Sub-20 nm fabrication on polyimide plastics enabled by directed self-assembly

Li Tao,[1] Hsiao-Yu Chang,[1] Kevin Gotrik,[2] Jeong Gon Son,[2]
Caroline A. Ross,[2] and Deji Akinwande[1,*]
[1]*Microelectronic Research Center, The University of Texas at Austin, TX 78758*
[2]*Department of Materials Science and Engineering, Massachusetts Institute of Technology, MA 02139*
[*]*Email: deji@ece.utexas.edu;*

One of the candidates for next generation lithography technique in the international technology roadmap for semiconductors (ITRS) is directed self-assembly (DSA). The key advantage of DSA, compared to conventional self-assembly, is its capability to define sub 20 nm patterns in a long range order owing to amplification of lithographically defined patterns.[1-3] Numerous applications such as electronic, magnetic, optical, and energy devices have been demonstrated with DSA on traditional hard substrates over the past decade.[2, 4] However, successful creation of DSA patterns on a flexible/plastic substrate has rarely been reported because of the thermal constrains and surface roughness of plastic surfaces. Herein, we apply solvent-assisted DSA,[5] onto the plastic substrate, which holds great potential to enable novel nano- materials or devices.

The pattern fabrication process as shown in Figure 1a-c, starts with the deposition of 50-100 nm SiO_2 or Al_2O_3 on the polyimide supported by silicon wafer. Guiding patterns with 40 nm depth and width from 100-1000 nm were lithographically defined in the oxide layer with slow reactive ion etching (2 nm/min) to minimize the surface roughness. A brush layer (hydroxyl-terminated PDMS, 5k) was grafted onto oxide surface and then polystyrene-block-polydimethylsiloxane (PS-b-PDMS, 43.5k) spin-coated on top was annealed in a solvent environment (heptane:toluene=1:5) at 20 ^{o}C, 35% humidity for 5-8 hrs.[5] Phase separation of each homopolymer in this di-block copolymer due to enthalpic over entropic force will form in-plane cylinders (~17 nm diameter). After selective etching of the polystyrene component using oxygen plasma, oxidized (ox-) PDMS gratings will be left as seen in Figure 1d. The remaining ox-PDMS patterns can serve as a mask to etch the underlying layer such as SiO_2 (Figure 2) using fluorine plasma with a selectivity of 1.2:1 (SiO_2:ox-PDMS) shown in Figure 3. One note here is that the line edge roughness (LER) in the guiding trenches could result in broken or missing gratings (circled in Figure 4a), whereas smooth side walls defined by e-beam lithography (Figure 4b) yields high fidelity. Nanoimprint as a scalable approach could also provide smooth side wall for highly uniform DSA. On the other hand, in a smooth trench (Figure 4c) one can intentionally control local LER to create complex patterns (Figure 4d).

In this work, we have demonstrated sub-20 nm features including lines and spaces via DSA on polyimide plastics which can subsequently be used for making nanoscale devices for flexible applications. Line edge roughness in DSA process was utilized to improve or manipulate the quality of the resulting patterns. Due to the ability to achieve high resolution and compatibility with wafer-scale imprinting or printing techniques, DSA could pave the way to fabricate advanced flexible nano-materials or devices in a scalable manner.

1.T. Thurn-Albrecht, et al., Science **290** (5499), 2126-2129 (2000). 2.C. Ross, Annu. Rev. Mater. Res. **31** (1), 203-235 (2001). 3.J. Y. Cheng, et al., Adv. Mater. **15** (19), 1599-1602 (2003). 4.C. R. K. Marrian and D. M. Tennant, J. Vac. Sci. Technol. A **21** (5), S207-S215 (2003). 5.Y. S. Jung and C. A. Ross, Nano Letters **7** (7), 2046-2050 (2007).

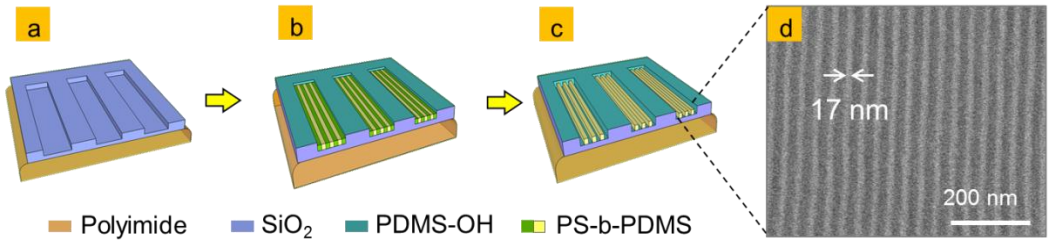

Figure 1: Directed self-assembly (graphoepitaxy) of polystyrene-block-polydimethylsiloxane (PS-b-PDMS) on polyimide plastics: a) forming guiding patterns on SiO_2 film on ploymide substrate; b) applying brush layer (PDMS-OH) and then di-block copolymer PS-b-PDMS followed by solvent-assisted annealing; c) selective etching to remove polystyrene component and leave oxidized (-ox) PDMS via plasma; d) SEM image of ox-PDMS gratings with 17 nm half pitch.

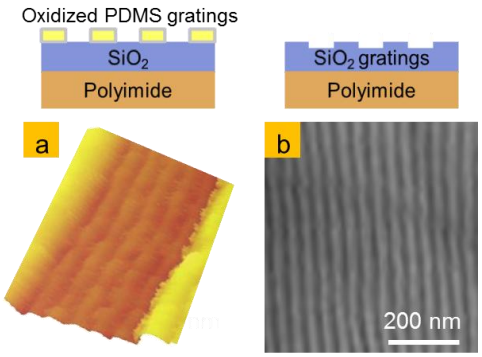

Figure 2: Transfer of directed self-assembly (DSA) gratings into SiO_2 on polyimide. a) AFM image of oxidized polydimethylsiloxane (ox-PDMS) gratings resulted from DSA process; b) SiO_2 gratings obtained by fluorine plasma etching with ox-PDMS gratings as a mask.

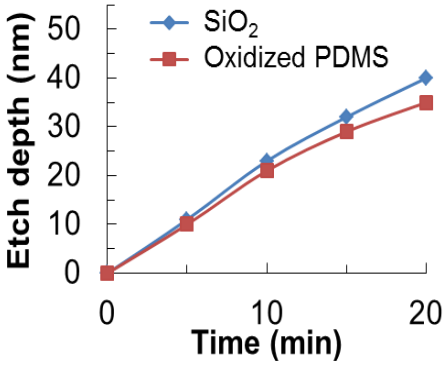

Figure 3: Etching rate of SiO_2 and polydimethylsiloxane (PDMS) under a CF_4 based plasma at 5 mTorr. This is the plasma etching conducted in Figure 2b with a slow etching rate and selectivity of *SiO_2:PDMS*=1.2:1.

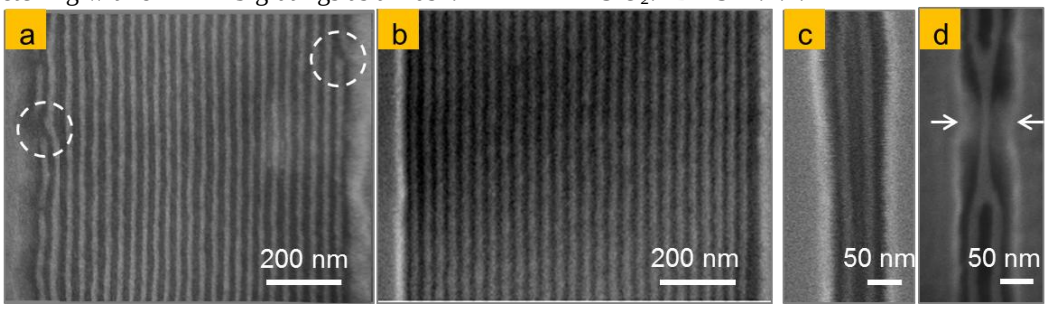

Figure 4: The effect of line edge roughness (LER) on the fidelity of the directed self-assembly patterns: a) guiding trenches defined by photolithography resulted in rough edges that show defects as highlighted in circles on DSA gratings, b) e-beam defined guiding trenches that yield defect-free gratings; c) smooth trench without disruption and d) controlled local disruption can be used to intentionally create complex structures as shown as a fork pattern.