Vibrational Indentation Patterning of Grating Structures with Real-time Period Tunability

S. H. Ahn,[1,†,‡] J. G. Ok,[1,†] M. K. Kwak,[2,§] and L. J. Guo[1,2]
[1]*Dept.of Mechanical Engineering,* [2]*Electrical Engineering and Computer Science*
The University of Michigan, Ann Arbor, MI 48109
[†]*The authors equally contributed to this work.*
[‡]*Current address: Molecular Imprints, Inc., Austin, TX 78758*
[§]*Current address: School of Mechanical Engineering, Kyungpook National University, Daegu 702-701, Korea*

Most of the micro- and nanopatterning techniques require the use of a mask (as in photolithography) or a stamp (as in nanoimprinting). The mask making can be very challenging for large area patterning (e.g. roll-to-roll nanoimprinting) or can be of high-cost if it relies on e-beam lithography. To address this issue, we recently demonstrated Localized Dynamic Wrinkling (LDW)[1] method to create nanoscale metal gratings which is spontaneously generated via buckling by using a sharp flat edge such as a cleaved Si wafer sliding over a metal-coated polymer surface. Although LDW achieves continuous fabrication of period-controllable gratings at high speed, it still has a challenge in generating perfectly straight lines due to its nonlinear principle of the wrinkle formation.

Here we introduce a highly versatile and low-cost nanopatterning process, Dynamic Nano-Cutting (DNC), to create micro- and nano-scale gratings on various materials by high-speed vibrational indentations which can be easily extended to continuous roll processing. Similar to LDW process, DNC uses a tilted flat edge of hard material without any pre-patterning (e.g. a cleaved Si wafer), and high-frequency vibration makes sequential nano-indents on a moving substrate (Figure 1) to continuously create perfectly straight line patterns that LDW is not able to achieve. When the tool (Si wafer) vibrates at the frequency of f and indents a substrate moving at the linear speed of V, the period of pattern λ is simply given as $\lambda = V / f$. Thus, by controlling vibration frequency and substrate feeding speed in real-time, nanograting patterns having varied periods can be created in a single process step. (Figures 2a,b) Also, DNC enables a single-step fabrication of faithful blazed gratings simply by controlling the indenting angle θ (Figure 2c). Since DNC bases on mechanical indentation, sequential processing along multiple directions leads to a facile fabrication of multidimensional micro- and nanostructures (Figure 2d). DNC is therefore a "first generation patterning" process that does not require costly and area-limiting master stamps.

The outstanding real-time period tunability and the simple geometry programmability enable a one-step fabrication of chirped and blazed grating structures on any materials softer than an indenting tool, which potentially will lead to the mass-production of large-area functional gratings that can be widely capitalized to optics, electronics, and energy conversion devices.

---

[1] S. H. Ahn and L. J. Guo, *EIPBN 2010*; *Nano Lett.* **10**, 4228 (2010).

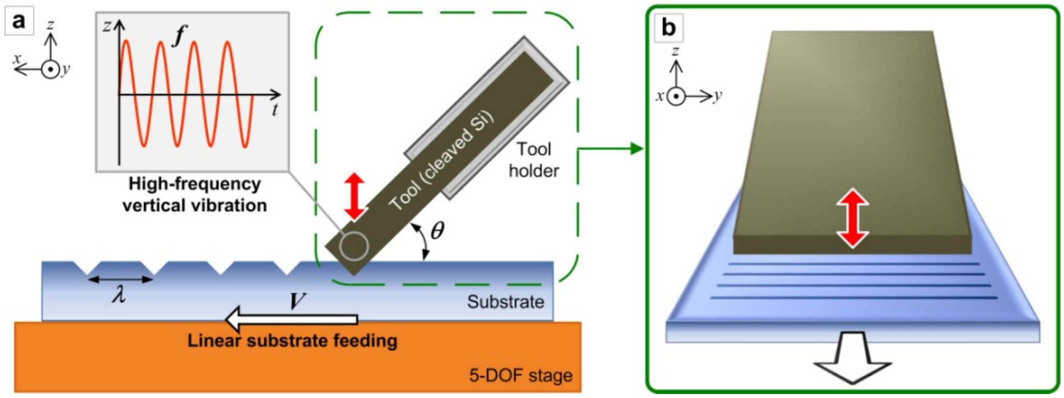

Figure 1: Schematics of Dynamic Nano-Cutting (DNC) with the process controlling parameters indicated: (a) side view and (b) perspective view from the front. The mass eccentrically mounted to the high-speed moter generates high-frequency vertical vibration at the tool tip which periodically indents the moving substrate to produce micronanograting structures.

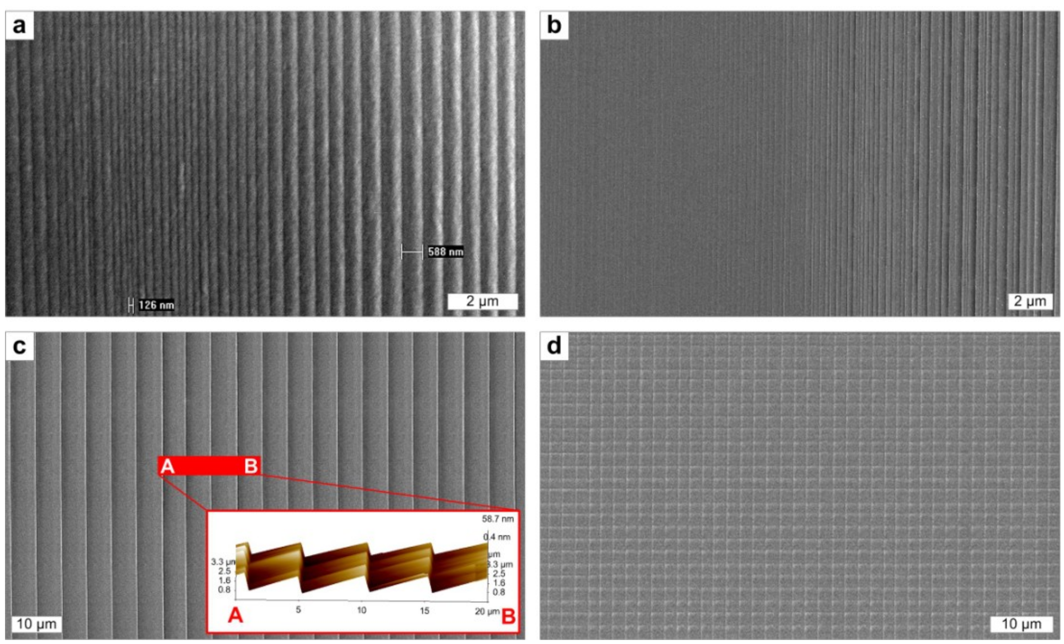

Figure 2: Grating pattern having variable periods (chirped grating) (a) fabricated on a PET substrate by modulating the substrate feeding speed between 10 and 100 µm/s under the 200 Hz vibrational indentations and (b) fabricated on a polycarbonate substrate by modulating the vibration frequency between 30 and 200 Hz under the 100 µm/s. (c) Blazed grating structure with the 5 µm period fabricated on a polycarbonate substrate by controlling the indenting tool tilting angle to 20° during the DNC process. Inset to (c) shows the enlarged topology characterized by AFM across the four pitches, indicating clear blazed grating profile. (d) 2.5 µm-period 2-D grating fabricated on a polycarbonate substrate by sequential DNC processes along the two axes with 90° feeding angle difference.