Scalable Nanopatterning using Roll-based Jet and Flash Imprint Lithography

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ABSTRACT

The ability to pattern materials at the nanoscale can enable a variety of applications ranging from high density data storage, displays, photonic devices and CMOS integrated circuits to emerging applications in the biomedical and energy sectors. These applications require varying levels of pattern control, short and long range order, and have varying cost tolerances.

The Jet and Flash Imprint Lithography (J-FIL^{TM}) process uses drop dispensing of UV curable resists to assist high resolution patterning for subsequent dry etch pattern transfer. The technology is actively being used to develop solutions for memory markets including Flash memory and patterned media for hard disk drives.

In this paper we have developed a roll based J-FIL process and applied it to technology demonstrator tool, the LithoFlex 100, to fabricate large area flexible bilayer wire grid polarizers (WGP) and high performance WGPs on rigid glass substrates.

Keywords: jet and flash imprint lithography, J-FIL, nanoimprint, wire grid polarizer, displays

1 INTRODUCTION

Roll to Roll (R2R) printing, or web printing involves the patterning of flexible materials such as plastics or metal foils. The flexible material, or web, is unwound from a core, processed, and then returned to a second core at the end of the sequence. R2R processing is in use today by industry and many R2R processes already exist for etch and deposition. Lithographic processes are also established for micron scale manufacturing and for applications that only require polymer embossing without any subsequent processing.[i] Recent work has investigated devices requiring metal etching in conjunction with imprint lithography, but again at a micron scale.[ii] However R2R patterning of arbitrary patterns with thin residual layer control (needed for subsequent pattern transfer) at the nanoscale is far more challenging, particularly at a cost structure suited for commodity applications. If successful, the potential applications include thin film transistors, flexible displays, color filters and many types of nanophotonic devices including wire grid polarizers, and solar devices. The challenge, as always, is to create a process that is scalable and meets defectivity, throughput and cost of ownership requirements.

The Jet and Flash Imprint Lithography (J-FIL^{TM})[iii,iv,v,vi,vii] process uses drop dispensing of UV curable resists to assist high resolution patterning for subsequent dry etch pattern transfer. A Drop-on-Demand (DoD) ink-jetting approach is used to reduce material waste and achieve very thin and uniform residual layer thicknesses (RLT) by matching the amount of low viscosity resist dispensed to the actual relief images in the imprint template. Following deposition, a controlled pattern fill step is used to fill the relief images. The process takes advantage of the capillary force created between the mask and substrate, and requires no additional pressure during filling, thereby minimizing any distortion or damage to either the mask or substrate. The technology is actively being used to develop solutions for memory markets including Flash memory and patterned media for hard disk drives.

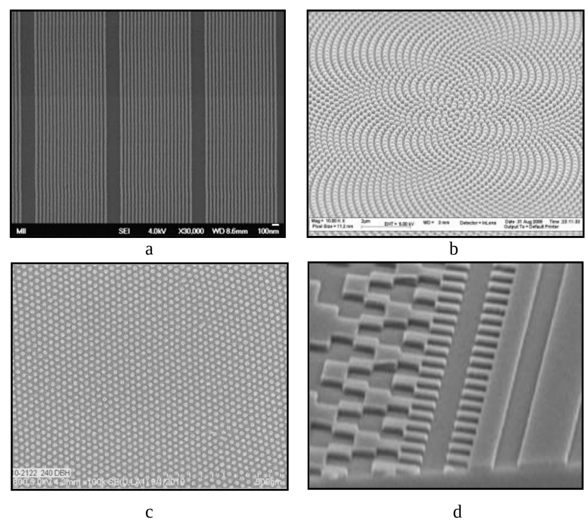

Figure 1: Examples of the J-FIL patterning process.

What sets technology J-FIL apart from any other imprint process is its ability to meet both the lithographic requirements of a given technology and deliver the performance at a fraction of the cost. This is achieved through: 1) high throughput (the process is performed at room temperature with fast filling low viscosity resists), 2) employing low cost exposure sources, and 3) eliminating the material waste typically encountered with technologies requiring spin-on resist processes that typically discard most of the resist applied to the substrate. This combination of performance and low Cost of Ownership (CoO) has resulted in the placement of pilot operation tools for both industries.

In this paper we address the key challenges for roll based nanopatterning by introducing a novel concept: Ink Jet based Plate-to-Roll Nanopatterning. To address this challenge, we have introduced a J-FIL based demonstrator product, the LithoFlex 100. Topics that are discussed in the paper include tool design and process performance (including process longevity). In addition, we have used the LithoFlex 100 to fabricate high performance wire grid polarizers on both fused silica wafers and flexible polycarbonate (PC) films.

2 EXPREIMENTAL DETAILS

a. Tool development

The roll based concept tool discussed in this section, the LithoFlex 100, allows exploration of key technology risks associated with an inkjet resist driven nanoimprinter. Figure 2 illustrates the basic imprint tool concept using a template and a roll module, where the flexible film can be patterned. Imprinting is performed by moving the roll module and the template is only translated up or down.

The process sequence is as follows: First, fluid dispensing with pico-liter volume drops is performed by moving the linear stage onto which the roller module is mounted. Drop patterns are pre programmed based on the template pattern geometry. Once the fluid drops are dispensed on the film, the roll module is moved to the opposite side of the template while the dispensed portion of the film is rolled backwards by the counter clockwise roller motion. Imprinting is performed by the synchronized motion of the roll module and bottom linear stage so that the dispensed portion of the film is brought into contact with the template similar to a laminating process. This is followed by a UV curing step, where a broadband UV spectrum is used and a separation step, where synchronized motions of the roll module and linear stage induce a peeling separation from the template starting at one side and ending at the other side of the template.

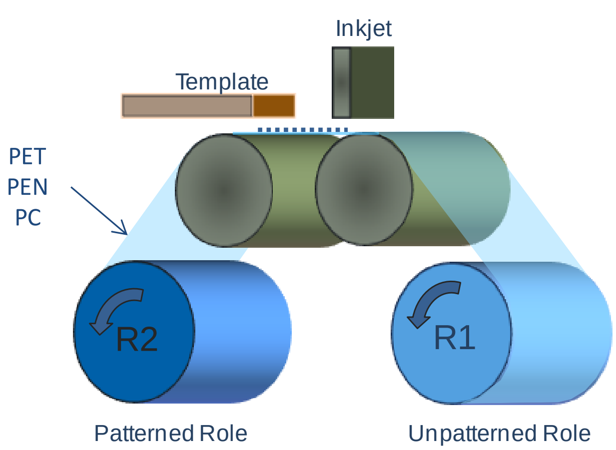

Figure 2. Imprinting scheme selected for high throughput flexible film imprinting.

The process steps of the “technology demonstrator” are sequential and therefore, it is expected that its throughput will be limited as compared to cases where all process steps are done in-parallel. A next generation tool will address parallel processing.

Figure 3. A partial view of LithoFlex100 being used for process development.

b. Template form factor and fabrication

The template blank is a six inch fused silica wafer, identical to the blank used on the NuTera™ HD7000 high throughput media imprinting systems. Patterning of the template can either be done directly or by replication using an existing master template. For most of the experiments performed, a replication process was employed. The primary pattern consisted of 50nm and 65nm half pitch gratings. For the earlier experiments, the grating field size on the master template was either 5mm or 25mm on a side, and a step and repeat J-FIL tool was used to replicate the pattern on to the six inch round blank. Other replicated patterns included 120nm curvilinear structures, 100nm dense pillars and 25nm dense holes. Larger area templates were created by patterning a 300mm silicon wafer using an immersion-based 193nm scanner. SEM images of a grating master with a 65nm half pitch are shown in Figure 4.

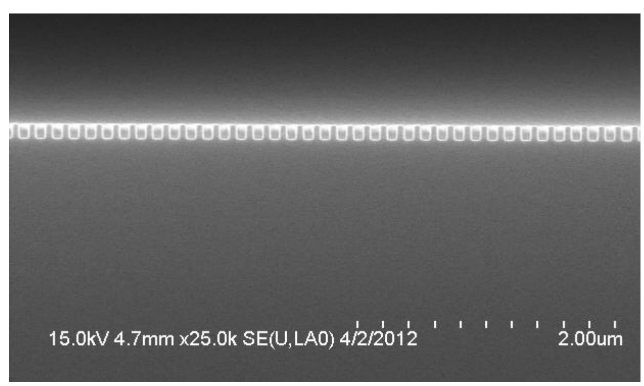

Figure 4. SEM cross section of a silicon master. The grating half pitch is 65nm.

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c. Patterning Results

Several pattern types were tested to insure that imprint non-fill and separation induced defects were addressed. The initial test pattern consisted of curvilinear 120nm features on a 300nm pitch, in order to understand if there were any separation issues resulting from pattern direction. Figure 5a shows a 10m roll (over 100 imprints) printed with this pattern, and a close-up of the printed lines. All fields were cleanly imprinted. A second longevity experiment using a 50nm grating with a 20mm x 20m field was also run. After more than 1000 consecutive imprinted fields, no pattern degradation was observed (See Figures 5b and 5c.)

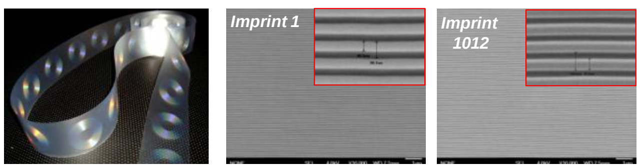


Figure 5. a) imprinted pattern covering 10 meters of the polycarbonate substrate. b and c) Demonstration of 1012 consecutive imprints.

Once the process was established, resolution was tested by imprinting three different patterns: 100nm dense pillars, 50nm half pitch lines and dense 25nm holes All patterns were faithfully resolved. Aspect ratios of up to 3:1 were also demonstrated for 50nm lines.

3 WIRE GRID POLARIZER RESULTS

a. Bilayer Wire Grid Polarizers

Wire grid polarizers (WGPs) are already used in digital projectors. The combination of performance and temperature durability makes their use an attractive choice for this market. Their application to larger displays, including mobile phones, tablets, monitors and TVs has been limited by an inability to scale the WGP to the required areas for these markets. A roll based printing process enables printing over substantially larger areas and therefore addresses the requirements of both performance and CoO.

Using imprinted 50nm half pitch gratings (covering a 50mm x 50mm area), samples of a bi-layer wire grid polarizer were fabricated by depositing a thin layer of aluminum (Al) over the printed resist. The quality of a WGP can be quantified by measuring optical transmission and extinction ratio. Extinction ratio (ER) is defined as the ratio of the Transverse Magnetic (TM) mode over the Transverse Electric (TE) mode (in which the polarizer is rotated by 90 degrees), or TM/TE. The transmission and ER of the device (at 700nm) were >80% and >4500, respectively (Figure 6).

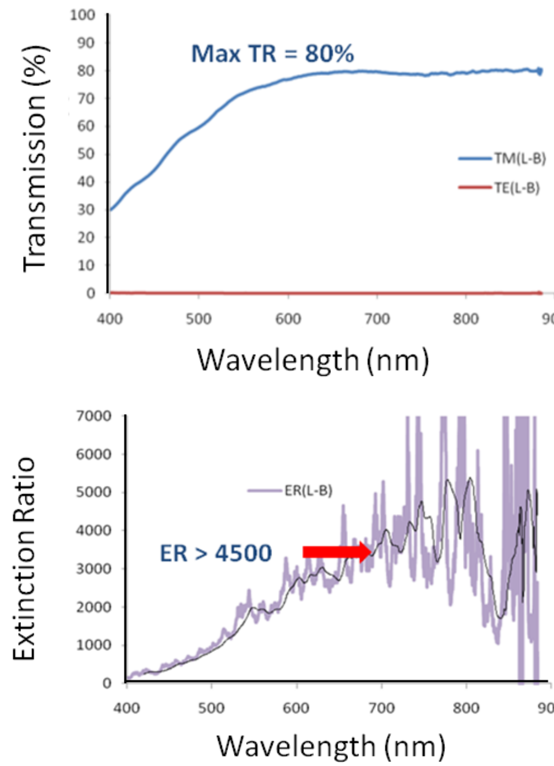
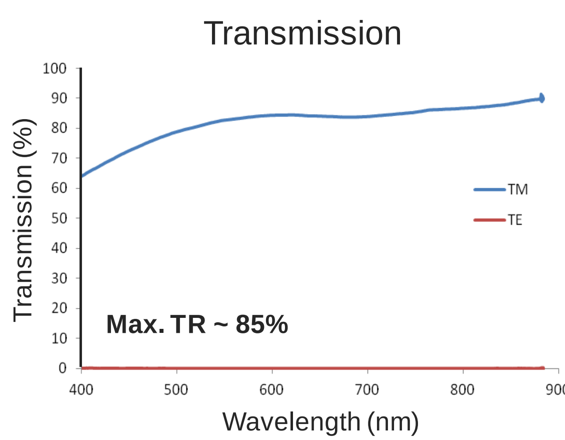


Figure 6. 50mm x 50mm bilayer WGP fabricated on a film using roll based J-FIL and Al deposition.

Note the substantial roll-off in both transmission and extinction ratio at the lower visible wavelengths. One method for minimizing this problem is to deposit the metal at an angle, thereby restricting the deposited material primarily to the sidewall of the resist feature. Figure 7 depicts the performance of a flexible polarizer in which the angle of deposition was set to 80^{o} relative to the plane of the polarizer. A transmission of better than 60% is now observed at a wavelength of 400nm. Figure 8 shows an example of a large area bilayer polarizer with a measured diagonal of 5.7 inches. The polarizer has been placed on top of an iPad display and has been rotated by 90^{o} in order to demonstrate performance of both the TM and TE modes.



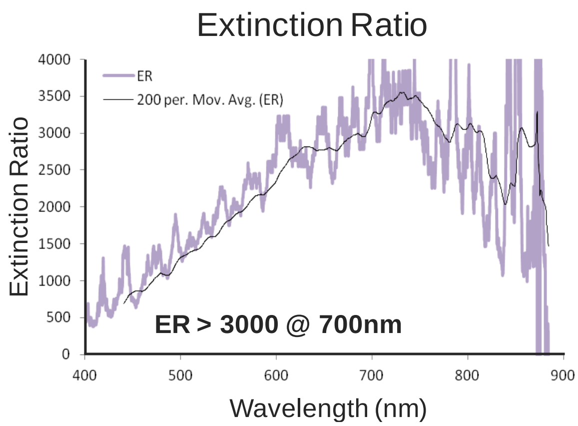


Figure 7. Improved performance of a WGP was obtained by depositing the aluminum at an angle of 80° relative to the plane of the polycarbonate film.

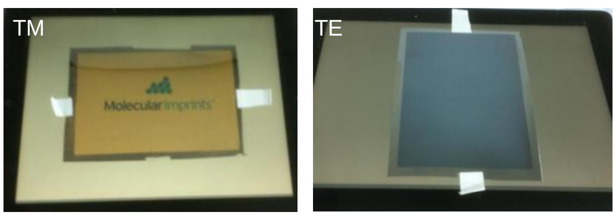


Figure 8. Optical performance of a 5.7" flexible WGP

b. Wire Grid Polarizers on Glass

Aluminum based WGPs formed on glass are typically fabricated by depositing the Al on the glass, patterning the resist grating, and then using the resist as mask to etch the Al. Gratings with half pitches on the order of 50nm typically have transmissions and ERs that are superior to the bilayer WGPs discussed above. In the example below, a WGP with an extinction ratio of greater than 10000 was fabricated using a template with a half pitch of 65nm.

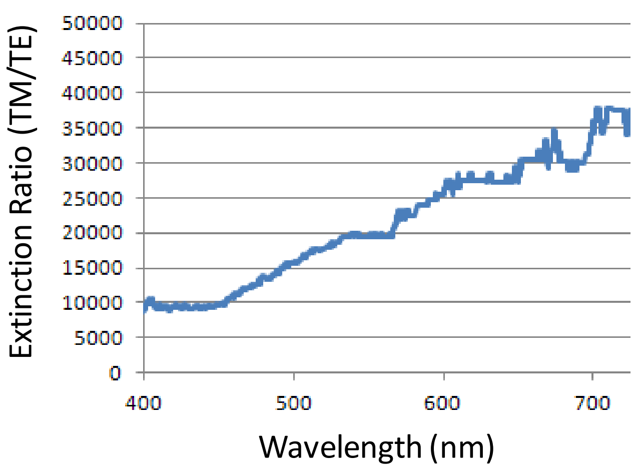


Figure 9. Etched wire grid polarizers. The extinction ratio was greater than 10000 across the entire visible spectrum of light.

CONCLUSIONS

A novel imprinting scheme, the LithoFlex 100, was successfully implemented for roll-based J-FIL patterning on continuous polycarbonate films. A roll module was developed and a prototype roll based J-FIL tool was assembled and successfully tested. Several different templates, including 50nm half pitch gratings and 25nm half pitch dense hole arrays were used to evaluate the imprinting scheme. The system has been used to fabricate large area flexible bilayer WGPs as well as high performance WGPs on glass.

Now that the prototype tool is performing efficiently and providing repeatable results, the next step is to scale the tool and process to address industry requirements for both area and throughput. To do this will require both a new template infrastructure and an imprinting scheme with a parallel processing configuration. These topics will also be the subject of future work.

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REFERENCES

i Worgull, Matthias, *Hot Embossing: Theory and Technology of Microreplication*, William Andrew, 2009.

ii C. Taussig, et. Al. "Roll-to-roll Manufacturing of Backplanes for Paper-like Displays," SID 2010 Digest.

iii M. Colburn, S. Johnson, M. Stewart, S. Damle, T. Bailey, B. Choi, M. Wedlake, T. Michaelson, S. V. Sreenivasan, J. Ekerdt, and C. G. Willson, Proc. SPIE, Emerging Lithographic Technologies III, 379 (1999).

iv M. Colburn, T. Bailey, B. J. Choi, J. G. Ekerdt, S. V. Sreenivasan, Solid State Technology, 67, June 2001.

v T. C. Bailey, D. J. Resnick, D. Mancini, K. J. Nordquist, W. J. Dauksher, E. Ainley, A. Talin, K. Gehoski, J. H. Baker, B. J. Choi, S. Johnson, M. Colburn, S. V. Sreenivasan, J. G. Ekerdt, and C. G. Willson, Microelectronic Engineering 61-62 (2002) 461-467.

vi R. S. Sasaki, T. Hiraka, J. Mizuochi, A. Fujii, Y. Sakai, T. Sutou, S. Yusa, K. Kuriyama, M. Sakaki, Y. Morikawa, H. Mohri, N. Hayashi, Proc. SPIE Vol. 7122, 71223P (2008).

vii S.V. Sreenivasan, P. Schumaker, B. Mokaberi-Nezhad, J. Choi, J. Perez, V. Truskett, F. Xu, X, Lu, presented at the SPIE Advanced Lithography Symposium, Conference 7271, 2009.