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)
  o How to miniaturize a microscope
  o Objectives and Timing
  o Progress

• Concluding remarks
The Future of 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.

![Biological images with time stamps 00, 05, 12, 18, 22, 29]

**ERC SOLUTION**

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

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.

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

**Miniaturize** microscope and incorporate illumination strategies and algorithms from SPA1.1.

Objective: *in vivo* live-cell imaging!
Lensless Microscope: Project Integration Year 2

Year 1

Year 2

Q1

Q2

Q3

Q4

Year 3

**Systems Project SPA1: Bio-Imaging**

SPA1.1: Live-Cell Imaging (Alexy Khodjakov, John Wen, Kim Boyer)

- Photon Dosage Control
- Image Analysis (cell phases)
- LED Imaging Workstation

**Testbed**

Mitosis Study

SPA1.2: Lensless Microscope (Steve Hersee)

- Prototype NanoLED
- Nanowire LED & Microscope Simulation
- Prototype NanoLED Array

**Materials Project MP1: Coaxial Nanowire LED**

MP1.1: Nanowire LED Design & Fabrication (Steve Hersee, Christian Wetzel)

- Prototype NanoLED v1
- Incorporate Simulation data
- NanoLED design v2, fabricate addressable NWLED Array
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

BIOLOGICAL CELL

MINIATURIZED MICROSCOPE

dielectric coating
LED n-side metal
dielectric growth mask
LED p-side metal
indium bump-bonds
ROIC (readout integrated cct) CMOS technology

ROIC
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
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)
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](http://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 \textit{n-side metal thickness} and the \textit{growth mask thickness}.

\textbf{NOTE:} This model can be configured for nano-scale or macro-scale and could be useful for modeling other ERC SMART LIGHT systems.
ISSUE:
The refractive index of the cell is close to water.

Reflected light intensity will be small
Optics Sim: Double-Sided Lensless Microscope
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