On Wednesday, March 14, 2012, around 11:30 AM, Stephen Fahey officially joined the ranks of well-known Microphysics Laboratory (MPL) graduates and earned the right to place “Ph.D.” next to his name. The committee, consisting of four Physics faculty, the Vice-Rector of University Namur, Belgium—also an Adjunct Professor at Physics and a Research Scientist from the U.S. Air Force Research Laboratory (AFRL), Kirtland, NM, gave their seal of approval for his dissertation entitled “Selective Area Epitaxy of CdTe on Nanopatterned Substrates”1 after a more than 90 minute long intense question and answer session behind closed doors.

Stephen arrived at his office in MPL around 6:00 AM for his 9:00 AM thesis defense presentation on March 14, which took place in front of his thesis committee members, his peers from MPL and other Physics faculty, staff, and most notably, Mrs. Jennifer Woodard, who is the Associate Vice Chancellor for Civic and Corporate Relations at UIC2. Mrs. Woodard met Stephen on March 1, 2012, on her second visit to MPL. Stephen gave her an extensive tour of the laboratory, explaining the research topics explored in the MPL and their applications. She was impressed with Stephen’s research and made plans to attend his thesis defense. After Stephen finished presenting his dissertation, Mrs. Woodard took a few minutes to make some remarks before the audience. She complimented him on his presentation skills, his enthusiasm and motivation to educate his audience about his subject and his skillful ways on describing a very complex topic in layman’s term so that a non-Physics person like her, who has a judicial background, can easily understand the topic and its applications.

1Go to page 6 to read Stephen’s abstract.
2On March 6 2012, Mrs. Jennifer Woodard was appointed by Governor Pat Quinn to the Illinois Medical District Commission (IMDC), which oversees the largest urban medical district in the country, as she continues her role as Associate Vice Chancellor at UIC. Source: http://www.illinois.gov/PressReleases/ShowPressRelease.cfm?SubjectID=19&RecNum=10074
Developing an Interest in Science

When asked about the catalysts for his pursuit of science, Stephen remembers that he had a strong interest in exploration in his childhood. When he was 4 or 5 years old, he says he lived in a house with river-bed rock landscaping. He would play with rocks and break them apart to see what’s in them. “I still remember the amazement and satisfaction that I had when discovering one day that I could use a large rock to break apart otherwise mundane small rocks to occasionally find beautiful colorful mineral patterns inside. Every rock was different, and each one was challenging” says Stephen “As I remember, the challenge was two-fold: first, to predict the cross-sectional pattern of the interior by examining the exterior size and weight, and second, to actually break the rock in half”. He analyzed his nanopattern materials data in a similar fashion.

Early Years of Graduate Study

Stephen’s love for science gained momentum as he enrolled in the Physics Graduate program at UIC in 2005. He was motivated to challenge himself, explore the natural world and contribute to the society. His first interactions with MPL started with a laboratory tour by Dr. Yong Chang and a lunch with Dr. Siva Sivananthan, the Director of MPL. His first interaction with the OPUS molecular beam epitaxy (MBE) chamber was facilitated by Thomas Seldrum, then a visiting graduate student from the Laboratory of Physics Electronic Material Studies of the Department of Physics, University Namur, Belgium, who was studying the MBE growth mechanisms of patterned CdTe layers. Stephen says MPL attracted him as a research environment grounded in real world applications, focussed on nanotechnology and with resources to do the research. He had an experience in a research environment before coming to MPL. He was an intern at the NASA Glenn Research Center for 6 months in 2003 working on quantum dot solar cell development. “I had been briefly introduced to semiconductor technology and MOCVD crystal growth previously at NASA, so I had an awareness of the value of such a research environment.”

As he occupied himself with reading the literature on various CdTe and HgCdTe-related studies and exploring various topics, he was drawn into improving alternative substrates for infrared semiconductors. “In general I believe that the power of nanotechnology is even yet unrealized. When I heard from Siva that a particular nanotechnology could improve more conventional semiconductor technology in the infrared sensor world, I had to know more”. Afterwards he spent his time studying, experimenting and eventually writing his thesis, “Selective Area Epitaxy of CdTe on Nanopatterned Substrates”. The obstacles he faced were logistical, such as getting all procedural details aligned to ensure success. He spent most of his time learning subtle characteristics of MBE, technologically a challenging process, and sample preparation. “There is a running joke that the time-constant of MBE is at least one day; that is, most things the [MBE] experimenter may want to explore with the system and process, will take at least a matter of days to observe”.

3 OPUS MBE Chamber in MPL: http://www.uic.edu/depts/mplab/laboratory/opus.html
**Research Topic and New Directions**

In his 237-page thesis, Stephen describes how he experimentally and theoretically made significant advances towards his original goal of improving the crystalline quality of thin films of CdTe grown on Si substrates by MBE through lowering the dislocation density terminating at the surface of CdTe by utilizing a nano-patterned CdTe-Si interface. One of the earliest works along these lines was conducted by Dr. John Reno⁴, an alumnus of MPL, at Sandia National Laboratories. “The research I did on this topic was essentially an exploration and development of an idea that had been floating around MPL to use selective growth to improve MCT diodes. I was not able to show that the idea will definitely work, but I was able to contribute several key new observations and results that will help other researchers to continue this line of research” say Stephen as he summarizes the outcome of his thesis work.

Dr. Yong Chang, Research Associate Professor of Physics and a member of Stephen’s thesis committee, points out that Stephen’s research concept follows the footsteps of the similar studies that were performed at Rockwell Science Center (known as Teledyne⁵ today) and the U.S. Army RDECOM CERDEC Night Vision Electronic Sensors Directorate⁶ (NVESD) at Fort Belvoir, VA. He also acknowledges similar work that was published by Dr. Thomas Seldrum⁷. Having said that, Dr. Chang emphasized how Stephen’s research took previous work on this topic to the next level. He highlights that the results that Stephen obtained contributed to a better understanding of nanopatterned structures on Si.

On the future prospects of his work, Stephen says that his research was primarily directed toward improving alternative, silicon-based substrates for MCT infrared diode fabrication. He suggests “That application may possibly benefit from the results I have already established, but is more likely to benefit further down the road, as this research topic is further explored in the future”. On the same topic, “Tremendous efforts are required to achieve what we plan to achieve” says Dr. Chang as he stresses the need for future work. In fact, as Stephen points out, some of the potential questions that have risen from his thesis for further investigation are:

1. Can a nanopatterned interface structure trap deleterious dislocations and capture point impurities efficiently enough to improve diodes 10 or 20 micrometers away?

2. Can electron-beam patterning be used to grow thin films with identical dislocation densities to the highest quality crystals known for that material (bulk-grown material)?

---

⁶ “HgCdTe Heteroepitaxy On Si Substrates For Low-Cost, Large Format, Dual-Band Infrared Focal Plane Arrays” L.A. Almeida, M. Groenert, J. Molstad, M. Carmody et al., Proceedings for the Army Science Conference (24th) held on 29 November to 2 December in Orlando FL (2005).
(3) Can this technology be used to improve other heterojunction devices; for example can it be used to make multijunction solar cells more efficient?

Receiving Guidance

Stephen’s thesis committee consisted of six members: Siva Sivananthan (chair and adviser), Chris Grein, Yong Chang, Robert Klie from UIC, Robert Sporken§ from University of Namur, Belgium and Chris Morath from AFRL Kirtland AFB, NM. Throughout his research, he consulted his thesis committee many times and published peer-reviewed papers with most of them. “I am grateful to all of them for listening to many of my presentations in MPL, and bringing key concepts into the foreground for me” says Stephen as he acknowledges their valuable feedback. Dr. Yong Chang had long been working with Stephen on various projects at MPL. “He is a very good engineer and [he] deeply understand[s] the physics behind [this topic] and explore[s] new approaches to accomplish the goal” says Dr. Chang and adds that Stephen knows how to focus on details, which may be considered one of his strengths.

As he consulted with his committee members, Stephen had countless discussions and debates with his peers and other Physics faculty. In fact, Stephen mentions one particular group that helped him figure out the logistics of his research: the Physics machine shop. Located on the first floor of SES, the Physics machine shop is a go-to-place for many scientists and engineers, who want to design, fabricate and construct complex laboratory apparatus and instruments. Stephen says he gained considerable knowledge from this group by discussing designs and machining techniques. “Without exception, every time I visited them with a set of ideas to bring to life, they would have something to show me or teach me in order to reach an optimal final product”.

Path to a Successful Dissertation

When asked about the actions he took for his successful thesis defense, he says “Most of the “defending” occurred in my mind, as I prepared my thesis against my own interrogations”. He describes his thesis manuscript is as his core document. At the very early stages he drafted an outline of his thesis chapters. He defined the steps and modified the outline as he advanced through the stages. He says if the manuscript is good, there is not much defense to do; it’s a matter of explaining it. Another thing that helped him prepare a strong thesis was asking all the possible questions. He constantly made an effort to see others’ point of view and experiment with different arguments. “Think about the document [your thesis]; its value to the people and why; what supporting information will it need; what are the conclusions and the interpretations of the data” says Stephen.

8 Dr. Robert Sporken has an adjunct Physics Professor appointment at the Department of Physics.
as he identifies the key factors that contributed his thought process.

Stephen is familiar with presenting his work to a panel of professors. Indeed he was a recipient of a Graduate Assistance in the Areas of National Need (GAANN)\(^9\) fellowship in Applied Physics for four consecutive years from August 2007 until May 2011. GAANN fellowships, supported by the U.S. Department of Education, are awarded to graduate students by their departments with excellent records who demonstrate financial need and plan to pursue the highest degree available in their course study at the institution in a field designated as an area of national need. As a GAANN fellow, his research progress was reviewed by a group of UIC professors who served as internal and external reviewers of this program. Stephen gave five presentations in front of these reviewers, who not only gave feedback on the quality and progress he made in his research but also on his presentation skills at meetings called GAANN Student Forums. Stephen gives credit to GAANN Student Forums as they helped him understand other points of view and develop his presentation and critical thinking skills. The feedback helped him be aware of the assumptions he made throughout his research, make accurate statements and to see how well his predictions and data are tied to each other.

Over the years Stephen has worked with and mentored many graduate and undergraduate students. He has become MPL’s go-to person whenever a laboratory tour is needed, particularly to potential students and visiting faculty. Eric Colegrove, a Ph.D. student in MPL whose research interest is CdTe solar cells, acknowledges Stephen’s contribution in his decision to come to MPL and enroll in the graduate program of the Physics department. “I’m not sure if he realizes this, but Stephen is part of the reason I am in MPL today” says Eric. “I took a tour with him while visiting the university as a senior undergrad [from Hamline University, Saint Paul, MN] and was enthralled by the facilities and his passion for the physics surrounding this equipment\(^{10}\) and the devices they can produce. I’m certain that Stephen will go far and his thesis will most definitely be an invaluable resource as I continue my study here” adds Eric as he further commented on his first interaction with Stephen.

Future Aspirations and Final Advice

After his graduation, Stephen hopes to be working as a post-doc at the U.S. Air force Research Laboratory, Kirtland AFB, Albuquerque, NM, where he spent the summer of 2011 and two weeks in January 2012 as an intern with the Advanced Electro Optics Space Sensors Group. Academia is also an option for Stephen as he can see himself as a professor in a university helping younger generations reach their own insights.

Finally, Stephen has two suggestions for the new graduate students and senior undergraduate students considering applying for a graduate program:

---

\(^9\) For more information on GAANN program, please visit: http://www2.ed.gov/programs/gaann/index.html

\(^{10}\) OPUS MBE Chamber in MBE: http://www.uic.edu/depts/mplab/laboratory/opus.html
“(1) There is a lot of work to be done in science today. That means you get to chose something of interest and value to you, as well as the broader community. (2) Don’t balk at simple problems; many problems are much more involved and valuable than they first appear.”

**THESIS ABSTRACT**

**Selective Area Epitaxy of CdTe on Nanopatterned Substrates**

Stephen Fahey

Advisor: Professor Sivalingam Sivananthan

HgCdTe/Si devices can potentially be significantly improved by the use of nanopatterned substrate structures on Si to control point and extended crystal defects. This thesis contains an exploration of one such nanopatterned substrate structure on Si. The results include the demonstration of selective area molecular beam epitaxy of single-crystalline CdTe against Si₃N₄, SiOₓ, and diamond-like carbon mask materials; as well as the coalescence of CdTe grown in selective areas, against Si₃N₄ mask. The coalescence is shown to have an in-plane asymmetry related to step-flow growth of CdTe(211). The coalesced film is also shown to have small surface corrugation, related to the initial separation of neighboring seed islands. This thesis further reports on the feasibility of a patterned 500nm-pitch Si₃N₄ and CdTe interface structure to reduce the dislocation density intersecting the final surface of CdTe/ZnTe/Si(211) grown by molecular beam epitaxy. It is found that the patterned substrate structure tested in this thesis work is likely insufficient to reach that goal, as the strongest x-ray diffraction peak from the patterned samples reported here is 7 times wider, and so implies the dislocation density is higher than unpatterned growth of CdTe/ZnTe/Si(211) under identical growth conditions. To achieve a comparative reduction in dislocation density on a patterned substrate, the fabrication of smaller and closer seeding islands is recommended.

About Microphysics Laboratory, at the Department of Physics, University of Illinois at Chicago, IL, USA. The Microphysics Laboratory (MPL) at the University of Illinois at Chicago is currently the only university laboratory in the US performing fundamental research on HgCdTe (a.k.a. MCT) by Molecular Beam Epitaxy (MBE) since its inception in early 1980s. It is a center for applied physics research with an emphasis on II-VI materials and devices for infrared sensing and imaging and photovoltaic cells. Since 1982, MPL has been awarded over $30 million in external research support to develop better night vision and photovoltaic applications. Professor Sivalingam Sivananthan is the director of MPL since 1994 and has worked in semiconductors and infrared and night vision detector technology, helping to pioneer the synthesis of the now-dominant high-end infrared detecting/night vision semiconductor material, MCT. MPL’s research is focused on the optimization of the MBE growth of MCT, the study of in-situ/ex-situ doping and transport, and the growth of high quality alternative composite CdTe/Si substrates to be used for the growth of large area HgCdTe. MPL’s fundamental research activities have resulted in the training of experienced MCT scientists who have transferred the lab’s knowledge base and traditions of excellence to many industrial and governmental research institutes including DRS Technologies,
Northrop Grumman, Teledyne Scientific & Imaging, the Army Night Vision Laboratory, and the Army Research Laboratory. There are six faculty and a project coordinator, who work on MPL projects, programs and initiatives. It is also a home to six graduate and three undergraduate students, who typically obtain internship opportunities at Army agencies or industry due to our strong network of collaborators.