Next-Generation Optical Components and Communication Solutions Based on GaN Nanowires

Just as the widespread excitement over material sciences generated by the awarding of the Nobel Prize in Physics for experiments with graphene in 2010 has quietly subsided, it’s been suddenly rekindled by this year’s award for the invention of blue light emitting diodes (LEDs). LEDs have been known as early as the 1950s when the first infrared and red LEDs were developed using semiconductor materials such as gallium arsenide. This was followed a few years later by the demonstration of yellow and green LEDs. The shortest visible wavelength, blue, remained elusive until the 1990s. The challenge was to create a semiconducting material with a sufficiently large gap in the electronic band structure to be commensurate with high energy of blue light photons. Additionally, semiconductor crystals needed to be almost entirely defect-free. While gallium nitride (GaN) had the appropriate band gap in the ultra-violet region, growing defect-free thin films was quite difficult. After some painstaking research into GaN growth, it was only in the 1990s that blue LEDs based on GaN heterostructures were first demonstrated by the researchers - an achievement that later led to energy-saving white LED lighting and leading further to countless advances in digital displays such as backlit smartphones, TV and computer LCD screens, and Blu-ray players.

It is noteworthy that material science has had a significant role to play in the progress that we observe around us. The discoveries that we make in the materials research labs today may not make their way into consumer products for some years. Almost all the technological advances that we take for granted today in electronics, medical instruments, telecommunications and elsewhere have been enabled by innovations in advanced materials. What is also noteworthy is that these innovations have been propelled further by parallel and rapid advances in the field of nanotechnology. Nanotechnology has helped to further the original materials innovations and often allowed for quick industry uptake of novel materials by providing inexpensive fabrication routes and use of small amounts of material for the

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realization of devices with the same or higher levels of performance.

In the Menon Laboratory, over the last 12 years we have been capitalizing on nanotechnology to carry out R&D activity with our eye on the next-big innovation. One material that we are actively researching at present is GaN. Unlike GaN thin films structures used in the blue LEDs, our lab is developing high quality, single crystal GaN nanowires using an inexpensive in-house chemical vapor deposition process. The Lab has made significant contributions in the controlled growth of GaN in unique nanoarchitectures such as horizontally-aligned hexagonal networks of GaN nanowires and perfectly periodic serrated GaN nanowires. Not only are the fabrication methods low-cost, they are also scalable which significantly improves the chances of their commercial viability. The Lab has also studied the optical and electrical behaviors of diverse nanoarrays, and we have shown that their characteristics can be tuned for specific applications.

There are several potential applications of GaN nanowires, including next-generation nanowire LEDs, solar cells, etc. One application that is of particular interest to the Lab are the arrays of nanowire-based lasers for optical communications. Free space communications applications are switching from using RF wavelengths to the optical end of the spectrum. The shift is being driven by imperatives for faster, cheaper and higher bandwidth solutions. NASA, for instance, has already successfully demonstrated the use of free space optical technology for data transmissions to and from the moon (LADEE project). The inherent material properties of GaN such as good radiation hardness, high carrier mobility, and high speed switching make GaN nanowires a perfect candidate material for free space optical communication applications. Menon Laboratory is poised to make an impact in this area due to its extensive experience with GaN nanomaterials which can lead to miniaturized low-cost, high-performance solutions. With this goal in mind Menon laboratory is partnering with a start-up venture, Nano Beam Technologies, for R&D activities in this application field for eventual commercialization.

Research at the Las Campanas Observatory

One of the most exciting prospects for graduate students in astrophysics is the opportunity to visit a large ground based telescope. My first such opportunity arrived in May 2014 when I travelled to the Las Campanas Observatory in Chile for two nights of observing. Home to the twin Magellan Telescopes, the Las Campanas Observatory lies 200 km into the desert, off the small town of La Serena and is operated by the Carnegie Institution for Science in Washington. The dry atmosphere in the region ensures approximately 300 cloudless nights a year making it a great place for large telescopes.

“Las Campanas”, which in Spanish means “the bells”, received its name due to the metallic rocks present in the area which, when struck, resonate a musical tone. You can find these rocks scattered in an around the observatory which is itself, a masterpiece of architecture. Two towering structures house the twin optical reflector telescopes, named after astronomer Walter Baade and philanthropist Landon Clay. Each consists of a giant mirror 6.5 m in diameter and can detect an object the size of an iphone, 36,000 km away.

Together with my advisor Dr. Saku Vrtilek, I set out to obtain data on low mass X-ray binaries (LMXBs) using the Magellan Baade telescope. LMXBs are systems with two stars rotating around each other where the primary star is a neutron star or a black hole. The secondary star, referred to as the ‘donor’, usually accretes matter onto the primary. Due to its angular momentum, matter cannot fall directly onto the primary star but instead forms a disk encircling it. As matter spirals inward through this disk, it heats up and emits radiation at ever increasing energies. Thus, each part of the resulting electromagnetic spectrum reveals information characteristic of particular segments of the disk. We concentrated on optical wavelengths which usually reveal the behavior of the outer disk and the donor star.

The resolution necessary to form direct images of these systems is orders of magnitude away from being available. Hence we use Doppler tomography, an indirect imaging technique that plays an important role in the study of these systems. Doppler Tomography can be compared to performing a CT Scan on a binary system. Spectra from XRB systems usually show characteristic double peak profiles which provide the radial velocities of a cross-section of the accretion disk. A time series of spectral “snapshots” of these line profiles taken as the binary rotates, allows us to reconstruct an image of the disk in velocity space. Such a reconstruction provides valuable information about the dynamics of the outer disk and the donor star, which helps in understanding how these systems function.

As the telescope zoomed into an ultra-tiny section of the night sky it allowed us to peer deep into our galaxy. The enormous number of stars in the resulting images just blew my mind. Even with the system coordinates at hand, finding the specific system we wanted to observe posed a challenging task. There have been instances where observers have obtained data on an incorrect system and we certainly did not want that to happen. Luckily, good finding charts enabled us to find the exact object we were looking for. The weather remained clear and we obtained sufficient data for our studies. Thus, our observing run turned out to be a fruitful one. We hope that the data gathered will contribute toward shedding light on the functionality of XRB systems and help us better understand how matter behaves as it approaches a neutron star or a black hole.

--Charith Peris, Graduate Student
Graduate Student Profile: Huan Yang

One year ago I took two large suitcases and arrived in Boston after a twisted two-day travel. I was tired, excited and more than a little bit scared of the brand new country, and the completely different life lying in front of me. One year later, when I look back, I won’t say life this year has been perfect, but I’m grateful that I met so many interesting and nice people who made my life lively.

The first year here was stressful. Four courses each semester and a TA job made me feel that I was overwhelmed, but this schedule made me be productive every day. I miss those days when all of us sat together complaining about how hard the homework was, how inhumane the Jackson text was, and how misleading the lab manual was. We laughed about all those little details, pouring our tiredness out to each other and then we continued with our day: having lectures, solving problems together, preparing and teaching labs.

I kept hearing people say pursuing a PhD degree in science is a long and really painful process. However, with all the great people around, the process became really interesting to me. I feel really happy that there are so many social opportunities in the department. I always had a great time talking with other graduate students and professors during department events such as the department cookout, the ice cream social, the Lawrence awards and the graduate coffee hour.

My research experience here is quite joyful. I feel lucky to have been able to do research in Prof. Whitford’s group the second semester and summer I. My research is focused on modeling the ribosome system. The Ribosome system is a large system with over 150,000 atoms, hence the modeling of the system usually takes months to finish. In order to cut the computing time I’m working on finding the optimized boundary conditions for a reduced system with some specific part of the ribosome system which we are interested in. Though it’s only a small project for summer I, I am very interested in related research on the ribosome system and I look forward to future research in Professor Whitford’s group.

—Huan Yang

Department Nota Bene

Honors

Arts and Sciences Distinguished Professor of Physics and Director of the IGERT Nanomedicine Science and Technology NCI/NSF Center, Sri Sridhar received a $1.15M grant from the NIH’s National Cancer Institute to train the next generation of cancer nanomedicine scientists and clinicians through a unique experimental training program.

Associate Professor Latika Menon was named a Fellow of the Institute of Physics this year. She was also elected Fellow of the Institute of Materials, Minerals, and Mining last year.

Professor Mark Williams received a $950K NSF grant to probe single molecule DNA-ligand interactions.

Congratulations to Trithep Devakul (Physics ’16) for winning a 2014 President’s Award. The President’s Awards go to the top students in the graduating classes of 2014, 2015, and 2016.

Undergraduate James Maniscalco (Physics ’14) received a Hodgkinson Award this past spring. The Harold D. Hodgkinson Award is a university-wide award that is one of the highest honors a senior at Northeastern University can receive. The award is based primarily on distinguished scholastic achievement with due consideration of character, personality, qualities of leadership, cooperative work experience, and service in voluntary organizations and activities. James was accepted into the Accelerator Physics PhD program at Cornell University and is attending this fall.

Highlights

The Physics Department and College of Science will be hosting the 8th North American Mössbauer Symposium, January 8-9, 2015. This symposium is the only conference devoted to multidisciplinary applications of nuclear resonance spectroscopy. Speaker profiles and registration information can be found at www.northeastern.edu/cos/mossbauer.

Lawrence Awards

The 2014 Lawrence Awards were held on April 14 at Northeastern’s Raytheon Amphitheater. Congratulations to our winners.

Excellence in Teaching

First Year: Andrew Spisak
Second Year: Christopher Lane
Advanced: Alexander Hyde
Undergraduate: Jack Helmann

Graduate Academic Excellence

Prasad Bandarkar
Christopher Lane
Wei Fan

Journal Club Speaker Award

Rohan Gala

Undergraduate Scholastic Excellence

Trithep Devakul
Keith Harrigian
Nicholas Haubrich
Sara Klem
Tushar Swamy
Nicholas Haubrich
Julie Wiedemann
Jacob Wolfsberg

Undergraduate Research

Nicholas DePorzio
Trithep Devakul

Graduate Co-op Fellowship

Andrew Clark

Lawrence Awards 2014: Department Chair Paul Champion, undergraduate Trithep Devakul, and Professor George Alverson.

Lawrence Awards 2014: undergraduate seniors Justin Dowd, Laura Fleming, and James Maniscalco.
**Congratulations to our 2013/2014 Physics Degree Recipients**

**Doctor of Philosophy**
- Sujeeet Akula
  Advisor: Professor Pran Nath
  Exploring Models of Supercosymmetric Grand Unification with LHC and Dark Matter Phenomenology
- Badih Assaf
  Advisor: Professor Don Heiman
  Magnetotransport in Thin Films and Heterostructures of Topological Matter
- Arda Halu
  Advisor: Professors Ginestra Bianconi and Alessandro Vespignani
  Dynamics of and on Complex Networks
- Mengxi Liu
  Advisor: Professor Pran Nath
  Theory Space of Supersymmetry in View of LHC Data on Higgs and SUSY Mass Limits
- Zheng Ma
  Advisor: Professor Latika Menon
  Synthesis, Properties, and Applications of GaN Nanowires
- Yangpeng Ou
  Advisor: Professor Jeffrey Sokoloff
  Investigations of Mechanical Properties of Polymer Brushes and Hydrotgels Through Molecular Dynamics Simulation

**Master of Science**
- Gregory Peim
  Advisor: Professor Pran Nath
  Multicomponent Dark Matter: Possible Signatures at Colliders, Satellites, and Underground Experiments
- Yuhan Sun
  Advisor: Professor Paul Champion
  Investigations of Protein Induced Heme Distortion Using Raman and Vibrational Coherence Spectroscopy
- Dashun Wang
  Advisor: Professor Albert-László Barabási
  Statistical Physics in the Era of Big Data
- Hao Wu
  Advisor: Professor Mark Williams
  Nucleic Acid Chaperone Activity of Retroviral Nucleocapsid Proteins

**Bachelor of Science**
- Andrew Allerdt
  James Eakins
  Brittnay Haffner
  Robert Henley
  Christopher Lane
- Mitchell Lawrence
  Dina Mistry
  Michael Percuoco
  Daniel Rubin
- Meriem Bahira
  Akhil Balraj
  Justin Dowd
  Laura Fleming
  James Maniscalco
  Susie Nimittpattana
  Mannis O'Brien
  Michael Spens
  Rachael Tompa
  Cung Tran

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The Physics Challenge is an opportunity to make a lasting contribution to the future of the Physics Department and the University.

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Your support is essential to furthering our mission to provide our students with education and experiences that will help transform their lives.

For more information on how to give, please contact

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