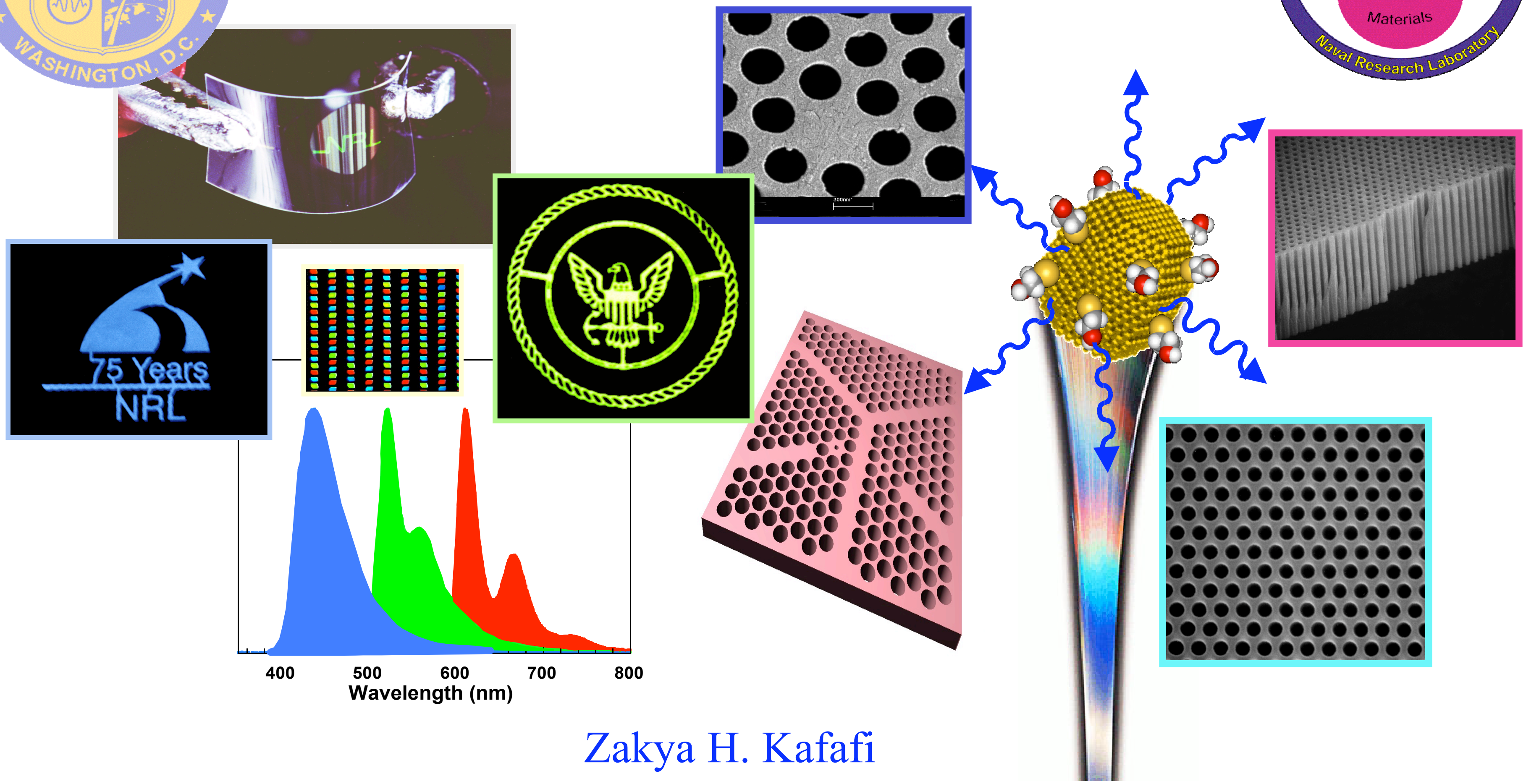
NANOSCIENCE RESEARCH IN OPTICS



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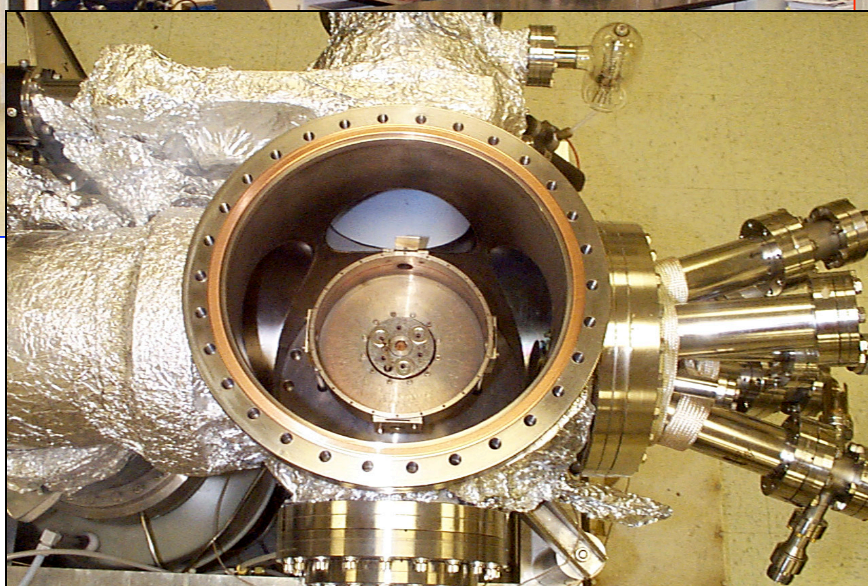
E-mail: kafafi@ccf.nrl.navy.mil

RESEARCH FACILITIES IN OPTICS

Synthetic Chemistry

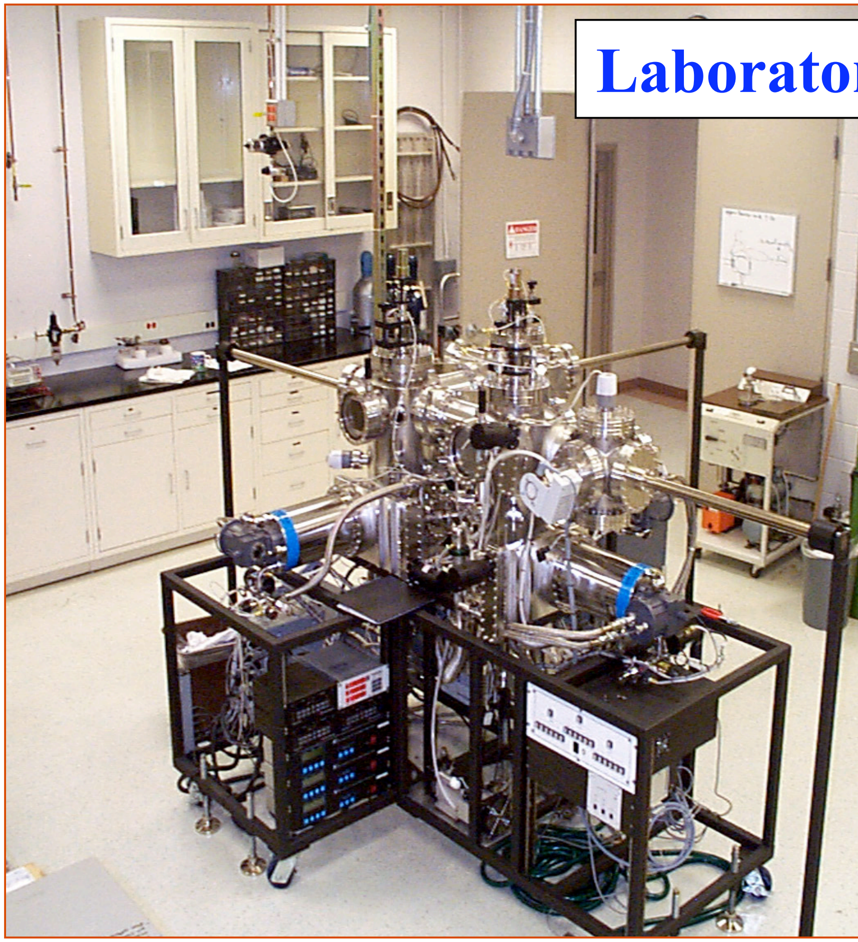
Optical & Device Characterization



Top View of the Multi-surface Vacuum Deposition Apparatus

RESEARCH FACILITIES IN OPTICS

Laboratory for Organic Optoelecronic Devices

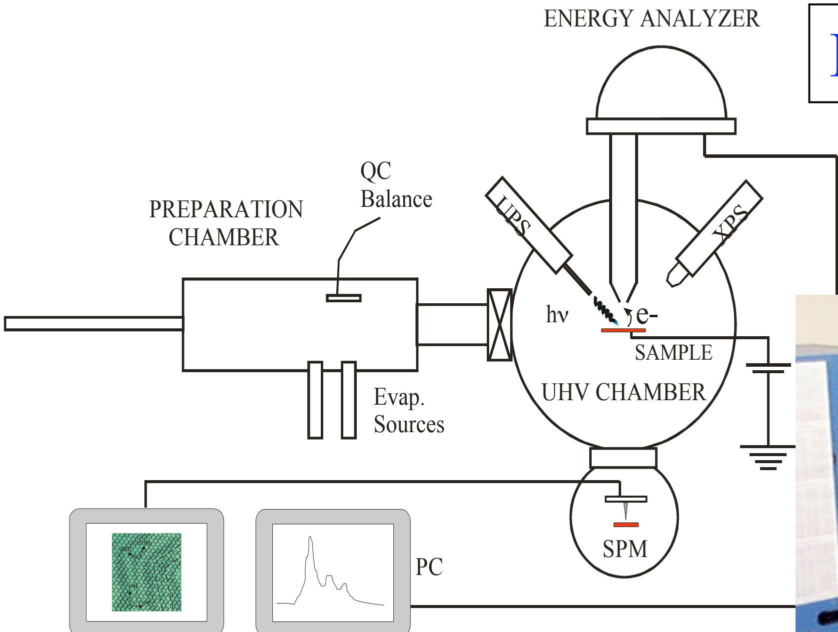


Multi-chamber Vacuum Deposition Apparatus

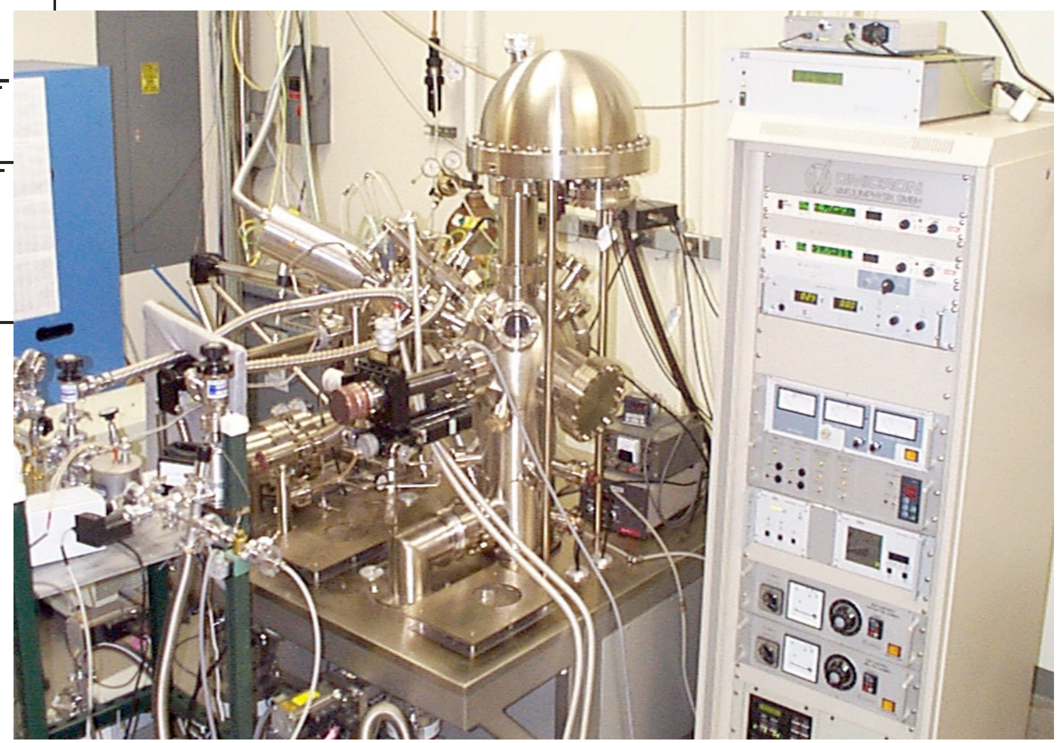
RESEARCH FACILITIES IN OPTICS

Laboratory for Surface Science

UPS / XPS / AFM / STM



Omicron AFM/STM



Omicron Multiprobe XP

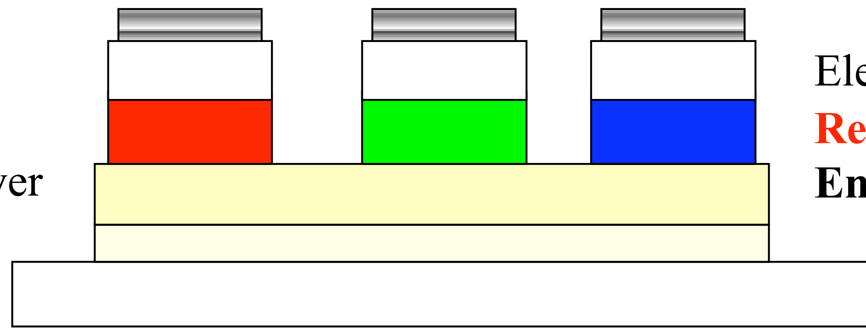
ORGANIC LIGHT-EMITTING MATERIALS & DEVICES

Zakya H. Kafafi
E-mail: kafafi@ccf.nrl.navy.mil

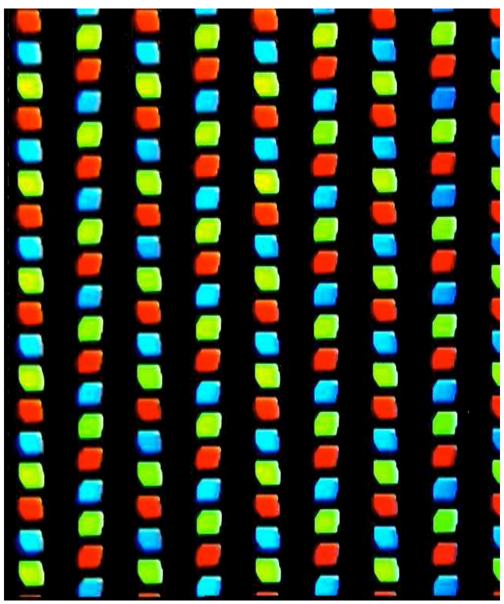
Objective: Develop the science base for thermally-stable, long-living, multi-colored, highly-efficient, organic light-emitting displays

Impact: Command & control centers; maps & battle field simulators; helmet mounted displays; tank & aircraft cockpit displays; portable computers & communications

Organic Light-Emitting Pixel

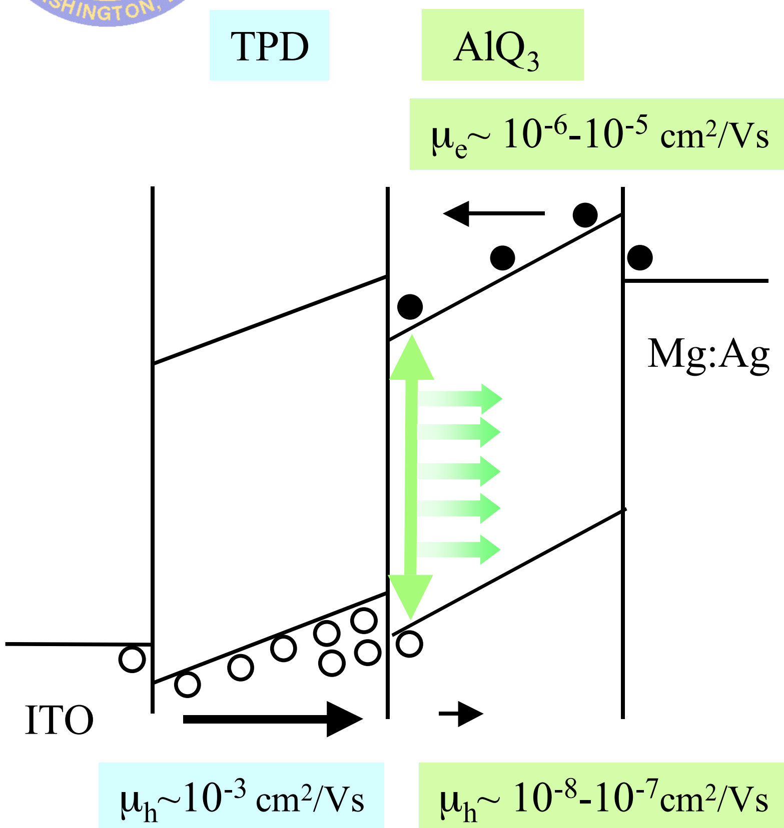


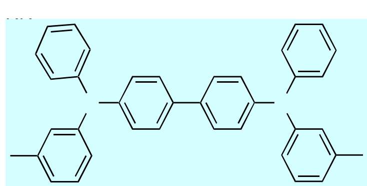
ADVANTAGES

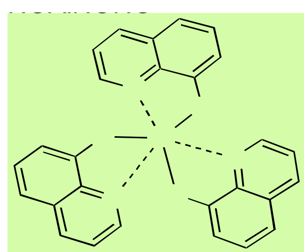


- **Rigid or flexible, thin and very light-weight displays**
- **Self-emissive** ***(no need for high-powered backlight)***
- **Color tunable** ***(achieved by molecular engineering)***
- **Extremely bright displays** ***(not susceptible to sunlight washout)***
- **Sunlight readable and dimmable for night vision**
- **High durability** ***(lifetime >10,000 hrs @ 300 cd/m^2)***
- **Wide operating temperature** ***(-150 ºC to 200 ºC)*** **range**
- **Excellent viewing angle** ***(>170° with no loss in brightness)***
- **High resolution** ***(pixel size as small as 12 µm or smaller)***

Control Device based on TPD/Alq_3 Heterostructure







Important Issues

- **Efficient electron injection**
- **Improved electron transport**
- **High solid state PL quantum yield**

$$\eta_{EL} = \alpha\, \gamma\, \eta_r\, \phi_{PL}$$

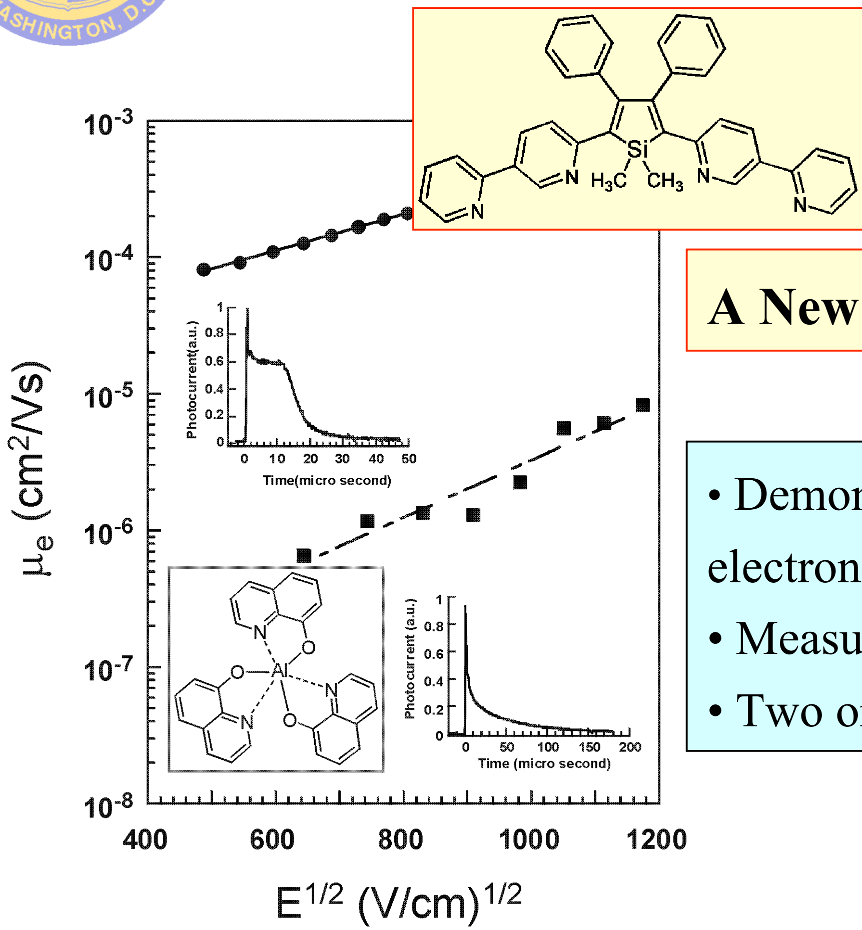
α: Light output coupling factor ~ $1/2n^2$

γ: Probability of carrier recombination

η_r: Production efficiency of excitons

ϕ_{PL}: Photoluminescence quantum yield

Novel Electron Transporters Based on Silole Derivatives



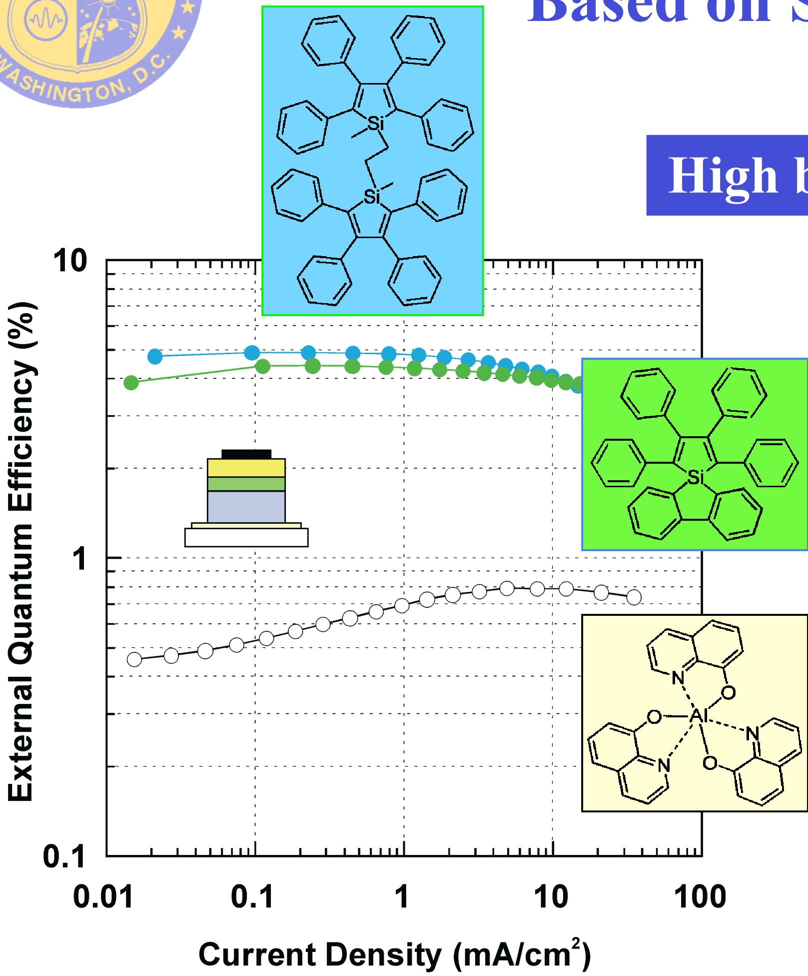
A New *Air-Stable* Electron Transport Material

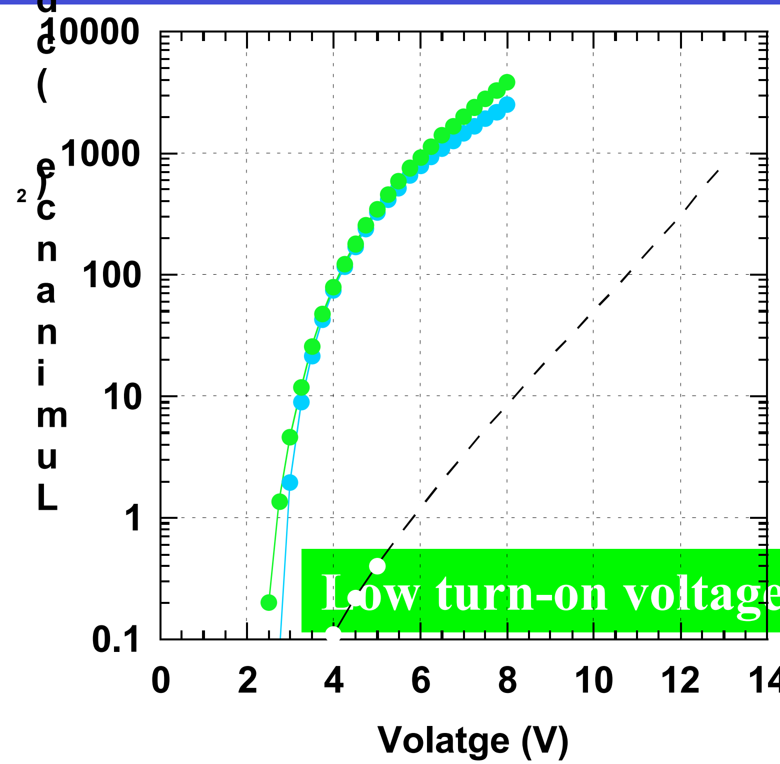
- Demonstrated non-dispersive "trap-free" and fast electron transport
- Measured high electron mobility in air
- Two orders of magnitude larger than that of Alq_3

Murata, Malliaras, Uchida, Shen, Kafafi, Chem. Phys. Lett. 339, 161 (2001)

Highly-Efficient Electroluminescent Devices Based on Silole Derivatives

High brightness (4000 cd/m²) at low voltage (8V)



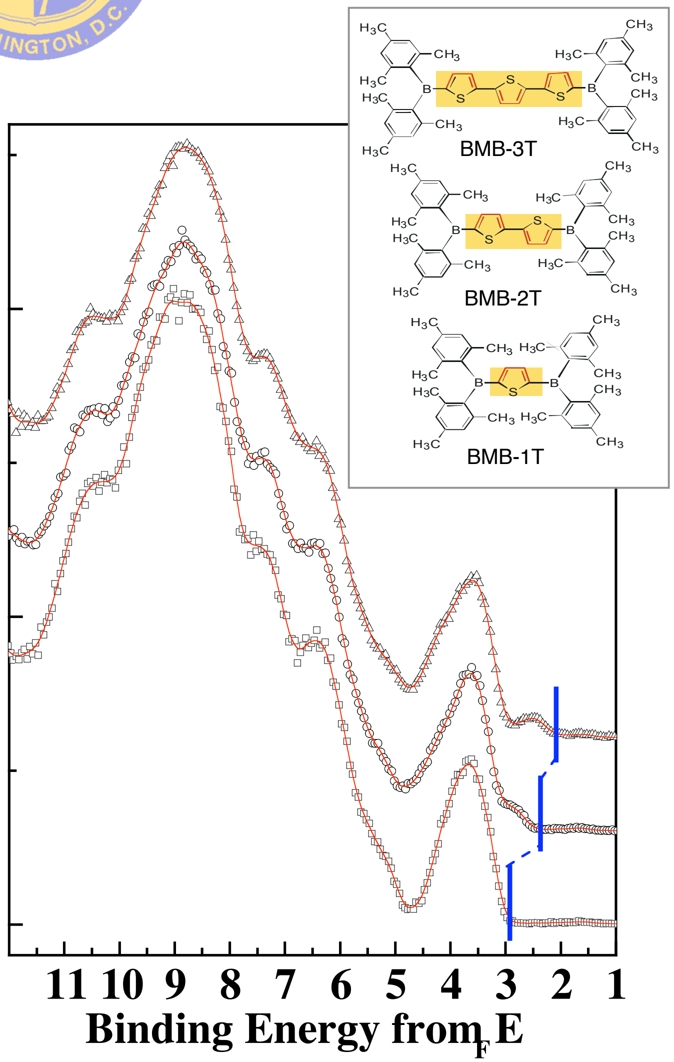


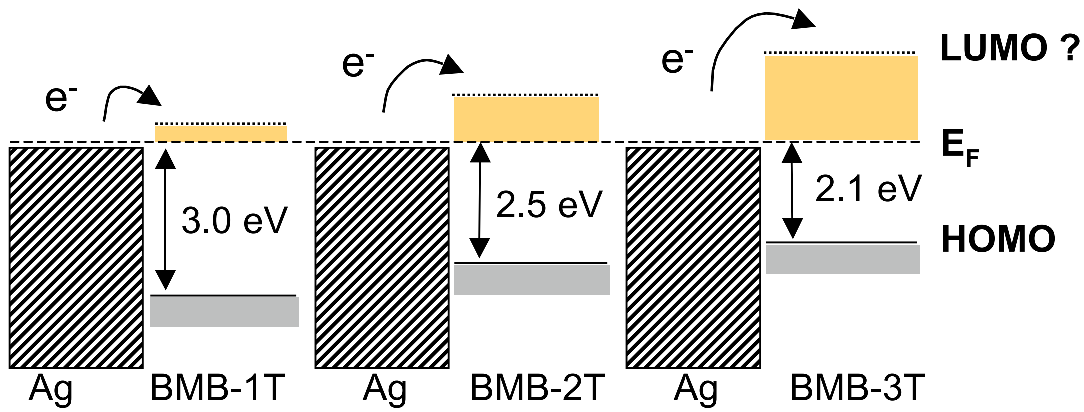
Low turn-on voltage (2.5V)

EL quantum efficiency close to the theoretical limit!

Murata, Uchida, Kafafi, Appl. Phys. Lett. 80, xx (2002)

Energy Levels Alignment at Metal/BMB-nT Interfaces



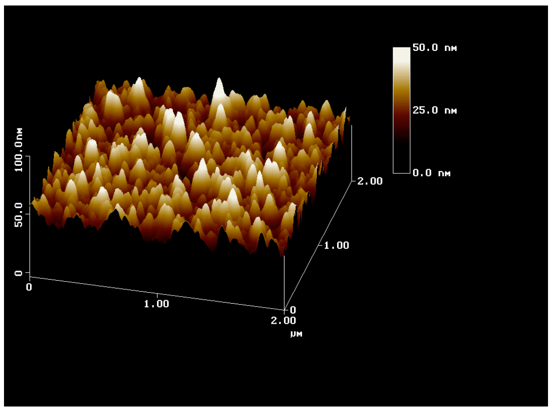
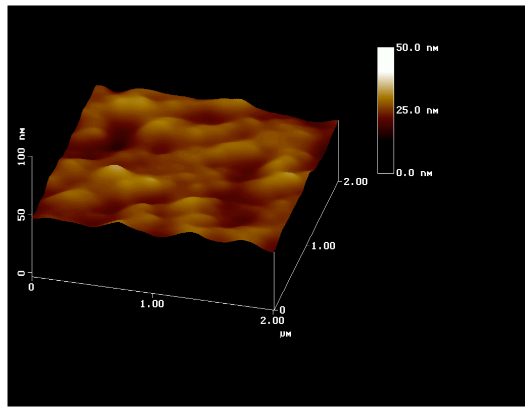
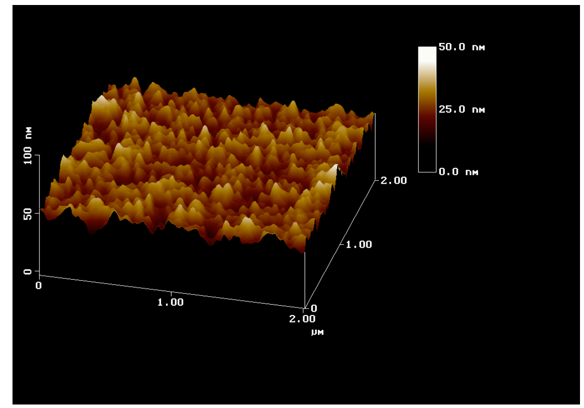


- Determined barriers to hole (E_{h+}) injection
- Estimated barrier to electron (E_{e-}) injection
- Showed that E_{h+} decreases and E_{e-} increases as a function of the π electron delocalization length (number of thiophene rings)

BMB-1T is the best electron transporter

Mäkinen, Shirota, Kafafi, et al. Appl. Phys. Lett. 78, 670 (2001)

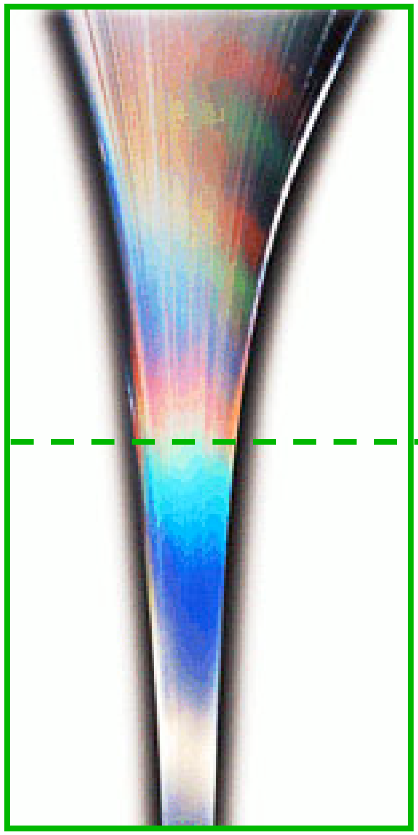
AFM Pictures of Transparent Electrodes Grown by PLD on Plastics

Bare PET	ITO on PET	AZO on PET
		
• RMS roughness: 8-10 nm	• RMS roughness: 2-3 nm • Transmission: 80% • Work function: 4.5 eV	• RMS roughness: 3 nm • Transmission: 80% • Work function: 4.0 eV

- **PLD TCO films planarize substrate and reduce surface roughness**
- **AZO is a good candidate for transparent cathode due to low WF**

H. Kim *et al.*, APL 79, 284 (2001)

2D Photonic Crystals



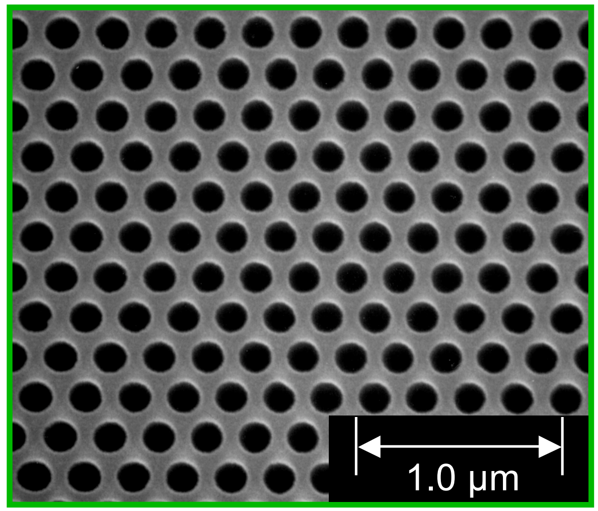
A composite glass material:

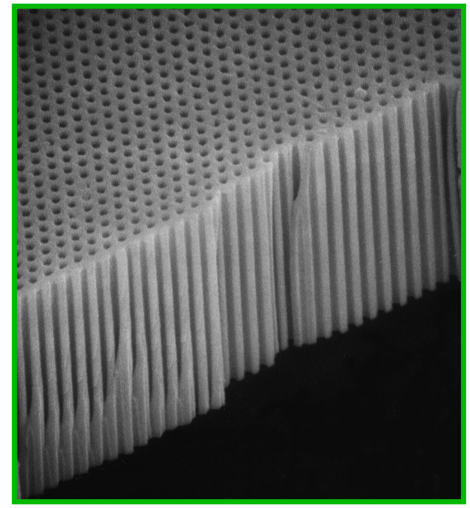
fabricated as a regular array of glass cylinders in a glass matrix

after wet etch: array of holes in a glass matrix

length scale of array is ~λ of light

⇨ ***Prototypical 2D photonic crystal***





R.J. Tonucci, B.L. Justus, A.J. Campillo, and C.E. Ford, Science ***258****, 783 (1992)*

Typical for this composite glass:

- Hole diameter: ~5 µm to ~30 nm
- Triangular lattice, a~3r
- ~10^7 elements in a wafer

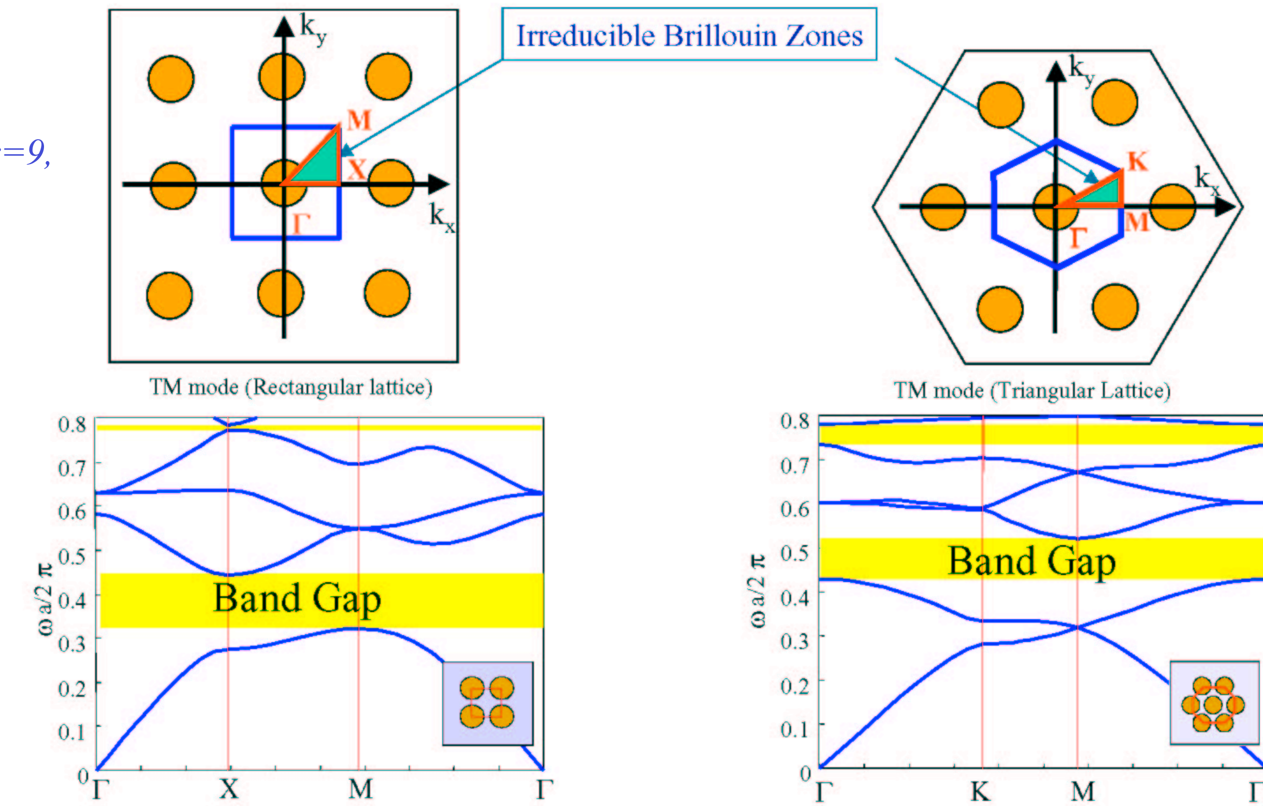
Photonic Band Gap Materials

Armand Rosenberg
NRL Code 5613
202-767-9522

2D Photonic Band Structure

Examples

holes in ε=9, r=0.2a



holes in ε=13, r=0.5a

Objective: decoupling of the electronic and optical properties…

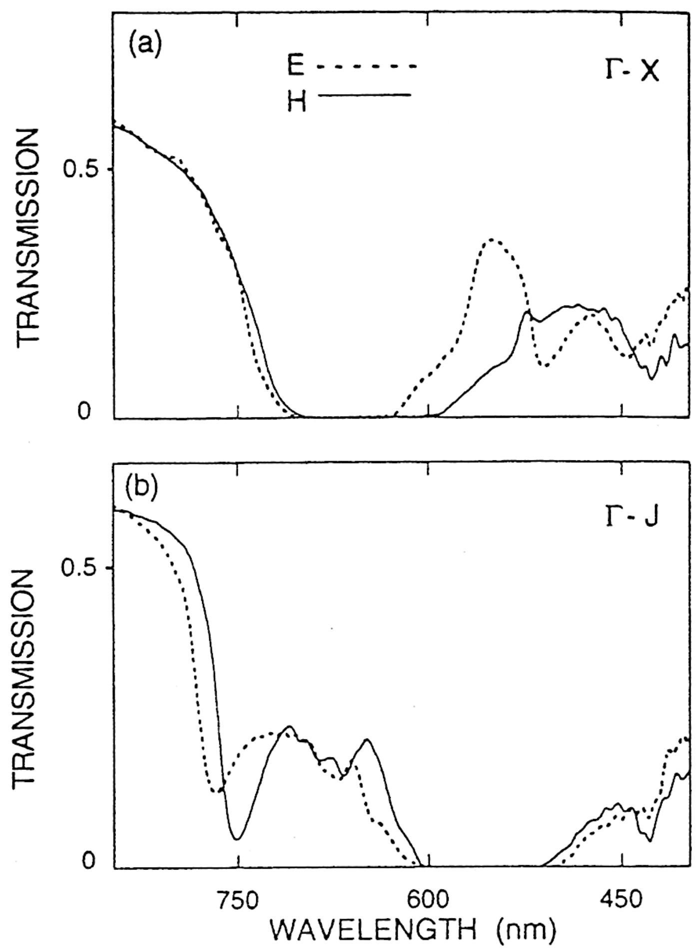
- Electronic band structure arises from the intrinsic material properties [*scale: ~1 Å*]
- Photonic band structure arises from structural control (patterning) of the material [*scale: ~λ of light*]

⇨ combinations of optical/electrical properties unavailable in nature

Observation of 2D Photonic Band Structure

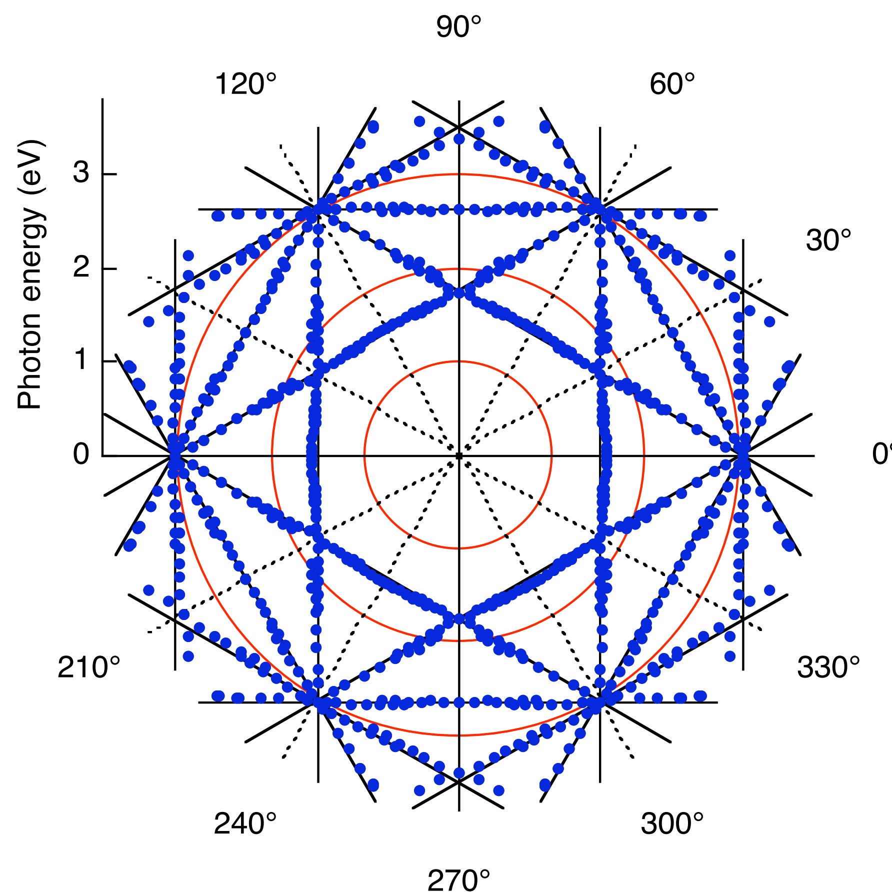
First experimental demonstration of 2D photonic band gap effects in the visible/near-IR based on NRL's composite glass

a = 220 nm , Δn ≈ 0.45



H.B. Lin et al., Appl. Phys. Lett. ***68****, 2927 (1996)*

a = 280 nm, Δn ≈ 0.02



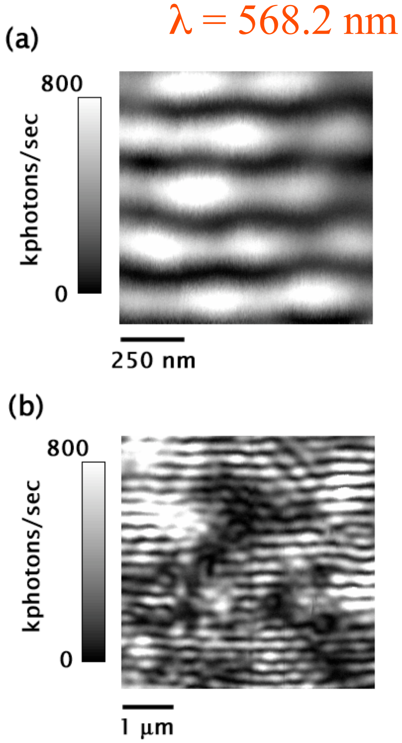
A. Rosenberg et al., Appl. Phys. Lett. ***69****, 2638 (1996)*

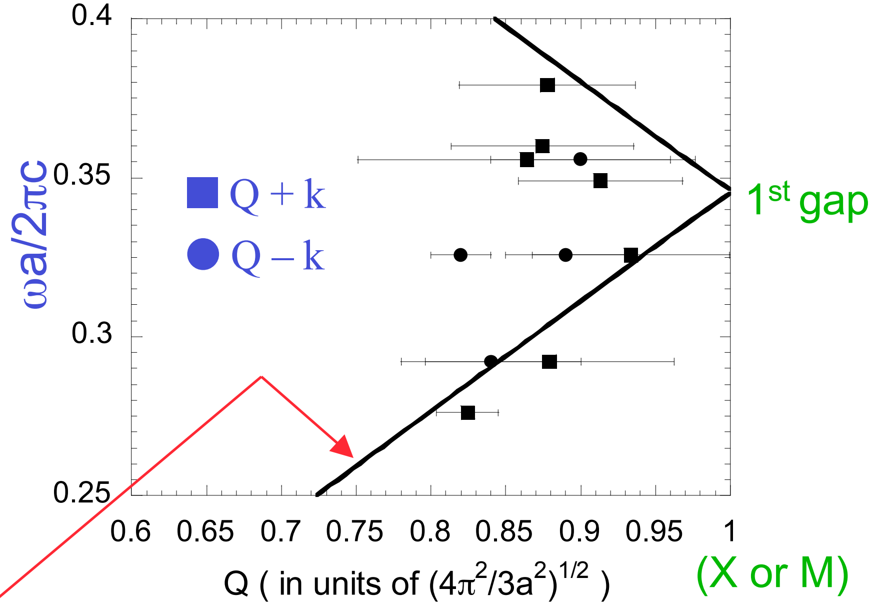
NSOM Studies of PBG Properties

First direct mapping of the spatial distribution of optical intensity within a 2D PBG structure based on NRL's composite glass

- NSOM probes the evanescent field of light propagating in a 2D PBG structure
- Results below are for glass cylinders in a glass matrix (small index contrast)
- Probe tip perturbs field at higher index contrast

λ = 568.2 nm





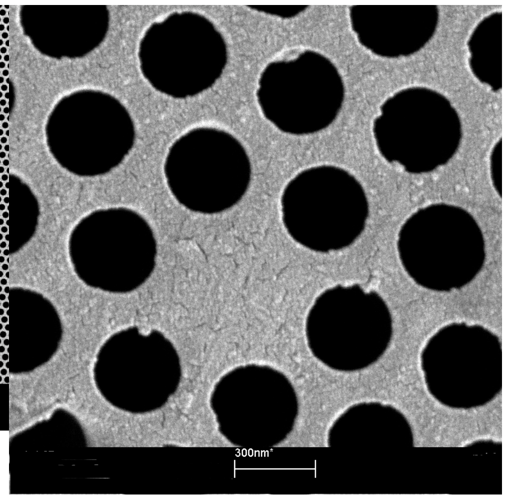
Calculation: n_{cyl}=1.68, n_{matrix}=1.66, a=185 nm, d_{cyl}=135 nm
no adjustable parameters

A.L. Campillo et al., J. Appl. Phys. ***89****, 2801 (2001)*

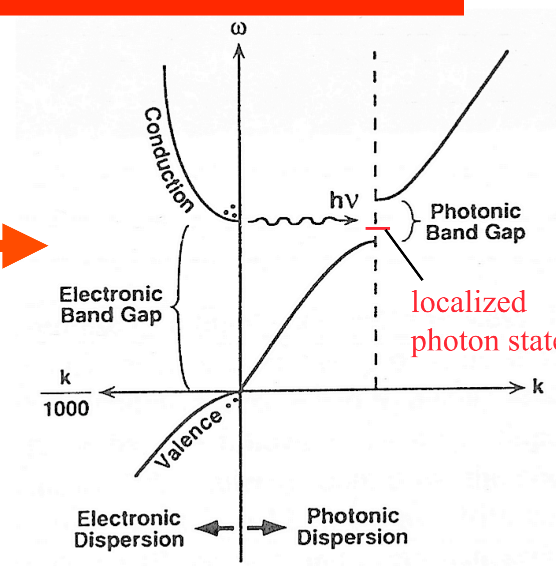
PBG Optoelectronic Components

Objective: Demonstrate miniaturized optoelectronic devices based on PBG components

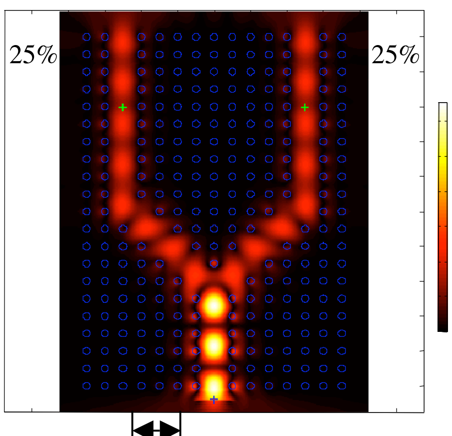
PBG Cavity



~300 nm holes

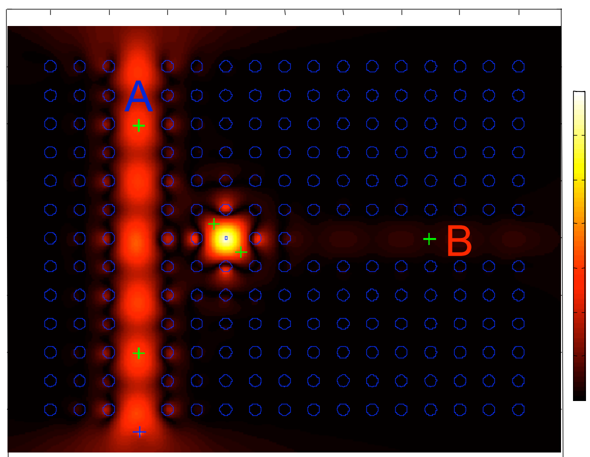


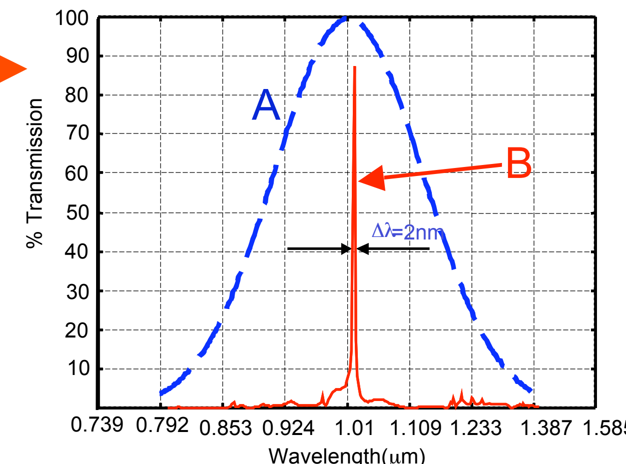
PBG Channel Waveguides with Sharp Bends (Splitter)



scale: ~λ

PBG Cavity + Channels (Add/Drop Filter)





A. Sharkawy, S.Shi, D.W. Prather, Applied Optics , ***40****, 2247 (2001)*

Future PBG Optoelectronic Devices based on GaN

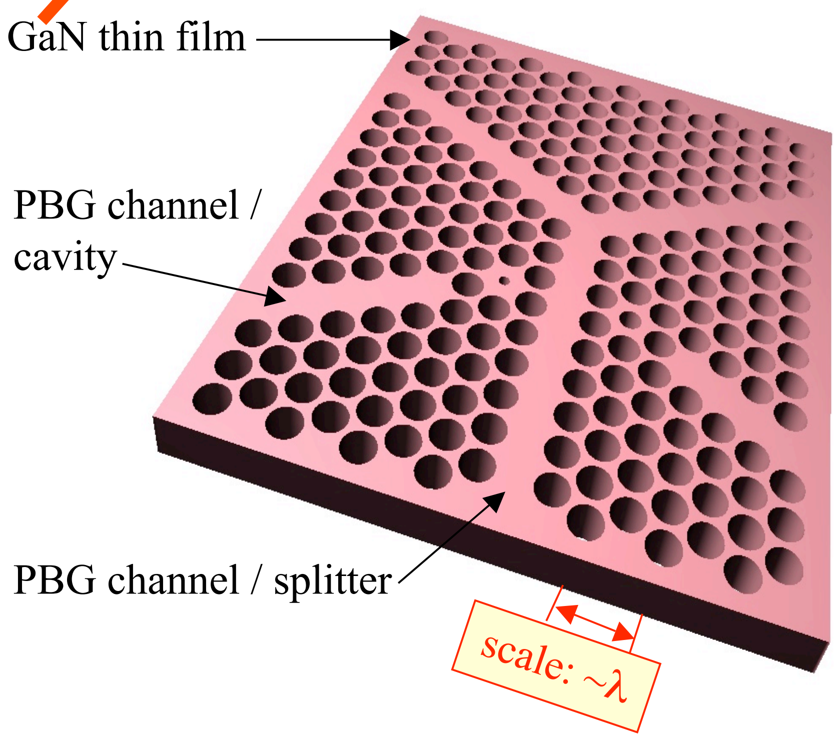
GaN is a “new” material: requires process development

Approach: Fabricate 2D PBG patterns in wide-band semiconductor planar waveguide

Initial goal: Demonstration of PBG components in GaN

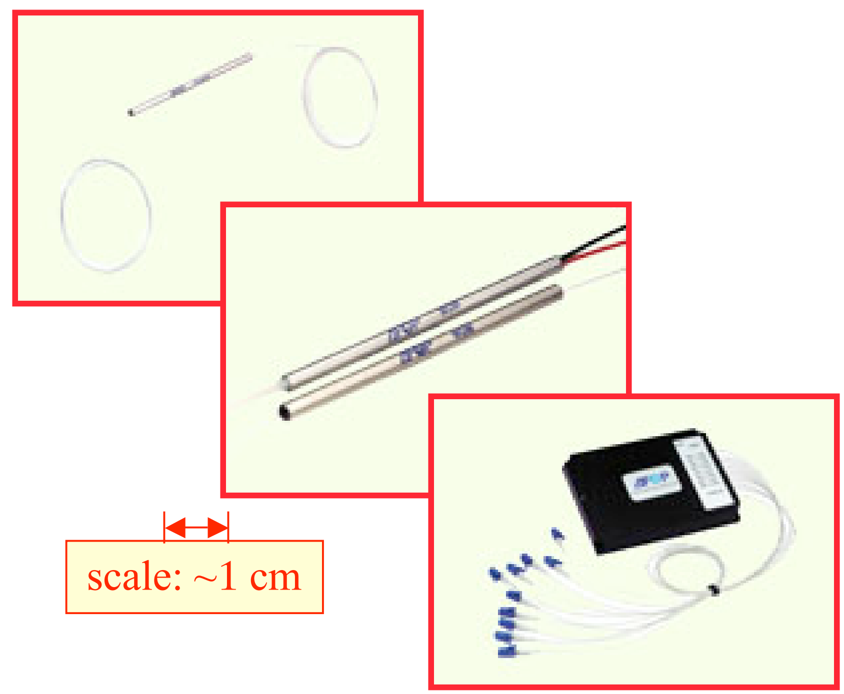
One of the highest refractive indices in a material that is transparent throughout the visible and infrared

Future PBG Device



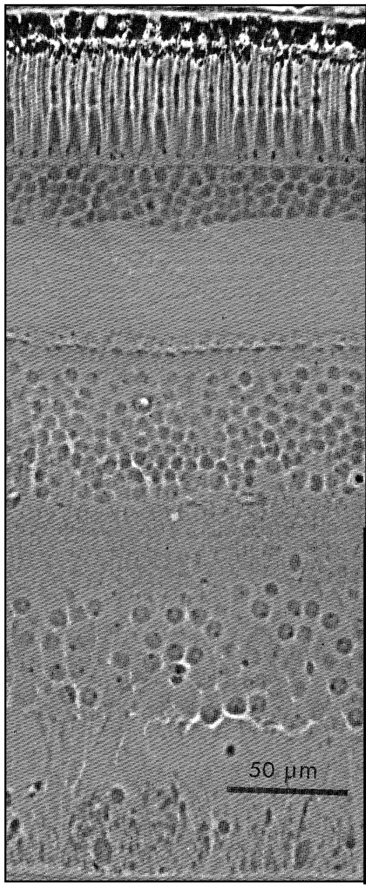
“vs”

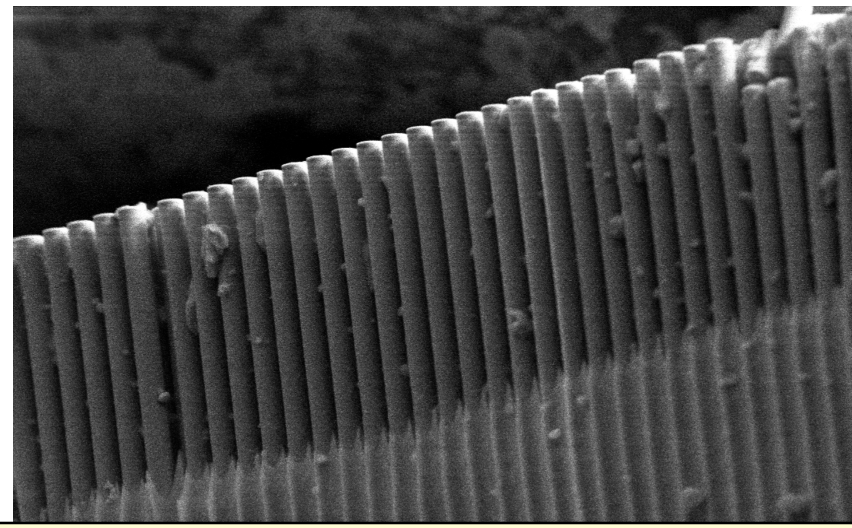
Current Devices



Neural-Electronic Interfaces

Principal Investigator: Dean Scribner (scribner@nrl.navy.mil)
co-PI: Brian Justus (justus@nrl.navy.mil)





Objectives:

- **Develop a large, dense bio-electronic interface array for communicating with neural tissue**
- **Learn how biological tissue processes information on a massive, parallel scale**

Nanochannel Glass Microelectrode Arrays

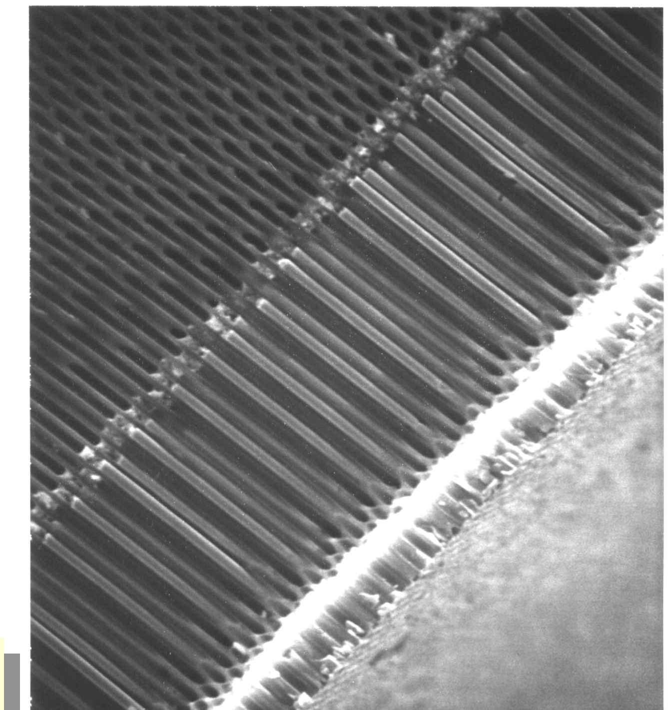
Nano-channel glass technology enables connections to millions of neurons

Advantages:

- **Compatible with biological tissue**
- **Conformable to curvature of any neural surface**
- **Uniform array of millions of metal electrodes**
- **Micro-nanometer scale spatial resolution**

Current features:

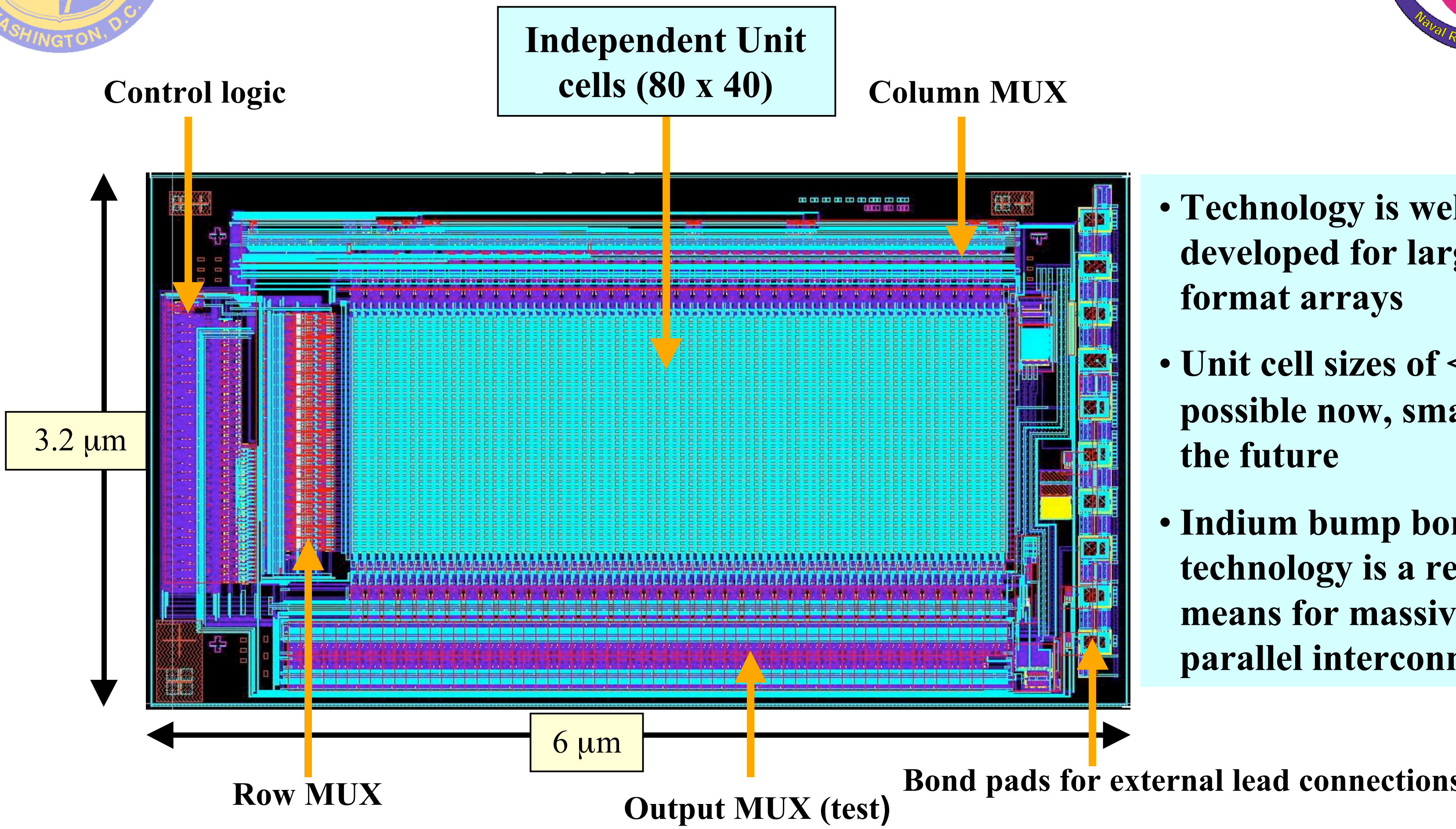
- **Small electrodes (D = 5.5 μm)**
- **Large array area (> 1 cm^2)**
- **No channel cross-talk**



Electro-deposited Pt wires

NRL Nano-channel glass technology is capable of providing large, parallel arrays of small, high aspect ratio conductors

2-D Multiplexer Arrays



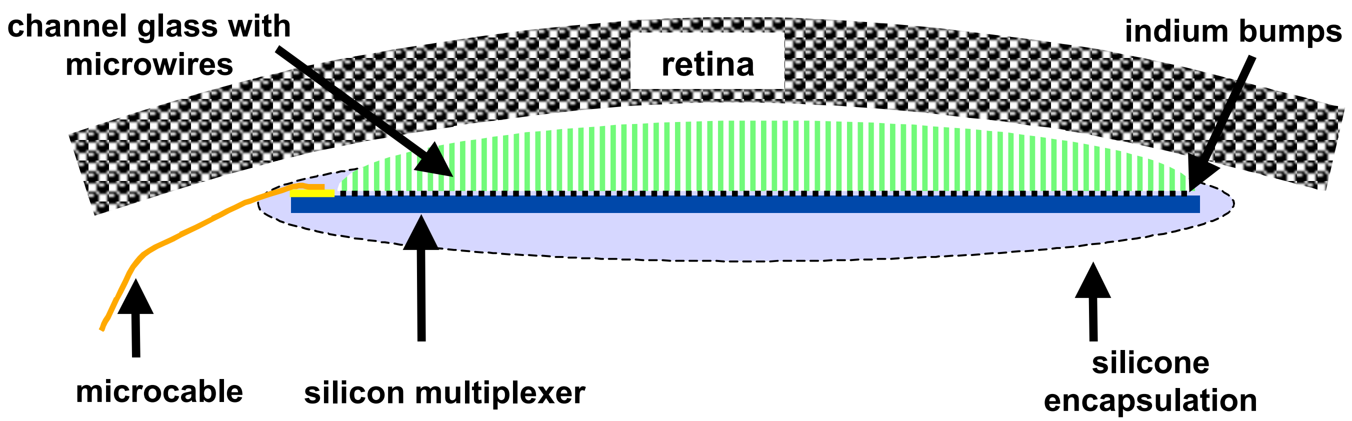
- Technology is well developed for large 2-D format arrays
- Unit cell sizes of <15 μm possible now, smaller in the future
- Indium bump bond technology is a reliable means for massive parallel interconnections

Multiplexer connects thousands of neural sites to outside world via a handful of external leads

A Model Neural-Electronic Interface: Artificial Retinal Stimulation

Ultimate goal is to restore visual capabilities to patients with retinitis pigmentosa and macular degeneration affecting >10 million people in U.S.

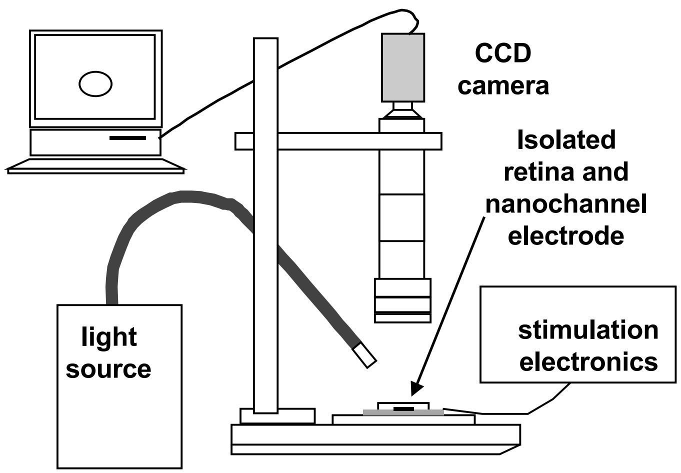
The nanochannel glass will allow for a curved surface with low impedance



Combining nano-channel glass and silicon multiplexer technologies provides a powerful new approach for simultaneously addressing thousands of neurons

Neural Computation in Biological Systems

What Can we Learn & Apply to Navy Sensors?



A retinal imaging system

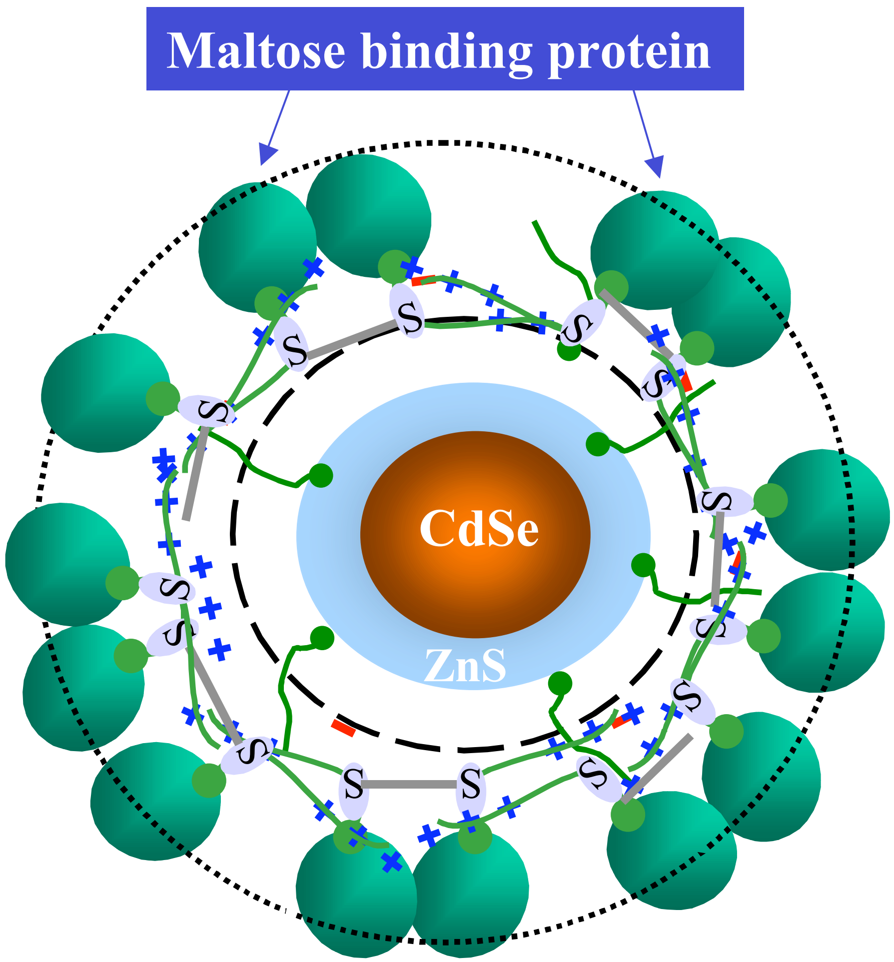
The areas of the retina stimulated by the electrode will appear as regions of increased brightness

A movie of electrical potential changes. After mechanical stimulation (arrow) the system detects a change in the retina light scatter. In this example a "wave" of potential change moves across the retina.

Biologically Conjugated Luminescent Quantum Dots

Hedi Mattoussi and Brian Justus

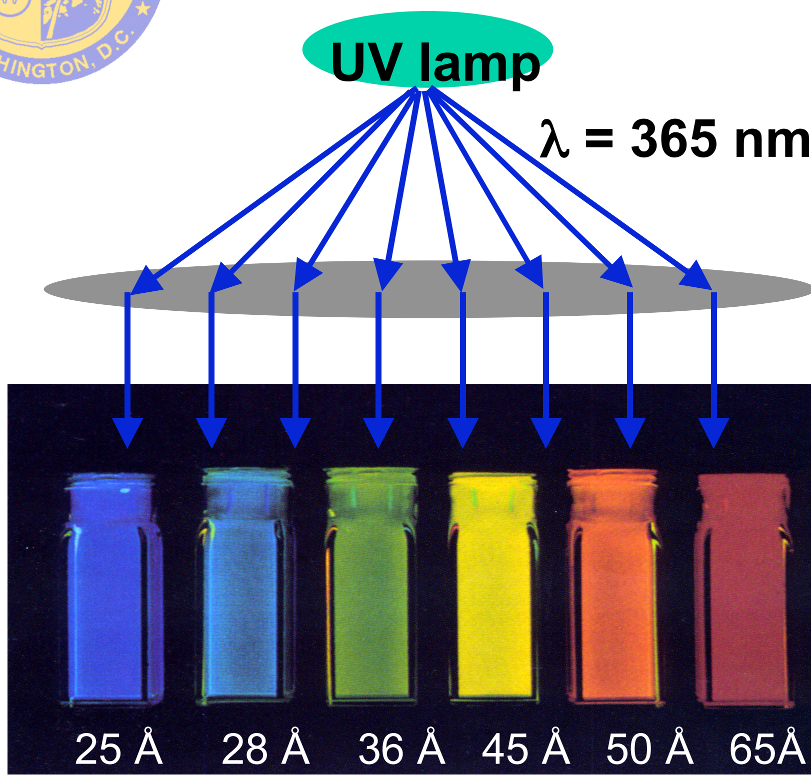
Phone: 202-767-9473; Email: hedimat@ccs.nrl.navy.mil



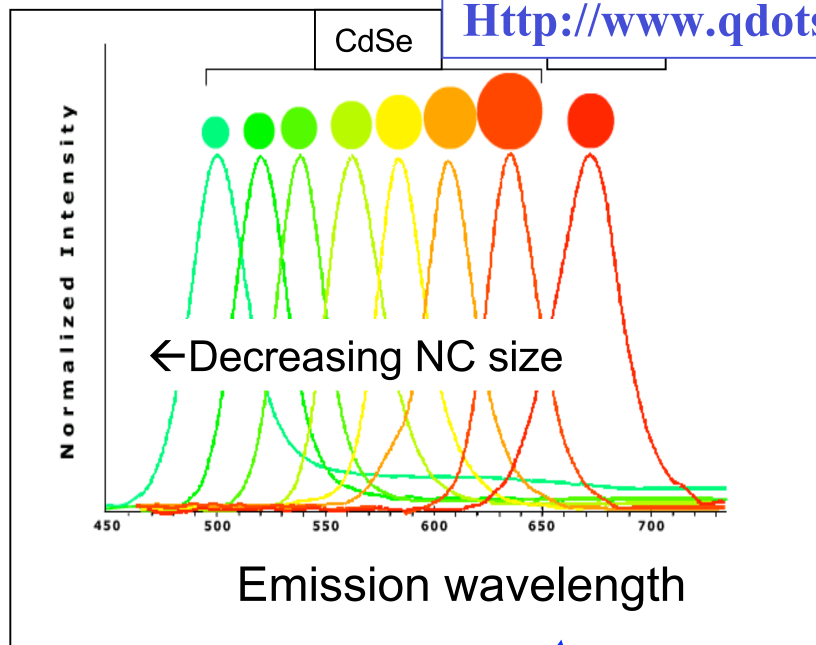
Objectives:

- Develop novel semiconducting nanocrystals that are both luminescent and biologically active
- Develop ultrasensitive detection of chemical and biological materials via these luminescent quantum dot bioconjugates.

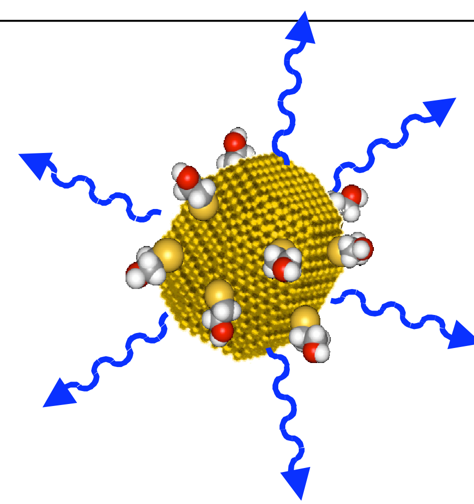
Luminescent Nanocrystalline Particles



Http://www.qdots.com



- Control of nanocrystal size
- Solution phase synthesis
- Size selective precipitation
- Capping layers
- Tunable band gaps



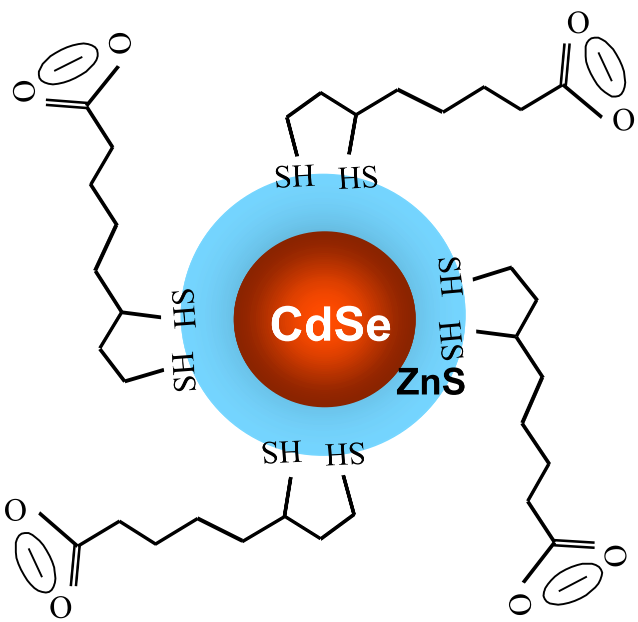
B.O. Dabbousi, et al., *J. Phys. Chem.* **101**, 9463 (1997)

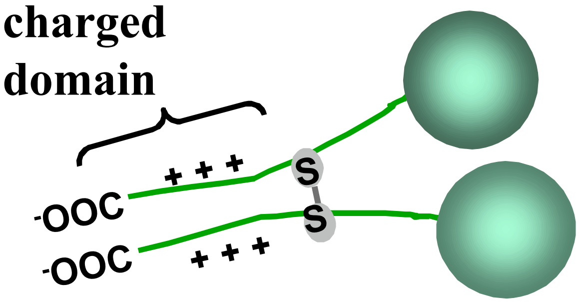
Electrostatically Driven Self-Assembly of Quantum Dot Bioconjugates

Electrostatic attraction

Negatively charged, lipoic acid-capped nanocrystal

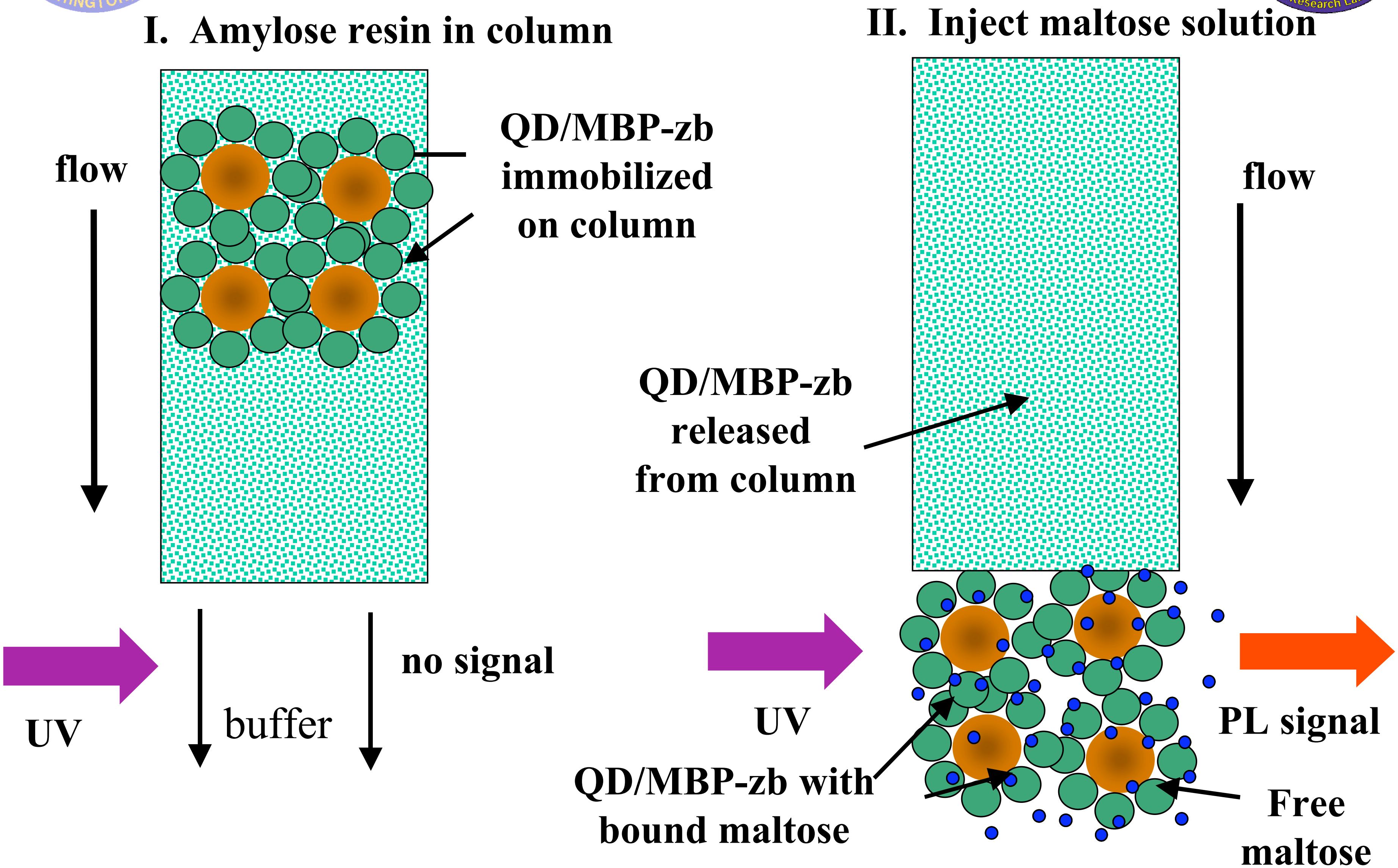
Positively charged, 2 domain protein



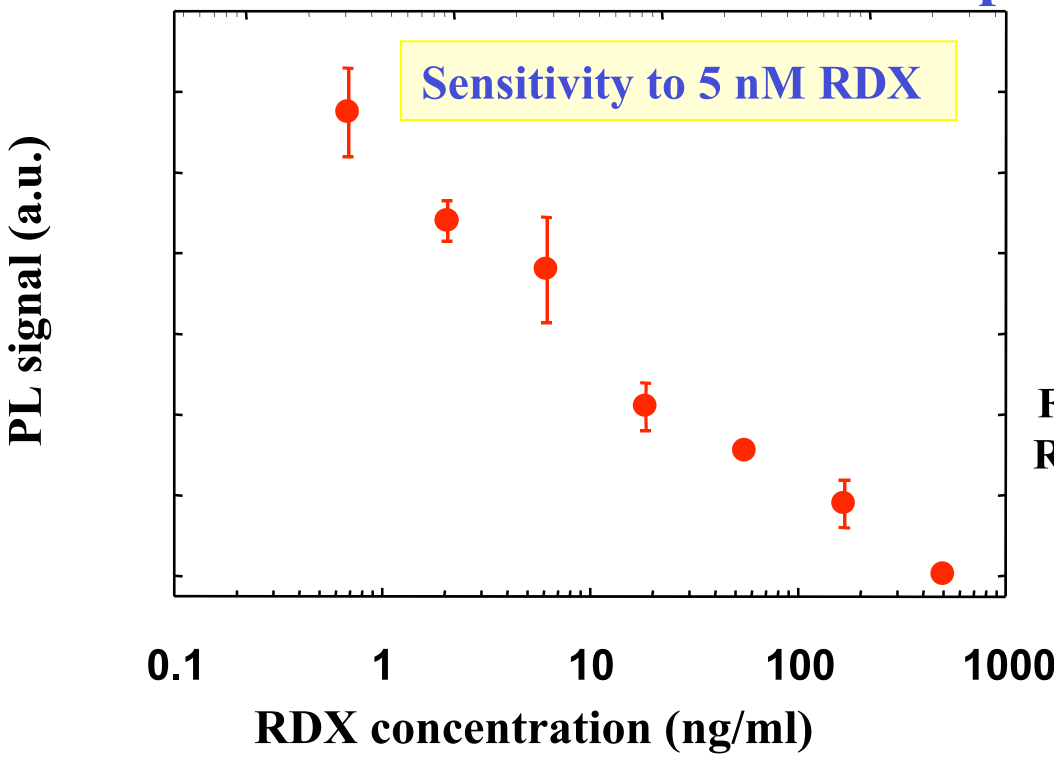


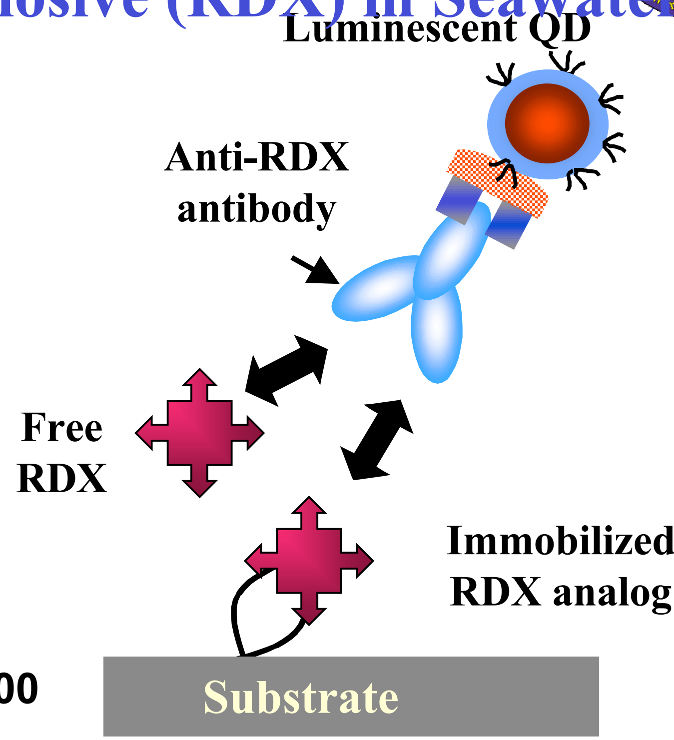
H. Mattoussi et al. *J. Am. Chem. Soc.*, 122, 12142 (2000)

Maltose binding protein (MBP): Fluorescence assay for maltose



Detection of Trace Levels of Explosive (RDX) in Seawater



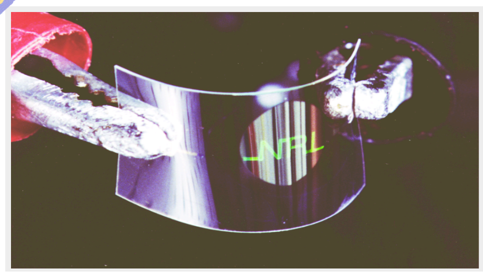


Competition Assay

- Prepare QDs conjugated with anti-RDX antibodies
- Measure PL of QD-bioconjugates bound to a surface prepared with RDX analogs
- Free RDX competes for bioconjugate and reduces PL signal

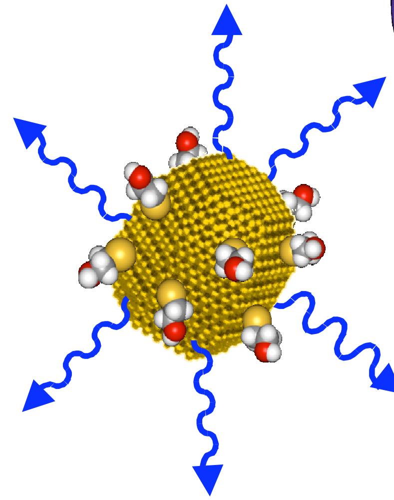
E. R. Goldman, in press, *Analytical Chemistry* (2001)

NANOSCIENCE RESEARCH IN OPTICS



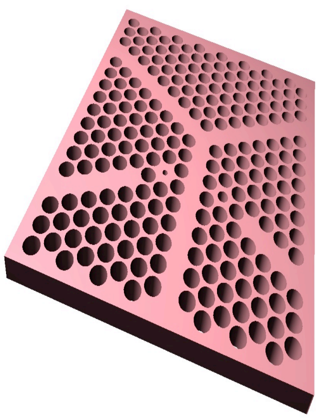
Organic Light-Emittting Materials & Devices

Zakya Kafafi
(kafafi@ccf.nrl.navy.mil)



Biologically Conjugated Luminescent Qdots

Hedi Mattoussi (hedimat@ccs.nrl.navy.mil)
Brian Justus (justus@nrl.navy.mil)



2D Photonic Crystals

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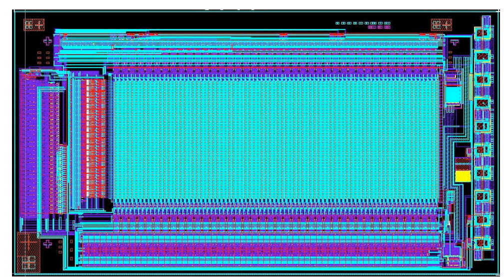

Neural Electronic Interfaces

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