TRANSPARENT PHASE SHIFTING MASK

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ABSTRACT

The transparent phase shifting mask having a simple structure with a single patterned layer of phase shifter has been developed. The mask has been demonstrated to improve the resolution of the conventional i-line stepper and to facilitate the fabrication of various patterns. The transparent phase shifting mask is promising for fabricating deep submicron patterns for 64MDRAM.

INTRODUCTION

Photolithography has been widely used in the production of VLSI. The conventional g-line and i-line photolithography is expected to allow patterning the half micron devices adequately. However beyond 0.5 µm, an alternative lithography will be required. KrF excimer laser lithography [2],[3] and phase shifting lithography [1] are major candidates for sub-half micron VLSI technology. The shorter wave length of KrF excimer laser brings many technical problems such as light absorption in the lens and resist materials and the stability and the life of the light sources. Another way to achieve higher resolution is using the conventional g, i-line light with a phase shifting mask [4]. Recently, many types of phase shifting masks have been reported [5]-[7]. The barrier against putting phase shifting lithography into practical use is the difficulty in mask making, inspection and repair. Another barrier is that only the limited patterns can be fabricated using a phase shifting mask. To overcome above problems, we have developed a transparent phase shifting mask which consists of a single patterned layer of the phase shifter, without opaque chromium (Cr) apertures. The mask can be easily fabricated and improve the resolution of various patterns for VLSI.

In this paper we describe the concept and the experimental results of a transparent phase shifting mask.

CONCEPT AND FABRICATION OF TRANSPARENT PHASE SHIFTING MASK

The schematic illustrations of the mask structures and the light intensity distributions obtained through the masks for (A) an ordinary transmission mask, (B) a conventional phase shifting mask and (C) a new transparent phase shifting mask are shown in Fig.1. The transparent phase shifting mask has an extremely simple structure consisting of the transparent substrate and the 180° phase shifter as shown in Fig.1(C). Since the interference between the waves through the substrate and the phase shifter minimized the light intensity at the boundary of the phase shifter, high resolution patterns can be printed along the phase shifter boundary in a photoresist layer on wafers as shown in Fig.1(C-1). To use the transparent phase shifting mask for practical device fabrication, it is necessary that the opaque region can be composed of transparent phase shifter patterns. If the phase shifter patterns are smaller than the resolution limit of optical tools, the destructive interference minimizes the light intensity at the whole area of repeating patterns as shown in Fig.1(C-2). The fine repeating patterns beyond the resolution limit work as an opaque (shading) area. Various patterns can be fabricated by using the combination of these patterns.

The procedure for fabricating the phase shifting masks is illustrated in Fig.2. Two masks were prepared with (a) a polymeric shifter layer and (b) an inorganic shifter layer. The polymeric phase shifting layer was fabricated on the quartz (QZ) substrates with a 150 Å transparent antistatic layer. A 3700 Å thick poly(methyl methacryrate), PMMA layer was coated onto the mask substrate. The patterns were defined by conventional electron beam lithography. The fabricated PMMA patterns were used as the polymeric phase shifter as shown in Fig.2(a). An alternative procedure for fabricating a phase shifting mask with the SiN shifter is shown in Fig.2(b). A 2300 Å SiN phase shifting layer was deposited onto the antistatic layer. After the resist

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pattern fabrication, the resist patterns were transferred into a SiN layer using reactive ion etching (RIE) and the remaining resist was removed. While the phase shifting mask with an inorganic phase shifter is hard and cleanable, we used the phase shifting mask with a polymeric shifter, which has proved sufficiently sturdy for the purpose of our initial experiments.

Patterns are printed in a 1.2 μm thick photoresist, PFI-15 (Sumitomo Chemical) using an i-line stepper (Nikon, x5, NA 0.45, σ=0.5).

RESULTS AND DISCUSSION

FABRICATION OF LINES AND SPACES

The improved resolution was obtained by using a transparent phase shifting mask. The comparison of printed line and space patterns using an ordinary transmission mask and a transparent phase shifting mask is shown in Fig.3. The resolution limit of the i-line stepper with a transmission mask is 0.4 μm and the resolution limit is enhanced to 0.3 μm by using a transparent phase shifting mask.

FABRICATION OF OPAQUE REGION

In order to evaluate the shading performance of fine repeating shifter patterns on a transparent phase shifting mask, the photoresist was exposed through the mask. After the exposure, the wafer was developed and the remaining resist thickness was measured. The shifter pattern sizes on the mask were 0.5-1.5 μm which correspond to the projected pattern sizes of 0.1-0.3 μm on the wafer. Figure 4 shows the resist sensitivity curves. The light intensity through the 1.0 μm lines and spaces (0.2 μm on wafer) was about 1%.

Figure 5 shows the light intensity through the fine line and space patterns and checker patterns measured from resist sensitivities. The light intensity through the repeating shifter patterns reaches a minimum and slightly increase with decreasing the width of shifter patterns L. The optimum size of repeating sifter patterns to fabricate the opaque region is 0.75-1.25 μm for line and space patterns and 1.0-2.0 μm for checker patterns.

FABRICATION OF MEMORY CELL PATTERNS

Various high resolution patterns can be fabricated by using the transparent phase shifting mask with a fine shifter patterns near the resolution limit and below the resolution limit. For the example of the shifter pattern layout for LSI patterns, shifter pattern layout for contact holes is shown in Fig.6. The light intensity profile along line AA' is identical to Fig.1(C-1). The light intensity profile along line BB' is illustrated in Fig.6(C). The destructive interference between the neighboring apertures suppresses the spread of light intensity profiles through the larger patterns and minimizes the light intensity through the smaller apertures.

Memory cell patterns with the design rule of 0.3 μm (minimum pitch : 0.6 μm) were fabricated using the transparent phase shifting masks. Figures 7(a-2) and (b-2) show the fabricated resist patterns for the word line and contact hole using the transparent phase shifting masks shown in Figs.7(a-1) and (b-1), respectively. The resolution has been improved not only for the line and space patterns but also for contact hole patterns. Figures 7(c-2) and (d-2) show the reversed images of the patterns for isolation and storage node formed by the transparent phase shifting masks shown in Figs.7(c-1) and (d-1). To fabricate devices, the negative resists or image reversal processes are required. Extremely fine separations between windows can be obtained as a result of the interference between neighboring apertures.

CONCLUSION

A transparent phase shifting mask has been demonstrated to improve the resolution of conventional i-line stepper and to facilitate the fabrication of various deep submicron patterns for VLSI. The present new mask having a single patterned layer of phase shifter can be easily fabricated and it may be easily inspected and repaired compared to the conventional phase shifting mask having double patterned layers of the Cr layer and the phase shifter layer. The transparent phase shifting mask is promising for fabricating sub-half micron patterns for 64MDRAM.

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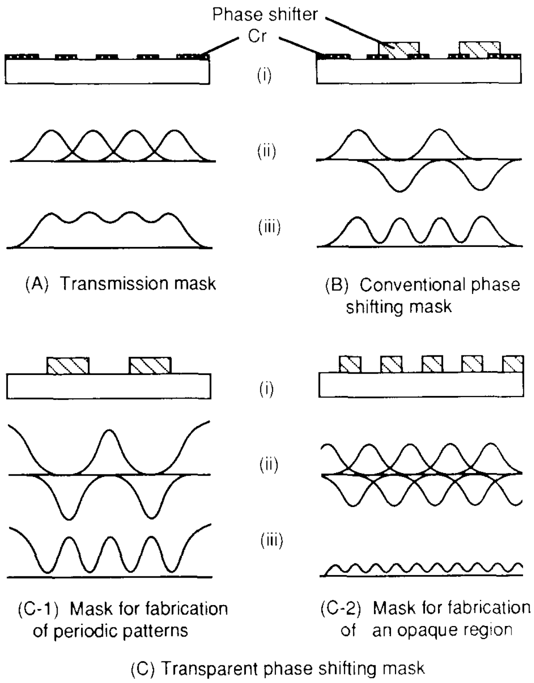


FIG.1. Comparison of (i) mask structure, (ii) light amplitude through each apertures at wafer and (iii) light intensity at wafer.

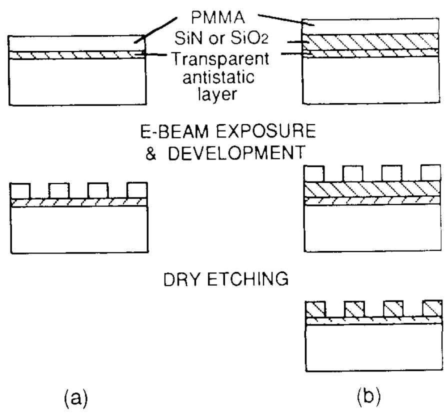


FIG.2. Process sequence of transparent phase shifting mask with (a) polymeric shifter (PMMA) and (b) inorganic shifter (SiN or SiO_2).

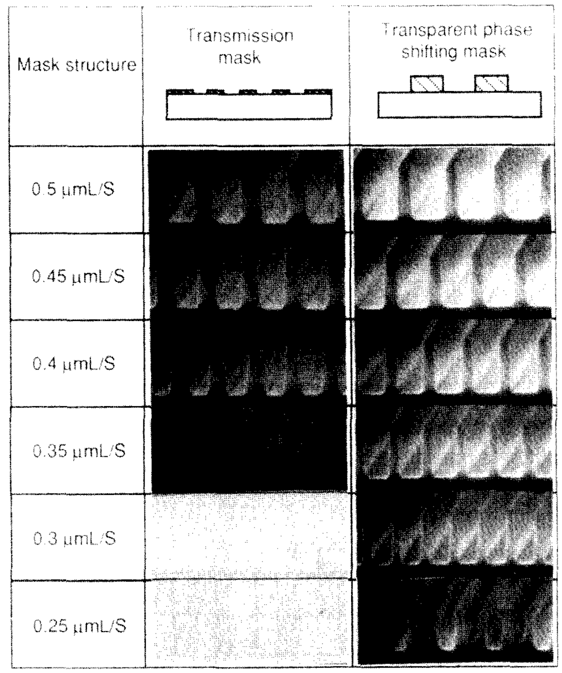


FIG.3. SEM micrographs of lines and spaces obtained with ordinary transmission mask and transparent phase shifting mask.

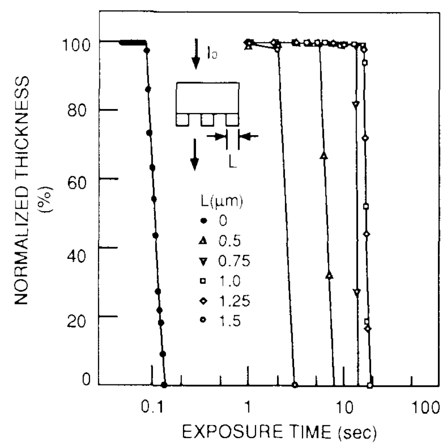


FIG.4. Photoresist thickness reduction vs. exposure time through the mask having fine line and space shifter patterns.

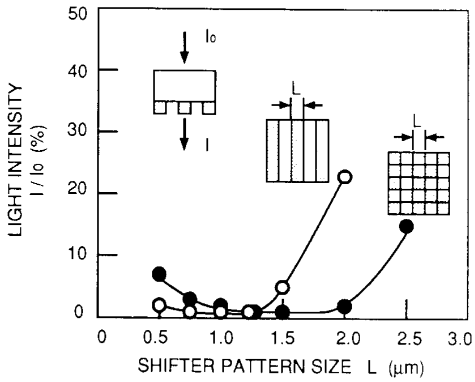
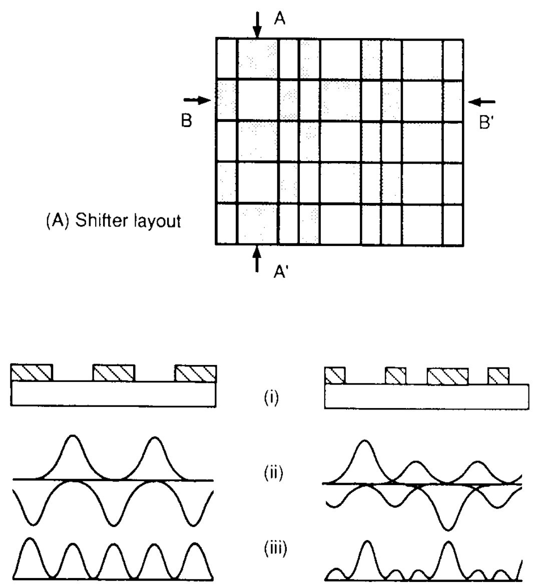


FIG.5. Light intensity through repeating shifter patterns measured by resist sensitivity.



(B) Cross-sectional view and light intensity profile along line AA'

(C) Cross-sectional view and light intensity profile along line BB'

FIG.6. Shifter layout of transparent phase shifting mask for Contact holes. (A) shifter pattern layout, and (i) mask structure, (ii) light amplitude through each apertures, (iii) light intensity profiles for lines (B) AA' and (C) BB'.

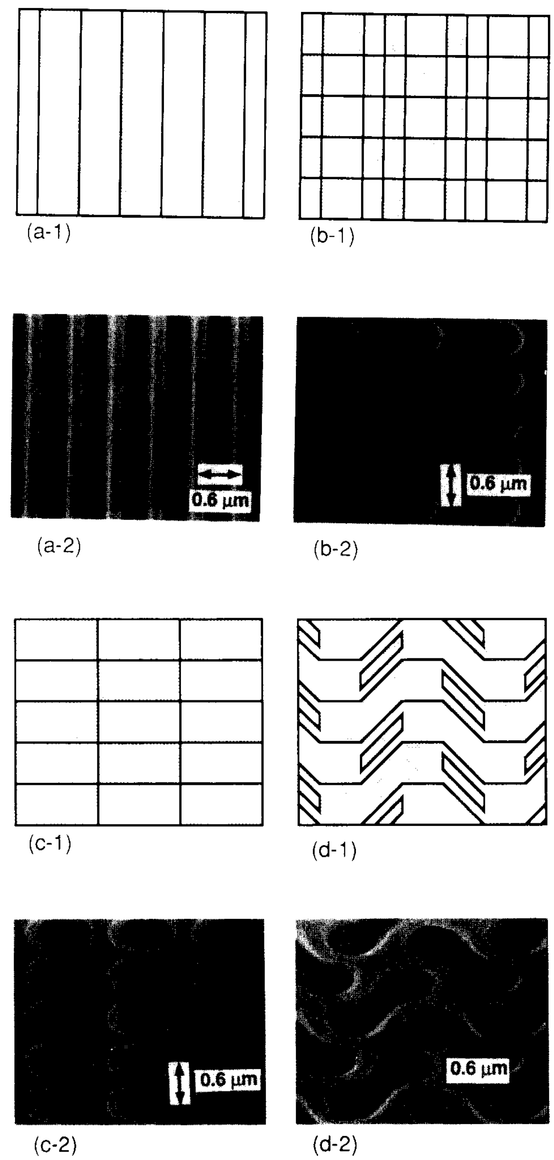


FIG.7. Shifter layout of transparent phase shifting mask and fabricated memory cell patterns of 0.3 μm design rule in a 1.2 μm resist. (a) Word line, (b) Contact hole, (c) Storage node, (d) Isolation ; (c) and (d) are reversed images.