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0.35 μm PATTERN FABRICATION USING QUARTZ-ETCH ATTENUATE PHASE-SHIFTING MASK IN AN I-LINE STEPPER WITH A 0.50 NA AND A 0.60 SIGMA

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A new method, namely, top critical dimension exposure-defocus tree (TCD E-D Tree), has been developed in this paper and used to analyze simulation results for quartz-etch attenuated phase-shifting mask (APSM). Simulation studies using Depict-3 (from TMA) on isolated and dense patterns indicate that numerical aperture (NA) 0.5 has greater depth of focus (DOF); NA 0.6 has larger exposure latitude (EL); best degree of coherence (σ, sigma) value is between 0.6~0.7; best intensity transmittance (IT) range is 4~6 %; the effect of mask bias on DOF and EL is rather small. The effect of sigma on space patterns including contact holes shows an inverse trend compared with lines. While conventional binary intensity mask (BIM) shows a 0.9 μm total DOF for dense line; APSM in our study (zero mask bias, 4% IT, 0.5 NA, 0.6 sigma) shows a 1.2 μm total DOF (30% improvement). The experimental results are highly in agreement with simulation. However, APSM shows only an insignificant improvement for EL in this study. Stepper with a NA of 0.5 and a sigma of 0.6 is very suitable for line, space and dense line/space pattern transfer using APSM in this study.

1. Introduction

It is well known that phase-shifting mask (PSM) could improve both resolution and depth of focus (DOF) without changing much to the current work horse of exposure system which is 5X i-line stepper for feature size range of 0.25~0.35 μm. The only thing needed to be modified is the using of lower degree of coherence (σ, sigma) for stepper. Among the various types of PSM, such as Levenson (alternate), subresolution (also known as assist-slot or outrigger), rim, attenuate, shifter only, multi-shifter etc., attenuate PSM (APSM), especially the quartz-etch or monolayer attenuated PSM, seems to be preferable to IC industry. The APSM has the merits of using less data preparation, smaller positive bias, smaller image size, self-alignment of shifter, simpler fabrication process, longer durability and application to all the patterns. The disadvantage of the attenuated PSM is its marginal improvement (10~20%) of resolution and difficulty to improve the originally narrow process latitude of dense line/space [1~4]. Since i-line steppers with a NA of 0.5 and a sigma (degree of coherence) of 0.6 are still most commonly used in today's IC fabs. This paper reported the optimization and application of APSM suitable for being used in this kind of stepper. The results indicated that this kind stepper is very suitable for line, space and dense line/space pattern transfer using APSM.

2. Experimental

The simulation tool is Depict-3 from TMA, USA. The blank mask with an intensity transmittance (IT) of 4 % and with optical positive-tone resist AZ 5200 for patterning is from Hoya. Patterning on APSM is achieved by a TETC, CORE-2564 laser exposurer with a wavelength of 350 nm . The etch of quartz is performed by ion milling using Ar at 45 degree, 130 mA and 600 V. The etching rate is about 340 Å/min. After etching by ion-milling, the mask was treated by BOE (buffered oxide etcher, NH_4F:HF=20:1) for about 1 min to obtain smoother sidewall profile. A 5X Nikon NSR I8 i-line stepper (λ 365 nm, NA 0.5, sigma 0.6) is used for 0.35 μm patterning on wafer. The positive-tone resist used for simulation and

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patterning on wafer is TOK-IP3100. SEM used is JEOL JSM 6300F. Atomic force microscope (AFM) used is Digital Nano Scope 3.

3. Results and Discussion

In the study of resolution and process latitude, the often used bottom critical dimension, resist sidewall slope as well as remained resist thickness can not exactly indicate the real results. In some cases, misinterpretations occurred. A new method, setting allowed minimum criteria of top critical dimension (TCD) and applied to exposure-defocus tree (E-D Tree) for 0.35 µm design rule, has been developed to analyze simulation results for quartz-etch APSM in this paper as indicated in Fig. 1. Simulation studies on 0.35 µm dense line by using TCD indicated that using TCD of 0.08 µm (resist slope ~83°) fitted the best against DOF with experimental results for both conventional BIM and 4 % APSM when compared with CD, slope and resist thickness. The simulation results are shown in Fig. 2. In general, simulations indicate that NA 0.5 has greater DOF than that of NA 0.6; best sigma value is between 0.6~0.7; best intensity transmittance (IT) range is 4~6 %; the effect of mask bias on DOF and exposure latitude (EL) is rather small. The detailed results are discussed below.

The effect of sigma on exposure dose from isolated lines (pitch is greater than 1.0 µm) and lines with pitch 1.0 µm shows an inverse trend with other patterns as shown in Fig. 3. In the case of the effect of sigma on DOF, the space patterns shows an inverse trend when compared with three different lines (1. dense line with pitch 0.7; 2. line with pitch 1.0 and 3. isolated line) as shown in Fig. 4. Small sigma will have greater exposure latitude for all patterns as shown in Fig. 5. From the Figs. 3, 4 and 5, it is quite clear that for patterning various spaces and lines under the conditions of NA 0.5, the best sigma value is within the range of 0.6~0.7 for obtaining both greatest exposure dose latitude and DOF.

The AFM measurements of APSM and conventional BIM dimensions are analyzed. The etching of quartz is done by ion-milling using Ar. The much better gases for etching quartz (SiO_2) are CHF_3+H_2 or CHF_3+Ar. Due to the limitation of facilities, the control of etching depth and sidewall profiles is not totally satisfactory.

The degree of phase-shift of 4% APSM is calculated as 187.2° which is 7.2° higher than designed. A deviation of 10° phase-shift away from 180° is generally accepted. The dimensions of dense lines of both APSM and conventional BIM have also some deviations. The effect of this small linewidth deviation from designed value on DOF is generally known as insignificant.

While APSM in our study shows a 1.2 µm total DOF for dense line; conventional BIM shows a 0.9 µm total DOF. The resist profiles are shown in Fig. 6 and Fig. 7, respectively. The experimental results are highly in agreement with simulations. The DOF improvement is about 30% which is higher than reported results [2]. However, APSM shows only an insignificant improvement for exposure latitude in this study.

Stepper with a NA of 0.5 and a sigma of 0.6 is still most commonly used in today's IC fabs and is very suitable for line, space and line/space pattern transfer using APSM. For patterning the contact holes, smaller sigma is highly expected in this study. There is a dilemma between printing contact holes and lines (or spaces) by using same stepper.

APSM with an IT higher than 4 % will generate moderate to serious side-lobe effect, and not studied throughly in this paper.

Stepper with NA 0.6 shows larger exposure latitude, but smaller DOF in our simulation studies.

Besides the line and space, the patterning of polylayer of DRAM is also studied. This layer consists of 1.6 x 0.6 µm lines and 0.6, 0.4 and 0.3 µm spaces. In order to meet the dimension requirements under one exposure dose, the biased 4 % APSM is designed. The simulated E-D tree and resist profiles are studied. The optimized exposure dose range for this polylayer has been found. The patterning study of this poly layer on the resist will be reported soon.

The large use of APSM is very rare so far. Recently, because of the development of monolayer APSM [5] (also known as embedded APSM), the APSM fabrication and repair become as easy as conventional BIM. Therefore, APSM is very promising in the near future.

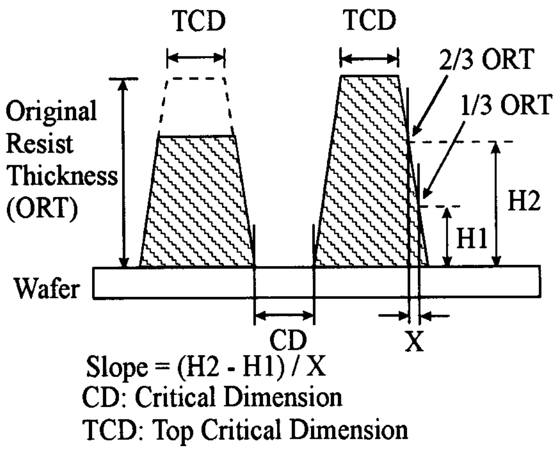

Fig.1 Illustration of resist slope, CD, TCD and original resist thickness (ORT).

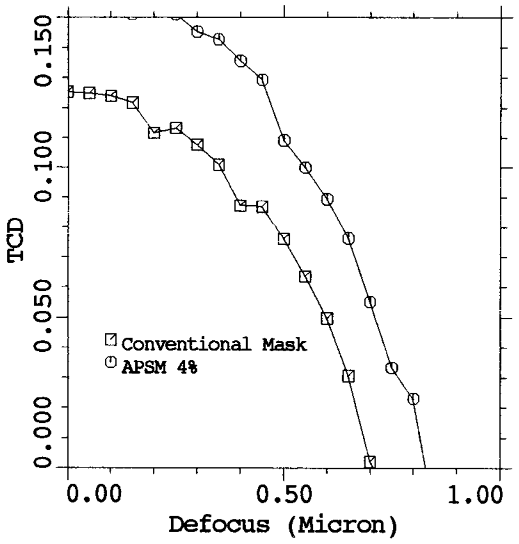

Fig.2 The simulation studies of effects of TCD on DOF. (λ 365 nm, NA 0.5, sigma 0.6, 0.35 μm dense line).

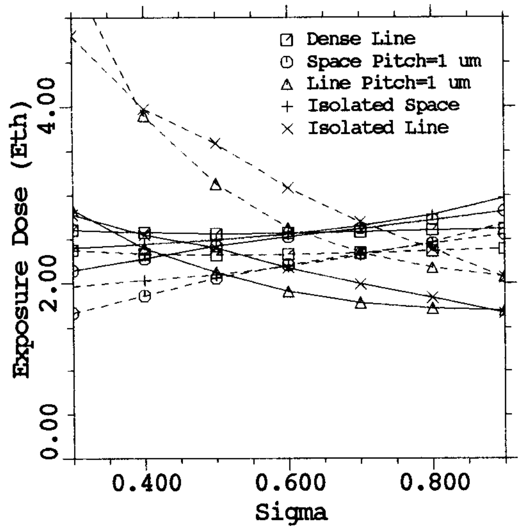

Fig.3 Exposure dose vs. sigma at NA 0.5 for 4 % APSM. Solid line: 0.315 μm (-10% of CD). Dashed line: 0.385 μm (+10% of CD)

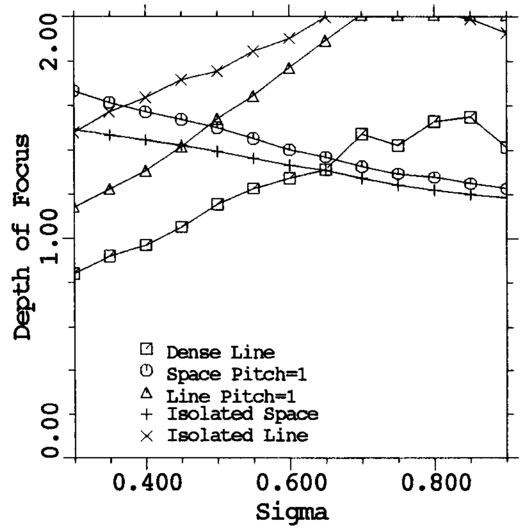

Fig.4 Depth of focus vs. sigma at NA 0.5 for 4 % APSM.

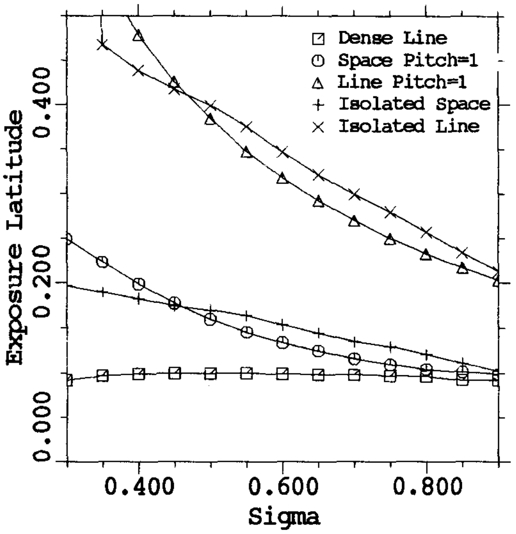

Fig.5 Exposure latitude vs. sigma at NA 0.5 for 4 % APSM.

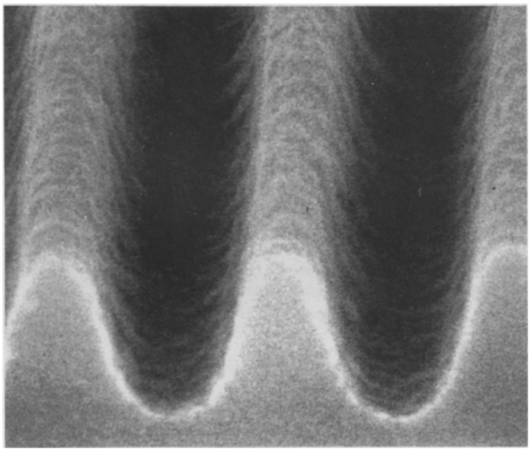

Fig.7 SEM micrograph of dense line/space (pitch 0.70 μm) cross-sectional profiles under defocus of +0.9 μm from a conventional BIM. Total DOF is estimated as 0.9 μm.

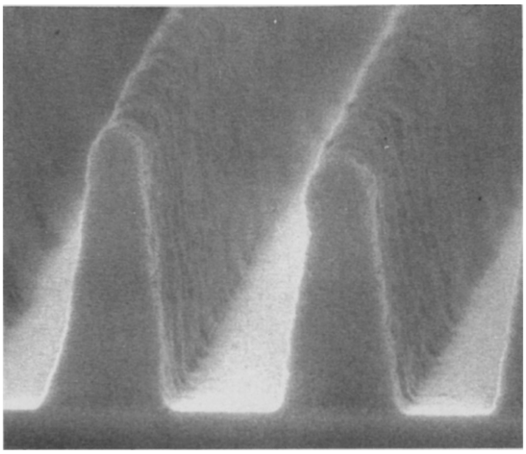

Fig.6 SEM micrograph of dense line/space (pitch 0.70 μm) cross-sectional profiles under defocus of +0.9 μm from a 4% APSM. Total DOF is estimated as 1.2 μm.

4. Conclusions

The improvement of the originally narrow process latitude of dense line/space by APSM is not easy. The simulation study in this paper found out that the process latitude of dense line/space could be largely improved by a stepper with a 0.5 numerical aperture and a 0.6 degree of coherence. Checked with 4 % APSM fabrication and corresponding resist lithography, the experimental results are in good agreement with simulations.

References

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