Single-digit patterning using EUV light

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The progress of semiconductor devices, following the so-called Moore's law, has been enabled with a continuous effort of developing novel device architectures and patterning methods. Further progress towards 11 nm technology node and beyond, faces substantial challenges, in terms of lithographic methods. In particular, patterning in the sub-10 range, or single-digit lithography, requires substantially different approaches. Extreme ultraviolet (EUV) lithography is currently considered as the most promising one for high-volume semiconductor manufacturing at technology nodes beyond 16 nm. In addition to the development of industrial projection systems, EUV interference lithography (EUV-IL) has recently been attracting growing interest as a powerful tool for academic as well as in industrial research due to its ability to provide high-resolution nanostructures over large areas with high throughput. In this paper, we demonstrate the extension of our patterning resolution down to sub-10 nm, and proof that EUV-IL is suitable as a single digit nanofabrication technique.

The most common experimental scheme in EUV-IL involves the illumination of a mask containing several diffraction gratings with a spatially coherent beam in order to overlap first-order or higher order diffracted beams at a certain distance from the mask and record the resulting interference pattern in a suitable photoresist. In addition to the interferometer stability and photoresists, the key point to attain high-resolution patterns approach the theoretic limit ($\lambda/4$) is the mask quality. With our recently developed mask fabrication process, in Figure 1, we show the high-resolution patterning capability of EUV-IL with an inorganic resists using first-order interference scheme. We were able to achieve well resolved line/space patterns down to 7 nm half-pitch (HP) with height of 15 nm (see Figure 2), marking the current record in photon based lithography. We also demonstrate the successful transfer of the patterns to silicon with optimized reactive ion etching (RIE) process (see Figure 3).

These results prove that EUV photons can achieve single-digit patterns. They also show the capability of EUV-IL as a powerful tool for providing development of photoresist and etching processes at sub-10 nm nodes for industry and academic. There are also various other applications at such size range, just as some examples, templated self-assembly, quantum physics, photonic devices.

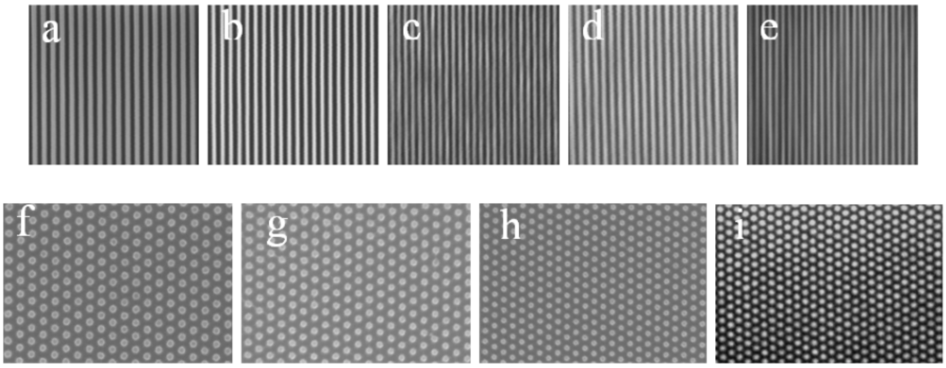

Figure 1: SEM images of high resolution patterns in HSQ. One dimensional line/space patterns (a) 11 nm half-pitch (HP), (b) 10 nm HP, (c) 9 nm HP, (d) 8 nm HP, and (e) 7 nm HP. Two dimensional dot patterns (f) 30 nm half-pitch (HP), (g) 22 nm HP, (h) 17 nm HP, (i) 11 nm HP.

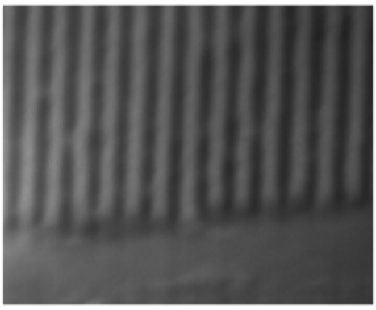

Figure 2: Bird-eye view (60 degree tilt) SEM images of HSQ line/space patterns with 8 nm HP.

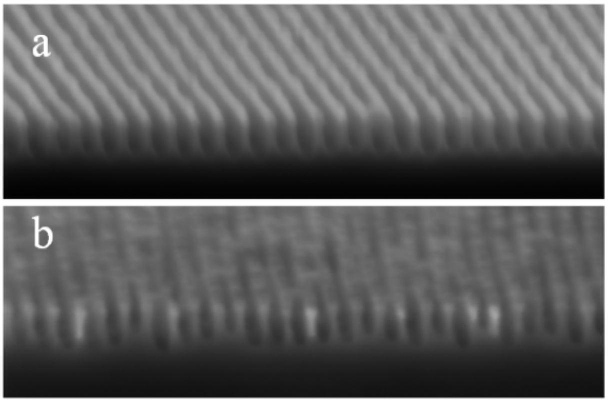

Figure 3: SEM images of high aspect ratio Si line/space patterns with (a) 15 and (b) 11 nm HP created using RIE etching.