Spatial-frequency Multiplication with Multilayer Interference Lithography

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We report progress in achieving large-area spatial-frequency multiplication using multilayer interference lithography (IL). In this fabrication scheme, multiple grating layers with a grating period p are patterned with different phase offsets and etched onto a single layer, effectively dividing the period [1] by an integer number. The linewidth in each grating layer is controlled with nm-accuracy by high-pressure plasma etching and an image-reversal process. Using this process, gratings with deep sub-diffraction-limited periods can be achieved with IL using a 351.1 nm laser.

There are several key challenges to make this process feasible, among which the most important are linewidth control and overlay accuracy. Linewidth control is important to ensure that the grating linewidths are consistent in every layer. This condition is essential in suppressing the fundamental spatial-frequency. In addition, for higher factor frequency multiplication, the duty-cycle of each layer needs to be as high as possible. High duty-cycle and linewidth repeatability are achieved through isotropic plasma etching and a novel image-reversal process, which is shown in Figure 1. Using this process we are able to achieve a duty-cycle of ~0.9 with nm linewidth repeatability using a 200 nm-period grating. Using such high duty-cycle gratings spatial-frequency multiplication with factors of 4-5 can be theoretically achieved.

High overlay accuracy is achieved by measuring the phase of a reference grating using homodyne interferometry before patterning each grating layer. By keeping the reference grating distortion-free in the fabrication process, the overlay accuracy is limited by the repeatability of our metrology system, the Nanoruler [2]. In previous efforts [3] we have demonstrated overlay accuracy of better than 3 nm over a 40 x 40 mm^2 area with 574 nm period grating layers. Figure 2(a) demonstrates that we now have achieved similar overlay accuracy of 200 nm-period resist and silicon nitride gratings.

The preliminary result of this process is illustrated in Figure 2(b), where the low duty-cycle resist grating shown in Figure 1(a) has been image-reversed, resulting in a 100 nm-period grating. The linewidths of the etched grating is on the order of 20-25 nm, and allow the addition of two more layers to achieve spatial-frequency quadrupling. Note that one set of etched lines (2nd layer) are straighter than the other (1st layer) — this is because the two layers were etched with different RIE processes. This will be discussed in more detail.

In this paper we present a multilayer interference lithography process that can achieve large-area spatial-frequency multiplication. Using this process the optical diffraction-limited problem can be solved with high precision metrology and well-controlled fabrication techniques. An image-reversal process that was used to achieve high duty-cycle and nm linewidth control will be highlighted. These results that we present are important in moving towards our goal of four-fold spatial-frequency multiplication.

REFERENCES

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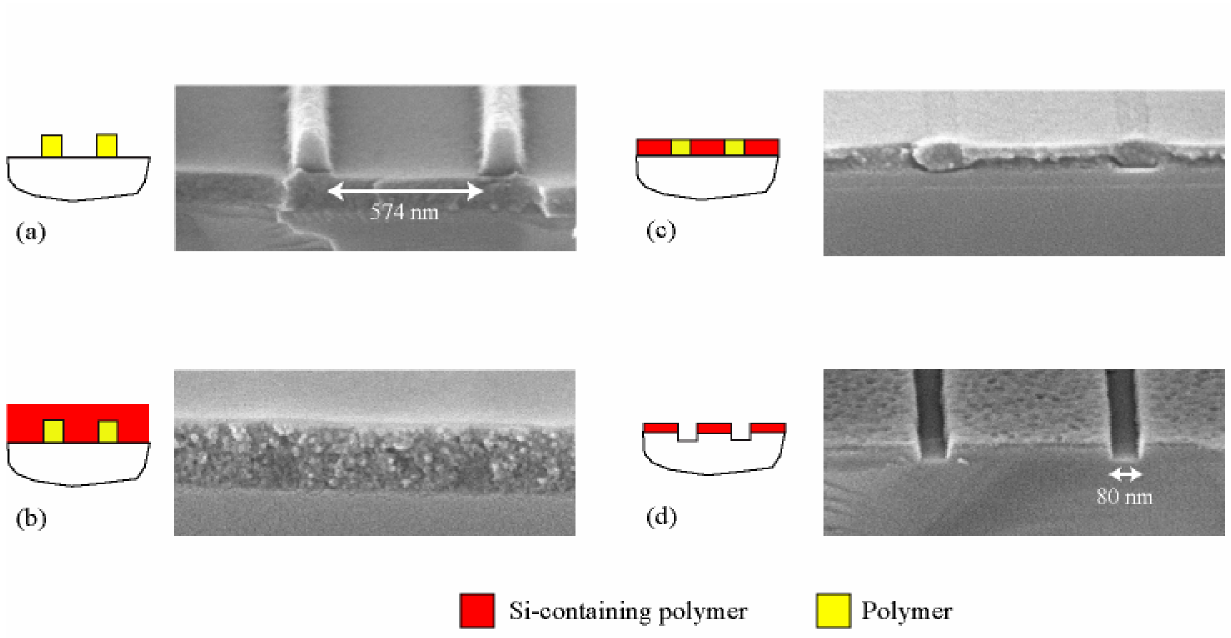

Figure 1. Image-reversal process for achieving high duty-cycle grating. Starting with (a) a low duty-cycle polymer grating, (b) a silicon-containing polymer is spun over the pattern. Several RIE steps are used to (c) expose the polymer, and (d) transfer the pattern into nitride.

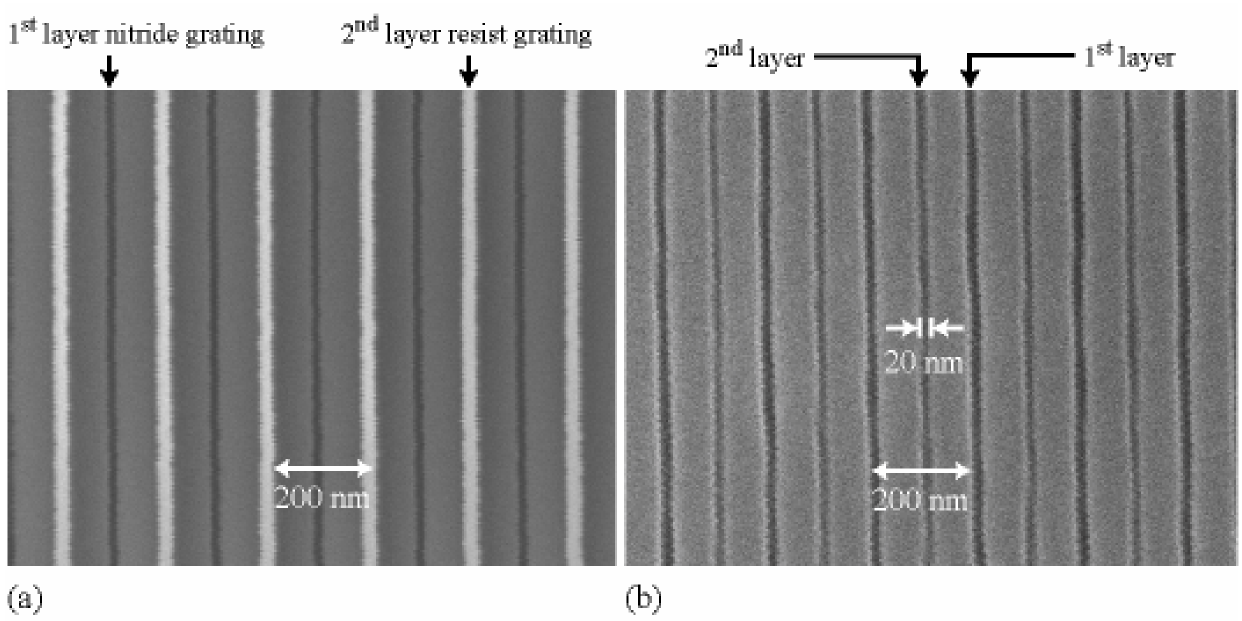

Figure 2. Top-view SEM of (a) 200 nm-period resist grating (narrow light lines) patterned on a 200 nm-period silicon nitride grating (narrow dark lines) with a π-phase offset. (b) The resist grating is image-reversed and etched, resulting in a 100 nm-period grating in nitride.