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THIS ISSUE

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- *More Principal Investigator Profiles*
- *2nd Annual Ontario Photonics Consortium Showcase Summary*
- *Manufacturing Fiducial Markings*

Undergraduate Research in the Nanofab

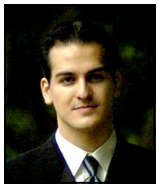
Welcome to our 2006 spring newsletter. In this issue we feature some of the spectacular research performed by undergraduate students with the help of the Nanofabrication Laboratory at Western. From fabricating waveguides with coupling grating for use in evanescent light for microscopic imaging to fabricating precisely positioned gold nanodots by electron beam lithography , it was a busy and exciting scholastic year. Congratulations to all graduating NanoUsers!

In addition, we feature an article by Dr. Rob Lipson about the exciting research of interference or holography lithography and using light to manufacture materials that control light.

Our next issue will be in the late 2006 summer and will feature more news into the research conducted with help of the Nanofabrication Laboratory at Western. Until then, have a great summer!

Nancy Bell
Nanofab Laboratory Technician
& NanoWestern Editor

Evanescent Field Waveguide Fluorescence Microscopy

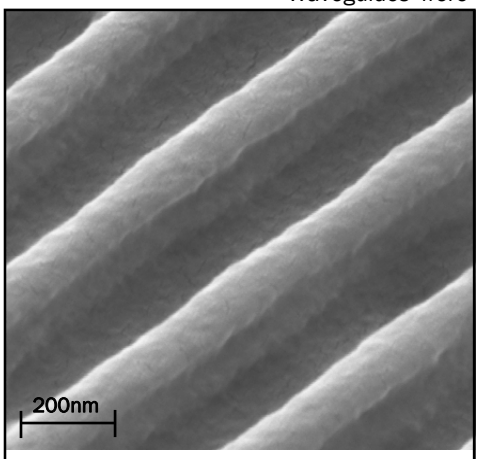


By Matthew Turnbull
4th year Physics student
University of Western Ontario

The evanescent field of a propagating waveguide mode can be used to illuminate microscopic objects located on the surface of the waveguide. The application of evanescent light in this manner is a novel imaging technique and can serve many purposes. For instance, it can be used for scattering light microscopy (where a contrast arises from areas with low and high scattering), fluorescence microscopy, and absorption phenomena. The objects under examination may be inorganic, organic, patterned surfaces, or biological objects like cells.

I worked in the Nanofab for part of my physics 491E senior research thesis on evanescent field waveguide fluorescence microscopy. This work is part of a group effort toward the use of evanescent light to excite fluorophores for fluorescence microscopy on slab waveguides. This approach is presumed to be simple and cost effective in comparison with total internal reflection fluorescence microscopy, and offers a huge spectrum of additional sensory and analytical possibilities. The aim of this effort is to perform cell substrate interaction studies in collaboration with the Schulich School of Medicine & Dentistry at the University of Western Ontario, involving cancer research and pH detection in the active sealed "reaction chamber" of living osteoclast cells.

Waveguides were fabricated via ion exchange with $AgNO_3$ on Schott BGG-11 glass substrates. An optical holography lab was built to create a custom diffraction grating on the waveguide surface. The grating pattern was then characterized using SEM and surface profilometry.



SEM image of grating pattern.

Future research includes using the Langmuir-Blodgett trough to deposit a monolayer of a stained and phase separated binary lipid mixture on the waveguide surface to test their fluorescent excitation.

Using Light to Control Light

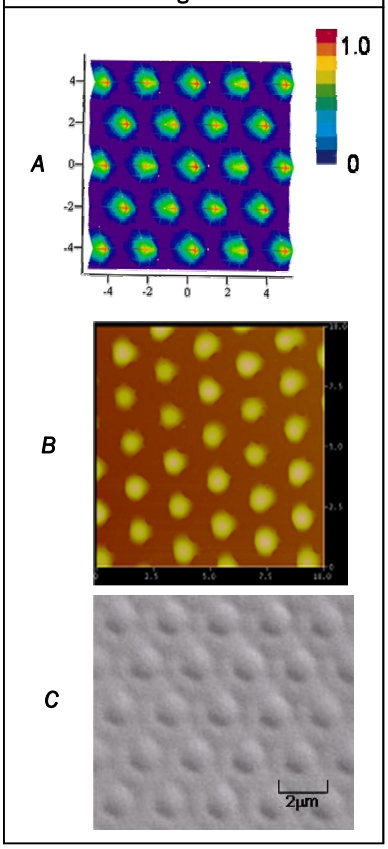
By Dr. Rob Lipson
Department of Chemistry
University of Western Ontario

Photonic band gap materials design and fabrication are synergistic pursuits at the interface of photonics and nanomaterials activities. Photonic crystals are structures with a periodically varying index of refraction. The interference between electromagnetic waves scattered within such media opens a band gap where certain wavelengths are prohibited from propagating. There is a world-wide effort in this field because in addition to their potential as perfectly reflecting mirrors, photonic crystals with implanted defects can act as a variety of optical devices including thresholdless lasers, waveguides, sensors, and filters.

Complete band gaps have been observed or predicted for a number of periodic dielectric lattices including two-dimensional square and hexagonal arrays, and three-dimensional simple cubic, face center cubic, and hexagonal close packed lattices. In recent years, a plethora of techniques has been developed to fabricate photonic crystals because of their enormous potential in numerous applications, including optical communications and low threshold lasers. Of these methods, interference (or holographic) lithography is emerging as one of the simplest, fastest, and cheapest methods of creating large scale periodic structures. The outputs of the most common lasers have micron to sub-micron wavelengths, dimensions that correspond to those most desired for photonic crystal applications and periodicities. How appropriate it is therefore that interference lithography uses light to manufacture materials that can control light.

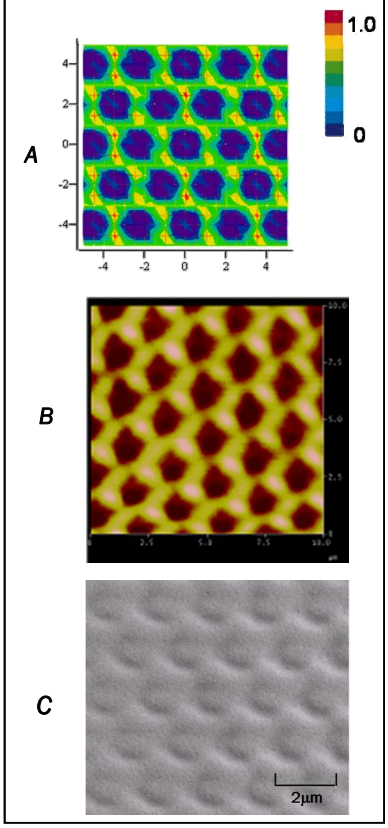
The dimensionality of the patterns created by interference lithography depends on the number of laser beams used. Two-beam lithography to write one-dimensional gratings is now a well established technology. Three and four beams are required to generate two- and three-dimensional patterns, respectively. Interfering four noncoplanar beams can generate any one of the fourteen three-dimensional Bravais lattices. One limitation of interference lithography however is the difficulty associated with controlling the structures that can be produced with a given experimental arrangement. Here, the structure and periodicity scale of a pattern are determined primarily by the wavelength of the laser light used (tunable light sources can be expensive), and/or the angles at which the different beams interfere with each other (which can be difficult to change readily). My group in the Department of Chemistry, with the excellent technical support of the Nanofab facility located in the Department of Physics and Astronomy, has capitalized on both diffraction effects and laser beam phase as a means to control the structure of two dimensional patterns produced by three-beam interference lithography.

Figure 1



According to Huygen's principle, when a beam of light passes through a diffractive element each point on the aperture can be regarded as a source of secondary wavelets. At a given distance and location from the mask these secondary wavelets can constructively or destructively interfere to produce bright and dark areas. In the near-field (Fresnel) region, ($r < a^2/\lambda$, where "a" is the greatest width of the aperture of the element and "r" is the distance between the diffraction element and plane of observation), the diffraction pattern will resemble the shape of the mask but will also exhibit fringing that depends strongly on r. Depending on the structure of the mask, different diffraction patterns can be formed with dimensions that vary strongly with the distance between the diffractive element and the photoresist. The optical proximity effects due to near-field diffraction provide a strong *a priori* degree of control on the microstructures that can be generated. We call this approach Diffraction Element Assisted Lithography or DEAL.

Figure 2



In one series of experiments, we used a two-dimensional triangular mask manufactured by e-beam lithography in the Western Nanofab as the diffractive element to pre-pattern the coherent ultraviolet output of a Nd:YAG laser in the near-field prior to its capture in a photoresist. The diffraction patterns were recorded in a ~1-2 μm thick SU-8 photoresist which was spin-cast onto a silicon substrate. The sample and mask were both mounted together on a high precision x-y stage with a precision of better than 100 nm in relative movement.

The two DEAL patterns generated when the distance between the mask and photoresist was set to z = 4012±0.1 μm and z = 4000±0.1 μm are shown in Figs. 1 and 2, respectively. The diffraction pattern produced by a relatively complicated element can be calculated as a sum of the patterns related to simpler sub-features. The resultant normalized colour simulations of the intensity distributions, shown in Figs. 1a and 2a, are in excellent agreement with the experimental results (AFM images: Figs. 1b and 2b; SEM images: Figs. 1c and 2c). In Fig 1a the wavelets from the three gratings making up the triangular mask are in phase while in Fig. 2a the phases of two of the wavelets are identical but that of

the third wavelet differs by π. In the former case the DEAL pattern is a two-dimensional array of islands while in the latter, a similar array was generated but this time, made of air holes.

Another route to control is manipulation of the phases of the beams used in conventional interference lithography. In a second set of experiments two-dimensional patterns in SU8 with ~1 μm periodicity were generated. Phase control was achieved by inserting a birefringent Babinet-Soleil compensator into the path of one beam.

Fig. 3A is a scanning electron microscope (SEM) image of the resultant pattern when the phases of the three beams were set to zero ($\varphi_1 = \varphi_2 = \varphi_3 = 0$), a configuration widely used in three-noncoplanar beam interference lithography. The result is a two-dimensional triangular post array. When the phase of one of the beams was shifted by π/2, the result was the inverse structure shown in Fig. 3D; a triangular hole array. Figure 3B and 3C correspond to ($\varphi_1, \varphi_2, \varphi_3$) = (0, 0, π/6) and (0, 0, π/3), respectively. It should be emphasized that mechanically the experimental arrangement used to fabricate the different structures is identical; only the phase of one of the beams has been changed using the Babinet-Soleil compensator.

Simulations were carried out to understand the phase effect on a three-noncoplanar beam interference pattern. The calculated results corresponding to ($\varphi_1, \varphi_2, \varphi_3$) = (0, 0, π/6), (0, 0, π/3) and (0, 0, π/2) and shown in Figs. 4A through D, respectively, agree very well with the simulations.

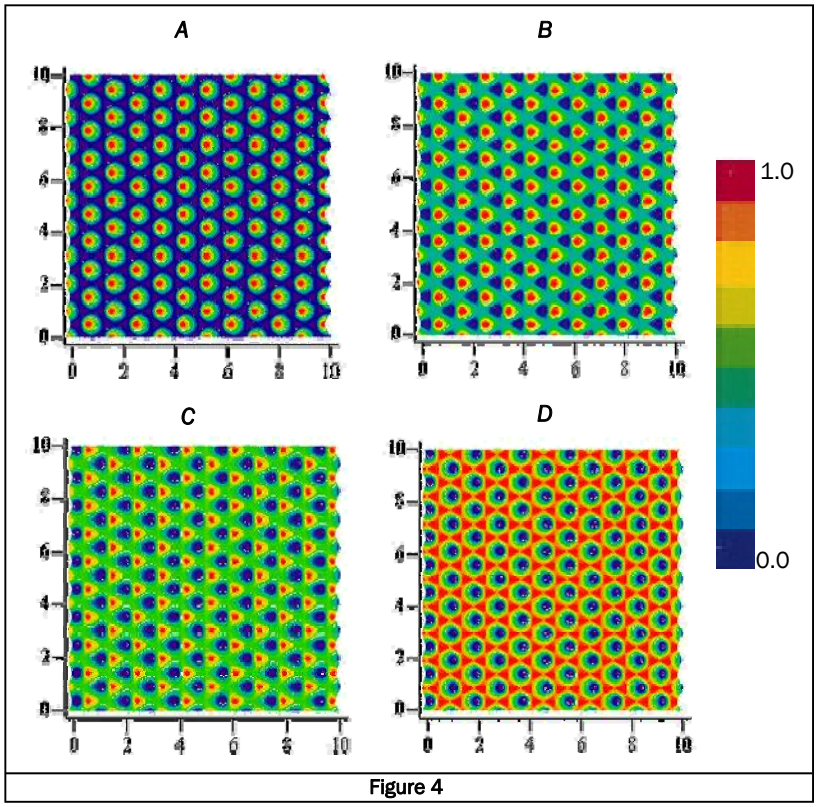


Figure 4

One pressing issue in interference lithography are the standard photoresists available. Currently, we are using well known carbon-based photoresists to develop our lithographic methodology. Unfortunately, relative to vacuum, these materials do not posses a high enough index of refraction contrast (typically Δn ~ 0.6) to exhibit a photonic band gap. Although we have used the resultant organic films as templates to etch patterns in higher index materials such as Cr and Si, we are also collaborating with Western organic chemist K. M. Baines to develop high index polymer resists containing Si, Ge, and Sn based moieties, so that photonic crystals can be made directly in one lithographic step. SU8 is a negative resist; that is, a material that becomes insoluble when exposed to optical radiation due to polymerization. These resists tend to swell in developing solutions which limits the smallest feature sizes that can be generated by optical lithography to > 100 nm. The polysilane, polygermane and polystannane polymers to be tested however operate as positive resists which are materials that exhibit enhanced solubility after light exposure usually because of main chain scission. Swelling is often not an issue here and, therefore, positive resists can yield the highest resolution lithographs. Initial tests using of poly[(p-methoxyphenyl)methysilane] films indicate that sub-50 nm features can be generated with our experimental arrangement. Unlike many other groups who are limited to fixed wavelength sources for lithography we will be able to synthesize a wide variety of polymers and explore different operating wavelength regions using the suite of tunable lasers (dye and OPO) found in our lab.

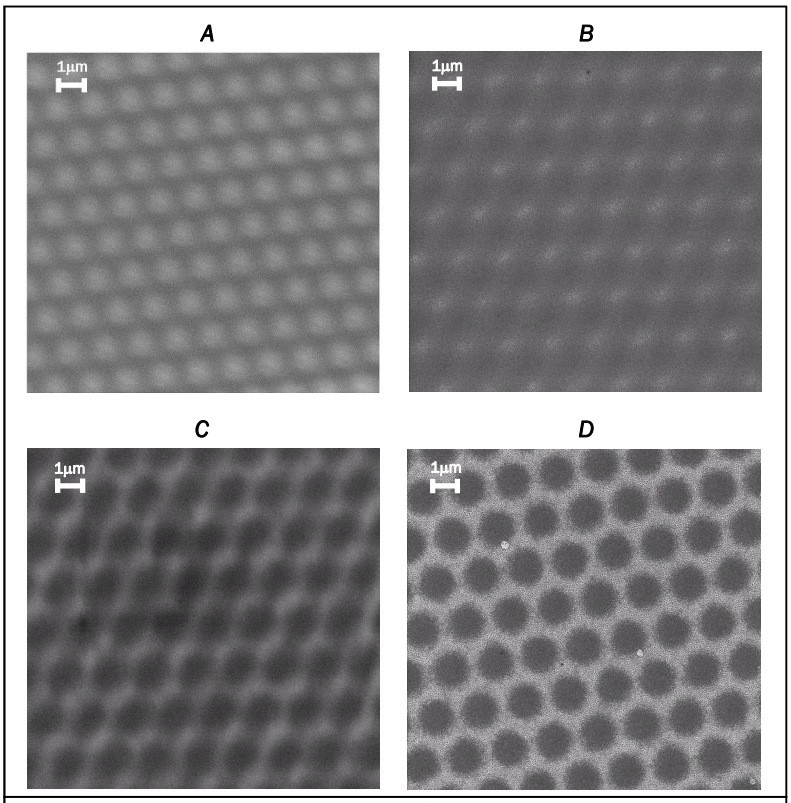


Figure 3

This work was supported by the Ontario Photonics Consortium through the Ontario Research and Development Fund, the Canadian Foundation of Innovation, the Natural Sciences and Engineering Research Council of Canada, and the University of Western Ontario. The Lipson Lab is part of the Western Institute for Nanomaterials Science (WINS) and the Centre for Chemical Physics (CCP). The members of the research team working on interference lithography at Western, past and present, are graduate students Cheng Lu and Yun Yang, research associates Xiaokun Hu and Stamen Dimov, and undergraduates Eva Dias and Jay Wickenden. Special acknowledgements are extended to our collaborators Professors Ian Mitchell (Physics and Astronomy), Kim Baines (Chemistry), and Zhifeng Ding (Chemistry). The technical mastery of Dr. Todd Simpson (Nanofab), Professor Jeff Hutter (AFM) and John Vanstone (electronics) is also gratefully acknowledged.

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Precisely Postioned Gold Nanodots Fabricated by E-beam Lithography

By Sean Douglas Murphy
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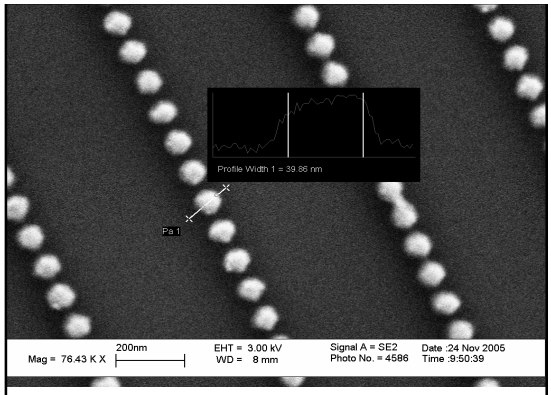
My undergraduate thesis involved the investigation of the surface plasmon resonance of gold nanoparticles.

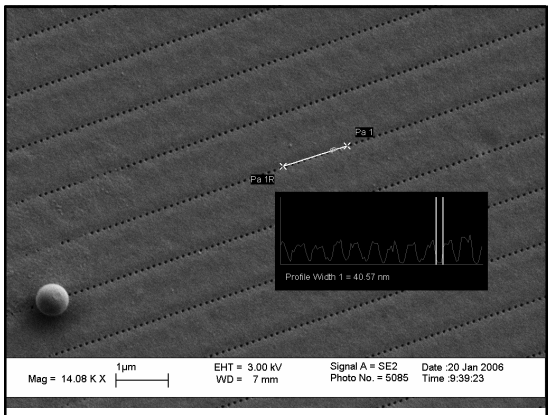
Noble metal nanoparticles (typically gold and silver) are well known for their strong interactions with light through the resonant excitations of the collective oscillations of the conduction electrons of the particles, the so-called surface plasmon resonances (SPR). When incident light is of the same frequency as these oscillations, a large absorption spectrum peak is measured.

To create the nanodots, an e-beam resist, PMMA (polymethyl methacrylate), was spin-coated on the substrate. The substrate was then exposed to the electron beam in the dot pattern. After exposure, the resist was developed resulting in nano-sized holes. Gold was deposited on top of the PMMA by e-beam evaporation. Acetone was then used to remove the PMMA thereby lifting off the gold around the pattern. The process was first perfected on a p-type Si wafer.

After achieving success on Si, the dots were created on a SiO_2 surface. The next step in the project was to create the dots on a glass substrate. For this, a microscope slide was used. A thin chromium layer (~ 10Å) was deposited before the gold for adhesion purposes. After perfecting the fabrication process, a larger pattern was created for measurement of the SPR peak.



SEM image of gold nanodots on Si substrate.



SEM image of gold nanodots on glass substrate before liftoff.

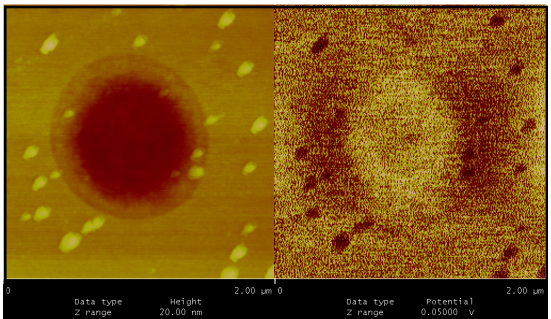
Future work involves reproducing the SPR absorption spectrum peak and investigating the shift in the SPR peak when different molecules are adsorbed on the surface of the nanodots.

Work Function Calibration of a Conducting Polymer

By Kevin O'Neil
4th year Physics Student
University of Western Ontario

As part of my undergraduate thesis project, I studied the correlation between the surface morphology, local conductivity and local dopant distribution in conducting polymer films under the supervision of Dr. Oleg Semenikhin from the Western Chemistry department.

An important aspect of the project was to measure the differences in the local work function of a conducting polymer using Kelvin probe force microscopy (KFM). To ensure the correctness of the local work function determination, an n-type (111) silicon sample patterned by means of gallium focused ion beam implantation was prepared by the Western Nanofabrication lab using the Leo 1540XB FIB/SEM and used as a reference standard in the KFM measurements.



2x2 micron AFM image of n-type (111) silicon patterned with Gallium ion implantation showing topography (left) and surface potential (right).