SMART LIGHTING ENGINEERING RESEARCH CENTER

Lighting Innovation for a Smarter Tomorrow

Smart Lighting ERC
Industry - Academia Day
February 5, 2010
Boston University

Poster Session Abstracts

Majority presented by students, engaged in poster competition

$1,000 for cash prizes provided by the BU Technology Development Office

Boston University Technology Development

Framework:

Questions to be addressed:

- What problem/challenge are you trying to solve?
- How do you address it?
- What is unique and different?

The students were instructed to prepare a 90-second 'elevator pitch'-type oral summary of the research highlighted in posters, answering the above questions. They received practice help from RPI's Severino Center for Technological Entrepreneurship, and had other sessions where they critiqued each other's presentations. You will hear the best elevator pitches (as selected by the students themselves the night before) as part of the agenda before the poster session, but all students will use their 'elevator pitches' in their discussions with visitors to posters.

Judging criteria: equally weight for:

- Scientific content
- Visual presentation
- Oral presentation – 90-second 'elevator pitch'

Abstracts:

* Faculty presenter

** Undergraduate presenter (separate category in the student poster competition)

***Post-Doc

SPA1.1: Intelligent Illumination for Green Fluorescent Protein Marker Tracking in Live Cell Imaging (Zachary Schilling)

John Wason[+], Zachary Schilling[+], John Wen[+], Kim Boyer[+], Valentin Magidson[*], Alexey Khodjakov[*], [+]Rensselaer Polytechnic Institute, Troy, NY, [*]Wadsworth Center, NYS Department of Health, Albany, NY

Live cell imaging using Green Fluorescent Protein (GFP) Markers is a relatively new technique that allows individual molecules to be tracked within a living cell. The markers can be configured to bind to specific molecules of interest, and time lapse three dimensional images can be recorded of the motion of the molecules. While the imaging procedure is effective, the large dosage of illumination required capturing the time lapse and three dimensional information is toxic to living cells. By applying intelligent illumination it is possible to selectively illuminate only the regions of interest and prevent over exposing the cells. The intelligent illumination is accomplished through the use of real-time image processing, feature tracking, and adaptive shutter control.

SPA1.2: *Lensless Bio-Microscopy Enabled by Nanowire LEDs (Prof. Hersee)

S.D. Hersee, A.K. Rishinaramangalam, C. Mendez, A. Darabi, J. Xu, J. Simpson, M. Hayat, P. Sen, P. Zarkesh-Ha

The ability to form massive and dense arrays of individually addressable nano-LEDs creates an opportunity to fabricate a revolutionary digital microscope system that has no lenses, is ~ mm2 in size, and is highly portable. For imaging, the object (eg. a biological cell) needs to be within the Fresnel diffraction range of the microscope surface.

The unique nanoLED array illumination of this microscope will allow excellent control of illumination intensity of and the duration of the imaging process. Both parameters will be optimized in order to minimize cell phototoxicity and to "stop" cell movement. This transformative microscope will also explore the use of a digital-fovea concept, where only selected areas the image field will be illuminated and viewed in high resolution. This digital-fovea approach will further reduce the probability of cell phototoxicity.

Future iterations of the microscope will explore further miniaturization with the longer term objective of creating a microscope that is so small that it can be inserted into a tumor, allowing the in-vivo imaging of cancer cell dynamics for the first time.

It should be noted that while this instrument is undoubtedly complex, it is being fabricated using scalable semiconductor technology. We envisage that, like the integrated circuit, this revolutionary approach to microscopy will eventually be cost-effective.

We are seeking an industrial collaborator for this project and the IP associated with this invention is available for licensing by ERC industry members.

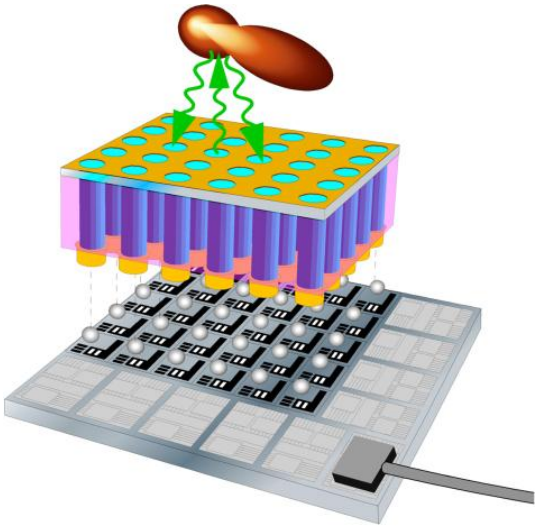


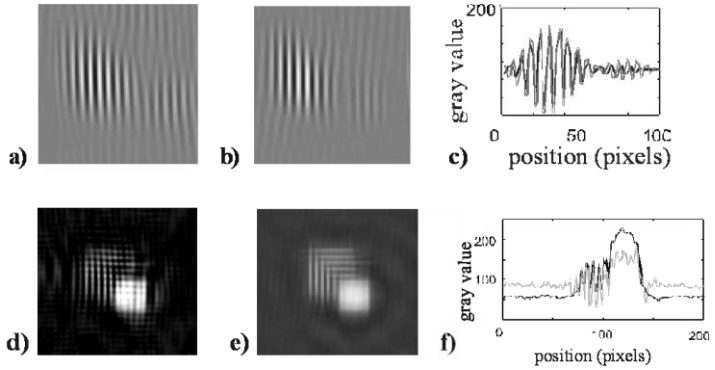
Fig.1 The lensless microscope portraying the emitter and the detector functionality, along with the read out circuit.

SPA1.3: Imaging Interferometric Microscopy (Alexander Neumann)

Alexander Neumann, Yuliya Kuznetsova and S. R. J. Brueck

Keywords: synthetic aperture, superresolution,

Traditional microscopy is limited in resolution by diffraction as first described over a century ago by Ernst Abbe and Lord Rayleigh. The highest spatial frequency accepted by an optical system is $\lambda/2NA$, where λ is the optical wavelength and *NA* is the numerical aperture of the optical system; this leads to a limiting "resolution" of ~ $\lambda/4NA$. Imaging interferometric microscopy is a novel synthetic aperture technique that extends this resolution to $\lambda/4$ in air and to $\lambda/4n$ for immersion techniques where *n* is the refractive index of the immersion medium. For a HeNe laser (λ = 633 nm) and a modest 20x objective (NA = 0.4) we have demonstrated a resolution of an arbitrary object to 150 nm ($\lambda/4.2$) and will describe our plans for extending this to ~ 50 nm ($\lambda/12$) with solid state immersion. Importantly, IIM retains the depth of field, field-of-view and working distance of the low-NA objective. In addition to the enhanced transverse resolution, sectioning and imaging o multiple stacked objects is possible with multiple wavelength sources. Recent progress will be discussed.



IIM of a 150 nm structure using evanescent illumination and a tilted optical system. a) High-frequency image obtained by evanescent wave illumination of tilted object plane b) high-frequency image simulation, c) comparison of Manhattan structures crosscut with the model

SPA2.1.1: SRIB Field Diagnostic Unit (Alex Reddington)

Alex Reddington, Michael Ruane

Accurate, inexpensive, easy-to-use, and portable rapid diagnostic tests (RDTs) for viruses and parasites like hepatitis, influenza or malaria, are needed for furthering global health. Current diagnostic devices requiring a trained individual and/or a well-equipped laboratory do not support point-of-care treatments, especially in third world countries. A portable, inexpensive RDT derived from the laser-illuminated spectral reflectance imaging biosensor (SRIB) invented at BU for detection of viruses and parasites holds promise for fulfilling RDT requirements. Recent work has shown that LED illumination achieves picometer height sensitivity while decreasing cost by orders of magnitude. Processing time has been similarly improved through lookup tables instead of nonlinear fitting. Preliminary results show cell phone quality camera sensors or handheld-digital microscope sensors, such as the HR Proscope from Bodelin Technologies, can replace the expensive and heavy scientific imager of SRIB.

SPA2.1.2: Protein Microarray Diagnostic Platform (Margo Monroe)

Margo R. Monroe, Michael Ruane

The goal of this project is to design an effective surface that optimizes probe and target capture to increase signal detection in a portable, rapid diagnostic device for infectious diseases such as hepatitis, malaria, or influenza. Design of a protein microarray diagnostic platform that is inexpensive, label-free, multiplexed (both antigen and antibody probes), and high-throughput relies heavily on the efficiency of biomolecular binding between the probes and a solid support. A stable and uniform linkage between molecules and the surface depends on the chemistry that occurs between the biomolecules and the surface: a high probe density, accessible probes for target binding, preserved bioactivity of the probes and targets, and low non-specific binding. A 3-D polymeric coating (copoly-(DMA-NAS-MAPS)), introduced by Italian colleagues Chairi *et al.*, has met these requirements and is currently in use in DNA and protein microarray detection studies. The coating has three functional groups. One creates a stable bond between the probe and coating. In addition, the coating preserves the native conformation of biomolecules by elevating the active sites in solution, mimicking the conditions *in vivo* and thus preserving bioactivity. The exposed active sites achieve higher efficiency of target capture, essentially eliminating non-specific binding. Currently, research groups have been trying to discover proteins and DNA strands' signature to infectious diseases. Already, scientists have been able to isolate such proteins and nucleic acids to facilitate the design and development of diagnostic tools. Antibodies, ssDNA, and dsDNA will be spotted in 100 um spots on 500 um SiO_2-Si chips coated with polymer.

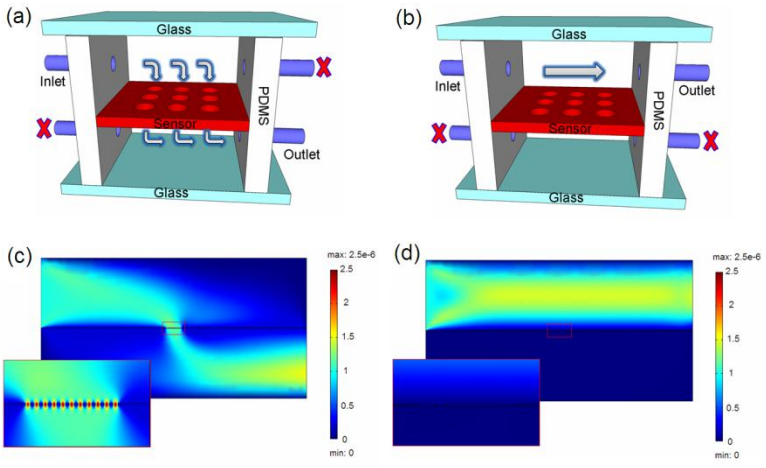
SPA2.2: Sub-Wavelength Nanofluidics on Photonic Crystal Sensors (Min Huang)

*Min Huang,[1] Ahmet Ali Yani[1] , Tsung-Yao Chang[2] and Hatice Altug[1],**

[1]Department of Electrical and Computer Engineering, Boston University, Boston, MA, 02215, USA
[2]Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge, MA, 02139, USA

Keywords: Nanophotonics and photonic crystals; Biological sensing and sensors; Subwavelength structures; Guided resonance;

We introduce a novel sensor combining nano-photonics and nano-fluidics on a single platform through the use of suspended photonic crystals (PhCs). PhCs offer great freedom to manipulate the spatial extent and the spectral characteristics of the electromagnetic fields. Also, nanoholes in PhCs provide a natural platform to transport solutions. By harnessing these nano-scale openings, we theoretically and experimentally demonstrate that both fluidics and light can be manipulated at sub-wavelength scales. In this scheme, the free standing PhCs are sealed in a chamber such that only the nano-scale hole arrays enable the flow between the top and the bottom channels. The nanohole arrays are used as sensing structures as well as nanofluidic channels. Compared to the conventional fluidic channels, we can actively steer the convective flow through the nanohole openings for effective delivery of the analytes to the sensor surface. This scheme also helps to overcome the surface tension of highly viscous solution and guarantees that the sensor can be totally immersed in solution. We apply this method to detect refractive index changes in aqueous solutions. Bulk measurements indicate that active delivery of the convective flow results in better performance. The sensitivity of the sensor reaches 510 nm/RIU for resonance located around 850 nm with a line-width of ~10 nm in solution. Experimental results are matched very well with numerical simulations. We also show that cross-polarization measurements can be employed to further improve the detection limit by increasing the signal-to-noise ratio.



(a) Illustration of the actively controlled flow scheme. (b) Conventional (passively controlled) flow scheme. (c) (d) Velocity distribution of solutions are calculated by solving the Navier-Stokes equations for actively and passively controlled flow scheme.

SPA2.2: Fabry-Perot Nanocavities in Multilayer Plasmonic Crystals for Enhanced Biosensing (Alp Artar)

Alp Artar, Ahmet Ali Yanik*, Hatice Altug**

**Department of Electrical and Computer Engineering, Boston University, Boston MA 02215*

In this work, a novel multilayered plasmonic crystal is investigated, which is formed by a coupled nanohole and a nanoparticle array. Structures are shown to support conventional extraordinary optical transmission (EOT) peaks and also a newly found mode that is a direct consequence of the photonic coupling inside the nanocavity. This new mode is identified as the fundamental Fabry-Perot peak and with numerical analysis it is shown to be very sensitive to bulk refractive index changes.

SPA2.3: **Ultraviolet Light Emitting Diode (UV LED) based Microbial Contamination Detection and Identification (Renato Li)

Renato Li , Nikhil Rao, Irina Barash, Shayla Sawyer

Keywords: Bacteria, Autofluorescence, Tryptophan, NADH, Ultraviolet, Light Emitting Diodes

Light emitting diodes (LEDs) provide a unique opportunity for reagentless detection and identification of high concentrations of microbial contamination in confined areas. An LED based contamination monitoring system offers near real-time monitoring of microbial contamination that require no sample preparation or handling. It can be used as a trigger for additional identification and analysis methods such as PCR or immunological methods. Applications include sewage overflow monitoring in local waterways, water quality evaluation in remote areas, and contamination source tracking. Tryptophan, other amino acids, and DNA are excited between 200-300 nm wavelengths. It can be used as a sensitive biological marker, however; all biological materials contain these fundamental building blocks. NADH indicates the metabolic function within living cells and are excited with wavelength between 340-360nm. It therefore provides additional selectivity between dead and living cells. This project focuses on the unique ability of 280 and 340 nm UV LEDs to induce autofluorescence through narrow excitation wavelengths with controlled intensity that target the above native fluorophores within cells. We present preliminary results of quantification measurements of *Escherichia coli* (ATCC# 25922) and *Enterobacter aerogenes* (ATCC# 13048) with 280 and 340 nm LED excitation. We also present the basis of our continuing efforts to add selectivity to identify bacteria. Identification requires multi-wavelength excitation and analysis of the emission spectrum across a range of wavelengths. Using principle components analysis of the emission spectrum, bacteria species and strains can be differentiated. LEDs therefore can provide an additional capability to switch between modes of contamination detection and identification.

SPA2.3: Biological Detection with Nanoparticle based Photodetectors (Liqiao Qin)

Liqiao Qin, Chris Shing, and Shayla Sawyer

Keywords: ZnO colloidal nanoparticles, autofluorescence, tryptophan

Lamp source-silicon PMT based systems are commonly used in biological autofluorescence detection, but these systems are limited by the high dark current, susceptibility to environmental changes, sensitivity to ambient light, and high power consumption of PMTs. An LED source-nanoparticle based photodetector system has been investigated for small signal autofluorescence detection. A visible blind ultraviolet (UV) photodetector was fabricated by dispersing zinc-oxide (ZnO) nanoparticles coated with polyvinyl-alcohol (PVA) onto quartz glass. These ZnO nanoparticles were created by reducing ZnO bulk material (bandgap 3.26 eV) via a top-down wet-chemistry method into colloidal particles tuned to absorb wavelengths less than 370nm. We present the characterization of this detector in comparison to a commercially available Si Photodiode. The photodetector was placed in our UV LED based microbial detection system. E-coli cells were illuminated by a 280nm UV LED to induce autofluorescence of the native tryptophan enzyme, which autofluoresced at 340nm and the intensity was measured by the ZnO nanoparticle based photodetector. A multiple spectrum LED source- coupled with an array of wavelength specific photodetectors, tuned by different nanoparticles can be created for sensitive electronically controlled and wavelength specific biological autofluorescence detection.

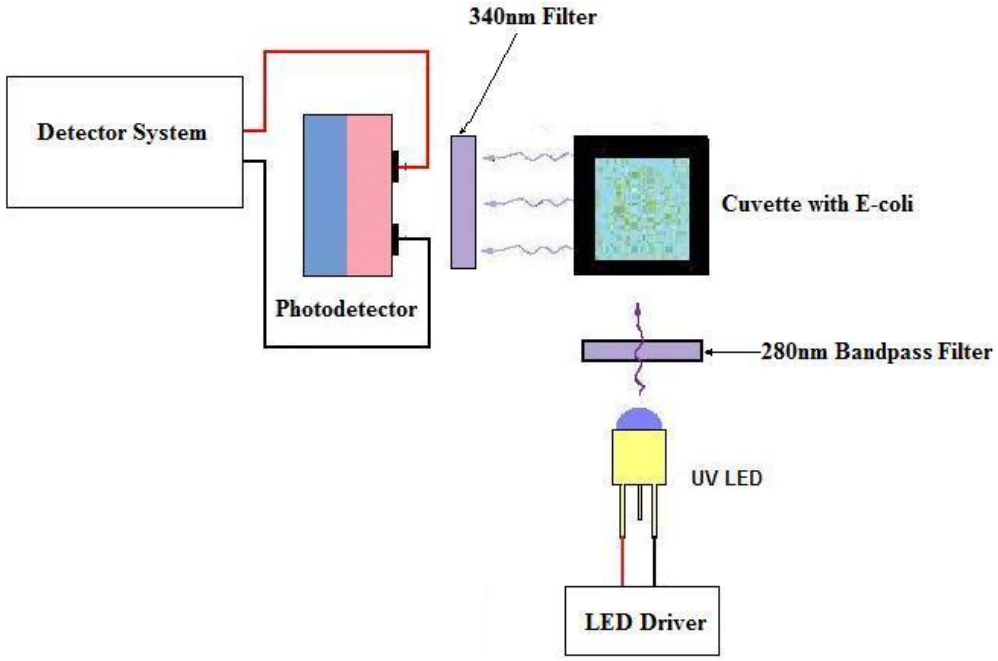


Figure 1: UV LED source – Nanoparticle based Photodetector System Setup

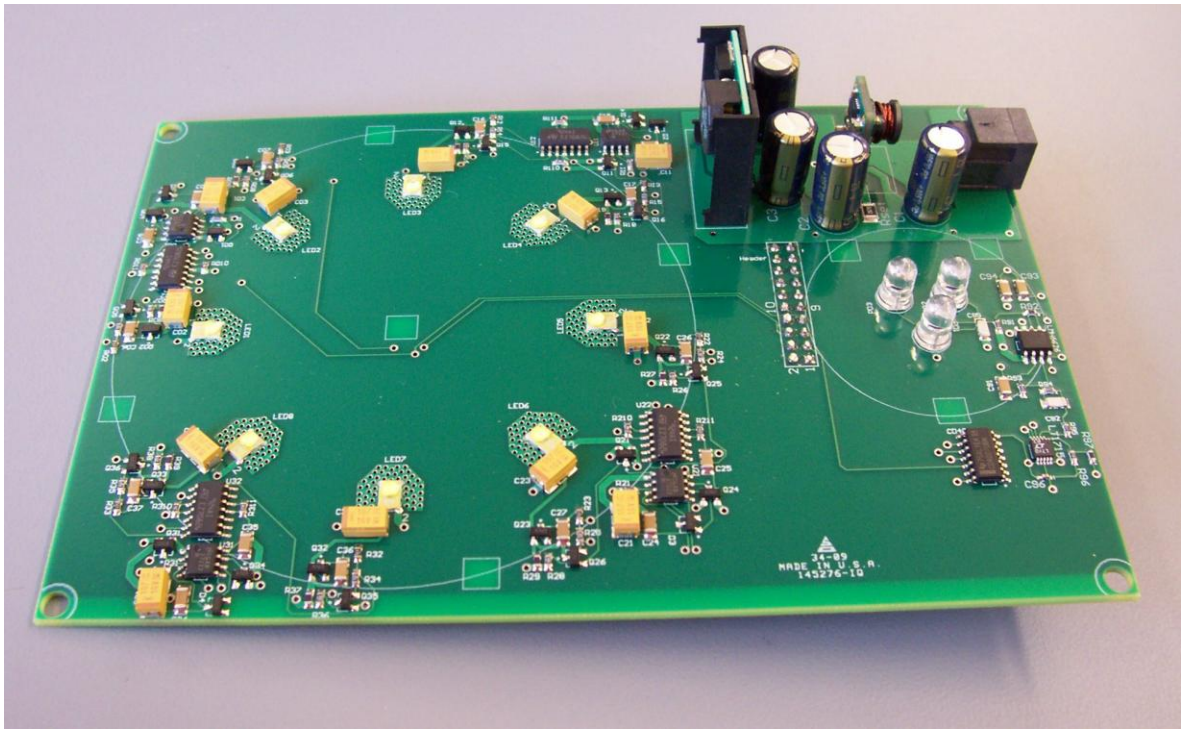
SPB1.1: LED Driver Design for an Optical Transmitter and Illuminator (Jimmy Chau)

Jimmy C. Chau, Thomas Little

Keywords: LED, light-emitting diode, driver, design, optical, transmitter, illuminator, constant current, free-space optical, lighting

Light-emitting diodes (LEDs), which may soon replace fluorescent and incandescent lighting as a more energy-efficient alternative, can rapidly switch on and off, allowing them to modulate light to transmit data. Combining the LED's ability to provide general lighting and to transmit data yields the potential to have networking and communication services wherever lighting exists. To enable this potential, a LED driver that can both provide a large, regulated current to power the LEDs for lighting, and quickly modulate this current to transmit data was needed. Unfortunately, no suitable off-the-shelf LED drivers have been found; all were either unable to drive enough current to produce a bright enough light or unable to modulate the current fast enough to allow for high data-rates.

This poster presents the design and analysis of a LED driver for Luxeon Rebel LEDs. The design separates the current switching and current regulation. The current switching portion accepts data as a 1Mbps Manchester-encoded signal, and only allows current to flow to the LEDs when the input signal is high. The current regulation portion uses a NFET, an op-amp, and a current-sensing resistor to form a negative feedback loop to maintain the current; additional components were added to hold the state of the feedback loop when the current switches off. Alternate designs for the LED driver and suggestions for improvement are also presented.



SPB1.1: System Level Modeling of High Bandwidth Density VLC for Indoor Dual-Use Communication and Lighting (Michael Rahaim)

Michael Rahaim, Tarik Borogovac

Keywords: Modulation, Transmitter, Channel, Recieiver, Bit Rate, Bit Error Rate

We present a model of visible light wireless digital communications with the purpose of aiding in the design of a VLC system that doubles as a fully functional indoor lighting system. The model incorporates constraints on operation that result from dual use: performing optimal communications while maintaining light color and desired brightness. For a desired lighting operation, a given set of design choices, and a specific environment, the model calculates the achievable bit rate at a threshold bit error rate. The design choices include Tx and Rx optical and electronic component specifications, modulation schemes, etc. The environment includes room size, barrier placement, locations of transmitters and receivers, noise profile, etc. In this way, the model informs the design process by predicting how changing any part of the system design or the environment will affect performance of the system as a whole. We present results of two case studies. In the first, we evaluate performance of various modulation designs. In the second, we evaluate effects of moving the receiver around the environment. The image below shows an overview of the system components that are incorporated in the model.

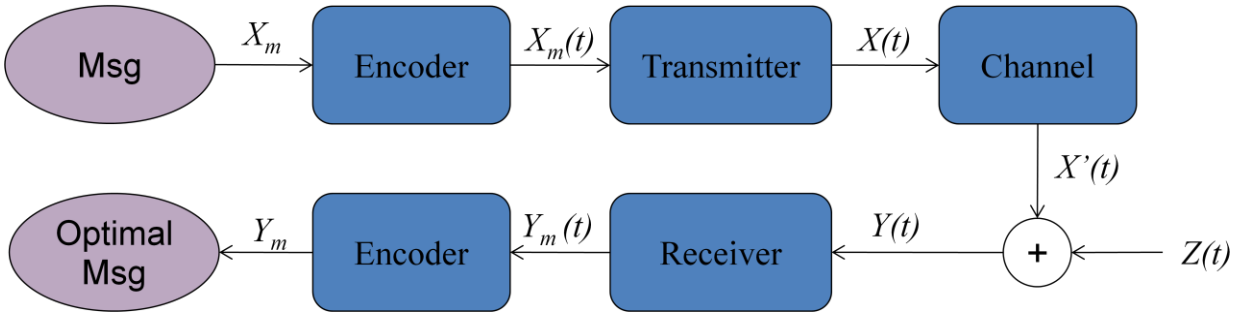


Figure 1: System Overview

SPB1.2: Physical characterization of a non-Line Of Sight visible communication system deploying High Flux white LEDs (Sruthi Muralidharan)

Sruthi Muralidharan, Partha Dutta

Smart Lighting ERC, and Department of Electrical, Computer and Systems Engineering,
Rensselaer Polytechnic Institute, 110 Eighth Street, Troy, NY 12180

Keywords: VLC, Non-LOS, White LEDs, Communication, FSO

The primary goal of this research is to design and develop simultaneous illumination and communication dual usage systems based on high power LED based general light sources. We are working on increasing the frequency of Visible Light Communication using High-Flux white LEDs. High Flux LEDs have a large pn junction area, and hence have intrinsically low modulation rates. The aggregate modulation bandwidth can be increased using various frequency modulation techniques. The modulation rate that can be reliably detected also increases with the use of focusing lenses for the photodetector, and collimating lenses for the LEDs. Novel modulation techniques for increasing the aggregate frequency bandwidth that can be achieved by high-flux LEDs would the focus of this poster. Various modulation techniques like multi-channel modulation, pulse shape modulation etc. have been investigated and will be presented in the poster.

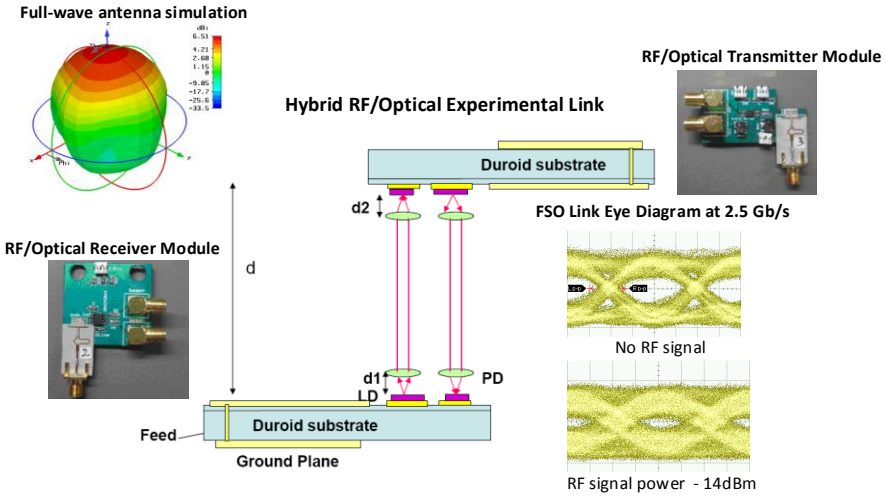
SPB1.3: RF/Optical Dual-mode Communication Modules Integrated with Planar Antennas (Jun Liao)

Jun Liao[1], Ali Mirvakili[2], Anatoliy Boryssenko[3], Valencia Joyner[2], Z. Rena Huang[1]

[1]Department of Electrical, Computer, and Systems Engineering, Rensselaer Polytechnic Institute
[2]Department of Electrical and Computer Engineering, Tufts University
[3]Department of Electrical and Computer Engineering, University of Massachusetts – Amherst

Keywords: Hybrid RF/Optical Communication, RF Antenna, High speed optical circuit, LED

Recent trends reflect a growing interest in hybrid communication systems to combine the advantages of unlimited bandwidth free-space optical (FSO) signaling and high mobility RF wireless transmission for future communication and network technologies with increased bandwidth, reduced power consumption, low cost, and high adaptability to dynamic operational environment. For indoor visible light communication, a combined hybrid RF/LED link improves reliability and bit error rate performance; and provides greater immunity to blocking. Hybrid system realization requires advanced integration and packaging techniques to account for several order dimensional discrepancy between antenna geometries measured in millimeters at microwaves and typical submillimeter dimensions of active optical components. This study reports result of ongoing multi-university R&D efforts to create compact RF/LED transmit/receive modules for combined RF/FSO wireless communication. Two novel hybrid packaging schemes using two different microwave printed antenna approaches are explored for the integration of RF and FSO front-end circuits on a planar compact printed circuit board (PCB) with shared electrical and structural components. A hybrid RF/FSO package design was developed, prototyped and experimentally studied using a modified quasi-Yagi antenna and microstrip patch antenna. Dual-mode link connectivity was investigated in simulations and experiments. A data rate of 2 Gbps was demonstrated for the optical channel despite 15-20 dB electromagnetic coupling between the optical and microwave circuits.



Overview of the RF/Optical demonstration setup with packaged module and the experimental results

SPB2.1: Evaluation of Nearest Neighbor Communication using Free Space Optics (Ashish Agarwal)

Ashish Agarwal and Thomas D.C. Little

Keywords: Free Space Optical communication, Analytical model, multi-hop, delay, performance

Free space optical communication uses light propagating in free space to transmit data between two points. A potential application of this technology is for short-range communication for indoor and vehicle-to-vehicle safety communication applications. In this work, we study analytically, a network implemented by short range multi-hop communication. Specifically, we study connectivity and delay in data propagation in a network implemented by short-range optical communication. We consider different models of communication and observe the performance of data transfer for the given scenarios.

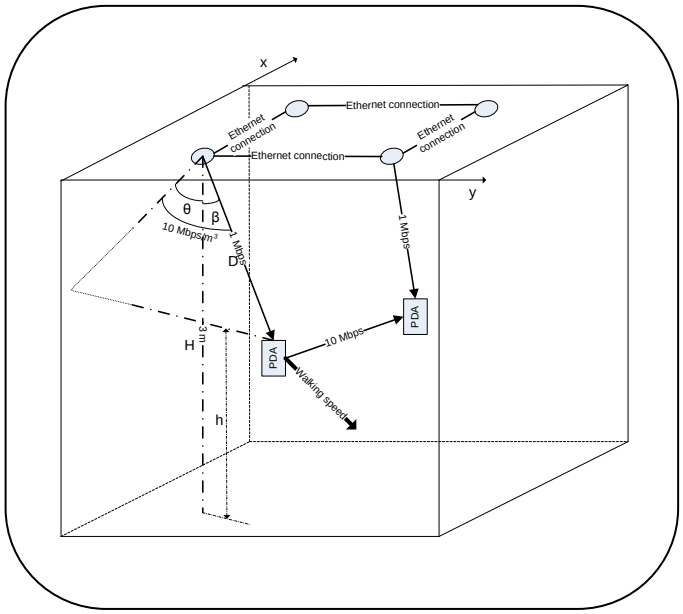
SPB2.1: Free Space Optical Networking with Visible Light: Modeling and Signaling (Zeyu Wu)

Zeyu Wu, Thomas Little

Keywords: Visible light communications, Multiple access, OFDM, CDMA, CSMA/CA

Currently, wireless communication is still dominated by radio frequency. However, several constraints limit its applications in certain scenarios. In the mean time, the rapid development of new light emitting diode materials and devices makes the LED based free space optical communication become a very attractive substitute or complement of RF techniques. Furthermore, it has been foreseen that visible LED with high power efficiency will replace most of incandescent and fluorescent lights in the next five to ten years. This will create a huge amount of opportunities in the area of FSO with visible light. However, it also faces many problems such as multipath distortion by diffuse link and dominant background light noise.

In our design, we present an original prototype system for indoor applications with hybrid network layers to flexibly adjust to different topologies. Then, two solutions for blocking problem will be introduced at network layer. Orthogonal Frequency Division Multiplexing will be discussed with optical signal constraints. It is widely used to reduce the multipath distortion which is a severe problem for diffuse link in FSO. Different modulation schemes are also used to accommodate different requirements. Furthermore its advantage on improving the channel capacity will be analyzed. Multiple Access is the other target for our design. Carrier Sense Multiple Access with Collision Avoidance can achieve it with simplicity. Direct Sequence Spread Spectrum is good to combat noise and interference while providing possible solution for simultaneous multiple access. Using it with OFDM signal for our design will be investigated.



SPB2.1: **Modular FPGA Based Networking Board for Visual Light Communication Systems (Dan Ryan)

Dan Ryan, Thomas D.C. Little

Keywords: Visual Light Communications, FPGA

The ultimate goal if Smart Lighting is to provide ubiquitous wireless networking through visual light communications. A necessary step towards achieving this goal is a bridge between the physical layer visual light link and the higher layers of the networking protocol stack. Our team has developed an FPGA based system to forge this connection. All components are mounted on a single 4" x 6" PCB, known as the "interfacing board". The interfacing board stacks directly on top of the transceiver board, and is responsible for sending both data and control signals to the transmitter. On the other end, the interfacing board contains an RJ-45 Ethernet connector that can provide networking services from the higher layers, thus completing the connection between the network and the visual light channel. An FPGA based design was chosen due to the high degree of modularity that reconfigurable hardware provides. As we move further along the development path, our system can be continually reprogrammed to incorporate higher levels of functionality such as CDMA, forward error correction, and new MAC protocols. Ultimately, we plan to port the HDL code implemented on our FPGA onto an ASIC.

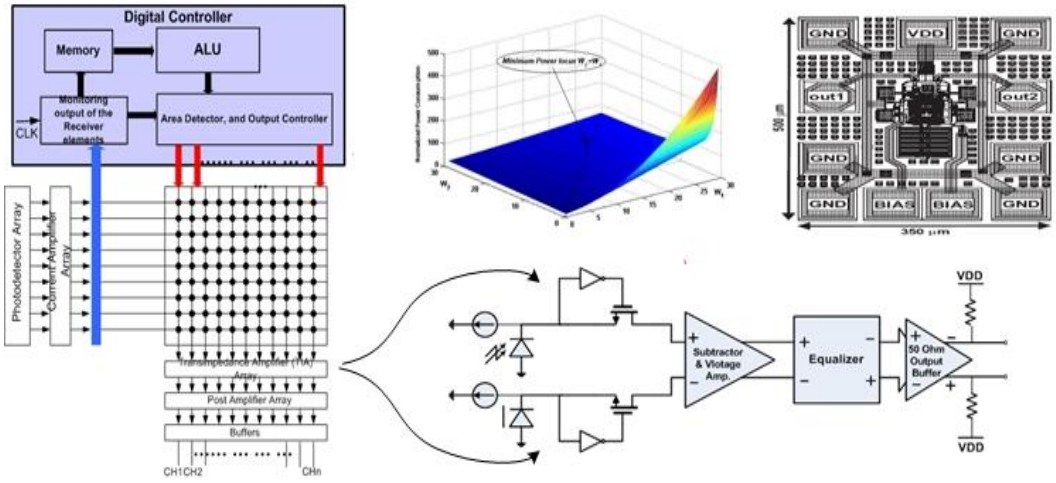
SPB2.2: Multi Element Fully Integrated CMOS Optical Receivers for Mobile Wireless Visible Light Communication (Behrooz Nakhkoob)

Behrooz Nakhkoob[1], Mona M. Hella[1]

[1]Department of Electrical, Computer, and system Engineering, Rensselaer Polytechnic Institute

Keywords: Integrated high speed optical receivers, wideband CMOS analog circuit design, CMOS-compatible photodiodes

Unlike omni-directional wireless communication systems, light exhibits primarily line of sight characteristics. Traditionally LOS detection/tracking has been addressed mostly for communication between static nodes or those with low mobility using opto-electro-mechanical beam steerers. The objective of this work is to design a digitally controlled optical transceiver array for multi-channel free-space-optical communication between mobile nodes while addressing cross-talk issues and electronic LOS tracking. We have successfully formulated algorithms for synchronizing the operation of the spherical-node optical transceivers to electronically detect and maintain LOS using embedded digital control. We will present a new imaging diversity receiver that employs the above algorithms and discuss implementation challenges such as the integration of large numbers of optical components with the transceiver circuitry to facilitate the control process and increase the communication speed. We target standard Si-CMOS technology as a platform for the proposed optical transceiver. The final outcome of our project is a *low cost*, *ultra-low power* single chip VLC imaging receiver capable of LOS tracking. The proposed low power transceiver architectures can be deployed for multiple indoor and outdoor scenarios, facilitating ubiquitous and secure communications that can be particularly effective in RF-restricted areas such as aircraft, spaceship, and hospitals.



Block Diagram of the designed Imaging Diversity Receiver, circuit and layout of the TIA/Equalizer and buffer

SPC1.2: Systems Modeling of Circadian Rhythm and Entrainment (Jiaxiang Zhang)

Jiaxiang Zhang[1], John Wen[1], Andrew Bierman[2], Mariana Figueiro[2], Mark Rea[2]

[1] Department of Electrical, Computer and Systems Engineering, Rensselaer Polytechnic Institute

[2] Lighting Research Center, Rensselaer Polytechnic Institute

Keywords: Circadian Rhythm, light stimulus, modeling and control.

The primary goal of this research is to control the human circadian pacemaker. Jet lag, shift-work, and non-24-hour schedules result in desynchronization of environmental time cues and the human endogenous circadian system from normal phase. Circadian misalignment can result in poor neurobehavioral performance, decreased sleep efficiency, and inappropriately timed physiological signals including gastrointestinal activity and hormone release. Frequent and repeated circadian misalignment is associated with long-term cognitive deficits and health problems.

The light receptor in the retina can affect the circadian rhythm. The nonlinear model of the effects of light on the human circadian pacemaker has been developed by Richard Kronauer. We are now working on simulation of the circadian model and using control and optimization methods to find out the time, duration and intensity of light stimulus which can rapidly change the phase of the circadian pacemaker and resynchronize the circadian rhythm with environmental time. With these methods, it is feasible to develop LED based goggles and lighting system to quickly achieve circadian entrainment and improve neurobehavioral performance for people who travel across time zones or work in night shift.

SPD1.1: Computer controlled solid-state lamp with high fidelity and saturation (Venkata Chivukula)

Venkata Chivukula[1], Arunas Tuzikas[2], Rimantas Vaicekauskas[3], Arturas Zukauskas[2], and Michael Shur[1]

[1]Department of Electrical, Computer, and Systems Engineering, Rensselaer Polytechnic Institute, 110 8th Street, Troy, New York 12180, USA

[2]Institute of Materials Science and Applied Research, Vilnius University, Saulėtekio al. 9-III, LT-10222, Vilnius, Lithuania

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We have introduced new metrics needed for evaluating the quality of LED lighting sources[1]. These metrics include color fidelity index (which is the percentage of accurately rendered colors) and color saturation index (which is the percentage of oversaturated colors). Using this new metrics, we optimized the wavelengths and relative powers of the LEDs composing a solid-state smart lamp for 8 values of correlated color temperature (CCT) specified by the ANSI standard (2700, 3000, 3500, 4000, 4500, 5000, 5700, and 6500 nm)[2]. We have designed and assembled a novel solid-state LED lamp with clusters of RAGB (red-phosphor based amber-green-blue) LEDs. The lamp comprises 7 clusters containing 4 LEDs each to obtain approximately 100 lm output. The relative powers of each LED were tuned to optimized values from numerical simulation by applying pulse width modulated (PWM) currents to obtain the trade-off between high fidelity and saturation indices. At the color saturation end point, the color saturation index of 67% and 80% for CCT of 6500 K and 3000 K, respectively. At the color fidelity end point, the color fidelity index of 75% and 87% for CCT of 6500 K and 3000 K, respectively. This lamp uses a microcontroller, which could be easily programmed and adapted to meet the user requirements and, therefore, is suitable for smart lighting applications that require the spectrum power distribution of light to vary depending on the illuminated object.

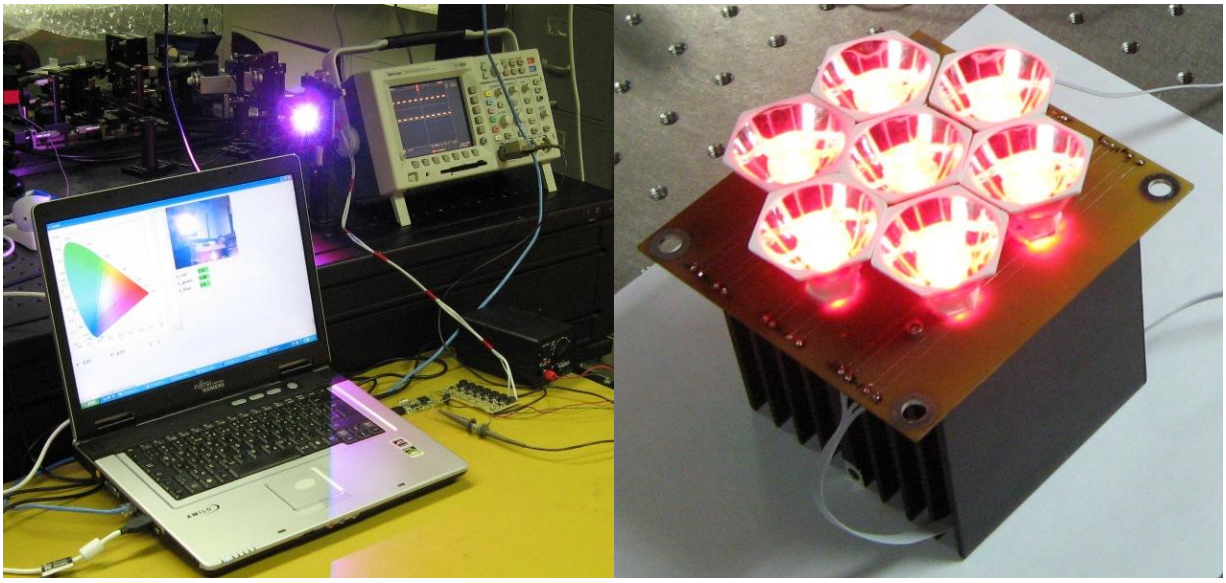


Figure 2 Designed and assembled LED based lamp cluster (right) and computer controlled user interface (left).

[1] A. Zukauskas, R. Vaicekauskas, F. Ivanauskas, H. Vaitkevicius, P. Vitta, and Michael Shur, "Statistical Approach to Color Quality of Solid-State Lamps," *IEEE J. of Selected Topics in Quantum Electronics*, 15 (5), pp. 1753-1762, 2009.

[2] A. Zukauskas, R. Vaicekauskas, and Michael Shur, "Solid-state lamps with optimized color saturation ability," - submitted

DP1: Nano-LED for light extraction enhancement and mode pattern control (Mei-Ling Kuo)

Mei-Ling Kuo, Mei-Li Hsieh, and Shawn-Yu Lin

There is a significant gap between the internal efficiency of light-emitting diodes(LEDs) and their external efficiency. We will show that by fabricating single nano-rod LEDs, the light extraction can be extremely enhanced and the radiation mode pattern can be controlled.

DP1: ***Optical ray-tracing simulations for the light extraction enhancement of UV light-emitting diodes (LEDs) with integrated surfaces (Yong Kim)

Yong Sung Kim, and Shawn-Yu Lin

Optical ray-tracing simulations show that integrated surface textures can effectively enhance the light extraction efficiency of UV LED. We will show the basic scheme of the Monte Carlo ray tracing method and the enhancements of the light extraction efficiencies of various various surface textures.

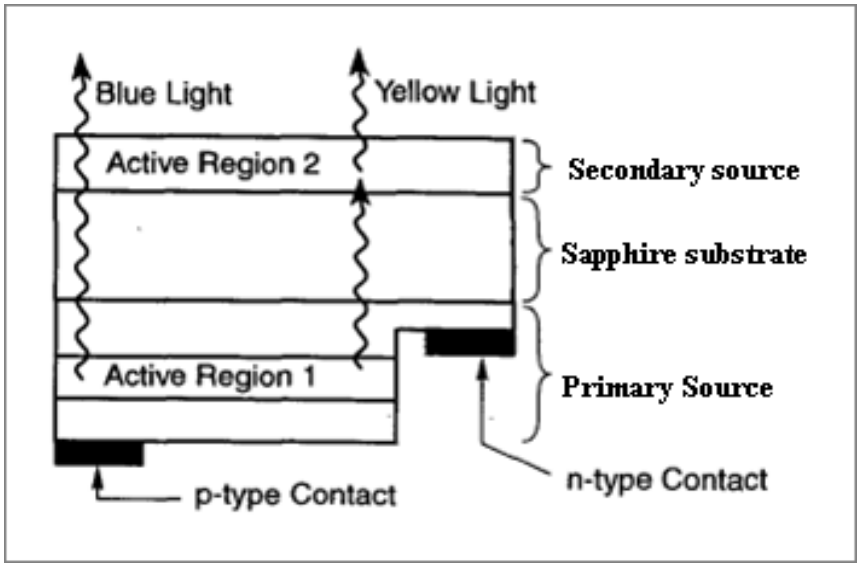
DP2: Melt grown optically transparent materials for down conversion LEDs (Adam Gennett)

Adam Gennett and Partha Dutta

Keywords: Growth from melt, LEDs, wavelength conversion structures, phosphors, green gap

Among the fundamental drawbacks of phosphor LEDs are (a) multi-phase phosphor particles

that leads to poor conversion efficiency except for well developed materials such as YAG, (b) scattering of photons from the phosphor layer due to randomly distributed particles with irregular shape, size and morphology, (c) opacity of the phosphor particles leading to photon trapping in the layer and re-absorption, etc. In this study we attempt to solve these issues by developing crystalline thin film based LEDs. These films will be poly-crystalline and optically transparent in nature, and be composed of selected high quantum yield materials grown from liquid phase onto ceramic substrates such as alumina, and grown layers may then be transferred onto other substrates such as glass or directly onto blue or UV LED chips. The emission wavelength of the down conversion LEDs will be tunable across the entire visible range between 470 and 700 nm. Of particular interest are materials with band gaps corresponding to wavelengths in the so called "green gap" of LED quantum efficiency, such as the ternary III-V compounds GaInP and GaAsP. The fundamental barrier is the attainability of high quantum efficiency crystalline films and the issue of re-absorption. In our research, we will focus on film growth conditions to address the quantum efficiency issue that is due to defects in the layer. In order to predict growth conditions such as temperature and melt composition necessary to grow the desired film compositions, phase diagram calculations are performed using commercially available Gibbs energy minimization software and validated by experimental results.



Schematic drawing of a light recycling system using thin film polycrystalline semiconductor material as a secondary source

DP3: Optical polarization of Non-polar GaInN/GaN LEDs (Shi You)

Shi You, Theeradetch Detchprohm, Mingwei Zhu, Wenting Hou, Christian Wetzel

Future Chips Constellation, and Department of Physics, Applied Physics, and Astronomy, Rensselaer Polytechnic Institute, 110 Eighth Street, Troy, NY 12180

Keyword: Optical Polarization, GaInN, Quantum Well (QW), Light Emitting Diode (LED), Nonpolar Plane

Light-emitting diodes (LED) that can emit polarized light would be greatly useful for many optical polarization sensitive applications, such as liquid crystal display (LCD) backlighting module. Improvement of epitaxial growth techniques enables the development of non-polar GaN-based LEDs, which shows strong in-plane optical polarization according to the polarization selection rule. Strong polarized light is observed from the m-plane GaInN/GaN based LED at the wavelength larger than 500 nm. At 20 mA the polarization ratio is estimated to be 0.62 with the peak emission wavelength at 507 nm. From the Photoluminenance measurement, the polarization ratio is seen increasing with larger emission wavelength in the blue and green range. The optical polarization of a-plane GaInN/GaN LEDs is also analyzed, which shows smaller polarization ratio compared with m-plane at the same emission wavelength. For the c-plane based LEDs, to get the same light intensity with certain polarization direction, its total light output power needs to be much larger than that of the m-plane based LEDs with high polarization ratio. Such great advantage of m-plane GaN based LED predicts its future application as the polarized LED.

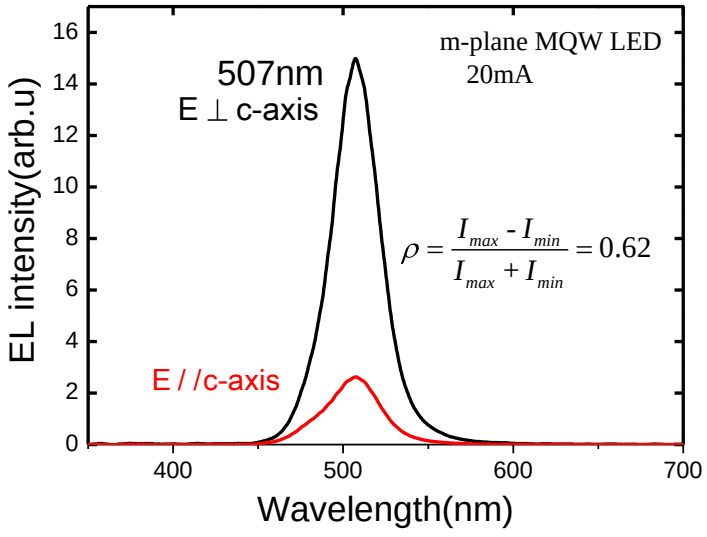


Figure 1. EL spectrum at 20 mA of m-plane LED with polarization direction along the c-axis and the axis with peak emission wavelength at 505 nm and 491 nm. I_{max} and I_{min} are measured with polarization direction along the a-axis and c-axis respectively.

MP1.1: GaN based NanoWire and NanoWall light emitting diodes (Ashwin Rishinaramangalam)

A.K. Rishinaramangalam, M.N.Fairchild and S.D.Hersee

The recent invention of a scalable process for the fabrication of uniform GaN nanowires has created a realistic opportunity for GaN devices, based on nanostructures, to transition from the research laboratory into industrial production. Previous work has demonstrated that the electrical, optical and semiconducting properties of c-plane GaN nanowires fabricated by UNM's pulsed-growth MOCVD process (Fig. 1) are of device quality. These nanowires exhibit an intense PL, in spite of their large surface-area to volume ratio, and lasing was observed when these nanowires were optically pumped at high intensity. This poster presents a revolutionary nano-LED based on a central nanostructure that is coaxially wrapped with an LED heterostructure (Fig. 2). This coaxial nano-LED will be naturally surface emitting and a high output coupling efficiency is anticipated. The active region is located on non-polar m-plane nanowire sidewalls, which should eliminate the quantum confined Stark effect and improve the radiative recombination efficiency. The demonstrated absence of TDs in these nanostructures, will further enhance the internal quantum efficiency of this LED, as well as reduce the reverse leakage current. Other anticipated benefits include the possibility of producing polarized electroluminescence, especially in the nanowall devices.

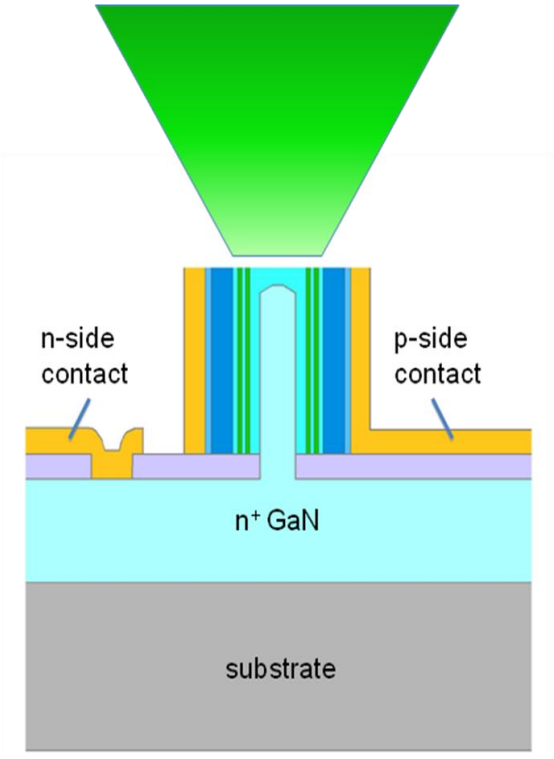


Fig 1. GaN nanowires grown on sapphire

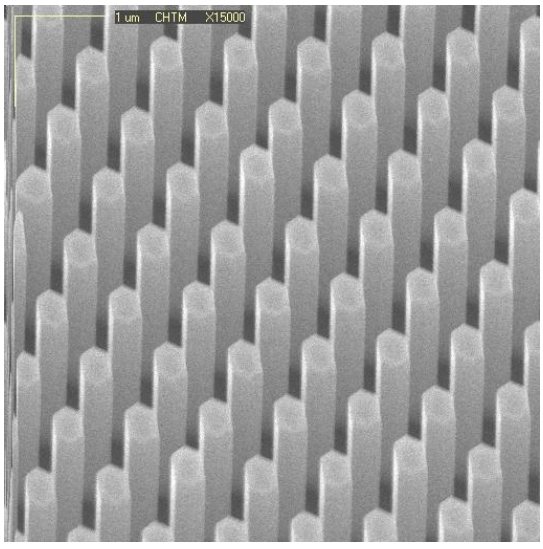


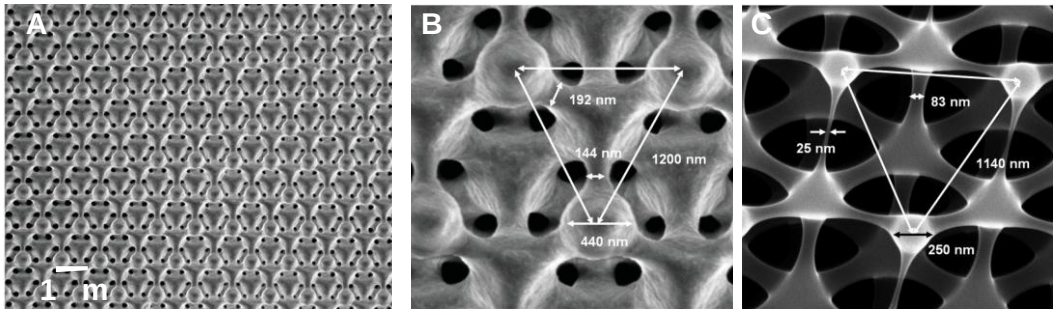
Fig 2. Core-shell GaN based nanowire LED

MP1.2: *Nanopatterning for Device Fabrication (Prof. Brueck)

S. R. J. Brueck

Keywords: nanoscale fabrication, large-area, interferometric lithography

Interferometric lithography, using of two or more coherent laser beams for maskless lithography, is a powerful technique for the inexpensive fabrication of large-area, nanoscale features. The critical dimension is $\lambda/4n\sin\theta$ where λ is the laser wavelength, n the refractive index of any immersion medium (typically water with an index of 1.44 at 193 nm), and θ is the half angle between the beams. The smallest features available are ~ 34 nm (using a 193 nm source with water immersion). Typical features for GaInN photonic crystals ~ $\lambda/2n_{GaN}$ are readily within reach. Both 2D and 3D patterns are possible. Examples will be given from a wide range of structures.



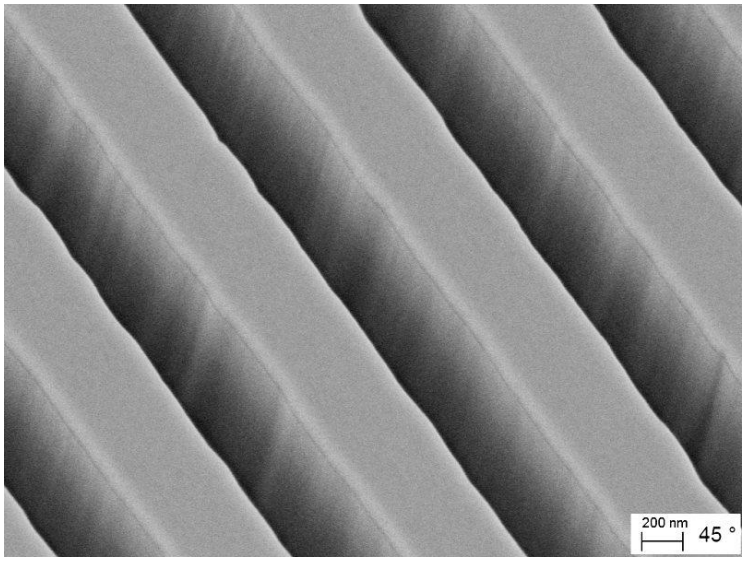
Low magnification view of 3D photoresist structure (NR-7) by 3 exposure, 2-beam IL. (B) High magnification view showing dimensions. (C) After pyrolysis showing amorphous carbon structures.

MP1.3: Nano-structured LEDs for structural wavelength control and enhanced light extraction (Christoph Stark)

Christoph Stark, Theeradetch Detchprohm, Christian Wetzel

Keywords: nano-fabrication, GaN, LED

LEDs are normally grown on large wafers and small non-uniformities during growth affect the final emission wavelength. This poses a problem for cases where a precisely defined wavelength is required. This challenge can be addressed by fine tuning the emission wavelength after the growth step by tailoring the piezo-electric fields inside green nano-structured AlGaInN LEDs. Spatial patterning is used to fabricate LEDs in the nano to micro-meter range. In these test experiments the photo resist patterns are generated by electron beam lithography, but any other high-volume method like deep UV lithography or nano-imprinting could be used. A durable Nickel hard mask is obtained by evaporation and a lift-off technique. This metal layer also serves as top contact to the nano-LEDs. The LEDs are etched by CAIBE or ICP of which the latter proves to be the method of choice in respect to uniformity and sidewall angles. These nano-LEDs are characterized optically and electrically and it is found that for feature sizes greater than 200 nm the light emission is still comparable to bulk LEDs. Even smaller dimensions are therefore required to shift the wavelength. This unique approach also offers the prospective that with smaller feature size we can enhance light extraction efficiency to increase the overall device performance. These novel and custom-tailored devices will be ideally suited for applications like live bio-imaging or specialized sensors.



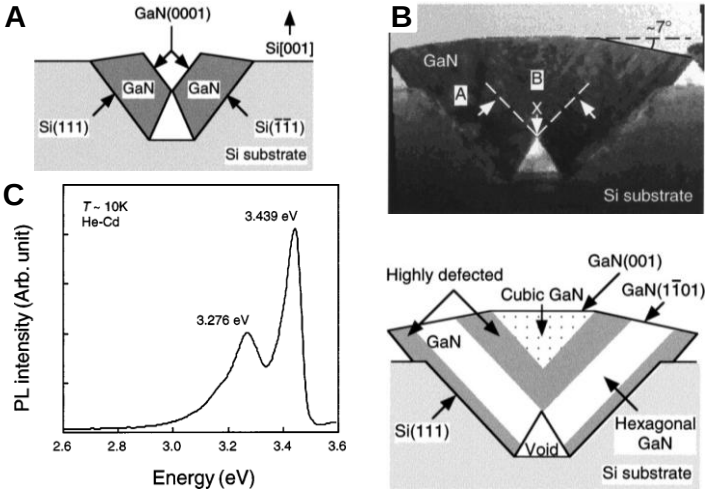
LED patterned with 500 nm wide finger structure.

MP1.4: *Cubic GaN Materials Development (Prof. Brueck)

S. C. Lee, M. Fairchild, S. D. Hersee and S. R. J. Brueck

Keywords: epitaxy, cubic phase, phase segregation, GaN on Si

Nanoscale growth is a new paradigm for crystal growth that can in principle avoid many of the constraints of conventional large area growth. Previously, we have demonstrated that phase segregation of hexagonal and cubic GaN occurs for growth on nanoscale V-grooves formed on a Si substrate. We describe approaches to extending suppressing the hexagonal phase and providing large area defect-free cubic GaN islands and films. Cubic GaN and related materials has many potential advantages for LEDs including: 1) higher p-doping densities; 2) higher mobilities and 3) elimination of polarization fields for growth along a (100) direction. Progress in growth and characterization of cubic GaN films will be discussed.



A. A schematic cross sectional view of the faceted Si surface along with selective growth of GaN on the Si(111) facets, leading to the formation of the secondary V groove. B. An XTEM image of a single groove of a 75-nm-thick as-grown GaN sample (top) and its phase map showing regions of hexagonal and cubic crystals separated by highly defected stacking fault regions (bottom). The point X corresponds to the initial coalescence point and formation of the secondary V groove. The surface of the GaN exhibits facets that are 7° off from the Si(001). C. 10K PL from the as-grown sample shown in B.

MP2.1: **$CdSe/SiO_2$ Nanophosphors for Daylight Quality Lighting Applications (Brian Akins)

Gloria Medina, Brian A. Akins, Tosifa A. Memon, Antonio C. Rivera, Gennady A. Smolyakov, and Marek Osiński

Center for High Technology Materials, University of New Mexico, 1313 Goddard SE, Albuquerque, New Mexico 87106-4343

Our objective is to develop nanocrystals optimized for various smart lightning applications. The application that we are focusing on is optimal lighting for color rendering from the point of view of human perception and energy efficiency. We are developing $CdSe/SiO_2$ nanophosphors through colloidal synthesis, with extensive structural and optical characterization. The choice of CdSe cores is dictated by their size-dependent broad color tunability. $CdSe/SiO_2$ core/shell quantum dots of different sizes will be produced, emitting from red to green. These crystals will be optimized by several multiple-stage improvements. The overall photoluminescence spectrum of the nanocrystalline mixture can be shaped in any desirable way by controlling the their sizes and concentrations. The composite nanophosphor material will be combined with a blue InGaN/GaN LED to produce white-LED's with spectral content approaching natural daylight.

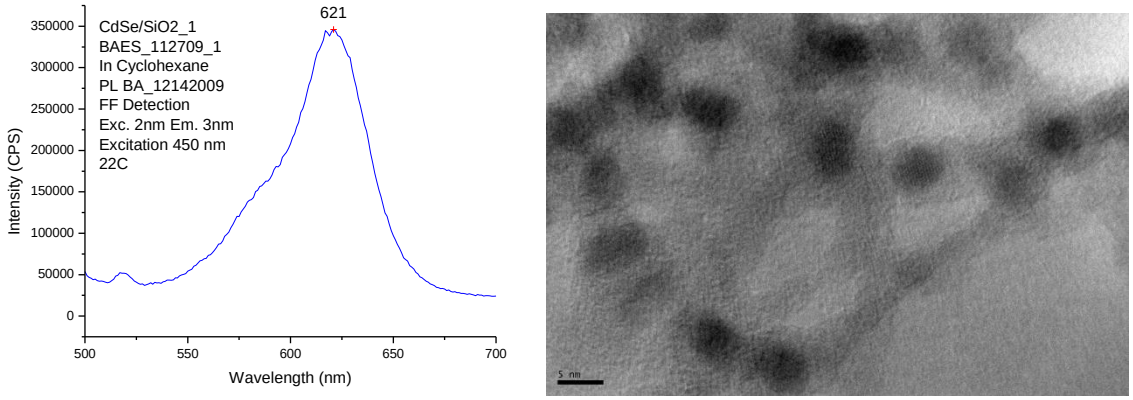


Fig. 1: (Left) PL spectrum of $CdSe/SiO_2$ NC's, (Right) high resolution TEM image of NC's scale bar 5 nm.

MP2.2: Nanofilled Polymers with High Refractive Index for Improved Light Extraction in LEDs (Peng Tao)

P. Tao[1], L. Schadler[1], R. Siegel[1], Y. Li[2], B. Benicewicz[2]

[1]Department of Materials Science & Engineering, Rensselaer Polytechnic Institute, Troy, NY 12180

[2]Department of Chemistry, University of South Carolina, Columbia, SC 29208

Key words: encapsulant, nanoparticles, phosphonate, click, grafted polymers

The low refractive index encapsulant materials severely limited the development of high-performance LED. In this work, well-dispersed titania nanoparticles were incorporated into polymer matrix to increase the refractive index of the encapsulant while keeping it transparent. Highly crystalline, near monodisperse TiO_2 nanoparticles (5 nm) have been prepared by well-controlled solvothermal reactions. The synthesized particles were surface modified through the design of versatile ligands, featured by a robust anchored phosphonate head group and a functional end group allowing for further modification. The good dispersion of nanoparticles was realized by compatibilizing the nanoparticle and matrix by grafting matrix polymer chains to the surface functionalized particles. The refractive index of the polymers can be tuned by controlling the loading fraction of TiO_2 nanoparticles, which in turn will improve the light extraction efficiency in LEDs tremendously.

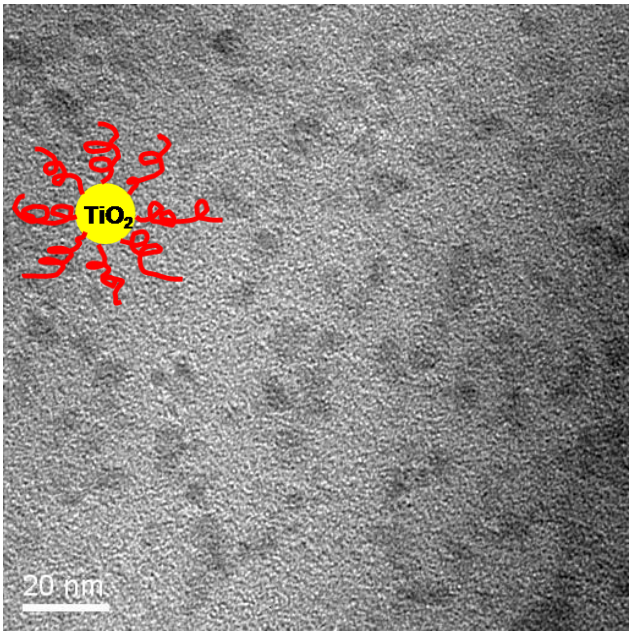


Fig 1 TEM image of hairy TiO_2 nanoparticles well-dispersed in polymer matrix

MP2.3: Novel Thin-Films for Optical Control in LEDs (Michael Riley)

Michael Riley

Keywords: nano-fabrication, LED, nano-spirals, oblique angle deposition, band-gap

The extraction efficiency of LEDs and terahertz sensors contributes to barriers preventing their widespread integration into all applications. Although anti-reflective (AR) coatings exist to mitigate and improve photon absorption, they have significant integration and performance restrictions. Here we investigate thin-film nano-spirals with customized morphologies grown on epoxy resins to improve light extraction for LEDS and terahertz windows. Utilizing physical vapor deposition and oblique angle deposition techniques, new levels controls of nano-structure morphology are demonstrated. Adding phosphorescing dyes to the nano-spirals will incorporate a photon energy down-shift strategy to control the quality of white light LEDs. Many extended potential applications exist for these materials once control is achieved, such as band-gap generation for photonic crystals, pressure sensing smart-materials, negative-index metamaterials, and possibly electrical actuation of spring height for band-gap/color tuning.

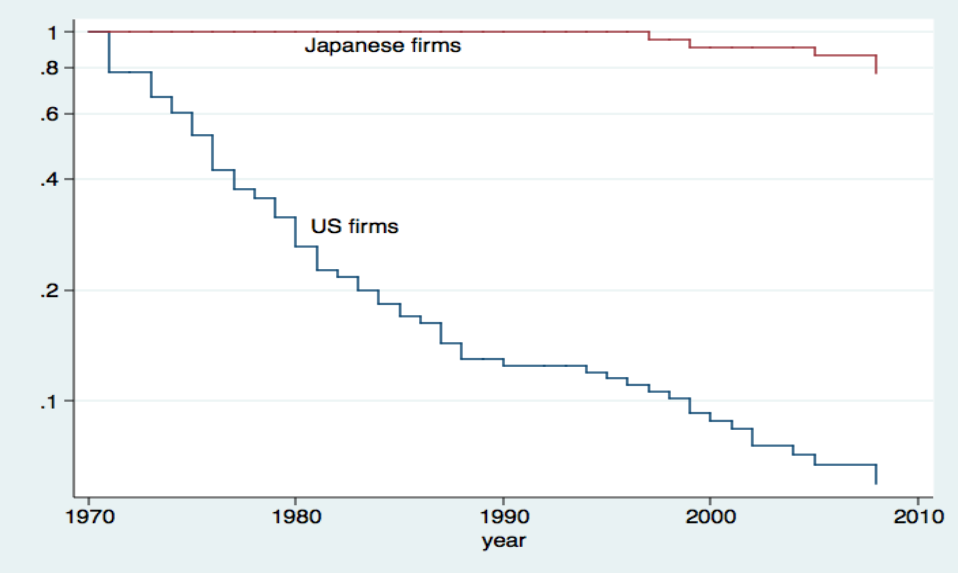
EP1: Firm survival and the dynamics of competition in the display industry (Murad Mithani)

Murad Mithani, Susan Sanderson, Kenneth Simons, Renessealer

Keywords: strategy, LCD industry, competition

A firm's success is associated with its ability to outperform the competition not just in the short run but frequently over decades. We studied entry and exit of firms in the global liquid crystal display industry (LCD) in the US and Japan from 1970-2007 using patent data, research literature on companies, and news media sources. Our research shows that the capability that a firm develops over time from its presence and success in an evolving market is a source of competitive advantage. The departure of the US firms that pioneered and led the industry at its outset shifted technological leadership to Japanese firms whose consistent investments paid off as new markets developed. We show that US firms, believing profits would be marginal, failed to make subsequent investments that would allow them to exploit their original technical advantage. Moreover, their early exit cost them dearly when the opportunity to capitalize on the new lucrative markets emerged as the technology matured. Electronic display is one of the fastest growing industries in the world with sales of $94 billion in 2006, expected to reach $200 billion by 2016 (OIDA, 2007, p. 101 - 2). This study has implications for firms developing innovative LED and OLED technologies and challenges them to find ways to persist in markets characterized by high uncertainty but where lack of persistence may undermine future competitiveness.

Firm survival in LCD industry by calendar year for Japanese versus US firms during the three stages of the industry between 1970 and 2008



EP1: **Technology Development and Commercialization of SSL in the global context (William Maio)

Kenneth L. Simons, Susan Walsh Sanderson and Team of Undergraduate Research Assistants, Presented by William Maio, URP, Renssealer

Keywords: SSL, commercialization, global competition

Project code: EP1

The determinants of successful development, commercialization and diffusion of SSL are not well understood particularly in a global context. Patent data provide one means to gain insight into these corporate and national R&D activities. However, existing SSL patent analyses have focused primarily on US patents. This study analyzes patents granted worldwide to probe differences between the U.S., Japan, Germany, the Netherlands, South Korea, Taiwan, and China, countries poised to play a key role in SSL's future. The growing role of Asian nations, corporate patent portfolios, the roles of individuals and universities, and relationships to national policy are analyzed.

The global context is crucial, because producers worldwide are competing to develop, manufacture, and market SSL technologies and products, with some nations promoting rapid development and adoption. Further study of this emerging technology in the context of the key firms and regions that are contributing significantly to its development would help U.S. firms and policy makers.

EDUC: High School Outreach at Boston University Using Smart Lighting (Travis Rich)

Travis Rich[1], Thomas D.C. Little[1]

[1]Electrical and Computer Engineering Department, Boston University

Keywords: Education, Outreach, High School, Mobile Studio Board

Students from all around the world register to take part in learning about visual light communication and smart lighting. Their experiences help them get a feel for college academics and the hands-on approach of Boston University engineering. The students, coming from 10^{th}-12^{th} grade, learn basic circuit theory, communication theory, and optics as well as the hands-on approaches that allow them to turn theory into practice. The course relies on the capabilities of the Mobile Studio boards to provide the tool set necessary for the students to explore these novel concepts. The students iteratively build up skills and knowledge to create a functional visual light communication system. The final system is built with two Mobile Studio boards and simple circuitry to facilitate a 5kb/s simplex visible light channel. The course additionally teaches the skills necessary for keeping a professional laboratory logbook, working in teams, and presenting scientific data.

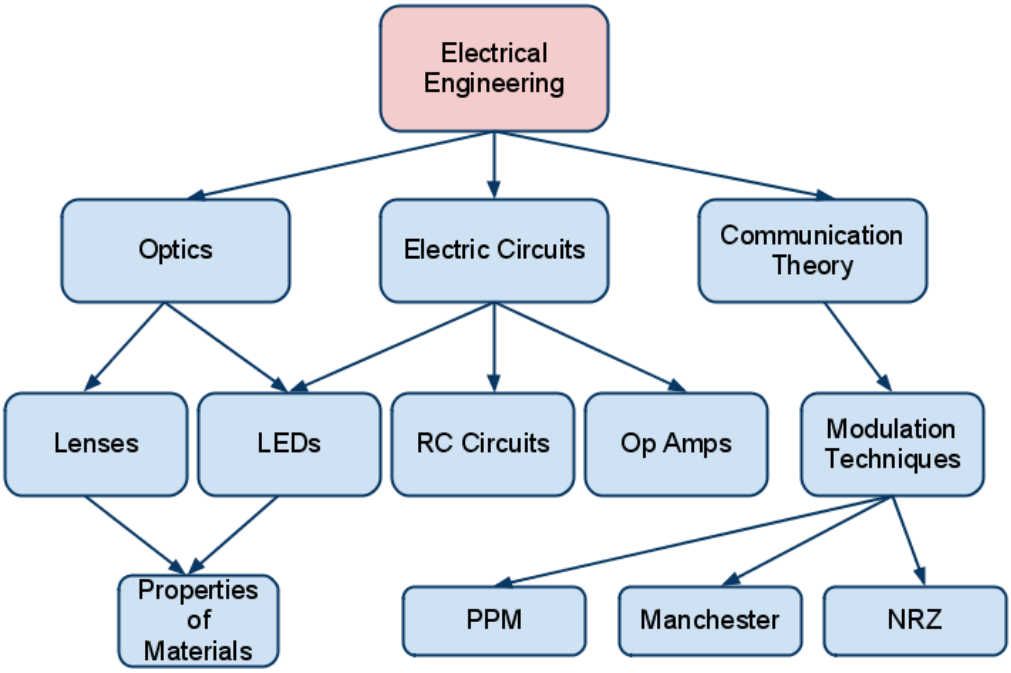


Chart depicting the material covered by the outreach program

EDUC: *NSF SMART LIGHTING ERC – Education Program (Prof. Connor)

Kenneth Connor, Don Millard, Thomas Little, Michael Ruane, Stephen Hersee, Fred Berry, Mohamed Chouikha, Charles Kim, Craig Scott, Yacob Astatke, Partha Dutta, Silvia Mioc, Mona Hella, Bill Brubaker and all ERC Investigators, Students and Staff

Keywords: Education, Outreach, High School, Mobile Studio Board

The **NSF SMART LIGHTING ERC** aims to create new lighting technologies to transform the way light is used and perceived. Two key components of our education and outreach programs are (1) ***Courses*** in smart lighting and related fundamental disciplines and (2) ***Learning Modules*** and other content for introductory and core courses in engineering and science. ***The Mobile Studio*** (http://www.mobilestudioproject.com/) provides a powerful, inexpensive instrumentation platform for our education and outreach activities. Additional details can be found at http://smartlighting.rpi.edu/.

An educational delivery experiment is being undertaken in which identical courses are being offered at all six ERC partner universities. To accommodate the quite different academic calendars, all lectures are recorded and are watched by students outside of regular class times. This method has been quite successful in fundamental engineering courses and is very similar in philosophy to the Studio Delivery method developed at RPI, which has not found widespread acceptance, largely due to the high costs of facilities common before the introduction of ***The Mobile Studio***.

The course materials developed will be made available to other engineering programs. To facilitate this transfer, a workshop was held in 2009 in which ECE department heads or their representatives from most HBCU engineering programs were introduced to the ***Mobile Studio*** and its potential to provide substantive hands-on experiences for their students in core courses (e.g. circuits, electronics, electromagnetics) in which Smart Lighting content is relevant. Smart Lighting educational content has also been incorporated in undergraduate design and research experiences at most ERC partner schools. To further build connections with our minority serving partners and to add to the pipeline of Smart Lighting and STEM students in general, an REU program is run as part of the Center. Preference is given to students from institutions with which the ERC has a significant relationship, so that follow up activities with faculty and students are possible.

EDUC: *NSF SMART LIGHTING ERC – Outreach Program (Prof. Connor)

Kenneth Connor, Don Millard, Thomas Little, Michael Ruane, Stephen Hersee, Fred Berry, Mohamed Chouikha, Charles Kim, Craig Scott, Yacob Astatke, Bill Brubaker, and All ERC Investigators, Students and Staff .

The **SMART LIGHTING ERC** aims to create new lighting technologies to transform the way light is used and perceived. Two components of our education and outreach programs are (1) ***Science You Can See*** that builds on the suitability of light for an accessible, engaging visual experience with strong societal impact and (2) ***The Mobile Studio*** (http://www.mobilestudioproject.com/) which provides a powerful, inexpensive instrumentation platform on which Smart Lighting education and outreach activities can be built. Additional details on our programs can be found at http://smartlighting.rpi.edu/.

Outreach activities involving ERC investigators and students have engaged students and teachers from a wide variety of K-12 organizations. A Smart Lighting learning experience was offered in the BU Summer Challenge program. For each two week session, high school students investigated and experimented with tools and technologies used in the development of novel LED lighting. Single day programs are also offered, such as the BU STEM Day and the RPI Exploring Engineering Day, which engage students in grades 3-6.

A variety of experiences are also offered for teachers. In addition to RET, workshops up to one week in duration, engage high school teachers in professional development focused on education in an engineering context. Teachers from Albany High School, for example, are part of a new Academy of Engineering, developed with guidance from the National Academy Foundation (http://naf.org/) Rose-Hulman also offered an intense one day workshop introducing Indiana High School teachers to the ***Mobile Studio,*** electrical engineering, and smart lighting. Future middle and high school teachers were also included in our summer REU program, which clearly benefited both the future teachers and engineering undergrads. The education students also participated in high school teacher workshops and were inspired by the highly committed teachers, especially those from experimental schools in Ohio, and the creative educational ideas discussed and implemented as the teachers developed their materials for the fall term.