5) ArF Lithography Patterning Test #2: Evaluation of L/S and Trench Patterns

Examples 3-1 to 3-14 and Comparative Examples 3-1 to 3-10

On a substrate, a spin-on carbon film ODL-50 (Shin-Etsu Chemical Co., Ltd.) having a carbon content of 80 wt % was deposited to a thickness of 200 nm and a silicon-containing spin-on hard mask SHB-A940 (Shin-Etsu Chemical Co., Ltd.) having a silicon content of 43 wt % was deposited thereon to a thickness of 35 nm. On this substrate for trilayer process, each of the resist compositions (Inventive R-1 to R-14 or Comparative R-15 to R-24) was spin coated and baked on a hot plate at 100° C. for 60 seconds to form a resist film of 100 nm thick. Using an ArF excimer laser immersion lithography scanner NSR-610C (Nikon Corp., NA 1.30, a 0.98/0.78, 4/5 annular illumination), pattern exposure was performed through Mask A or B described below.

Mask A is a 6% halftone phase shift mask bearing a line pattern with a pitch of 100 nm and a line width of 50 nm (on-wafer size). After exposure through Mask A, the wafer was baked (PEB) for 60 seconds and developed. Specifically, butyl acetate was injected from a development nozzle for 3 seconds while the wafer was spun at 30 rpm, which was followed by stationary puddle development for 27 seconds. As a result, the unexposed regions which had been masked with Mask A were dissolved in the developer, that is, image reversal took place to form a line-and-space (L/S) pattern with a space width of 50 nm and a pitch of 100 nm.

Mask B is a 6% halftone phase shift mask bearing a line pattern with a pitch of 200 nm and a line width of 45 nm (on-wafer size). After exposure through Mask B, the wafer was baked (PEB) for 60 seconds and developed. Specifically, butyl acetate was injected from a development nozzle for 3 seconds while the wafer was spun at 30 rpm, which was followed by stationary puddle development for 27 seconds. As a result, the unexposed regions which had been masked with Mask B were dissolved in the developer, that is, image reversal took place to form an isolated space pattern (referred to as "trench pattern", hereinafter) with a space width of 45 nm and a pitch of 200 nm.

Evaluation of Sensitivity

As an index of sensitivity, the optimum dose (Eop, mJ/cm^2) which provided an L/S pattern with a space width of 50 nm and a pitch of 100 nm on exposure through Mask A was determined.

Evaluation of Pattern Profile

The profile of a pattern printed at the optimum dose was examined and judged good or not according to the following criterion.

Good: rectangular pattern profile with perpendicular sidewall

NG: tapered pattern profile with largely slanted sidewall, or rounded top profile due to top loss

Evaluation of MEF

An L/S pattern was formed by exposure in the optimum dose (determined in the sensitivity evaluation) through Mask A with the pitch fixed and the line width varied. MEF was calculated from variations of the mask line width and the pattern space width according to the following equation:

$$\text{MEF}=(\text{pattern space width})/(\text{mask line width})-b$$

wherein b is a constant. A value closer to unity (1) indicates better performance.

Evaluation of DOF Margin

The exposure dose and DOF which ensured to form a trench pattern with a space width of 35 nm on exposure through Mask B were defined as the optimum exposure dose and the optimum DOF, respectively. The depth over which focus was changed that could form a resist pattern with a space width of 35 nm±10% (i.e., 31.5 nm to 38.5 nm) was determined and reported as DOF. A larger value indicates a smaller change of pattern size with a change of DOF and hence, better DOF margin.

Evaluation of Defect Density

Further, defects in the pattern as developed were inspected by a flaw detector KLA2800 (KLA-Tencor). A defect density (count/cm^2) was computed by dividing the total number of detected defects by a detection area. The pattern formed was an iterated 50-nm 1:1 L/S pattern. The defect inspection conditions included light source UV, inspected pixel size 0.28 μm, and cell-to-cell mode. In this test, the sample was rated good for a defect density of less than 0.05 defect/cm^2 and NG for a density of equal to or more than 0.05 defect/cm^2.

The results are shown in Table 7.

TABLE 7

		Resist composition	PEB temp. (° C.)	Eop (mJ/cm^2)	Profile	MEF	DOF (nm)	Defect density
Example	3-1	R-1	85	35	Good	2.45	105	Good
	3-2	R-2	85	30	Good	2.88	110	Good
	3-3	R-3	85	34	Good	2.90	90	Good
	3-4	R-4	85	28	Good	2.67	105	Good
	3-5	R-5	85	28	Good	2.70	100	Good
	3-6	R-6	90	36	Good	2.66	95	Good
	3-7	R-7	90	28	Good	3.01	105	Good
	3-8	R-8	90	27	Good	3.15	100	Good
	3-9	R-9	85	33	Good	3.15	100	Good
	3-10	R-10	90	30	Good	3.10	105	Good
	3-11	R-11	85	30	Good	2.90	125	Good
	3-12	R-12	90	36	Good	3.11	100	Good
	3-13	R-13	85	31	Good	3.14	105	Good
	3-14	R-14	85	38	Good	2.99	100	Good
Comparative Example	3-1	R-15	85	45	NG	3.89	85	NG
	3-2	R-16	85	49	NG	3.75	90	NG
	3-3	R-17	85	24	NG	3.90	80	NG
	3-4	R-18	85	41	NG	4.12	85	NG
	3-5	R-19	85	27	NG	3.85	90	NG
	3-6	R-20	85	48	NG	3.57	80	NG
	3-7	R-21	85	48	NG	4.44	70	NG