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Self-Aligned Double Pattern, No1

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1. Introduction
Self-Aligned Double Patterning (SADP) is a technique to realize a half-scaling of the original pattern using a single exposure followed by spatial-frequency doubling. Self-Aligned Quadruple Patterning (SAQP) is similar to SADP, but a quarter-scaling of the original pattern is realized by two time spatial-frequency doublings. Self-Aligned Multiple Patterning is considered to be one of the most promising advanced lithography, and can achieve the better resolution than the lithography tool owned, without additional expensive cost.

The goal of this project is to fabricate a 15 nm pitch pattern from a 60 nm pitch pattern using SAQP and the tools available at Quattrone Nanofabrication Facility (QNF), but this report describes shrink from 300 to 150 nm pitch pattern by SADP, as a preliminary. Figure 1 shows a process flow of SADP using e-beam writer Elionix ELS-7500EX.

2. Experimental Section
A. Deposition of 100 nm thick silicon nitride film
A Si wafer was sonicated in acetone and isopropyl alcohol (IPA) for 5 min each. A 93 nm thick silicon nitride film was deposited on the Si wafer, using Oxford Plasma Lab 100. Table 1 indicates silicon nitride deposition parameters. The deposition rate was 46 nm/min.

B. E-beam lithography
A 190 nm thick PMMA film was spin coated on a piece of the Si wafer at 4000 rpm for 60 sec, using PMMA A4 solution, followed by baking it at 180 °C for 5 min on a hot plate. The acceleration voltage was 50 kV, the beam current was 100 pA, and the objective lens aperture was 40 µm. The e-beam dose was 300 µC/cm², and the dose time was 0.75 µsec in the area of 300 x 300 µm² with the total dots of 60000 x 60000. The PMMA film exposed was developed for 30 sec in a 3:1 (v/v) mixture of IPA and methyl isobutyl ketone (MIBK). The sample developed was rinsed with IPA.

Figure 2 shows a SEM image of the developed PMMA film, indicating that the gap width was 200 nm, because the thickness of the sidewall Al deposition on the line pattern was ~65 nm when depositing 100 nm thick Al film. This will be described in the next section.
C. Al deposition

Figure 3 shows a SEM image of Al film deposited on the PMMA pattern in figure 2. A 100 nm thick Al film was deposited onto the developed PMMA film, using load lock PVD-75 DC/RF magnetron sputterer (Kurt Lesker) with the following condition: base pressure = $8.0 \times 10^{-8}$ Torr; process Ar pressure = 3 mTorr; DC power = 400 W; temperature = room temperature. The deposition rate was 8.9 nm/min.

When 100 nm thick Al film was deposited on the line pattern, the thickness of the sidewall Al deposition on the line pattern was ~65 nm, as shown in figure 3. The sidewall deposition on the developed resist film depends on both of the grain size and the sidewall angle of resist pattern. The grain size is roughly 30-60 nm, which seriously affects a line edge roughness (LER) of the pattern during silicon nitride etching, as shown in figure 1.

D. Al etching

The top of the 100 nm thick Al film was carefully etched, using Minilock-Phantom III (TRION Technology) with the following condition: process pressure = 15 mTorr; ICP RF power = 250 W; RIE RF power = 50 W; BCl$_3$ gas flow = 30 sccm; O$_2$ gas flow = 5 sccm; Cl$_2$ gas flow = 10 sccm; process time = 100 sec. The chamber was purged with Ar for 5 min after the etching. Figure 4 shows a SEM image of the PMMA line pattern with the sidewall Al deposition after the etching. The apparent width ~40 nm of PMMA line pattern indicates that the top of Al film is not completely etched. In addition, the tail of Al film on the gap is still observed.

Figure 2. A SEM image of 100 nm width line and 200 nm gap pattern of PMMA film.

Figure 3. A SEM image of 100 nm thick Al film deposited onto the line pattern shown in figure 2. The grain size of Al is roughly 30-60 nm, and the thickness of the sidewall Al deposition on the pattern is ~65 nm.

Figure 4. A SEM image of the PMMA line pattern with the sidewall Al deposition after etching the top of Al deposition.
E. PMMA removal by O₂ plasma
The PMMA line pattern was removed by O₂ plasma treatment, using Technics Asher with the following condition: base pressure = 90 mTorr; process O₂ pressure = 250 mTorr; RF power = 100 W; process time = 60 sec. Figure 5 shows a SEM image of the Al line pattern after PMMA removal.

F. Silicon nitride etching
The silicon nitride film was etched through the Al line pattern, as a hard mask, using Oxford 80 plus RIE etcher with the following condition: process pressure = 20 mTorr; RIE power = 150 W; CHF₃ gas flow = 50 sccm; O₂ gas flow = 5 sccm; temperature = 17.5 °C. The etching time was 92 sec.

G. Al stripping
The Al line pattern was removed by immersing the sample in Al etchant for 10 min. Figure 6 shows a SEM image of the line pattern on the silicon nitride film, transferred from the Al line pattern. As can be seen in figure 6, the 300 nm pitch of the PMMA pattern is shrunk to 150 nm pitch pattern. The ~65 nm line width is directly reflected by the thickness of the sidewall Al deposition. On the other hand, the line edge roughness is very poor because of the grain structure of Al film.

3. Result
The 300 nm pitch pattern was successfully shrunk to the 150 nm pitch pattern using SADP technique and the tools available at QNF. On the other hand, the issue on SADP was found out; the grain structure of Al film deteriorated the line edge roughness of the pattern transferred. To overcome the problem, a chromium film will be deposited on the PMMA developed film.

4. Summary
SADP technique was applied in QNF to shrink the pattern by a single e-beam exposure followed by spatial-frequency doubling. The 300 nm pitch pattern was successfully shrunk to the 150 nm pitch pattern. On the other hand, the issue on SADP was found out; the grain structure of Al film deteriorated the line edge roughness of the pattern transferred. To overcome the problem, a chromium film will be deposited on the PMMA developed film, and furthermore, the smaller pitch pattern will be reported.