Demonstration of sub-4 nm nanoimprint lithography using a template fabricated by helium ion beam lithography

Wen-Di Li, Wei Wu and R. Stanley Williams*
Nanoelectronics Research Group, Hewlett-Packard Labs, Hewlett-Packard Co., Palo Alto, CA 94304
*E-mail: stan.williams@hp.com

With the IC road map entering the single-digit nanometer regime, next generation nanolithography technologies have been attracting increasing research interests. Nanoimprint lithography (NIL) has demonstrated the capability of transferring 2 nm features using random carbon nanotubes as a template [1], although fabrication of NIL templates carrying arbitrary patterns at sub-10 nm scale is still a challenge. In order to achieve sub-10 nm arbitrarily designed patterns, electron beam lithography (EBL) has been developed to set a resolution record of 4.5 nm half-pitch lines in HSQ resist [2]. However, electron beam based lithography exhibits strong proximity effect that limits patterning of high-density sub-10 nm features over a large area and faces challenges to achieve higher patterning resolution due to its limited spot size.

Since the helium ion microscope was introduced recently, its value in nanolithography has been immediately recognized [3][4]. Helium ion beam lithography (HIBL) has a number of advantages comparing with EBL including smaller beam spot size, higher sensitivity and very low proximity effect, which combine to offer the capability of single-digit nanopatterning of dense structures over a large area. Moreover, with a much larger mass, focused helium ions are also excellent particles to directly mill the substrate for arbitrarily designed patterns at a resolution higher than conventional Ga ion based focused ion beam (FIB) lithography.

In this paper, we will demonstrate our results on sub-4 nm nanoimprint using a template fabricated by HIBL. Standard nested L patterns with various half pitches were fabricated in hydrogen silsesquioxane (HSQ) using a Carl Zeiss Orion Plus helium ion microscope equipped with a Raith ELPHY pattern generator in Hewlett Packard Labs. The developed nested L patterns in HSQ were used as a NIL template after properly treated with a surface release agent layer. UV-NIL was carried out in a custom-built nanoimprinter. Figure 1 shows the SEM pictures of the HSQ patterns fabricated by HIBL, with the smallest resolvable half pitch to be 3.5 nm. Figure 2 shows the imprinted L patterns in the UV-curable resist. Nanocracks seen on the SEM pictures were due to the stress of the deposited 2-nm-thick platinum layer for charge releasing and contrast enhancement. Nested L's with a 4 nm half pitch are resolvable on the nanoimprinted resist.

Furthermore, in order to overcome challenges in further improving the patterning resolution of both helium ion beam lithography and nanoimprint lithography, we explored fabrication of NIL templates by direct milling a thin layer of hard materials deposited by e-beam evaporation. By milling 10 nm thick chromium layer deposited on a 20 nm thick silicon nitride membrane, we achieved 5 nm half pitch nested L patterns. The chromium membrane carrying the milled patterns can be transferred into a bulk substrate to be used as a NIL template. Since materials with stronger

mechanical strength may be used in this approach, this approach is promising for further reducing the structure dimensions in nanoimprint lithography.

In summary, we have demonstrated sub-4 nm patterning resolution using HIBL and sub-4 nm NIL of arbitrary designed patterns. We also explored using direct milling to make NIL templates for further increasing the HIBL/NIL patterning resolution. Our work combining HIBL with NIL paves a promising and viable path towards device fabrication and physics study at single-digit nanometer level.

[1] F. Hua et al, "Polymer Imprint Lithography with Molecular-Scale Resolution," Nano Lett., 4(12), pp.2467-2471 (2004)
[2] J.K.W. Yang et al, "Understanding of Hydrogen Silsesquioxane Electron Resist for Sub-5-nm-Half-Pitch Lithography," JVST B, 27, pp.2622-2627 (2009)
[3] D. Winston et al, "Scanning-helium-ion-beam lithography with hydrogen silsesquioxane resist," JVST B, 27(6), pp.2702-2706 (2009)
[4] V. Sidorkin et al, "Sub-10-nm nanolithography with a scanning helium beam," JVST B, 27(4), pp.L18-L20 (2009)

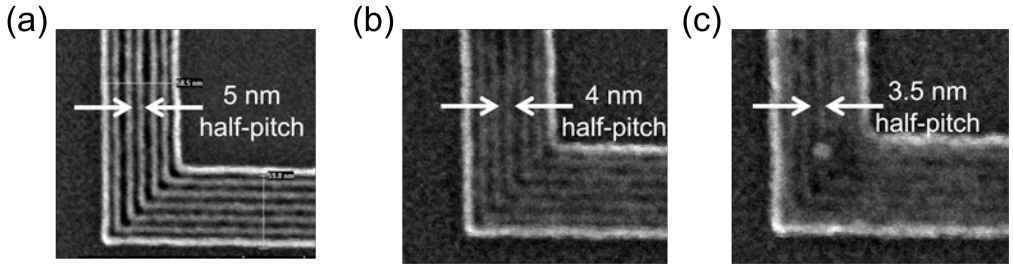

Fig.1 SEM pictures of (a) 5 nm, (b) 4 nm and (c) 3.5 nm half-pitch nested L's patterned in HSQ by helium ion beam lithography.

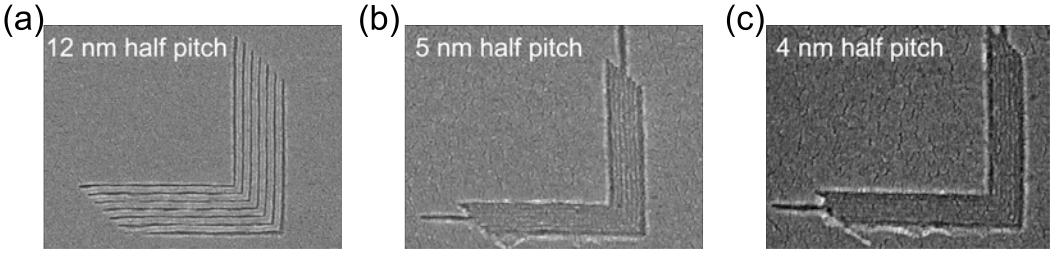

Fig.2 SEM pictures of nanoimprint results using the HIBL patterned template. Half pitch: (a) 12 nm, (b) 5 nm and (c) 4 nm.

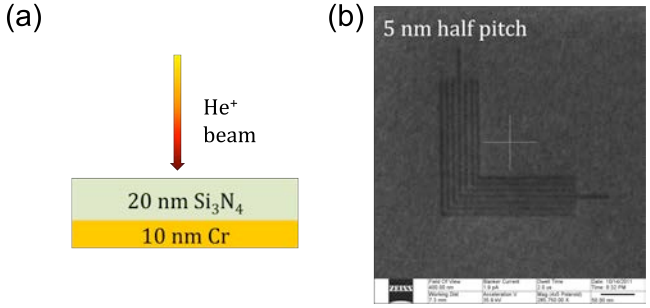

Fig. 3 Direct milling for NIL template fabrication. (a) Schematic of helium ion milling. (b) 5 nm half-pitch nested L's milled on 10 nm chromium.