# Lensless Microscopy Enabled by Nanowire LEDs

## (Project SPA1.2: started Sept 2009)

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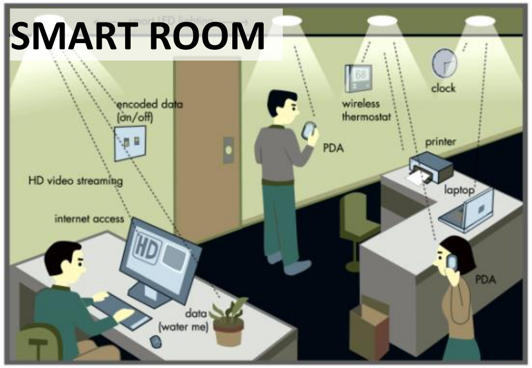
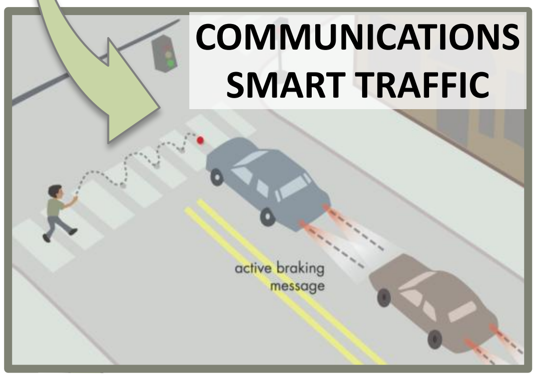
# OUTLINE

- **The Future of Smart Light**
- **Live-cell imaging for drug discovery**
- **The Lensless Microscope project (SPA1.2)**
  - **How to miniaturize a microscope**
  - **Objectives and Timing**
  - **Progress**
- **Concluding remarks**

# The Future of Smart Light Systems




PORTABLE SMART LIGHT SYSTEMS

**ERC Smart Light Systems:**
**Increased Functionality of Light, Health, Communications, Energy Savings**

**Initial deployment, fixed systems in Smart Rooms**

**Some of these Smart Light Systems will be miniaturized and ruggedized, and deployed in Smart Traffic or PORTABLE applications**

**Portable BIO-IMAGING and BIO-SENSOR Systems will be needed in future**

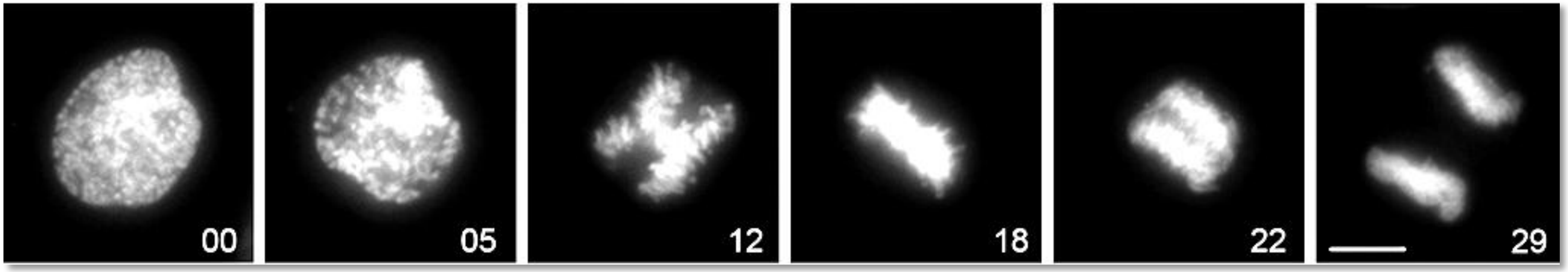
**Portable Health Monitoring:**

- Air/Water monitoring for bio-hazards
- Light intensity & spectrum monitor and correction
- Blood oxygenation, heart rate, Live-cell imaging

**Lensless Microscope Project SPA1.2**

# Bio-Imaging Thrust – Live Cell Imaging

**Key Technical Problem:** During live-cell imaging (example cell mitosis), the light typically used mercury lamp illumination can kill cells (phototoxicity) and stop mitosis. This limits usefulness of bio-microscopy for drug discovery.




**ERC SOLUTION**

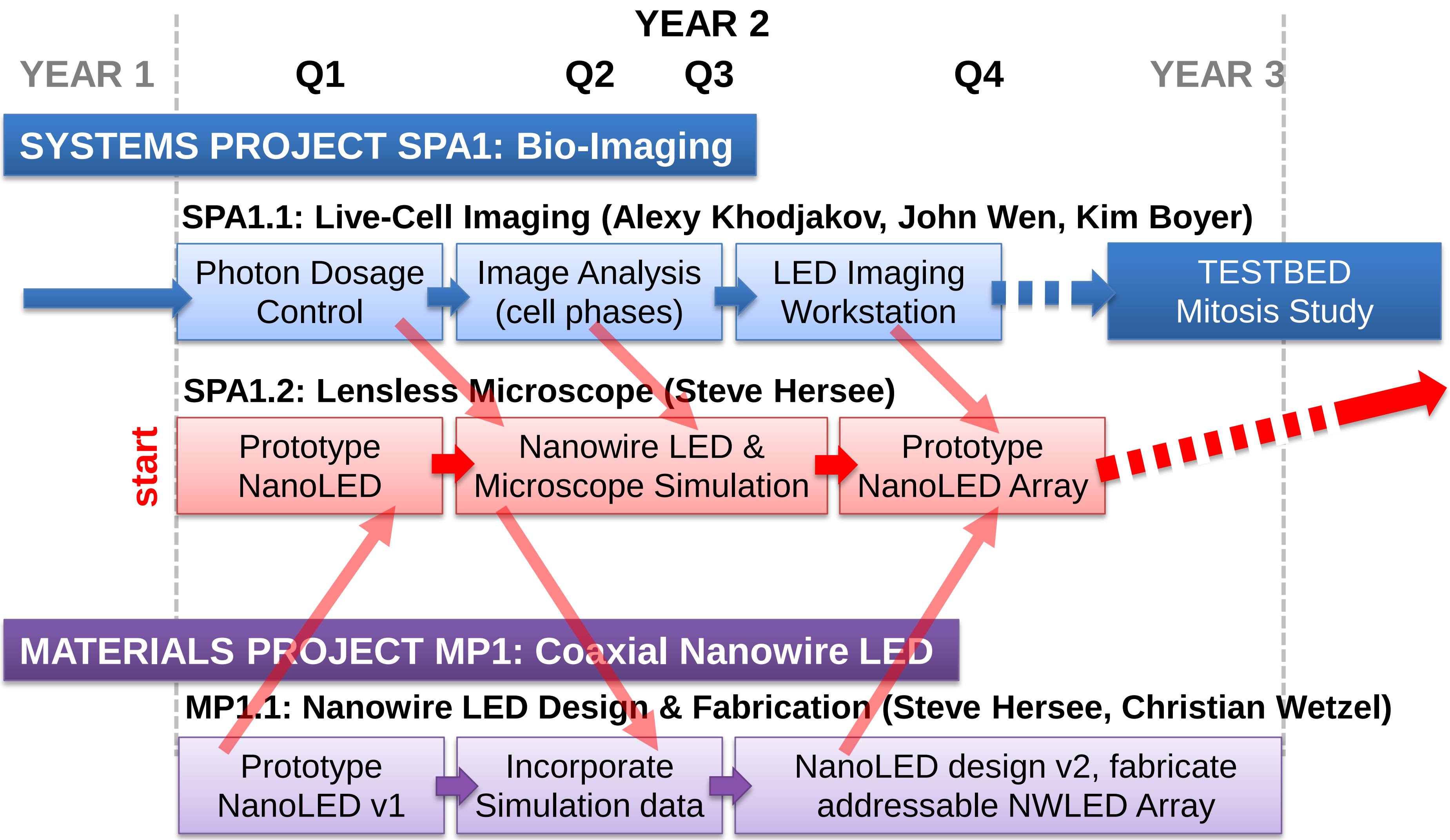
**<u>SPA1.1 (John Wen, Kim Boyer, Alexy Khodjakov, RPI & Wadsworth )</u>**

Develop SMART LIGHT microscope illumination that analyzes an image then adapts. Achieves optimum intensity, spectrum and pulse-duration, to allow LONG DURATION observation of live cells without phototoxicity

**<u>LONGER TERM SPA1.2 (Steve Hersee, UNM + SPA1.1 team + simulation team)</u>**

**Miniaturize** microscope and incorporate illumination strategies and algorithms from from SPA1.1. Objective: ***in vivo*** live-cell imaging !

# Lensless Microscope: Project Integration Year 2



# How to Build a Miniature Lensless Microscope

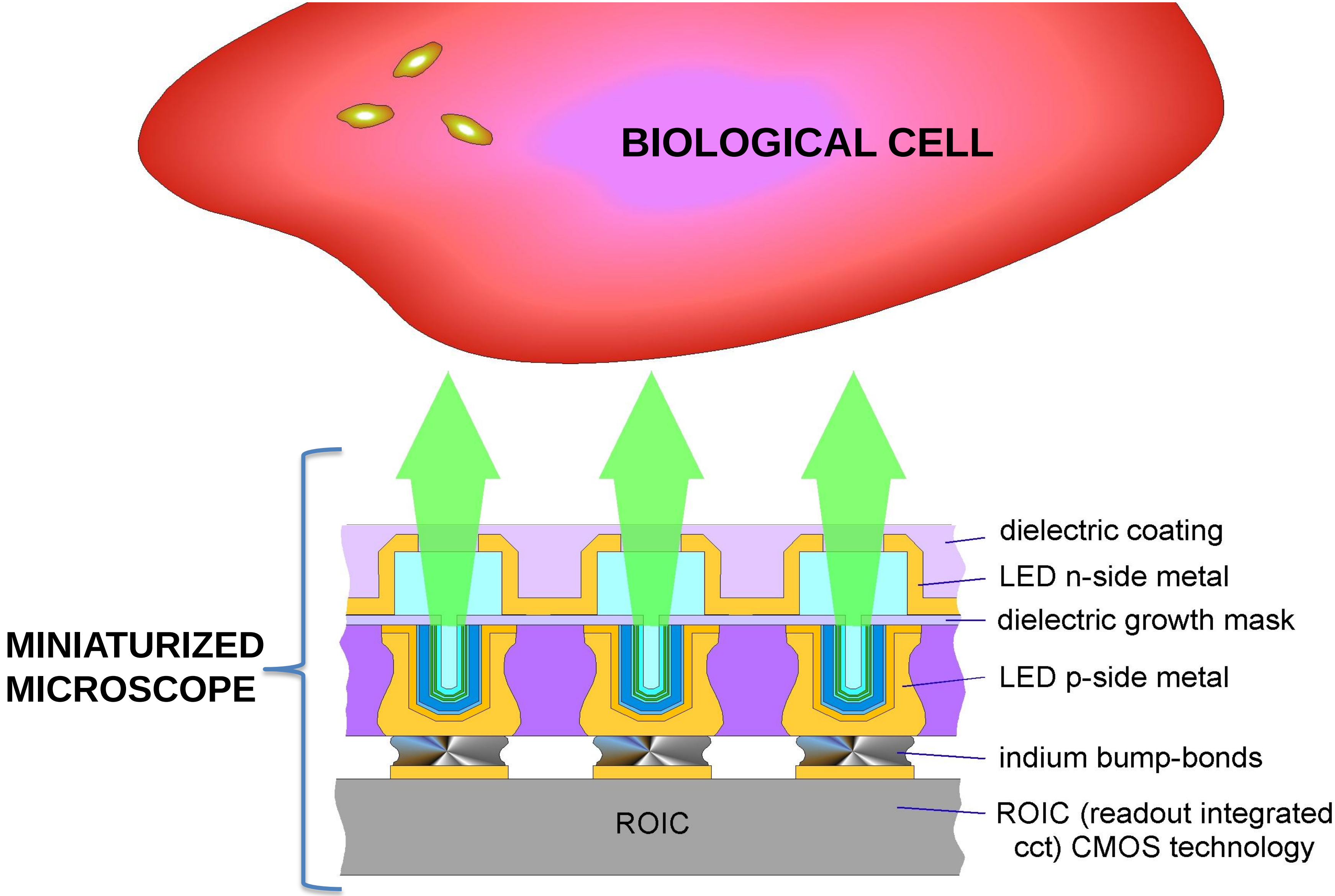
**Microscope is miniaturized by removing lenses and all moving parts – to give a solid-state, rugged chip**

**Use dense arrays of individually-addressable nanowire LEDs (see project MP1.1) to form light emitter/detector matrix**

**Microscope becomes a ~ mm size, near-field, digital imaging instrument that works in the Fresnel diffraction (near field) range**

**Optical resolution (~ 1 μm) is controlled by spacing between nanowire LED emitters and by advanced digital image processing.**

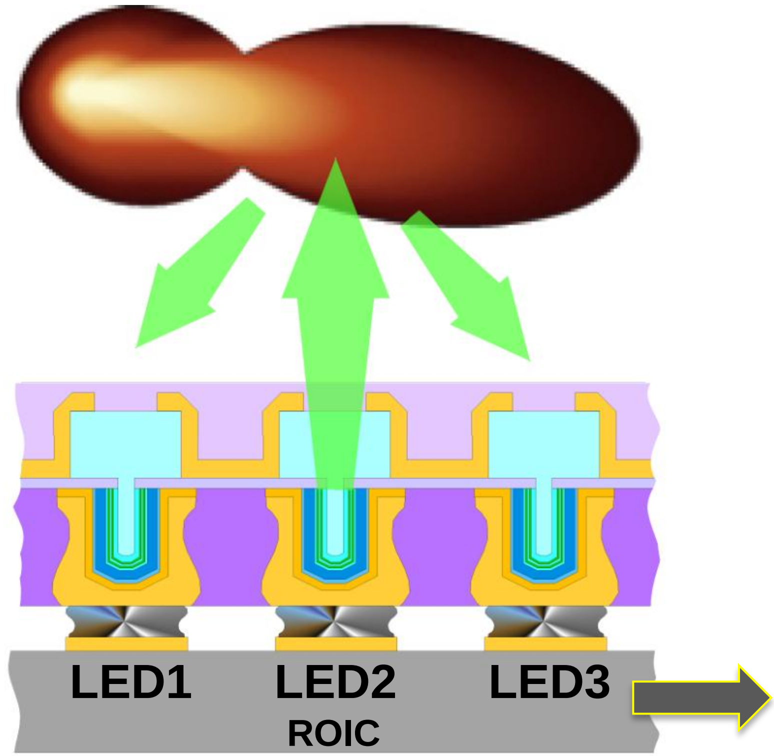
# Lensless Microscope Concept



# Lensless Microscope: Image is built pixel-by-pixel

**Each nanowire LED in array has three operating states:**

- **“EMIT”: forward bias, light emitted**
- **“DETECT”: reverse bias, detects light**
- **“OFF”:**

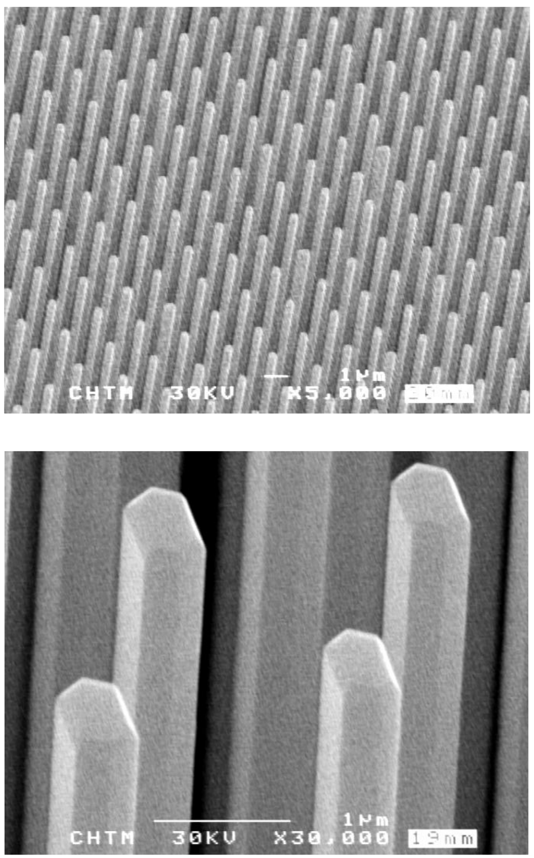


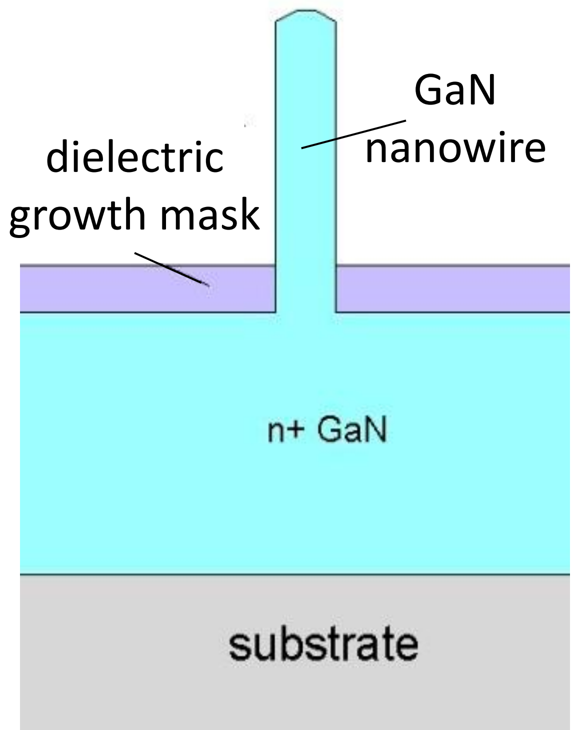

**Digital image builds pixel-by-pixel** (pixel size ~1 μm)

- LED 2 emits light which scatters from object close to array surface.
- LEDs 1 and 3 are reverse biased and detect scattered light.
- Photocurrent from LEDs 1 and 3 is stored by ROIC then sent to computer

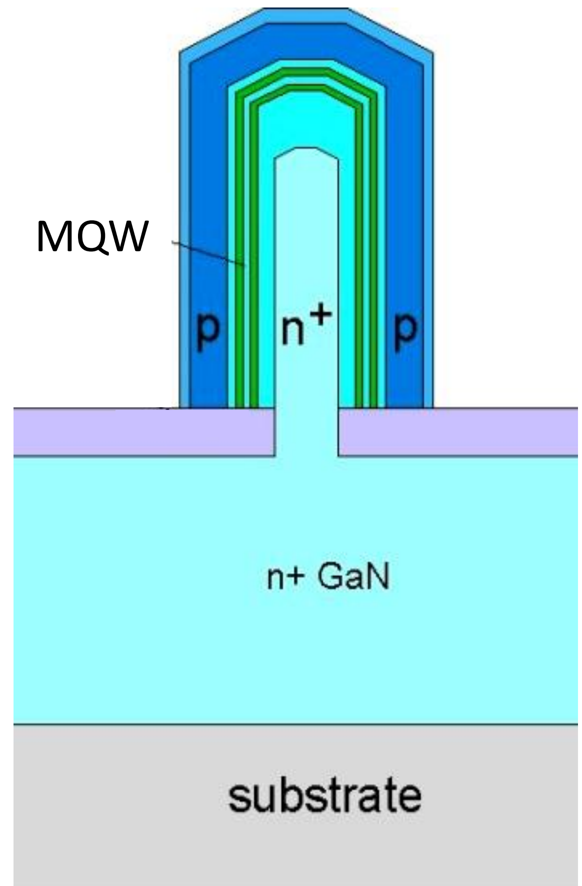
# Project MP1: Nanowire LEDs

## The revolutionary nanowire LED uses a scalable MOCVD process



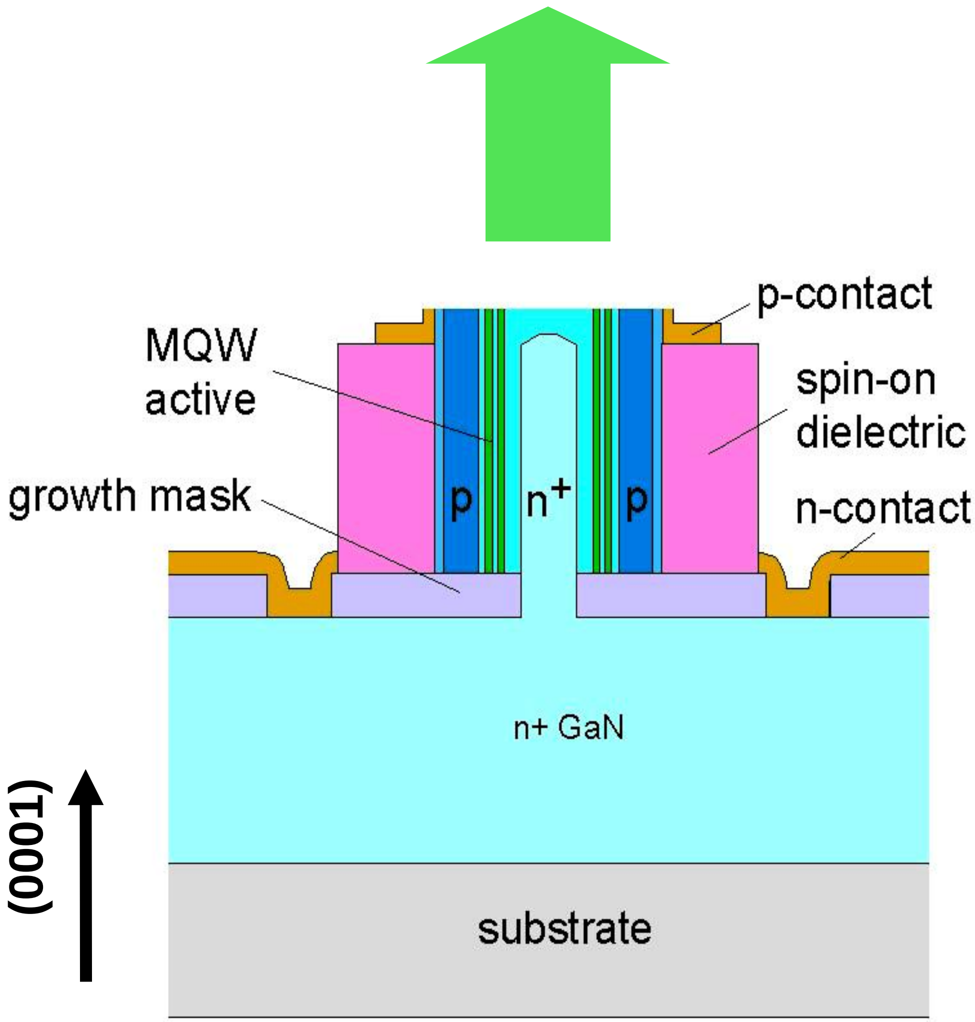




(a) Scalable GaN nanowire process allows vertical (0001) growth of defect free GaN nanowires (MP1.1)




(b) Growth of core-shell LED around nanowire

# Attributes of Nanowire LEDs (see poster MP1.1)




- No threading defects - high internal efficiency
- Vertical (0001) emission - high external efficiency
- Nanowire GaN sidewalls are atomically smooth {1-100} planes (m-planes) - eliminates QCSE, high internal efficiency.
- MQW active region area much larger than LED footprint, high efficiency
- Polarized emission possible
- Individually addressable NW LED arrays

# PHASE 1: Simulate Microscope System

**The Lensless microscope is a complex engineering system. We are starting the design process with a 4-part simulation.**

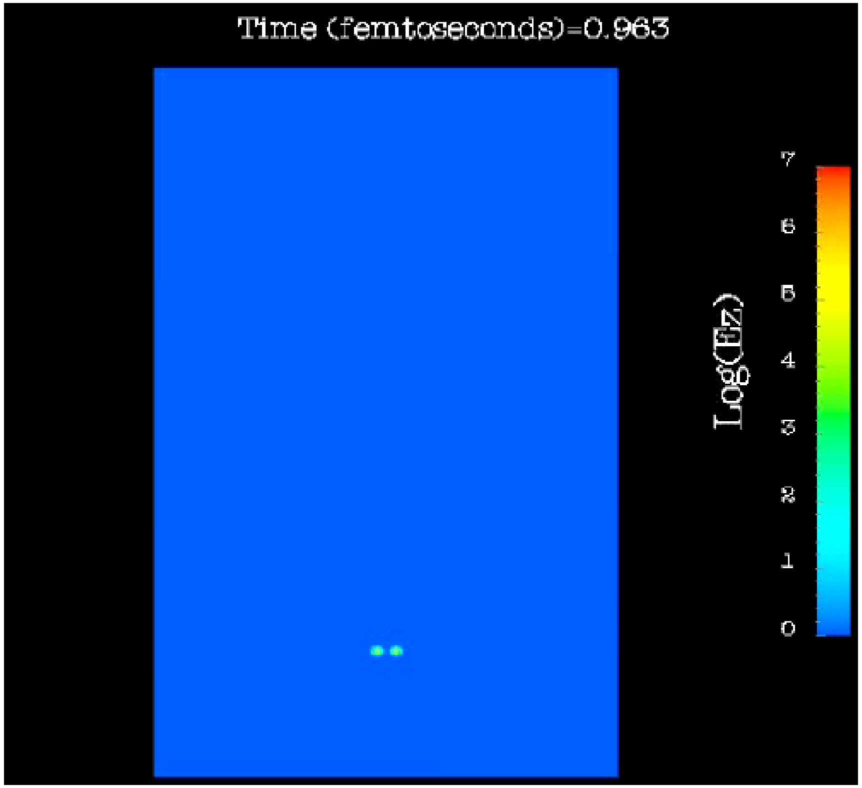
1. **Optics (Prof. Jamesina Simpson, Cesar. Mendez)**
   - How does light propagate with no lenses? - is Fresnel diffraction model (cf. contact aligner) appropriate?
   - Design LEDs for low optical leakage to nearest neighbor
   - Where do we put detectors for most light capture (single-sided or double-sided array)?
2. **Detection (Prof. Majeed Hayat, David. Ramirez)**
   - Best detector? Reverse-biased nanowire LED or Si APD on CMOS ROIC?
3. **ROIC design (Prof. Payman Zarkesh-Ha, Aliakbar Darabi)**
   - Minimum bump-bond pitch for ROIC (read out integrated circuit) ?
   - How much on-chip vs. off-chip functionality?
4. **Off-chip image reconstruction (Prof. Pradeep Sen, Jiawei Xu)**
   - Advanced image processing algorithms, (digital FOVEA, double-sided, pseudo-3D imaging)

# Optics FDTD Simulation – Prof. Jamesina Simpson

FDTD (Finite-Difference Time-Domain) numerical methods approach

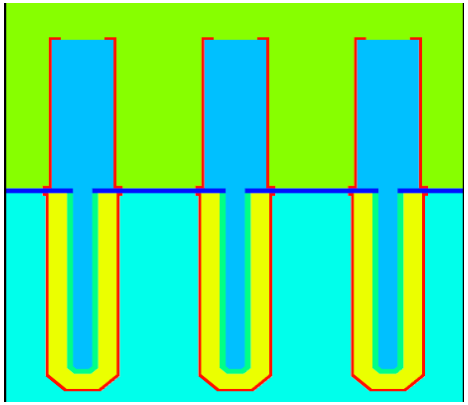
Solves Maxwell's equations within each cell of grid

The result is 6 coupled scalar equations for 6 vector field components: $E_x$, $E_y$, $E_z$, $H_x$, $H_y$, $H_z$

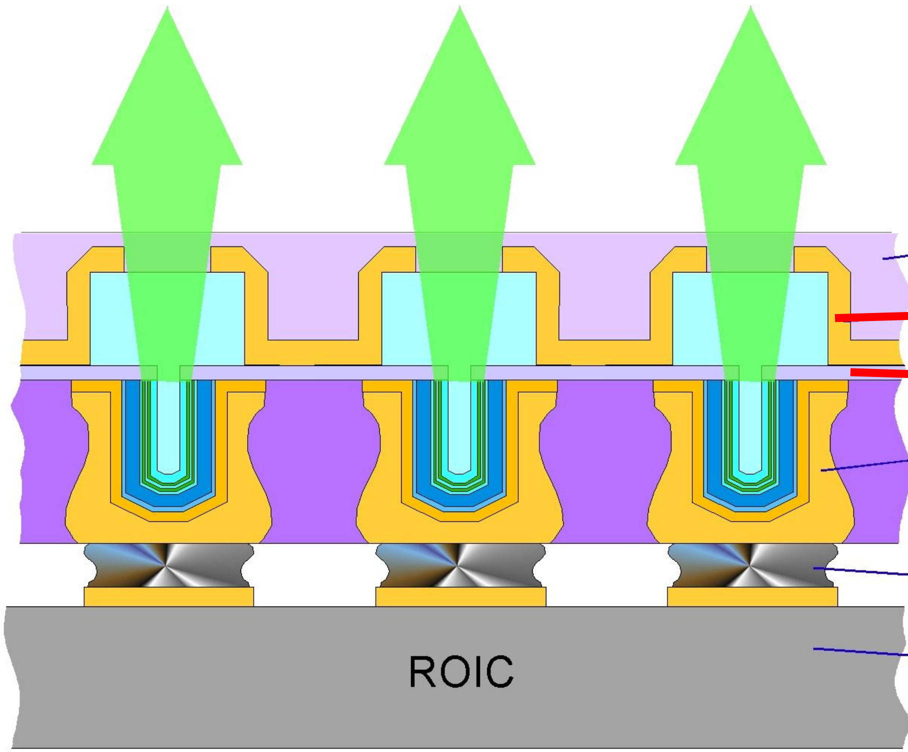



**Computing Power**

- Three supercomputers at UNM Center for Advanced Research Computing (CARC): www.hpc.unm.edu
- Access to **Encanto** at the New Mexico Computing Applications Center (World's 12th fastest computer)
- Access to **Bigben** at the Pittsburgh Supercomputing Center



# Optics Simulation reveals critical LED design areas



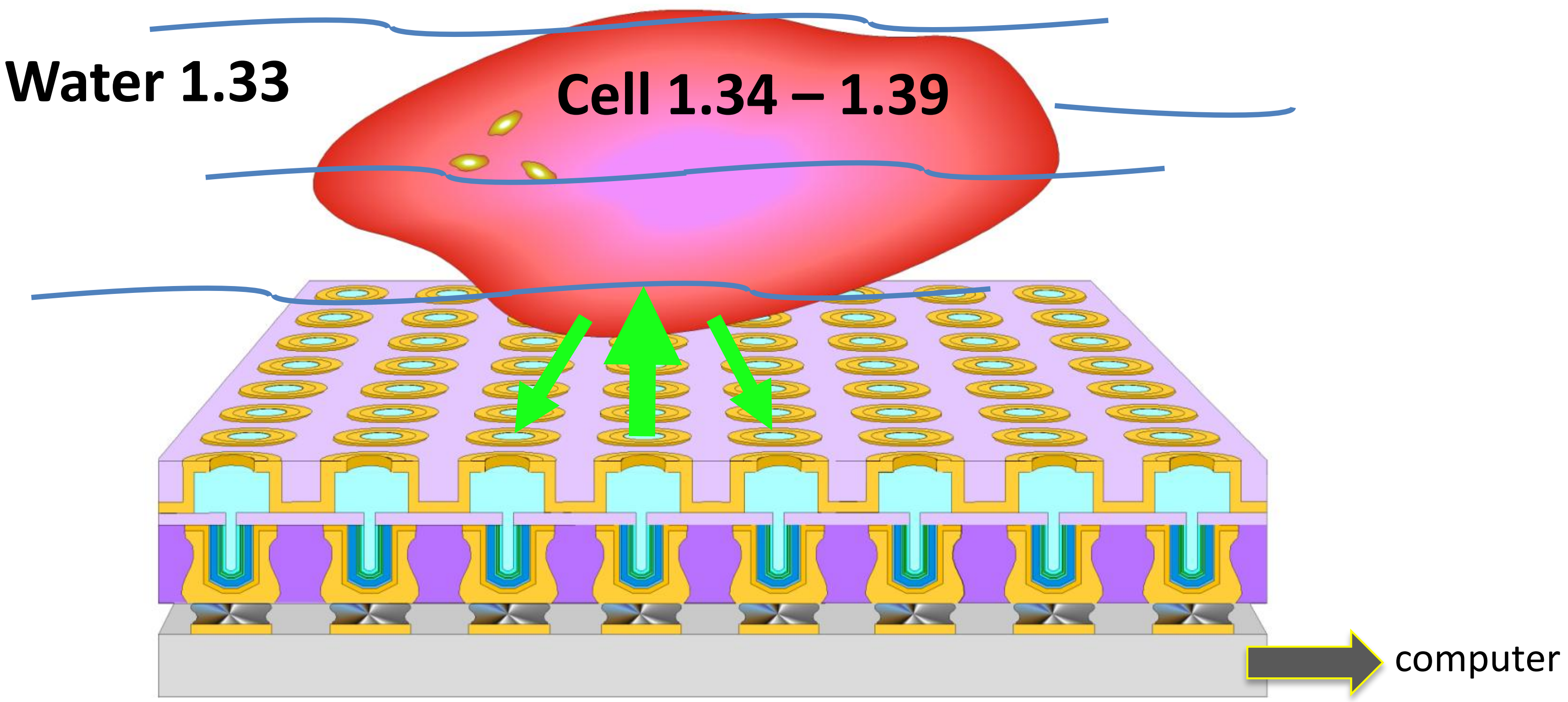

The FDTD optics simulation shows that optical leakage depends critically on the **n-side metal thickness** and the **growth mask thickness**.

**NOTE: This model can be configured for nano-scale or macro-scale and could be useful for modeling other ERC SMART LIGHT systems.**

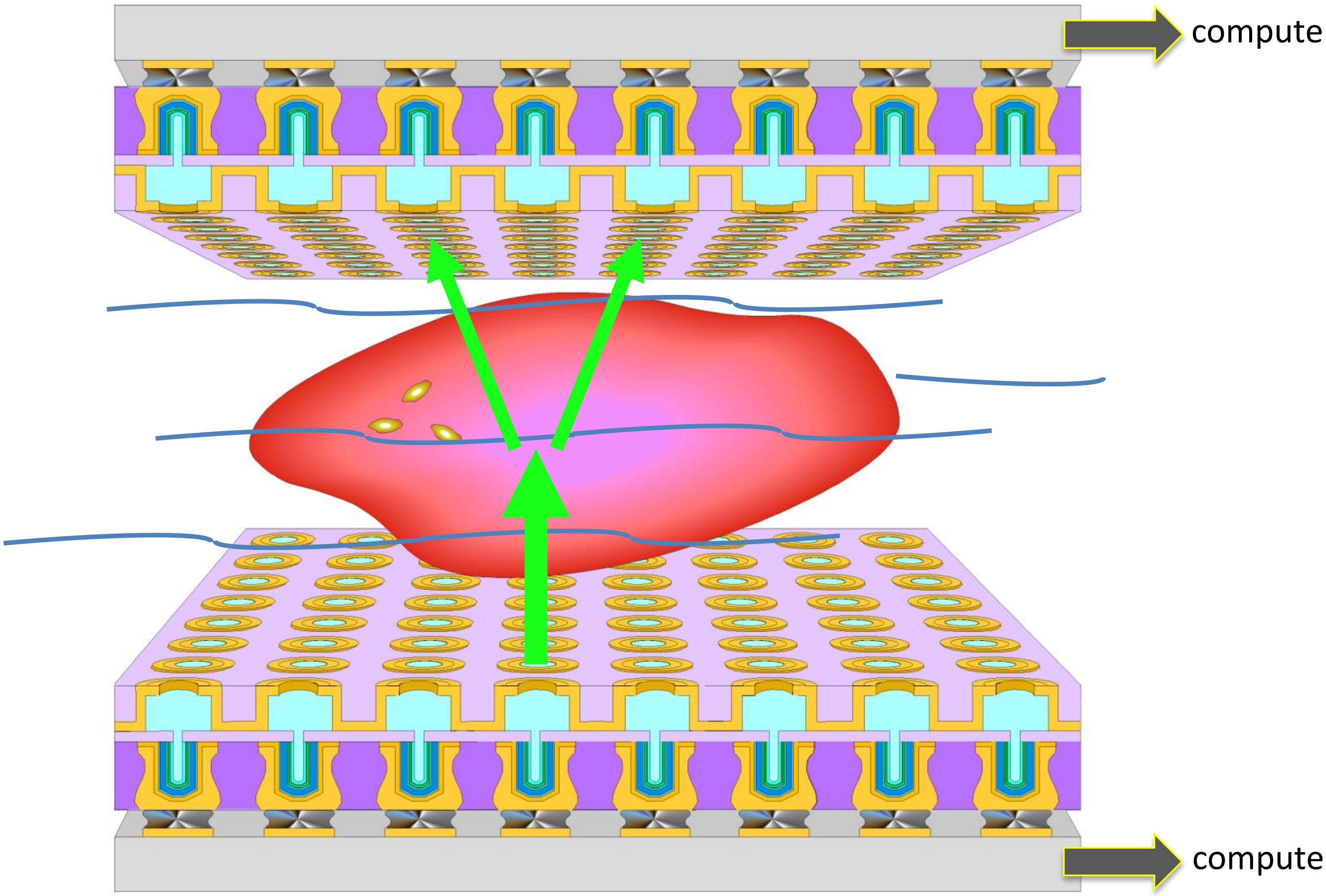
# Optics Sim: Single-Sided Lensless Microscope

**ISSUE:**
**The refractive index of the cell is close to water.**

**Reflected light intensity will be small**

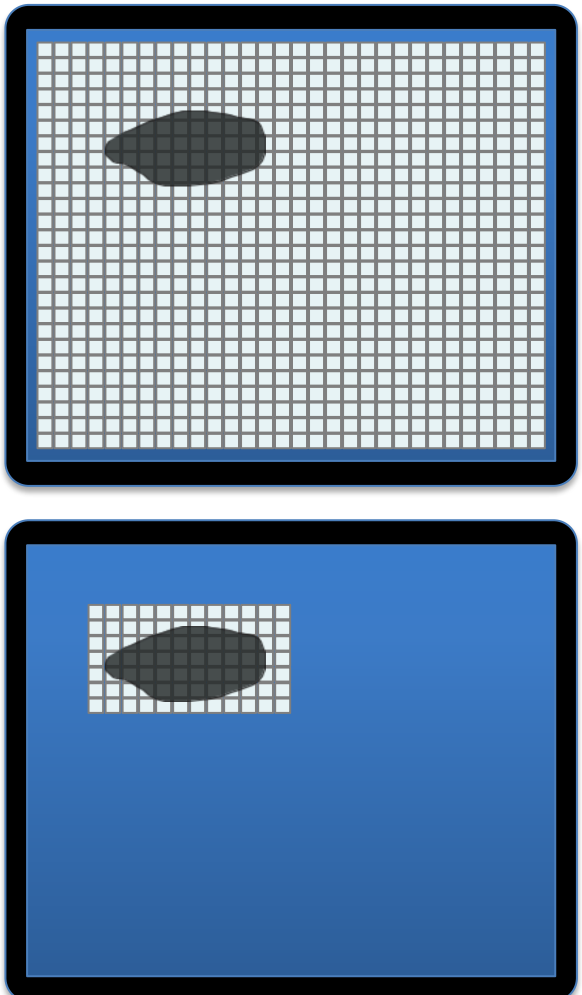


# Optics Sim: Double-Sided Lensless Microscope

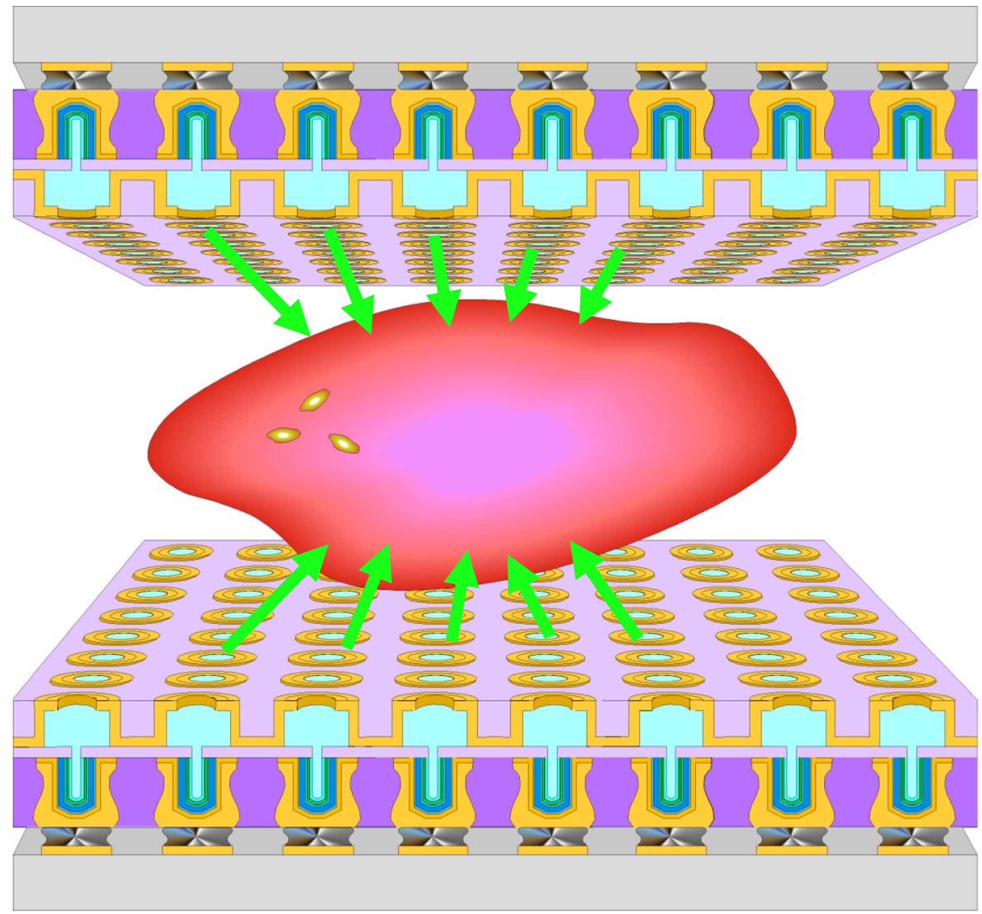


# Digital Imaging: Digital FOVEA, Pseudo-3D

**Digital FOVEA: Display only regions that are of interest**



**Pseudo-3D Imaging: Image the same object from both sides, using different LEDs – to create pseudo-3D**



# Concluding Remarks: Lensless Microscope

The lensless microscope is a **transformational** engineering system - a miniaturized, rugged, portable microscope that will eventually be small enough (~mm) for ***in-vivo*** observations
(first working prototype target: 2012 – 2013)

The project is integrated with the ERC bio-imaging thrust in live-cell imaging and will incorporate the smart illumination optimization strategies that are being developed for desk-top bio-microscopy

This project vertically integrates revolutionary ERC materials and device technology (scalable GaN nanowires and core-shell LEDs) into a portable bio-imaging system

**Please visit poster SPA1.2 for more discussion**

# References & Intellectual Property

## References


◆ "The Controlled Growth of GaN Nanowires", S.D. Hersee, X. Sun, X. Wang, *Nano Lett.*, **6**, 1808 – 1811 (2006).

◆ "Unusually strong space-charge-limited current in thin wires", A.A. Talin, F. Leonard, B.S. Swartzentruber, X. Wang, S.D. Hersee, *Phys. Rev. Lett.*, **101**, 076802 (2008)

◆ "GaN nanowire light emitting diodes based on templated and scalable nanowire growth process", S.D. Hersee, M. Fairchild, A Rishinaramangalam, M. Ferdous, L. Zhang, P. Varangis, B. Swartzentruber, A.A. Talin, *Electronics Letters,* **45** (2009) 75

◆ "Electrical transport in GaN nanowires grown by selective epitaxy", A.A. Talin, B.S. Swartzentruber, F. Leonard, X. Wang, S.D. Hersee, *J. Vac Sci & Technol. B*, **27** (2009) 2040-2043


## Intellectual Property

◆ **Patent Application Filed:** "Solid State Microscope", S.D. Hersee (4/2008)

◆ **Patent Awarded:** 7,521,274 B2: "Pulsed Growth of Catalyst-Free GaN Nanowires and Application in Group III-Nitride Semiconductor Bulk Material", S.D. Hersee, X. Sun, X. Wang, (2009)