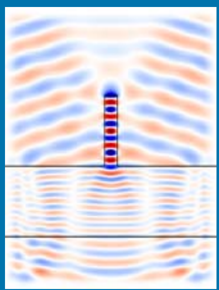




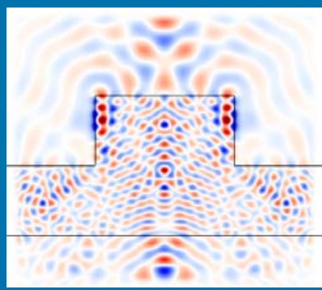
Next: 2D Array



d=100nm

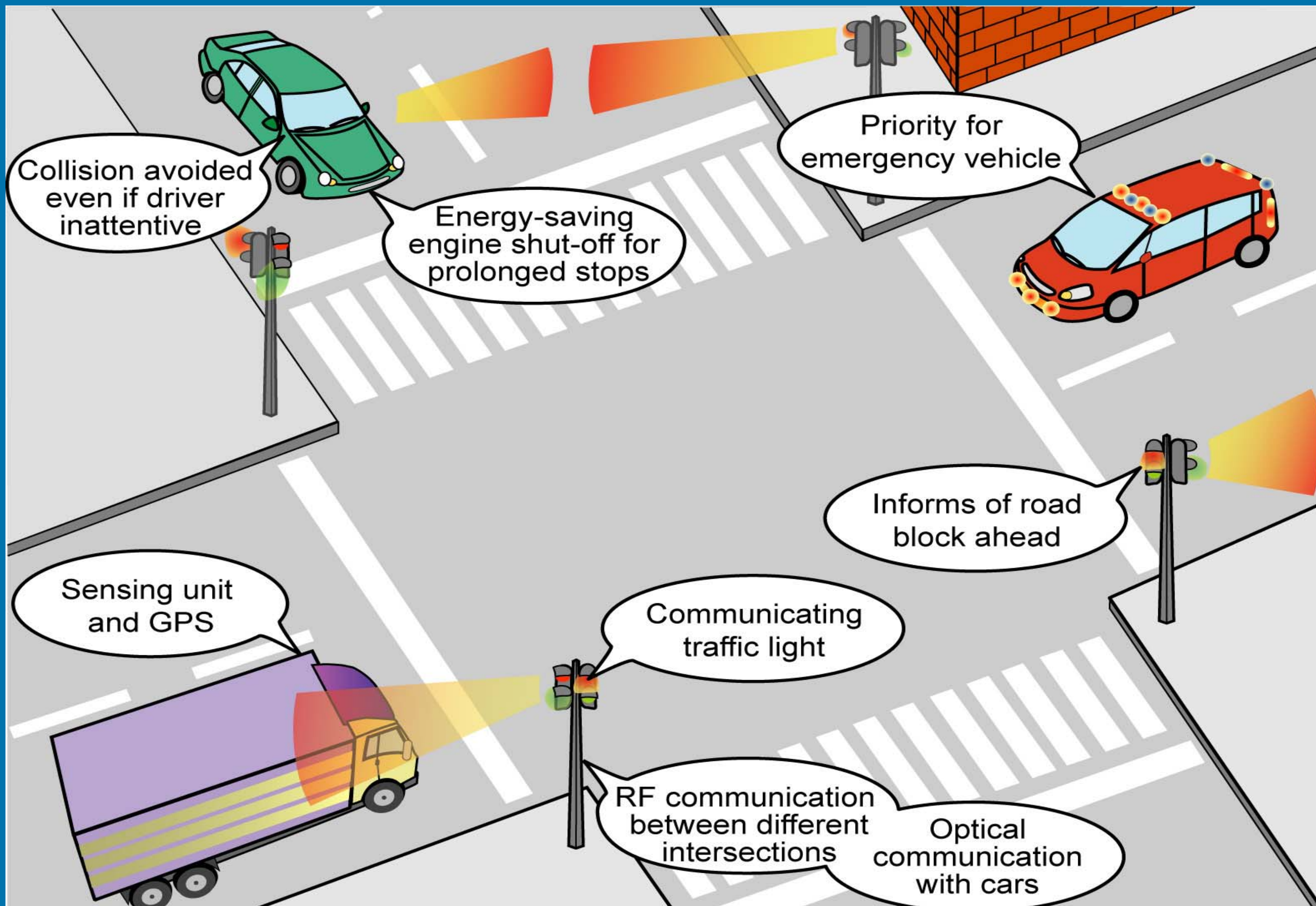


d=200nm



d=2,000nm

"Beam Shaping" for Lighting and Communication



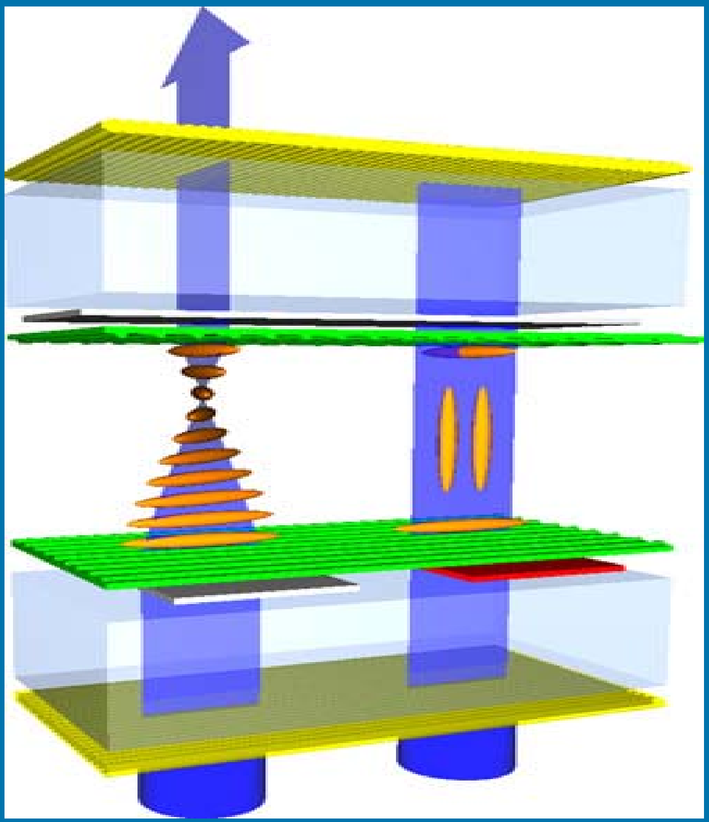
(Smart Lighting ERC/BU Dr. T Little)

“Polarized LED” for Display Application

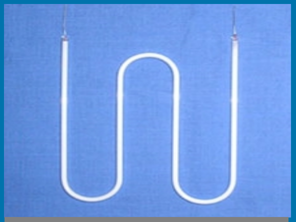
Polarizer

Liquid
crystal

Polarizer



Backlighting/
Edge injection/
Waveguiding



CCFL

High-power LED

“*Smart*” features :

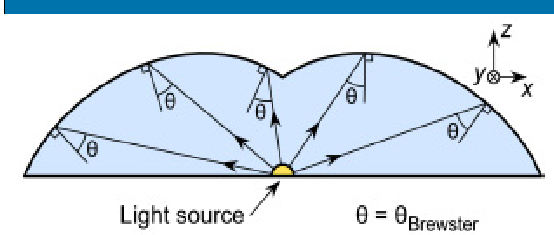
- Reduced motion blur by impulse driving
- Color filter-less LCD by sequential driving

The key performance attributes, characteristics- (II) polarization.

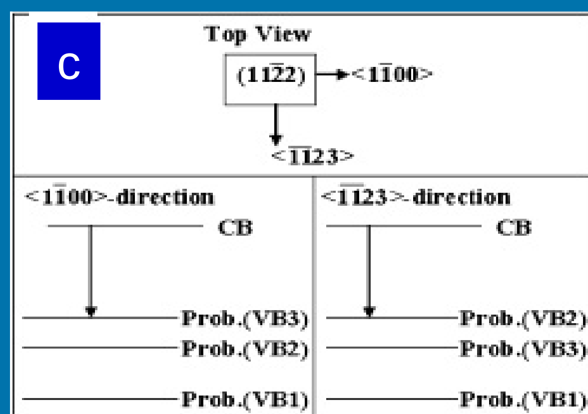
LED Device Grand Challenge

Approach	Principle	Polar. ratio	Comments	Source
a. External Reflector	Critical angle	2:1	Bulky; Emis. angle dependent	Op. Express 15, 11213, '09
b. Metallic grating	Metallic loss	2:1		APL 93, 23111, '08
c. strain engineering**	VB degeneracy	2:1 (522nm) **5:1** (588nm)	Growth intensive; High In-concentration;	JJAP 47, 7854, 2008
d. Metallic/ plasmonic photonic crystal**	Plasmonic coupling	**10:1** (expect)	Metal loss at visible Light focusing at corners	

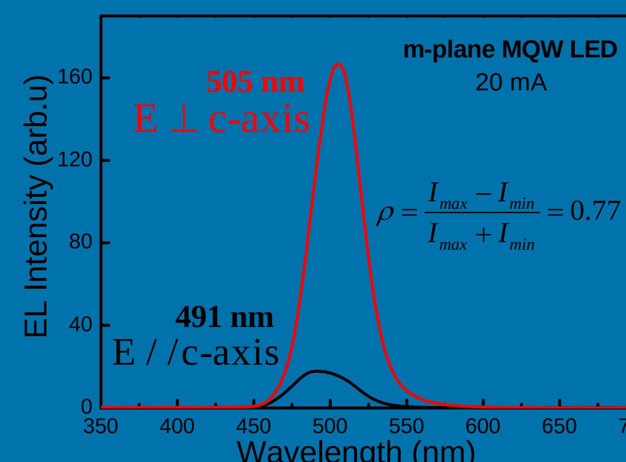
a



External reflector

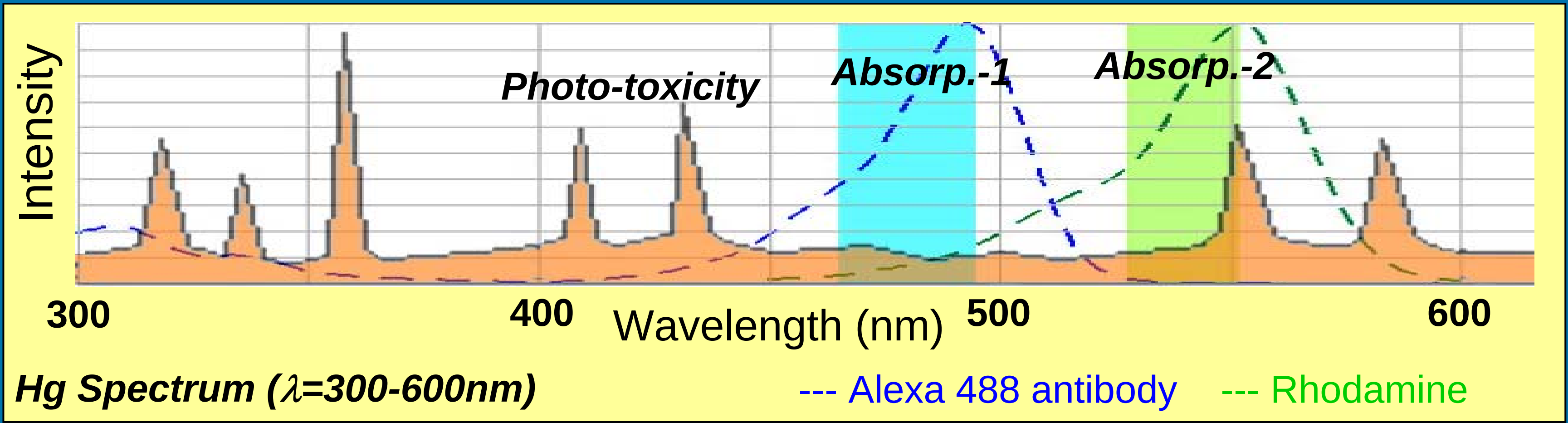


VB Strain Engineering



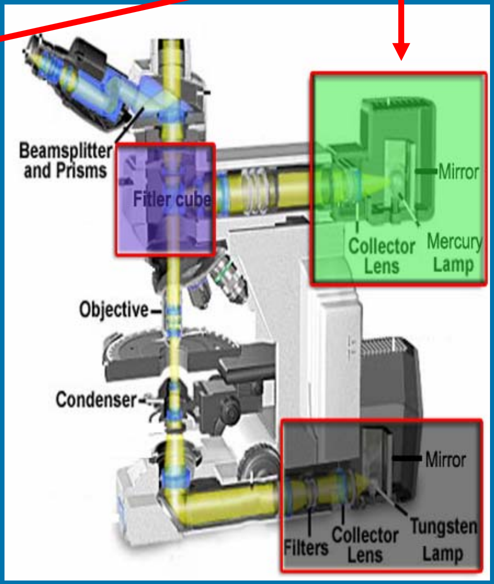
(from C. Wetzel et al.)

For Bio-Imaging Applications, There is a Need for Wavelength and Intensity Control.



LED Advantages:

- λ-selective
- Photo-toxicity
- Compact, low cost
- Full spectral
- Polarization



Approach for Bandwidth-Control and Wavelength-Tuning.

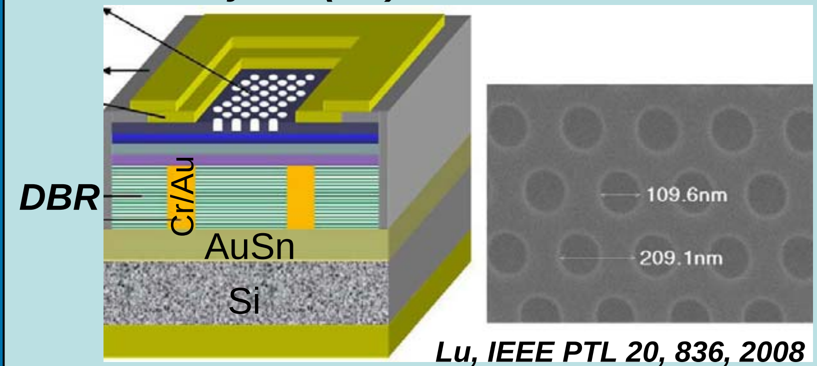
LED Device Grand Challenges (Bio-imaging)

Match LED-λ to fluorophore
Δλ=30nm(desired), Δλ=10nm (ideal)

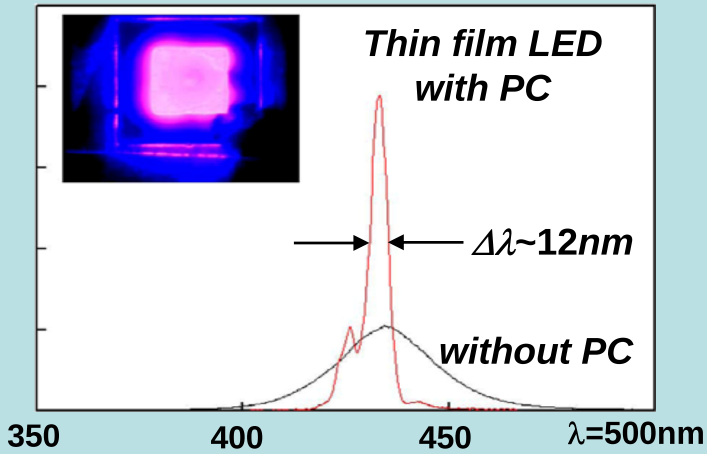
- Dynamic λ-tuning
- Polarized LED
- Collimated emission

	Abso.	Emission	
Y66W	436	485	
mKeima-Red	440	620	monomer (MBL)
TagCFP	**458**	**480**	dimer (Evrogen)
AmCyan1	**458**	**489**	tetramer, (Clontech)
mTFP1	**462**	**492**	dimer
S65A	471	504	
Midoriishi Cyan	472	495	dimer (MBL)
Wild Type GFP	396,475	508	
S65C	479	507	
TurboGFP	482	502	dimer, (Evrogen)
TagGFP	482	505	monomer (Evrogen)
S65L	484	510	
Emerald	487	509	weak dimer, (Invitrogen)

Photonic crystal (PC)



Lu, IEEE PTL 20, 836, 2008



Novel features:

- Engineering of op. modes
- Global resonance, not μ-cavity
- High Intensity
- Narrow Δλ

Next: DBR, tunable

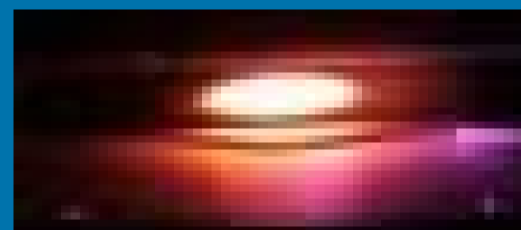
Phosphor Device: Bulk Crystal Growth of Multi-component, Rare Earth Doped Thio-gallate

- Growth of ($Sr_{1-x}Ca_xGa_yIn_{1-y}S$:Eu) from high temperature melt:
- Material selected for comparison with industry results on phosphor LEDs
- Fabricated preliminary ***down-conversion*** structures

(excitation @ 451 nm blue LED)

(emission area in photos : 3cm^2)


Emission Wavelength: 560 nm


Emission Wavelength: 620 nm ***(from D. Partha)***


ARTICLE IN PRESS

Journal of Crystal Growth ▪ (▪▪▪▪) ▪▪▪–▪▪▪

Contents lists available at ScienceDirect

Journal of Crystal Growth

journal homepage: www.elsevier.com/locate/jcrysgro

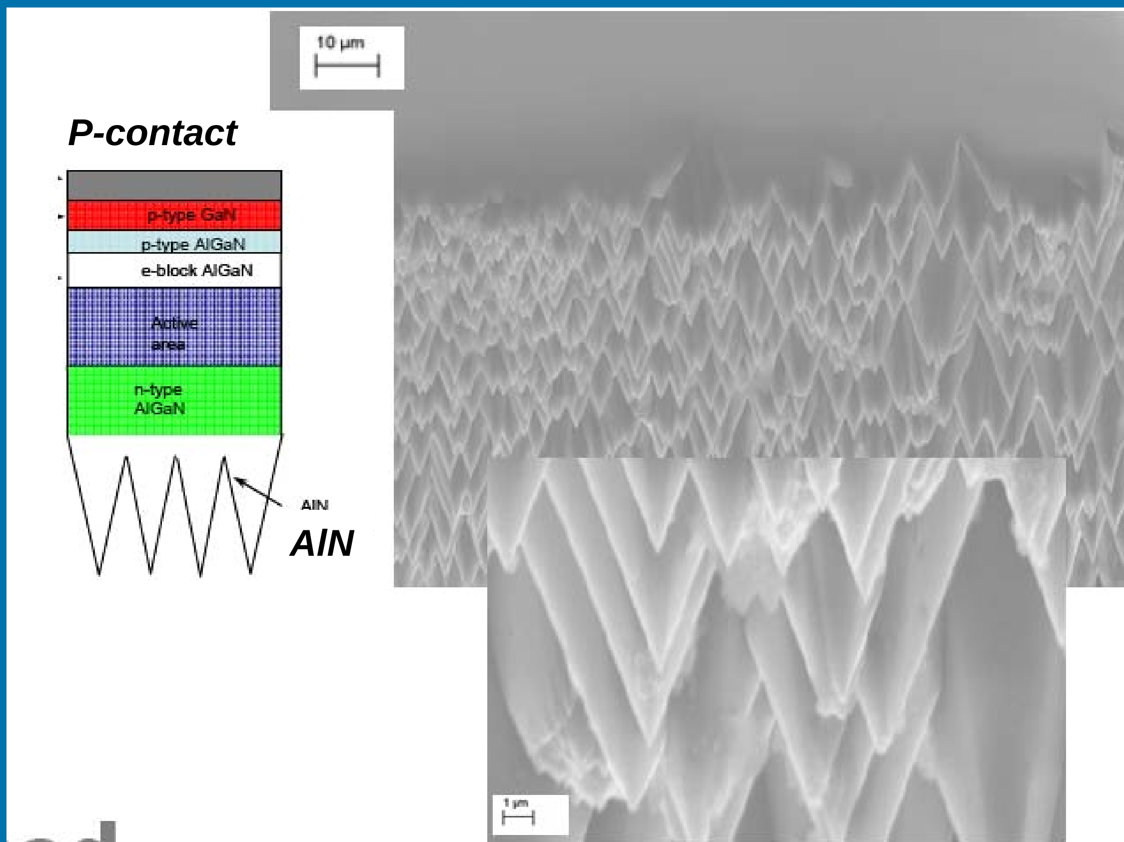
Low temperature growth of $Ga_{1-x}In_xP$ bulk crystals from InSb-rich melt

A. Gennett[a], D. Lewis[a], P.S. Dutta[b,*]

[a] Department of Materials Science and Engineering, Rensselaer Polytechnic Institute, Troy, NY 12180, USA
[b] Department of Electrical, Computer, and Systems Engineering, Rensselaer Polytechnic Institute, Troy, NY 12180, USA

We Have On-going and Active Industrial Collaborations With Our Industrial Partners.

"The biggest problem we face in UV-LED is extraction. We loss 95% of light due to a poor extraction." - Leo Schowalter of Crystal IS



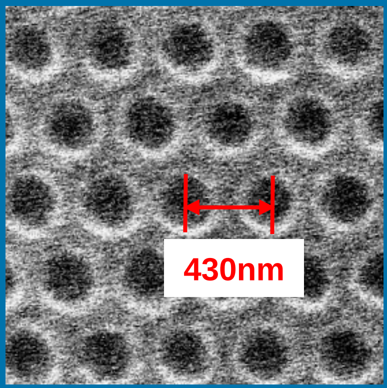
(from Crystal IS)

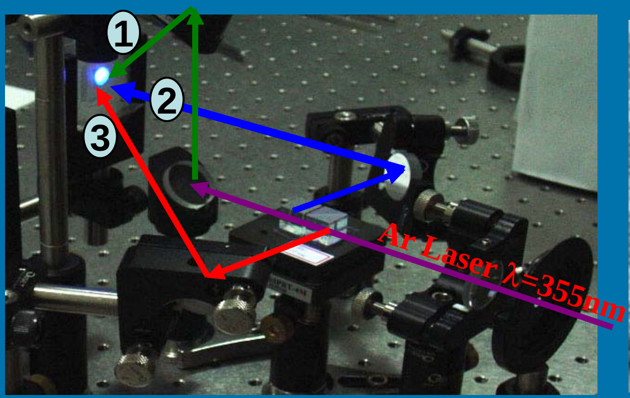
UV-LED Device Grand Challenge

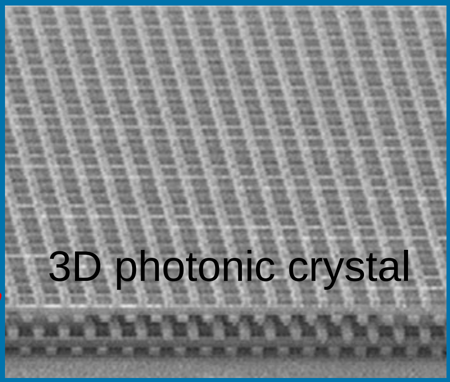
: backside emission/ thick epi-layer/ front absorption

On Fabrication Technology - Large scale and Low cost

Approaches	Feature size	Size Scale	Pro. speed	Comments
e-beam write	<10nm	300 x 300 μm^2	Slow	Expensive
Nano-imprint	50-150nm	5 x 5 cm^2	fast	Molding material
Interferometric lithography* (Steve Brueck/ UNM)**	50-150nm	5 x 5 cm^2	fast	Optics/ 2D pattern
Holographic lithography (RPI)	50-150nm	5 x 5 cm^2	fast	Optics/ 3D pattern







(SY Lin and Prof. M.L. Hsieh, NTNU, Taiwan)

Our team has world renowned expertise in nanofabrication.
Dr. S. Brueck, pioneers the interferometric lithography method.
Dr. S. Y. Lin pioneers the nanofabrication of 2D and 3D photonic crystals.

Thank you!