International Research and Education in Engineering (IREE)

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ABSTRACT: My experience was in every way rewarding- educationally, culturally, and personally. I left Colorado on a snowy, dry winter day and arrived in Buenos Aires, Argentina in the dead heat and humidity of summer where temperatures were soaring above 100º F. And so my unique and incredible experience began. During my three months stay at Universidad de Buenos Aires (UBA) in the Laboratorio de Electrónica Cuántica (LEC) under Dr. Oscar E. Martínez, I was able to apply my optics lab experience and knowledge from my current research at Colorado State University on full-field nano-imaging systems using compact extreme ultraviolet (EUV) lasers, to set up a knife-edge imaging system at UBA to perform full-field nano-surface photopolymerization of dye-enhanced resin using a Helium Neon (HeNe) laser. Although both of these nano-oriented systems rely on very different wavelengths of light, I found there to exist many correlations between the two systems. Further, through analyzing my setup for the polymerization system in Argentina I came to understand my imaging setup in Colorado on a more basic microscope level. The photolithography project I worked on at UBA also links to my future career goals to work in the semiconductor lithography industry. The IREE grant gave me the opportunity to travel abroad and experience another culture, while simultaneously allowing me to work in a foreign lab on a challenging project. My experience was rejuvenating, and I am extremely grateful to been given this opportunity.

INTRODUCTION

I, Courtney Brewer, am a graduate student studying at Colorado State University (CSU) in the NSF Engineering Research Center (ERC) for Extreme Ultraviolet (EUV) Science and Technology. The goal of this ERC is to instigate the routine use of coherent EUV light sources in a variety of applications for universities, industrial laboratories, and manufacturing facilities. To accomplish this, the EUV ERC is focused on developing small-scale, cost effective EUV light source systems and using them within various test beds to solve challenging engineering and scientific applications. My thesis work involves developing high-resolution full-field microscopes using two different compact EUV lasers built at CSU as illumination sources. By combining the short wavelength light with reflective multilayer mirrors and diffractive imaging zone plates, the systems are able to obtain high resolution images with short exposure times. The first system is based on a desktop-size Ne-like Ar fast capillary discharge emitting at λ= 46.9 nm. This microscope can image samples both in transmission and reflection mode.[1, 2] The second microscope employs a laser based on laser-created plasma at wavelengths of 13.2 and 13.9 nm. This system has the ability to capture images with sub- 38 nm resolution in exposure times of 20 seconds.[3]

I chose to study at one of the ERC's affiliated institutions, la Universidad de Buenos Aires in Argentina, to work in el Laboratorio de Electrónica Cuántica under Dr. Oscar Martínez. In this lab the main field of research is to study the interaction of light with matter, with an emphasis currently directed at applying photonics technology to the development of new tools for biology (biophotonics) and for nanoscience and nanotechnology (nano-optics).

I was interested at gaining experience in working on a microscopy system that exploits non-linear and ultrafast characteristics to do nano-scale resolution imaging using visible light to contrast with my thesis work at CSU where we exploit short wavelength light to do high-resolution imaging. The project I was assigned in Buenos Aires involved full-field imaging using visible light and additionally incorporated my interest in photolithography.

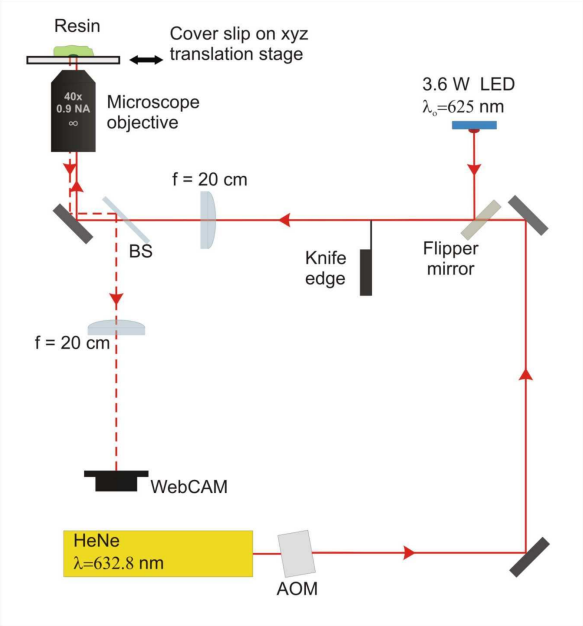
Beyond having the ability to encompass my research interests, I chose UBA because I wanted to work in a foreign lab in a country where the economic, political, and environmental surroundings are considerably different than those of the lab I work at in Fort Collins, Colorado in the United States. I felt that this change would challenge me and give me a new perspective.

At the time of the IREE proposal submission, I had been in graduate school for one year. Because of my interest to study at an affiliated foreign institution to gain both academic and global perspectives, my advisors and I felt that the IREE grant was an ideal opportunity. From January 29, 2007 until April 29, 2007, I worked full-time at the lab in Buenos Aires to develop and characterize a system to photo-polymerize a full-field image of a knife edge onto a dye-enhanced resin to form micro- and nano-sized polymerized step patterns. Along my journey I learned a lot about microscopy, research, and the Argentinean culture.

RESEARCH ACTIVITIES AND ACCOMPLISHMENTS OF THE INTERNATIONAL COOPERATION

My international research project was to set up an experiment to surface photopolymerize a full-field image of a knife edge onto a fluorescent dye-enhanced resin using a HeNe laser, and then to characterize the dependence of the polymerization process on the resin mixture and exposure dose of the incident light. This project was an extension of previous two-photon scanning photolithography experiments using a Ti:Sapphire laser that polymerized dye-enhanced resin to create fluorescent micro-patterns for biological applications[4] and fluorescent lines of heights down to 15-20 nm.

I began this new project by setting up a system to correctly image a knife edge onto the surface of a cover slip where a drop of resin is placed using a HeNe laser. A schematic of this setup is illustrated in Fig. 1. This required consideration of image formation, performing calculations, assembling the setup with the available materials, creating a LabVIEW program to expose the desired patterns, and devising repeatable alignment procedures. I then started to photopolymerize micro-scaled samples and, by analyzing these results, revised the setup several times. Fig. 2. is a visible microscope image of a polymerized sample containing micro-sized knife-edge image patterns. The lines surrounding the exposed spots serve as a marker to indicate the location of the spot patterns on the cover slip. In this sample three spots were polymerized for a specific dose (along the row), and then the time exposure time was increased from 2-8 seconds in steps of 1 second (along the column).



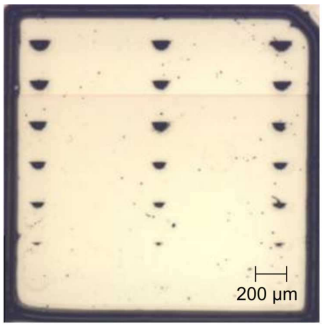


Fig.1. (Left) A schematic of the setup to photo-polymerize an image of a knife-edge in a drop of resin placed on a cover slip to form a hardened step pattern. **Fig. 2.** (Above) A visible microscope image of a processed sample containing micro-sized step patterns that were exposed for times incrementing from 2-8 seconds.

Once I was satisfied with the experimental setup, I focused on how the exposure dose (incident intensity × exposure time) was related to how the resin polymerized. Through using resin mixtures of same concentrations and over a period of time, I found that the

preparation and storage of the pre-exposed resin mixture is more critical than thought during the previous experiments, and I came up with ideas on how this experimental factor could be better controlled. In addition I showed that there is a dose threshold, meaning that there is a nonlinear process occurring in the surface photopolymerization process. I then decreased the exposure dose to start photopolymerizing nano-sized structures. Fig. 3 shows a visible microscope and an AFM image of a 114 nm high polymerized sample, in which the HeNe beam was imaged onto the resin sample without inserting the knife edge.

This project allowed me to combine my research experience, recall information that I have learned in my classes but not previously encountered in my research, and learn a lot. The project was not only complementary to my current research, but also to my previous internship and my future career goals. All of these experiences and aspirations incorporate working with light, optics, imaging, and photolithography. At Colorado State University (CSU) I develop compact short-wavelength EUV microscopes that are able to obtain high-resolution full-field images of nano-sized structures. My Master's thesis will include a chapter on a design for a future microscope setup using the λ= 13.2 nm laser at CSU to inspect the printability of defects for the next generation of photolithography masks. Through using special off-axis zone plates, the setup will have the ability to obtain reflection mode images that mimic what a wafer will see when being exposed during production. Two years ago I did a summer internship at Intel in Santa Clara, California in the Lithography Capital Equipment Development (LCED) group. There, in one of my projects, I compared critical dimensions of exposed lines on EUV wafers in which the exposure dose and illumination had been varied. After graduation I am interested in working in the lithography industry. All of the projects have common threads of using light to form full-field images and are related to photolithography and nano-sized structures. Gaining experience in these different contexts and places is allowing me to build up a unique base of overlapping knowledge which will contribute to my future endeavors.

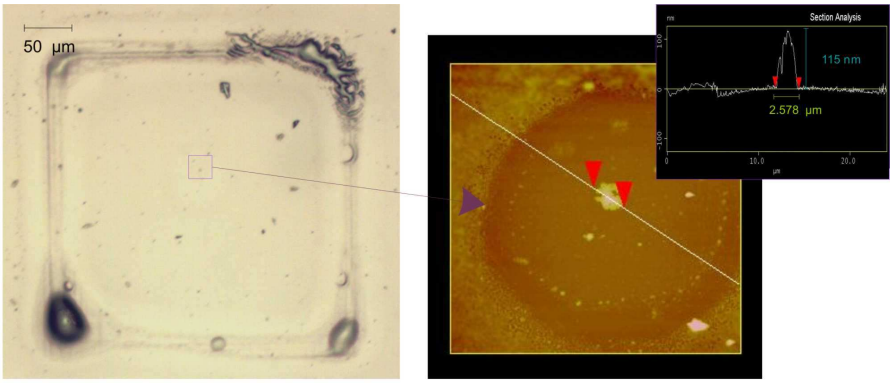


Fig. 3. A visible microscope image (left) of a singe photo-polymized spot that was exposed for 3.5 seconds. The spot is 115 nm high and 2.578 µm wide, as shown in the AFM image (right) and lineout.

BROADER IMPACTS OF THE INTERNATIONAL TRAVEL

"The latest trend on the economic battlefield is globalization of commerce, science, and technology development. … It is time for us to upgrade our tool sets and sharpen our scientific minds to integrate diverse perspectives. The new globalization paradigm requires adopting new tool sets (communication skills and perceptions) to turn negative energy into positive breakthroughs. They include cognitive, emotional, and behavioral upgrades and psychological makeover." This is a direct quote from an advertisement I came across for an engineer career management seminar developed by IEEE-USA held June 9, 2007 in Fort Collins, CO. The IREE grant gave the EUV Engineering Research Center, myself, and also the Argentinean students that I interacted with the incredible opportunity to address this new engineering globalization paradigm directly now and through future potential opportunities.

Scientific Impact: Before going to Argentina, I expected there to be a broad scientific impact in terms of sharing knowledge and learning about other student's research projects while telling them about my own in Colorado. This did occur, and was further strengthened when my US advisor, Dr. Carmen Menoni, visited the Universidad de Buenos Aires for a few days and gave a well-attended, by both graduate and undergraduate students, lecture in Spanish summarizing the different projects and goals of the EUV ERC. Interactions like this can always lead to attracting more Argentinean students to pursue their post-docs or graduate studies at the ERC in Colorado.

During Dr. Menoni's visit, we also took a tour of the lab and were able to share knowledge and discuss ideas with Dr. Martínez and his students for various experiments both at Buenos Aires and Fort Collins. This sharing of knowledge and research ideas has undenyingly widened the path for increased future interactions. Understanding each others' research strengths better will allow easy recognition of when a collaborative opportunity arises.

In addition, being the first American student to ever study abroad from our lab group at Colorado State University, I feel that my experience has opened the path for future students of the Center to consider an abroad graduate experience as an option, thus leading to even stronger collaborations or communication for the Center with foreign institutions. Additionally, it has been shown that international experiences are incredibly attractive to women.[5] Thus, this new marketing slant for our Center, in which they can now offer the possibility of working in a foreign lab, has great potential to attract more women to our ERC.

Cultural Impact: What I treasure most about my abroad experience is that I was able to immerse myself, both academically and socially, with only foreigners for the entire four months I was in Argentina. Because I was working in a lab, not just studying Spanish or traveling to a third world country for a good exchange rate, I was accepted and respected in a different way than as an average tourist. I was able to attend family and friend backyard parrillas (barbeques), go to a pro-soccer game, participate in protests, shop in supermercados (small supermarkets), and live a daily life completely surrounded by only Argentineans. This allowed me to see that Argentineans are gregarious, proud of whom they are, and passionate about their beliefs, rights, and food, which can all be partially attributed to their ancestors, society as a whole working together to overcome difficult government and economic situations, and an emphasis placed on social interaction.

It also allowed me to see first-hand how prevalent are Anti-Bush and Anti-Americanism feelings. I watched as multiple graduating students looked for post-docs in Italy,

Germany, and Canada rather than the US, and sympathized with one student struggling through the process of obtaining a visa to come work at a lab in the United States. Despite this overall aversion towards the US, I was always welcomed and treated with respect. Several people that I met during my stay told me I did not "seem" like a North American. This always made me smile, because I hope that I was able to make some people, even if only for a second, question their stereotypes about Americans and our country. I feel that one of the barriers that confront American scientists and engineers, as we seek to address this globalizing world and increase collaborations with people from different countries, is this underlying Anti-Americanism. We must show people from other countries that we are interested in understanding and accepting their cultures and backgrounds and from there harness our differences and similarities to progress forward and united in engineering research and business. One way for the science community to start working towards this goal is to increase the number of American scientist and engineer students studying abroad, and in turn make it easier for foreign students to obtain short-term visas to work at labs and attend conferences in the United States.

DISCUSSION AND SUMMARY

The international research experience is a fantastic way for the NSF to further embrace the emerging need and desire of globalization. Less than two years ago I attended the ERC conference in Washington DC, where the issue of a new globalization paradigm was raised, and I am thoroughly impressed with how quickly the NSF is responding to this movement. An international experience is now an added incentive that ERC's can offer in addition to their current advantages to attract students, and has the potential to increase diversity within the ERCs, as studies have shown that in general women are extremely attracted to international experiences.[5]

I am completely satisfied with the IREE Program, and do not have any recommendations for changes. The length of time of the visit, the funding, and the reporting were all set at acceptable levels. I also especially enjoyed the advisor short visit. All together I am thankful to have been given the opportunity to work in a foreign lab and am extremely supportive of the IREE grant.

ACKNOWLEDGEMENTS

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BRIEF BIOGRAPHY OF RESEARCHER

Courtney Brewer received a BS in Electrical and Computer Engineering with a concentration in Optical Electronics from Colorado State University in 2005 as Summa Cum Laude. She is currently pursuing her MS in Electrical and Computer Engineering at Colorado State University, where she plans to defend her thesis work in December 2007 on compact EUV high-resolution imaging.