行政院國家科學委員會專題研究計畫 成果報告

相同劑量下45奈米節點微影全程禁止間距及圖罩偏差增大因子之改善與相關薄膜研製

研究成果報告(精簡版)

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執 行 單 位 ： 國立交通大學應用化學系（所）

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計畫參與人員： 碩士班研究生-兼任助理人員：林建維

處 理 方 式 ： 本計畫可公開查詢

中 華 民 國 98年11月11日

中文摘要：

以 Prolith 模擬製備 45 奈米二維接觸孔，使用本實驗室研發之新型相移圖罩，主要爲減光-外架-緣邊型，搭配圓環偏軸發光，在不同間距維持相同劑量條件下，相較於其他圖罩，可得較長焦深，可消除大部份禁止間距；圖罩偏差增大因子亦可維持~1。缺點爲所需照射劑量較高，易造成側葉光強過強而顯影。此缺點可用光敏較佳阻劑克服。圖罩所需之減光層（背景層），經薄膜光學參數計算，可以 SiO_xN_y 電漿濺鍍製備或使用正規嵌附層。

英文摘要：

The simulation studies of 2-D 45 nm contact hole by Prolith software, using firstly reported PSM from our lab, attenuated-rim-outrigger mainly, and combined with annular off-axis illumination, under the condition of same dose for varied pitches, DOF was found to be greater, most forbidden pitches will be eliminated, if compared to other masks, and mask error enhancement factor can also be maintained nearly in one. The shortcoming of this lithographic combination was higher exposure dose needed, easy to cause excessively sidelobe intensity, and therefore, sidelobe may be developed. This shortcoming can be overcome by using more sensitive photoresist. Based by optical parameters calculations of thin film, the attenuated layer of this new mask can be prepared by SiO_xN_y plasma sputtering or using regular embedded layer.

1. Introduction

The numerical aperture (NA) is less than one in dry lithographic system, however, NA can be greater than one in immersion (wet) system. Higher resolution is obtained with immersion because the optical system can collect a wider angle of diffracted light beams from mask.

The refractive index of pure water in 193 nm wavelength is 1.44, since the practically largest NA is estimated at 0.93 in dry system, therefore, NA=0.94*1.44=1.34 is possible in wet system. Theoretically, the resolution can be increased 1.44 times in pure water wet system than in dry. In general, the depth of focus (DOF) for photoresist on wafer can also be increased if compared under same resolution.

When two incident plane waves from opposite ends of entrance pupil (or projector) interfere in photorsist, an intensity interference pattern is formed at the image. At larger NA, such as NA>0.8 or NA>1, the angle of these two incident plane waves will be near 90 degree from TM (or P) polarization, no or weak interference occurs. The angle will be near 180 degree from TE (or S) polarization, strong interference occurs. In general, the contrast of image inside photoresist is low when two interfering plane waves have TM (or P) polarization and high when they have TE (or S) polarization.

Opaque scattering bars are commonly used for semi-isolated or isolated lines to improve the depth of focus (DOF) of forbidden pitches in clear field mask. However, partially transparent scattering bars which are called Attenuated Scattering Bars (ASB) were also used in this study. Combination of immersion, polarized light, PSM, Off-Axis Illumination (OAI) and Scattering Bar (SB) will greatly improve both the resolution and DOF, and is the trend for sub-wavelength lithography.

Mask error enhancement factor (MEEF) is an important indicator for the resolution. Keeping MEEF smaller is quite critical.

II. Experimental

Prolith version 9.0 from KLA-Tencor USA was used for simulation studies.

The required transmittance and phase change of ASBs were decided based on simulation studies. The film compositions and thickness of ASBs which meet the requirements were calculated through website of Prof. B. W. Smith of RIT, USA.

Two new types of PSMs firstly reported by our lab which are named attenuated-rim-outrigger and attenuated-rim respectively were used in this study for the fabrication of 2-D 45 nm contact hole mainly as shown in figure 1.

Taguchi Genichi（田口玄一）Design of Experiment (DOE) and Analysis of Variance (ANOVA) were generally applied to evaluate the optimizations of many optical parameters, however, due to the change of focus from optimizations of optical parameters to effects of keeping same exposure dose for varied pitches for both contact hole and line in this study, DOE and ANOVA were not used to simplify the study.

III. Results and Discussion

There are many optical combinations for lithographic studies, and each combination has many optical parameters needed to be tested, such as inner sigma and outer sigma for annular off-axis illumination, NA for immersion (range 1.0 to 1.44), transmittance for Att-PSM, width, location, transmittance and relative phase change for ASBs. It is impossible and unrealistic to test all the combinations and parameters thoroughly.

Hundreds of simulations were completed, for simplification, only two figures were reported here as shown in figure 2 and 3.

In general, the required DOF can be set around 3 times of resolution node. For example, 100 nm for 32 nm line, 135 nm for 45 nm contact hole. Any pitch which has less DOF than required DOF, is defined as forbidden pitch.

Mask enhancer (ME) which was reported few years ago is an excellent mask for the fabrication of contact hole [1-2]. The application and effect between ME and attenuated-rim-outrigger and attenuated-rim were compared. Under specific lithographic combination and conditions, attenuated-rim-outrigger showed better resolution and greater DOF for 45 nm contact hole. Most forbidden pitches can be eliminated by using attenuated-rim-outrigger but not ME.

Finally, according to the calculations from Prof. Smith’s website, several film compositions can meet the required properties for new mask and one specific ASB (not for all ASBs), for example, SiN_xO_y.is one of the suitable compositions.

IV. Conclusions

The lithographic simulation software of Prolith v. 9.0 from USA KLA-Tencor was used. The focus of this study was fabrication for 2-D 45 nm contact hole by using attenuated-rim-outrigger phase shifting mask. The 1-D isolated lines from 32 nm to 8 nm were also studied.

The fabrication studies for 2-dimension 45 nm contact hole, using firstly reported attenuated-rim-outrigger phase shifting mask, and combined with annular off-axis illumination, DOF was improved under specific conditions, mask error enhancement factor (MEEF) can also be maintained nearly in 1. The shortcoming of this combination was very high exposure dose, easy to cause excessively strong sidelobe intensity, and therefore sidelope images may be developed.

Some other important findings are reported as following:

1. The fabrication for 1-dimension 28 nm line, the positive bias method combined with rim attenuated scattering bar (R-ASB) and center attenuated scattering bar (C-ASB), DOF increasing effect was found the be the best, forbidden pitches can be improved. The two methods which are positive bias and the adding of side attenuated scattering bar (S-ASB) have shown to have approximate effect to the DOF increase. By observation of aerial image from space, C-ASB can be added only when the interference waves formed by edge effect began to separate. If the interference waves have not yet separated, the adding of C-ASB will affect the aerial images of main lines instead, and DOF will be decreased.

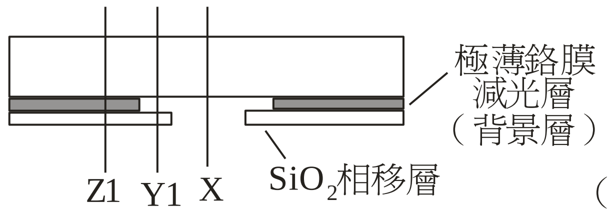
2. The fabrication of isolated lines will not be hampered by the general formula of half pitch resolution ($R = K_1 \frac{\lambda}{\sin \beta}$). When NA was set as 1.35, 22 nm and 16 nm isolated lines can be fabricated by positive bias. When the Dupont second generation immersion liquid (refractive index n=1.64) is used, transmittance of main lines of attenuated phase shift mask raised, and NA enlarged to 1.50, 12 nm and 8 nm isolated lines can be fabricated.

References:

1. T. Yuito et al., “Mask Enhancer Technology for 45 nm Node Contact Hole Fabrication”, Proc. SPIE, Vol. 5754, p. 1377 (2005).
2. T. Yuito et al., “Mask Enhancer Technology on ArF Immersion Tool for 45 nm Node Complementary Metal Oxide Semiconductor with 0.249 μm^2 Static Random Access Memory Contact Layer Fabrication”, Jpn. J. Appl. Phys., Vol. 45, No. 6B, p. 5396 (2006).

(a) 減光-緣邊型（計畫主持人實驗室發表），文獻原名：半透-緣邊(Halftone-Rim)

原型



X：Δϕ=0°，T%~100

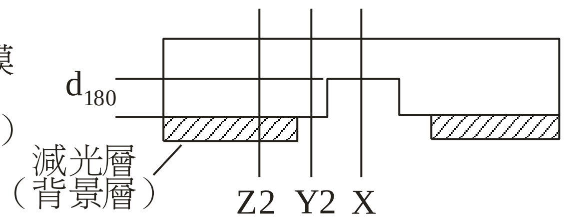
Y1：Δϕ=π，T%~100 (SiO_2)

Z1：Δϕ=~(+5°)+π~185°，T%<9，λ=365 nm

Δϕ=~(–5°)+π~175°，T%<9，λ=248, 193 nm

（極薄透光鉻膜+SiO_2）

改良型



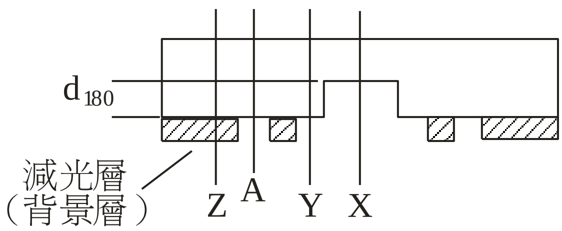
X：Δϕ=0°，T%~100

Y2：Δϕ=π，T%~100

Z2：Δϕ=π+π=2π，T%~6

以正規嵌附層作爲減光層或稱背景層

(b) 減光-外架-緣邊型（計畫主持人實驗室發表）



X：Δϕ=0°，T%~100

Y：Δϕ=π，T%~100（Y爲緣邊）

A：Δϕ=π，T%~100（同Y）（A爲外架）

Z：Δϕ=π+π=2π，T%~6

以正規嵌附層作爲減光層或稱背景層

註：1. 以上各型皆適合製備45奈米二維接觸孔。相位差2π(360°)光學干涉作用視同0°

2. 減光層（背景層）透射率T%<9爲宜，以免側葉光強過高，導致正型阻劑顯影，使成像品質劣化；或背景光強過高，無法成像

圖 1 計畫主持人實驗室先後發表之 2 種新型相移圖罩

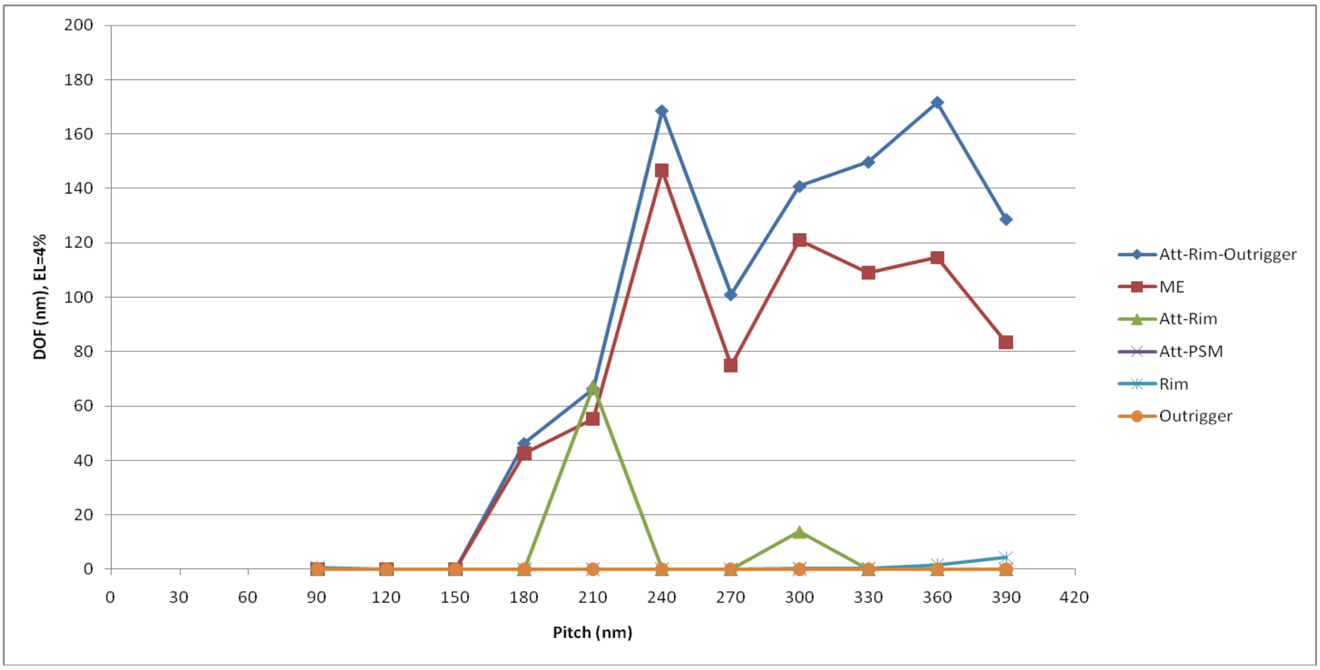


圖 2　45 奈米接觸孔，圓環偏軸發光，不同圖罩設計之間距與焦深關係圖

減光-外架-緣邊(Att-Rim-Outrigger)與減光-緣邊(Att-Rim)爲計畫主持人實驗室發表之二種新型相移圖罩。圖罩增強罩(Mask Enhancer, ME)爲數年前日本學者發表之相移圖罩

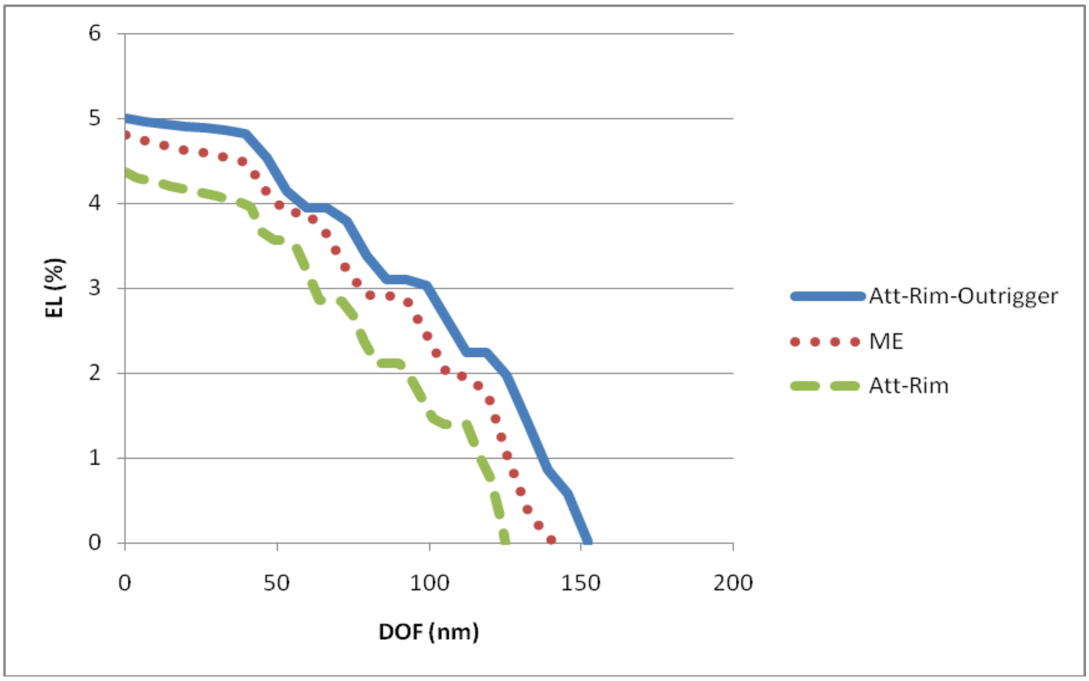


圖 3　45 奈米接觸孔，斜四扇面(Normal Quasar)發光，固定間距 240 奈米，扇角 20°，外徑相擾度當量值 σ_{outer}=0.88，內徑相擾度當量值 σ_{inner}=0.50，不同圖罩之照射寬容度(EL)與焦深(DOF)關係圖

附件二

可供推廣之研發成果資料表

☑ 可申請專利　　☐ 可技術移轉　　　　　　　　日期：98 年 11 月 10 日

國科會補助計畫	計畫名稱： 45 奈米節點相同劑量下全程禁止間距及 圖罩偏差增大因子之改善與相關薄膜研製 計畫主持人：龍文安　　　　單位：國立交通大學應用化學系 計畫編號：NSC 97-2221-E-009-159　　　學門領域：微電子工程
技術/創作名稱	新型相移圖罩
發明人/創作人	龍文安
技術說明	中文：減光-外架-緣邊型新型相移圖罩之研製與應用於二維接觸孔製備 英文：The preparation of attenuated-rim-outrigger new type of phase shift mask and its application on the fabrication of 2-D contact hole.
可利用之產業及可開發之產品	半導體製程之光學微影
技術特點	新型相移圖罩，適合未來需要
推廣及運用的價值	增進接觸孔解像度與禁止間距之焦深

※ 1. 每項研發成果請填寫一式二份，一份隨成果報告送繳本會，一份送　貴單位研發成果推廣單位（如技術移轉中心）。

※ **2. 本項研發成果若尚未申請專利，請勿揭露可申請專利之主要內容。**

※ 3. 本表若不敷使用，請自行影印使用。