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A High Contrast Submicron X-Ray Mask with Ta Absorber Patterns

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An x-ray mask with Ta absorber patterns is developed. For the fabrication of Ta absorber patterns, an all dry process using reactive sputter etching is proposed for high accuracy formation of submicron patterns and simplicity of the mask process. The stress in Ta film is maintained within ±10 kg/mm^2 by precise control of Ar gas pressure in rf sputtering. In the absorber etching process, an etching selectivity of Ta/PMMA higher than 10 is obtained by reactive sputter etching using the intermediate SiO_2 layer as the etching mask. A high contrast submicron x-ray mask is obtained, where minimum pattern width is 0.2 μm and maximum aspect ratio is higher than 3.

1. Introduction

X-ray lithography is a promising means for high throughput replication of submicron patterns. X-ray mask fabrication is the key technology in x-ray lithography, consisting of the preparation of transparent mask substrate and the formation of x-ray absorber patterns. A transparent SiN mask substrate has already been developed.[1] The essential requirements for x-ray absorber patterns are as follows: (1) high x-ray absorption ability, (2) small internal stress to prevent destruction or distortion of the mask substrate, (3) high accuracy formation of submicron patterns, and (4) simplicity of the mask process.

Gold has traditionally been used as an x-ray absorber material, with gold patterns being fabricated by lift off,[2] ion etching[3] or electroplating.[4] However, it is difficult for an Au absorber to realize submicron patterns with high contrast. Metals such as Ta, W and Re are attractive materials as x-ray absorber patterns because they exhibit high x-ray absorption ability. Moreover, fine patterns can easily be fabricated by reactive sputter etching. This paper describes a novel high contrast submicron x-ray mask with Ta absorber patterns.

2. X-ray absorption ability and mask fabrication process

In conventional x-ray lithography, soft x-rays from 4 to 10 Å are chosen to minimize the exposure time for resist pattern replication. It has been experimentally confirmed that x-ray attenuation of absorber patterns should be higher than 10 dB.[5]

Figure 1 shows the x-ray attenuation characteristics in Au and Ta with 1 μm thick. For the wavelength from 4 to 10 Å, the x-ray attenuation in both Ta and Au are higher than 10

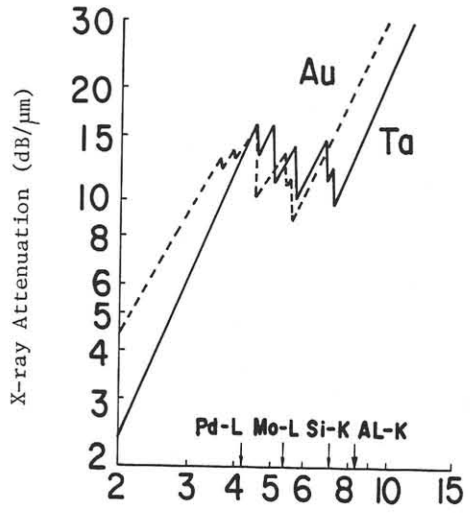


Fig.1 X-ray attenuation characteristics of Au and Ta absorber

dB. Therefore, Ta is as good an x-ray absorber material as Au.

Figure 2 shows the fabrication process of an x-ray mask with Ta absorber patterns. In this process, the mask substrate is SiN film prepared by LP-CVD.[1] Tantalum film with small stress is deposited on the SiN mask substrate by rf sputtering, and SiO_2 is deposited on the Ta absorber using ECR plasma deposition.[6] Submicron resist patterns are then formed by EB lithography. Next, resist patterns are replicated into the SiO_2 layer by reactive sputter etching, with SiO_2 patterns sequentially into the Ta layer as well. Finally, the silicon is removed by back etching with KOH solutions.

3. Experimental results and discussion

Tantalum film was deposited by rf sputtering using Ar gas. Figure 3 shows the dependence of Ta film stress on Ar gas pressure. The stress in Ta is nearly equal to zero at 6×10^{-2} Torr. However, the stress changes steeply from compression to tension with the increase of Ar gas pressure. In this process, the reproducibility of the stress in Ta was maintained within ±10 kg/mm^2 by precise control of gas pressure.

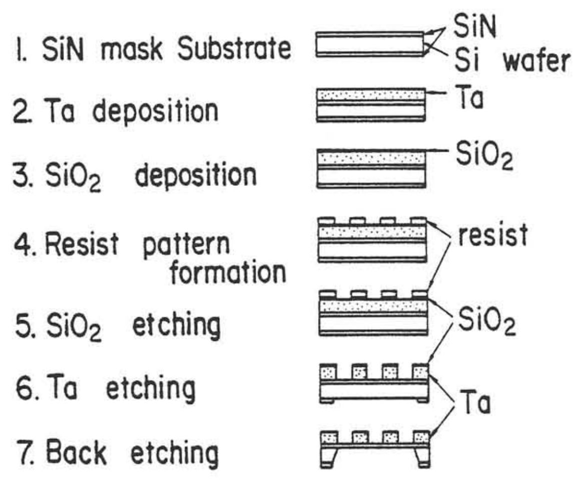


Fig.2 Fabrication process of X-ray mask with Ta absorber

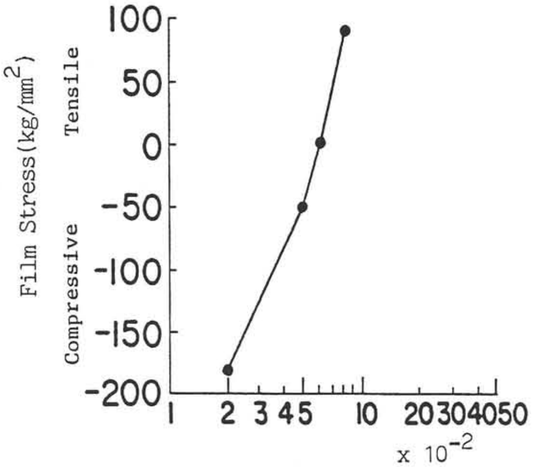


Fig.3 Dependence of Ta film stress on Ar gas pressure

Tantalum pattern fabrication by reactive sputter etching was also investigated. Figure 4 shows the etching characteristics of Ta, PMMA, SiO_2 and SiN by a reactive sputter etching using $CBrF_3$ gas at 15 cc/min.[7] The etching rates of Ta and PMMA increased steeply with the increase of rf power. On the other hand, the etching rates of SiO_2 and SiN increase gradually with rf power. Accordingly, the etching rate ratios of Ta/PMMA, Ta/SiN and Ta/SiO_2 are about 1.3, 4.5 and 7.0, respectively, at 50 W. Thus, Ta can be etched adopting thin SiO_2 as an etching mask. We then investigated the etching characteristics of PMMA and SiO_2 in reactive sputter etching using C_4F_8 gas. The etching selectivity of SiO_2/PMMA was about 2.0. From these results, it was possible to substantially obtain a higher than 10 etching selectivity of Ta/PMMA by adopting intermediate SiO_2 film as the etching mask. Moreover, etching of the SiN substrate hardly occurred during Ta overetching because the etching selectivity of Ta/SiN was high enough.

Figure 5 shows SEM photographs of Au and Ta absorber patterns formed using the 0.5 μm line-and-space resist patterns of PMMA. As seen in Fig. 5(a), the Au 0.5 μm line-and-space patterns could not be resolved due to the lateral shift of etching mask pattern edges and the redeposition of sputtered particles. Tantalum patterns prepared by the reactive sputter etching process were clearly resolved as shown in Fig. 5(b).

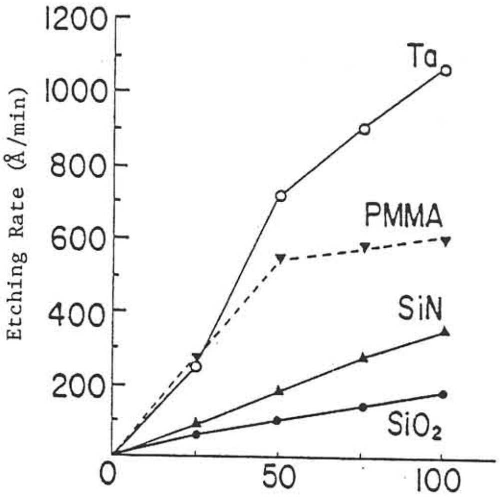
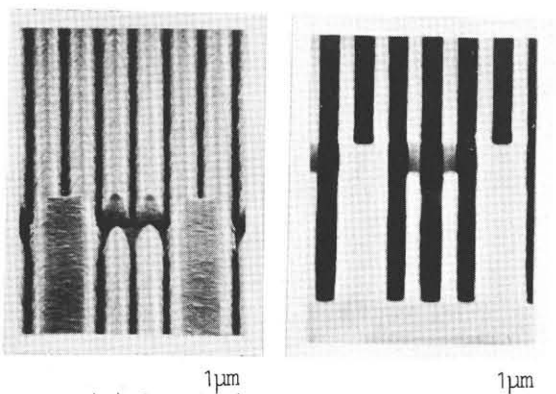


Fig.4 Characteristics of reactive sputter etching using CBrF3 gas



(a) Au (b) Ta

Fig.5 SEM photographs of Au and Ta absorber patterns formed by o.5 μm line-and-space resist patterns

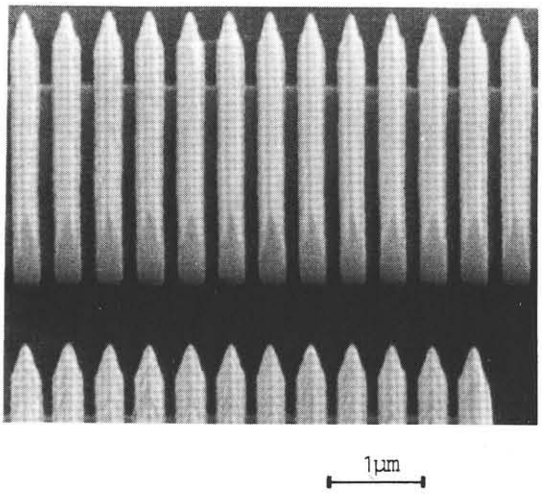


Fig.6 SEM photograph of high-aspect-ratio Ta absorber patterns

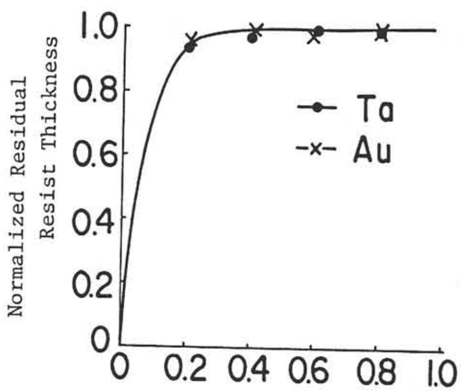


Fig.7 Effects of X-ray absorber thickness on residual resist thickness

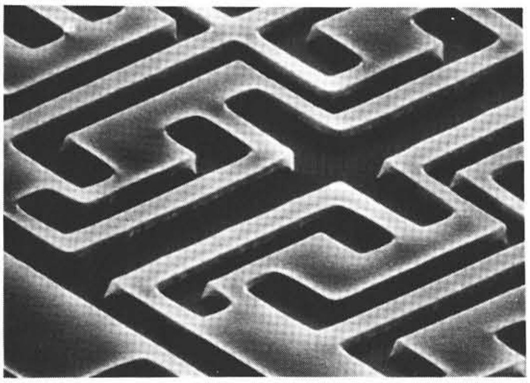
Figure 6 shows an SEM photograph of high aspect ratio Ta absorber patterns. The minimum pattern width is 0.2 μm and the maximum aspect ratio is higher than 3.

Replication characteristic of Ta absorber patterns were investigated in comparison with Au absorber patterns. Figure 7 shows the effects of Ta and Au absorber pattern thicknesses on residual resist thicknesses, where FBM resist was exposed by x-rays from Mo target. It is found from Fig. 7 that x-ray attenuation characteristics of Ta film are the same as those of Au.

Figure 8 shows an SEM photograph of FBM resist patterns replicated by the step-and-repeat x-ray exposure system[8)] with Mo target. The submicron patterns of FBM are easily obtained using an x-ray mask with 0.7 μm thick Ta absorber patterns. The high contrast submicron x-ray mask is now being used in SOR lithography as well.

4. Conclusion

A high contrast submicron x-ray mask with Ta absorber patterns was developed. For the fabrication of Ta absorber patterns, an all dry process using reactive sputter etching was proposed for the high accuracy formation of submicron patterns and simplicity of the mask process. By precise control of Ar gas pressure, internal stress in Ta film can be maintained within ±10 kg/mm^2 to prevent destruction or distortion of the mask substrate. By adopting reactive sputter etching of Ta/SiO_2 using $CBrF_3$ and SiO_2 /PMMA using C_4F_8, an etching selectivity of Ta/PMMA higher than 10 can be obtained. these process has been successfully applied to obtain a high contrast submicron x-ray mask.



1μm

Fig.8 SEM photograph of replicated resist patterns

5. Acknowledgements

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