Continuous and Scalable Fabrication of Functional films via Vibrational Indentation Patterning and Photo Roll Lithography

J. G. Ok,[1] S. H. Ahn,[1,†] M. K. Kwak,[2,3] K.-T. Lee,[2] C. M. Huard,[2] J. Y. Lee,[2] and L. J. Guo[1,2]

[1]*Department of Mechanical Engineering,* [2]*Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI 48109, USA*

[3]*School of Mechanical Engineering, Kyungpook National University, Daegu 702-701, Korea*

[†]*Current address: Molecular Imprints, Inc., Austin, TX 78758 USA*

Vibrational Indentation-driven Patterning (VIP)[1] is a template-free, high-throughput patterning technique that realizes continuous, period-tunable fabrication of micro/nano-scale gratings. In VIP, a tilted edge of a hard material (e.g. cleaved Si wafer) vertically vibrating at high frequency makes sequential indentations onto a moving substrate of any material softer than a tool, thereby continuously creating grating patterns at high speed. By modulating the tool vibration frequency, substrate feeding rate, and the tool tilting angle, the period-variable chirped gratings as well as angle-tunable blazed gratings can be easily achieved.

Combining Roll-to-Roll (R2R) technology with well-established but area-limited photolithography, Photo Roll Photolithography (PRL)[2] accomplishes the scalable fabrication of a variety of faithful micro/nano-scale features on the webbing substrates. A PRL system centrally comprises a flexible photomask and a hollow quartz roll containing UV source inside. A photoresist (PR)-coated substrate is fed beneath this mask-attached roll where a collimated UV illumination defines the pattern continuously. It is also noted that the pattern geometry can be tailored by controlling the mask-substrate speed.

We utilize these high-throughput patterning techniques to the continuous and scalable fabrication of functional films. First of all, we demonstrate a flexible metal wire-grid polarizer based on the blazed grating structure fabricated by VIP on a transparent polymer film, followed by shadow-evaporating a 50 nm-thick Al layer on one side of the blazed planes (Figure 1).[3] Then we present transparent conducting electrodes (TCEs) fabricated by the PRL patterning of invisible metal mesh structures on transparent substrates (e.g. glass or PET) as shown in Figure 2.[4] Depending on the metal thickness and mesh cell size, the sheet resistance and transmittance of fabricated TCEs can be tuned. Here we newly incorporate the background graphene layer to further increase the TCE conductivity with minimal decrease in transmittance.

Moving forward, VIP and PRL may be widely capitalized to the large-area and high-speed fabrication of more diverse applications such as in optoelectronics, photonics, and energy conversion.

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1 J. G. Ok, S. H. Ahn, M. K. Kwak, and L. J. Guo, *EIPBN 2012*.
2 M. K. Kwak, J. G. Ok, and L. J. Guo, *EIPBN 2012*.
3 J. G. Ok, S. H. Ahn, M. K. Kwak, K.-T. Lee, J. Y. Lee, and L. J. Guo, submitted to *Advanced Materials* (2013).
4 J. G. Ok, M. K. Kwak, C. M. Huard, and L. J. Guo, submitted to *Advanced Materials* (2013).

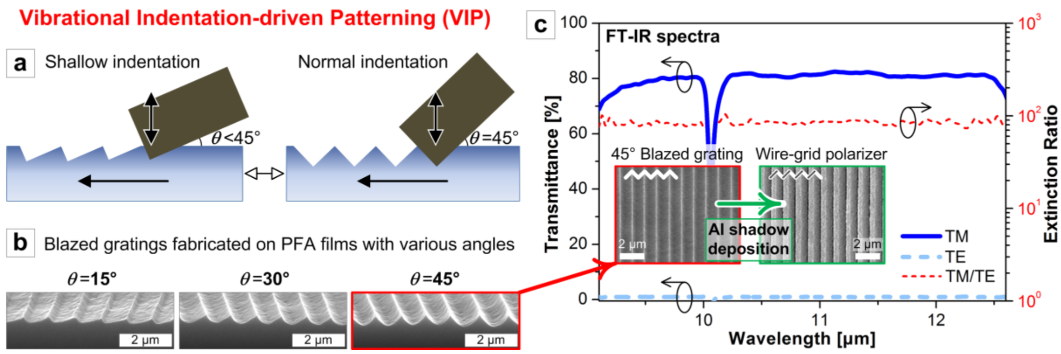

Figure 1: Fabrication of a metal wire-grid polarizer by VIP: (a) Schematic illustrations of blaze angle control by adjusting the tool tilting angle in VIP. (b) Cross-sectional SEM images of blazed gratings fabricated on perfluoroalkoxy (PFA) films by VIP with different tool tilting angles. (c) TM and TE transmission measured from the Al-deposited 45° PFA blazed grating, along with calculated extinction ratio (TM/TE). Inset to (c) shows SEM images of 45° blazed gratings formed on PFA, before (left) and after (right) the shadow evaporation of a 50 nm-thick Al layer.

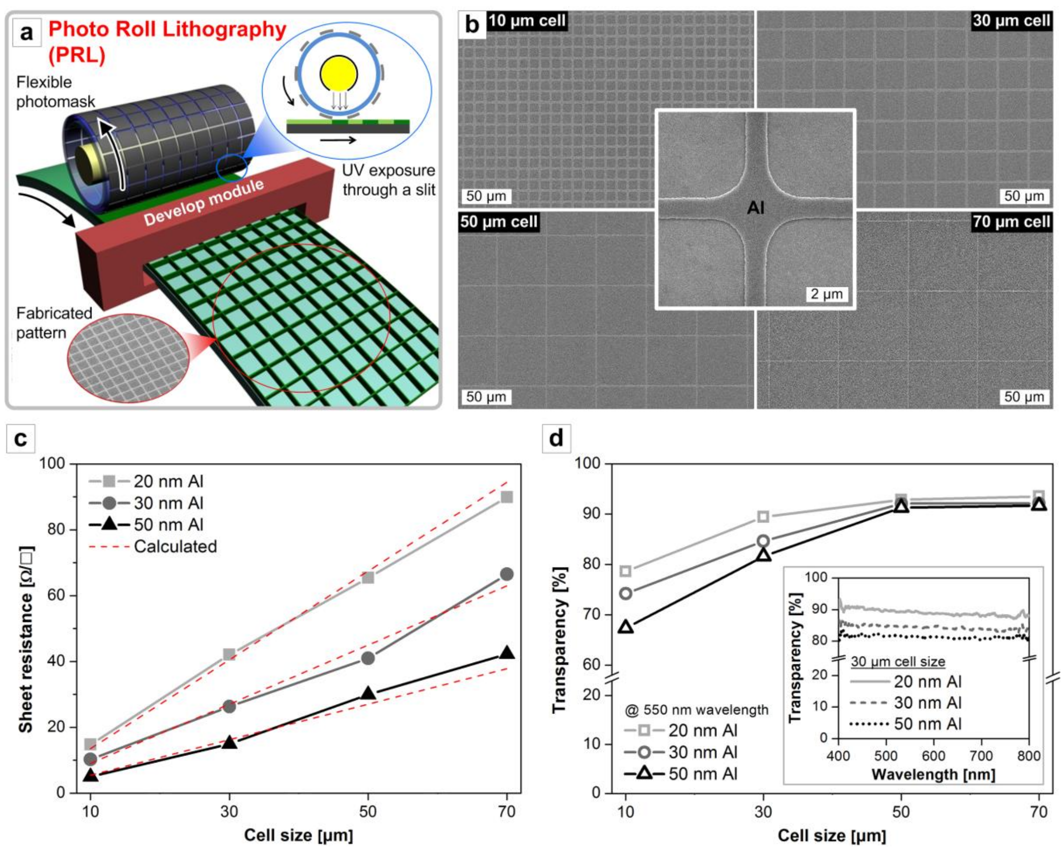

Figure 2: Application of PRL to TCE fabrication: (a) Schematic description of PRL. (b) SEM images of the PRL-fabricated TCEs having varying Al mesh cell sizes of 10, 30, 50, and 70 μm. A centered inset to (b) reveals clearly defined Al line patterns with 1 μm linewidth. (c) Sheet resistances and (d) transmittances at 550 nm wavelength of the TCEs fabricated with different mesh period and Al thickness. Dashed lines in (c) indicate theoretically calculated values. The transmittances of the 30 μm-period samples along the entire visible range are selectively shown in an inset to (d).