Final Sabbatical Report to the University of Wisconsin-Platteville

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My Spring 2008 semester at the University of Newcastle, Australia, was a rewarding experience professionally, academically, and personally. I worked with Professor Paul Dastoor’s group in the Centre for Organic Electronics and learned to fabricate and test organic solar cells. We also developed a new method to probe the physics underlying these devices, with some tantalizing early results. While “down under,” I also learned about the University overall, and prepared a web site to assist future UWP students and colleagues who wish to visit. Finally, I brought my wife and children with me, and the experience of bonding and living in a different country was priceless.

Pre-Sabbatical Goals
My research goals were to make a contribution in the field of plastic solar cells, to become better able to perform independent research in this field, and to continue this work back at UW-Platteville, involving students, and to enhance our developing educational program in nanotechnology. My goals related to teaching and advising were to gather information on prospective courses that UWP students and Study Abroad participants may take at Newcastle, to present our programs to Newcastle faculty and students, and to explore possibilities for international educational collaboration. These goals followed several of the Regents’ priority areas, and I feel I was successful in meeting these goals.

Research Goals and Outcomes
Preliminaries
Because this field was new to me, my host and I did not decide on a research direction until shortly before my arrival. I used the time before the start of the sabbatical to get caught up on the literature and to attend the Materials Research Society Spring 2007 conference to get a feel for how work was done in this field: what are the standard procedures, expectations, etc. In addition, I had several UWP students construct titanium dioxide nanocrystalline solar cells with me, in both an Independent Study course and the new “nano” course, Chem 4520, in order to gain some hands-on experience in advance of the trip. By the time I left on Christmas Day 2007, I was reasonably well versed on the state of the field, the terminology, and the underlying physics, and was ready to dive into the work.

Work done in Newcastle
Prof. Dastoor, UN Physics professor and director of the Centre for Organic Electronics (formerly the Centre for Organic Technologies), matched me with Garth Berriman, a new graduate student. Our project was to extend work Garth had done for his senior thesis and to improve the quality of the results.
This project studied the nanometer-scale distribution of current in an organic solar cell ("plastic solar cell") by illuminating a small (200 nm) patch of the device and measuring the photocurrent output. By scanning this patch over the device, a photocurrent map can be constructed: the technique is referred to as NSPM (near-field scanning photocurrent microscopy). Briefly, the organic solar cells consist of two materials that are mixed and allowed to crystallize. These materials serve multiple functions: they absorb the light, they accept (or donate) electrons to/from the other material, and they conduct the electrons out of/into the device, forming the photocurrent that can deliver power to the outside world. The relative concentrations of the materials at the nanometer scale is thought to have an important effect on the overall device efficiency, and NSPM is meant to be a tool to help quantify this effect.

This project given to us was to extend NSPM, which was developed in the group at Newcastle. NSPM utilizes a Nanonics SPM 100 system (Nanonics Imaging Ltd.), which performs atomic force microscopy (AFM) with a fiber optic drawn to a tip. The Nanonics setup thus allows near-field scanning optical microscopy (NSOM) to be done simultaneously with a topography scan. NSPM modifies this instrument so that light is sent to the organic solar cell through the fiber optic tip, creating a small photocurrent generated from the illumination of a nanoscale area of the device.

The new work added two wavelengths (blue and red) to the existing green, in order to investigate how the different materials in the device responded (and to see if the photocurrent is photon energy-dependent, and thus dependent on the local composition). Garth had taken the preliminary data by performing complete scans, done one wavelength at a time, for his senior project. Unfortunately, the drift in the system meant that it was hard to compare a "green" scan with the subsequent "red" and "blue" scans: each scan took over an hour, and thermal drifts meant that it was hard to scan the same area repeatedly.

With the input of Prof. Warwick Belcher, also of the Centre, we decided to improve the system so that it would scan each of the three colors at every scan point, eliminating the problem of drift. This required (1) controllable shutters, which were ordered right away; (2) a modified code to collect this data; (3) a means of modifying the Nanonics instrument to collect our desired data; (4) a means of performing the experiment under dry nitrogen gas.

This meant that I became very familiar with the workings of this instrument, from the internal timing electronics to the mechanical system – I even fixed the drifting problem that had plagued earlier efforts! Additionally, I became reacquainted with LabView to perform the data manipulation, a program I hadn’t used in 18 years. I was able to make some large VIs (LabView programs) in support of this project, and even got to do some hands-on construction of a structure in which we could perform the dry nitrogen measurements.
While we were waiting for the shutters to arrive (delivery of some equipment is slow in Australia), I received training in the fabrication of organic solar cells. In particular, I build P3HT-PCBM solar cells (poly(3-hexylthiophene) (P3HT)/[6,6]–phenyl C61-butyric acid methyl ester (PCBM)). The Centre has a chemistry laboratory, where we suspended the P3HT and PCBM into solution and spin cast them and other components (such as poly(3,4-ethylenedioxythiophene): poly(styrene sulfonate) (PEDOT:PSS)) onto conducting slides. We would then take these into the clean room for evaporative deposition of the final conductor, and device testing. This was exciting, as it constituted my first extensive time in a clean room.

Unfortunately, the shutters we’d needed for this project never did arrive. Fortunately, we had pushed on into other projects that proved fruitful. Based on a series of theoretical papers by Mihaileti, Blom and co-authors, we attempted to measure the wavelength-dependent dissociation probability of the devices. The dissociation probability is the probability that a molecule excited by light breaks up into an electron and an ionized molecule, which then conduct current—the photocurrent. A cheap, relatively new piece of technology was key: high-intensity LEDs. Though only $8 or so, they provided as much or more power per square centimeter as the ~$2000 lasers we had been using. Further, their intensity could be readily varied, allowing us to probe both wavelength and intensity dependencies.

This new project required us to construct an experiment inside the clean room, within a glove box. (See Appendix I.) Light from the LEDs was focused onto a solar cell, and the applied voltage was increased until the photocurrent saturated. This required yet another mammoth LabView program so that the experiment could be automated: each color required over an hour for its data! Once completed, we had a large set of data with very interesting results:

- the open circuit voltage of the cells, or the solar cell voltage when exposed to light, seemed to be wavelength dependent—a novel result;
- the photocurrent was much larger than expected, suggesting that using the different exciting wavelengths may indeed be used to probe the physics of the devices;
- the dark current of the devices—that is, the current they produce in the dark—increased with time as we exposed them to higher voltages;
- ironically enough, the dissociation probability measurements, which inspired the whole venture, were inconclusive due to the large variation in the dark current. Such is the nature of research.

By the end of my time in Newcastle, we had repeated the experiments in a variety of ways in order to check our unusual results. So far, they’ve held up. Since then, we’ve been analyzing the data and have submitted a poster to be presented at the 2009 Spring meeting of the Materials Research Society in San Francisco.
Outcomes of the Research

One of my research goals were to make a contribution in the (new-to-me) field of plastic solar cells and to become better able to perform independent research in this field. The sabbatical was priceless in this regard; it appears that we have tapped a potentially rich vein of research with some very suggestive early results. Prof. Dastoor has indicated he would like to bring me back during a summer or “Winterim” to continue our collaboration.

I took copious notes of the equipment available in his laboratory, and of the procedures used for fabricating and testing the devices: I am certainly better-prepared to do work in this field at UWP, having gained direct experience with solar cell construction and testing; clean room procedures; glove box work; and advanced metrology equipment such as the Nanonics instrument and profilometer. Finally, my ‘refresher’ in LabView has inspired me to incorporate this program into my course, EP4210 Sensors Laboratory.

Another of my research goals was to continue this work at UW-Platteville, involving students. I have already been able to begin this semester, thanks to a student working with me to complete his Minor in Microsystems & Nanotechnology. He has built up an apparatus to characterize our own high-intensity LEDs, and will test the wavelength response of titanium dioxide “blueberry” solar cells. Further, in an exciting recent development we plan to extend these measurements to devices made with Prof. Jim Hamilton’s new graphene films, made at UWP.

Finally, my experience in Newcastle has already helped me to better contribute to our campus’ nanotechnology efforts. I drew upon this experience as we met with the architects and others this summer and fall to specify the clean room and characterization facility. My experience also proved invaluable as we determined the equipment we’d need in our new laboratories; I had a much clearer picture of our chemistry-related needs.

Teaching and Advising Goals and Outcomes

Preliminaries

I was able to gather a large amount of information on the course offerings in engineering and physics at the University of Newcastle. Before leaving home, I’d tried to navigate their web site only to get frustrated. Therefore, I felt that a “personal” visit would help clear away a lot of the mystery that my advisees and I have felt while trying to choose courses from afar.

University of Newcastle information for UWP Students

As luck would have it, in the time between my sabbatical proposal and my arrival in Newcastle, they had completed a long-overdue upgrade of their web site: the information was much more readily available (and I could have done much of this work from the U.S.!) However, I was able to ‘translate’ much of their educational terminology so that it made sense to our students. I created a series of web pages to help future UWP students heading to Newcastle; the top-level page is at
http://www.uwplatt.edu/~evensenh/UN/UNadvisingStartPage.html (also see Appendix II). The site includes an overview of academics at UN, including links to current timetables and course offerings. It also features a breakdown of the courses by major, in order to help UWP students identify courses they could take “down under.” Finally, it also includes a section on “living in Newcastle,” with information on maps, transportation, mobile phones, internet service providers, banking, and more; these are the things I’d wished I’d known before leaving home!

International Educational Collaboration
I met with Catherine Browne, UWP’s on site program coordinator for study abroad students, and Alex Tagaroulas, UN’s regional marketing manager for international development services. They directed me to Ed Szczerbicki, UN’s Assistant Dean in charge of international endeavors. He expressed a willingness to work with me in the future on investigating ideas such as collaborative design projects between UN and UWP students.

Support for UWP’s Newcastle Programs
I worked with Associate Dean Lisa Riedle and her assistant Julie Clark in preparing “before” and “after” interviews that were used to promote studying (and working) abroad in Newcastle.

Post-Sabbatical Reflection
Personal
I took my entire family with me to Newcastle, and my three children enrolled in public school. This was a great experience for all of them – to be out of their “comfort zone” but to eventually make friends and be successful. My wife took a leave from her job, and once we had high-speed Internet at home, wrote several papers...! (She has published more from my sabbatical than I have, somehow.) We took family trips to New Zealand and the Barrier Reef, and my wife and I made it to the “Red Centre,” to see Uluru/Ayers Rock. I made friends with several of the people I worked with. The research group was friendly, and my family and I were invited to many “barbecues.” Overall, I am thrilled with the results of my sabbatical on many levels – the friendships, the family experience, the sights, and the research.

Research & Professional
I thoroughly enjoyed what I consider to be my best research experience, ever, anywhere. The work was fun and rewarding, and I learned a lot. Being more mature than when I was in graduate school, I took the setbacks in stride and greatly enjoyed myself, even though I worked very hard. The research turned out to be so rewarding, and consuming, that I didn’t get as much accomplished on pursuing educational collaborations as I’d expected. I kept waiting for a “lull” that never arrived – and before I knew it, May was upon me. Since I was able to make at least an initial contact in that area, I feel I made acceptable progress since the research work was so much more than I’d hoped for.
Appendix I: Research

The chemistry lab in the Centre for Organic Electronics. We fabricated the solar cells here.

Our experiment apparatus, in the glove box in the clean room. The lens (mounted in black ring) focused light from the LED (mounted in the rectangular aluminum bracket) onto the solar cell (backed with small rainbow-colored wires). You haven’t lived until you've aligned optics while wearing bulky glove box gloves...!
Yours truly, “gowned up” in the clean room. Our experiment is inside the glove box behind me.

Prof. Paul Dastoor, me, and Prof. Warwick Belcher. I greatly enjoyed working with them, and everyone else in the group at Newcastle.
Some sample data; this plot shows that for a particular type of device, the solar cell's output voltage depends on intensity (not a new result) and on the wavelength of light hitting the cell (new result).

This plot shows that the dark current of the cell increases with repeated exposure to high voltage; there's probably something hidden here about how the cells age.
Appendix II – Academics

Advising for UWP Students Considering Engineering Exchange/Study Abroad in Newcastle, Australia

The University of Newcastle, on the northeast coast of Australia (~1 hour north of Sydney), has a great location, several engineering programs, and many courses that don't exist on our campus. It's an opportunity at many levels!

Of course, you probably know this already. After some confusion trying to help two of my advisees schedule their Exchange, I spent a portion of my sabbatical looking into the Engineering Physics curriculum, a form of helping future UWP students and their advisors manage this more easily.

I've written this for two areas: Academic Issues and Living Issues.

Academic Issues

Useful University of Newcastle academic links for UW-Platteville engineering students.

<table>
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<th>Time-table &amp; calendar</th>
<th>Course offerings</th>
<th>UN's international student site</th>
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<tbody>
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<td>Academic terms</td>
<td>Prerequisites</td>
<td>Interested in research?</td>
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The UN timetable and current academic calendar.

Courses in Newcastle are at the Callaghan campus.

Semester 1 is from mid-February to mid-June.

Semester 2 is from mid-June to mid-September.

Breaking down the Academic Language Barrier:

- They use the term "Faculty" like we use the word "College" or "School"; therefore, "Faculty of Engineering and Built Environment" = "College of Engineering." Note also that what we call the College of Engineering, Mathematics and Science has been "split out" into two Colleges ("Schools").
- The word "Courses" can indicate a class, or it can indicate a series of classes that make up a degree - depending on the context.
- Australian students typically are on a three-year degree plan, in part because of the lack of a "General Education" component. Engineering students, however, are on a four-year plan. The fourth year is either "Honours" (in the sciences) or coastal to projects (engineering).

UN's site for international students:

- Plenty of helpful links that are applicable to visiting students. (See "About the University" and "Coming to Newcastle.")

Course Offerings of interest for UWP students in... (links will redirect to current offerings, then scroll down)

- Engineering Physics: Physics or Mathematics /Mechatronics courses
- Note that Physics is on "narrow" as a major and course offerings may be limited.
- Mechanical Engineering: Mechanical /Mechatronics
- Electrical Engineering: Electrical /Telecommunications /Computer Engineering
- Civil Engineering
- Environmental Engineering
- Software Engineering
- Chemical Engineering

Below are some UN course links that are "higher" than those above. These are another way to find relevant courses, if the above links fail. On these pages, select your major under "Study Options" this will lead to a list of courses at UN for that major.

- A list of all UN engineering programs
- College of Engineering (not including Electrical)
- Electrical /Computer /Software Engineering
- College of Science: Chemistry
- The Program Finder. If all else fails, you can search for your major here.
Appendix III – Trip Photos

New Year’s Day in New Zealand – ah, summer!

The “Three Sisters” in the Blue Mountains, west of Sydney.
The feature formerly known as Ayers Rock... now Uluru.

A portion of the Great Barrier Reef at low tide.