High-resolution patterning with EUV interference lithography

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Extreme ultraviolet (EUV) lithography is currently considered as the most promising alternative to the DUV immersion lithography for high-volume semiconductor manufacturing at technology nodes below 22 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. This technique provides high-resolution nanostructures over large areas with high throughput.

In this paper we show the high-resolution patterning capability of EUV-IL with different inorganic resists. We were able to achieve resolved line/space patterns down to 8 nm half-pitch and modulation down to 6 nm, as shown in Fig. 1, marking the current record in photolithography. These results are obtained by using second-order diffracted beams generated by optimized molybdenum phase shifting mask gratings.

In the most common scheme of interference lithography, spatially coherent beams interfere creating one- or two-dimensional periodic patterns. We show that various types of complex patterns can be generated by EUV-IL using the interference of phase-engineered multiple-beam schemes with diffraction gratings. With this method we were able to fabricate complex periodic nanostructures such as honeycomb and kagome patterns as well as two-dimensional quasi-periodic (Penrose) nanostructures resulting from 5- and 8-beam interference with feature sizes down to 50 nm (Fig. 2). These patterns are unique structures showing a long-range aperiodic order and rotational symmetries outside the traditional crystallographic classification scheme. Generally, in serial writing techniques, such as e-beam lithography, the fabrication of quasi-periodic structures is difficult to achieve due to their aperiodic translational order and the time-consuming data calculations. Faster and inherently accurate approach is given by the use of multiple beam interference and here we show high-resolution quasi-periodical patterning using EUV-IL. In addition, we also demonstrate the fabrication of arbitrary patterns using non-diffracting Bessel beams at EUV wavelength as shown in Fig. 3. These results prove that by employing advanced holographic methods EUV-IL is a powerful tool providing high-resolution and versatile nanostructures for various applications, ranging from templated self-assembly to photonic devices.

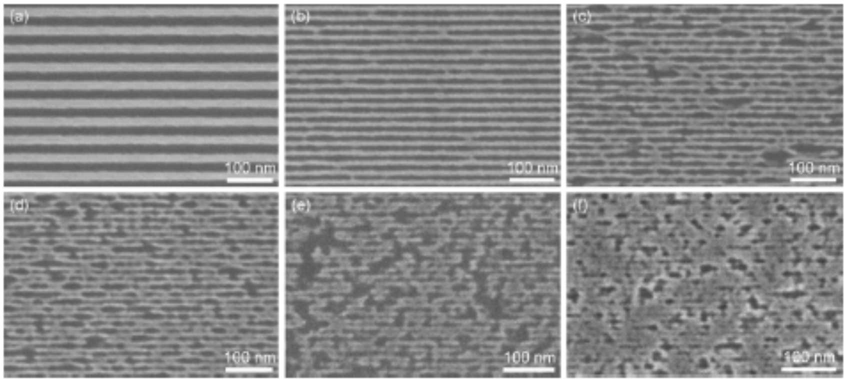

Figure 1: SEM images of high resolution line/space patterns in HSQ. (a) 20 nm half-pitch (hp), (b) 11 nm hp, (c) 9 nm hp, (d) 8 nm hp, (e) 7 nm hp, and (f) 6 nm hp.

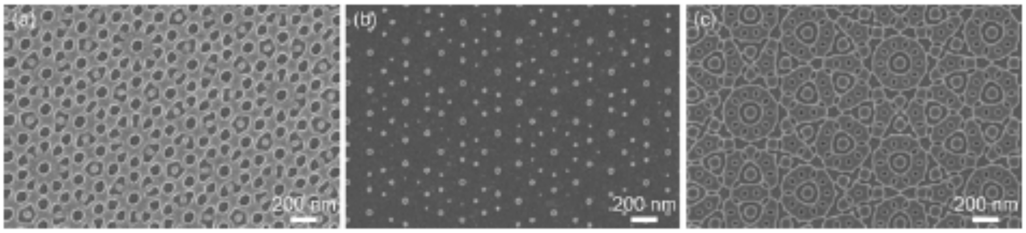

Figure 2: SEM images of Penrose patterns recorded in (a) PMMA and in HSQ with (b) low dose and with (c) high dose.

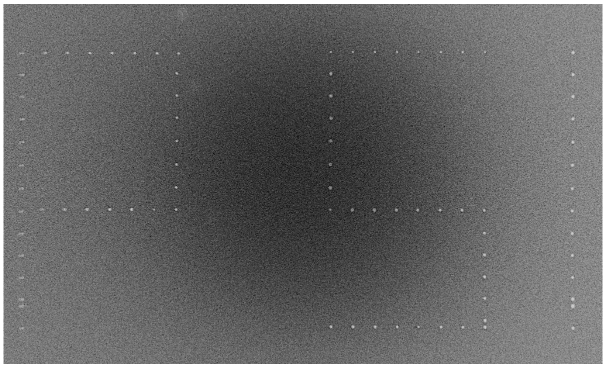

Figure 3: SEM image of an arbitrary HSQ pattern (PSI Logo) written with “EUV Bessel beam pen”.