Dry etching technologies for reflective multilayer

Yoshinori Iino,Makoto Karyu,Hirotsugu Ita,Yoshihisa Kase,
Tomoaki Yoshimori,Makoto Muto,Mikio Nonaka,Munenori Iwami
Fine Mechatronics Division,Shibaura Mechatronics Corporation
2-5-1 Kasama,Sakae-Ku,Yokohama-shi,247-8560,Japan

ABSTRACT

We have developed a highly integrated methodology for patterning Extreme Ultraviolet (EUV) mask, which has been highlighted for the lithography technique at the 14nm half-pitch generation and beyond. The EUV mask is characterized as a reflective-type mask which is completely different compared with conventional transparent-type of photo mask. And it requires not only patterning of absorber layer without damaging the underlying multi reflective layers (40 Si/Mo layers) but also etching multi reflective layers. In this case, the dry etch process has generally faced technical challenges such as the difficulties in CD control, etch damage to quartz substrate and low selectivity to the mask resist.

Shibaura Mechatronics ARES^{TM} mask etch system and its optimized etch process has already achieved the maximal etch performance at patterning two-layered absorber. And in this study, our process technologies of multi reflective layers will be evaluated by means of optimal combination of process gases and our optimized plasma produced by certain source power and bias power. When our ARES™ is used for multilayer etching, the user can choose to etch the absorber layer at the same time or etch only the multilayer.

Keywords：etching, multilayer, absorber etching, Extreme Ultra-Violet

1. INTRODUCTION

EUV (Extreme Ultra-Violet) lithography is the most promising, next-generation alternative lithography technology that may replace the photolithography technology, currently used as a mass-production technology for cutting-edge semiconductors, when photolithography eventually reaches its limits. According to ITRS 2011, EUV lithography is also a candidate lithography technology for 22-nm devices whose mass-production is expected to start in 2015. Unlike the optically transparent mask currently used in cutting-edge semiconductor technologies, the EUV mask is a reflective mask that marks a significant turning point. With the EUV mask, a wavelength of 13.5 nm is irradiated onto the mask, which is absorbed by the absorber stack and also reflected by the Mo/Si multi-layer stack at the opening of the absorber, and eventually taken into the projection optics. The absorber stack is constituted by TaO/TaN.

Here, specifically a mechanism of etching a multi-layer stack is reported. The mask etching system "ARES" by Shibaura Mechatronics was used for etching. "ARES" also supports such cutting-edge technologies as MoSi binary mask processing and phase shift mask processing, and represents an upgrade version supporting the EUV mask while still maintaining its basic design concept.

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2. EXPERIMENTAL

In this experiment, a 40-pair Mo/Si stack was formed on a quartz substrate and a Ru film was formed on top to produce multilayer, while another substrate was prepared by forming an absorber stack, and desired etching capability was proven with both of the substrates. It was also demonstrated that EUV mask from blank-A and blank-B could be etched favorably.

3. RESULT

Multilayer etching of the EUV mask encompasses the following three points:
[1] Etching without residue
[2] Vertical processing
[3] Selectivity against resist

This time, an etching mechanism is described which is capable of etching, without leaving residue, a Mo/Si stack consisting of as many as 40 pairs and having a Ru film at the very top, after which our unique OES (Optical Emission Spectroscopy) is presented as a means for ensuring repeatability.

3.1 Etching of Ru/Si Mixed Layer

Here, the term "Ru/Si mixed layer" refers to the Ru_xSi_y layer shown in Fig. 1. The photograph on the left is a TEM micrograph of the entire multilayer. The photograph on the right is an enlarged TEM micrograph of the top part of the multilayer. While the Ru film was formed with a target of 2.5 nm, the dark area in the uppermost layer indicates a thicker layer of approx. 3.8 nm. A more detailed observation of the dark area in the uppermost layer finds that this layer is divided into two. Accordingly, EDS (Energy Dispersive X-ray Spectrometer) analysis was conducted. The results are shown in Fig. 2.

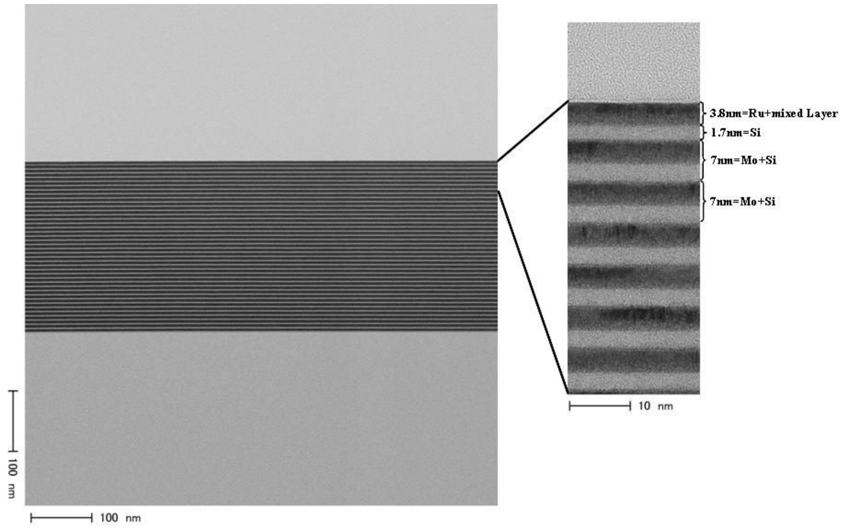


Fig. 1 Cross sectional TEM micrographs of multilayer

Fig. 2 shows that Si is dispersed in the uppermost Ru layer. If the Ru/SiO_2 selectivity deviates significantly when the Ru/Si mixed layer is etched, only one side will be etched in an island pattern and the resulting micro-mask will lead to etching residue. In fact, residue generated under the initial etching condition of SiO_2 etch rate >> Ru etch rate.

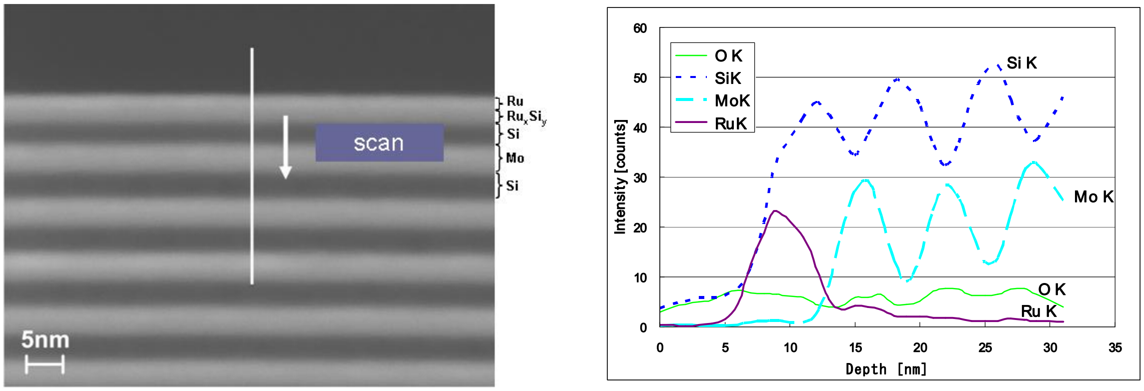


Fig. 2 Cross-sectional TEM Micrographs of multilayer for EDS (Left) and EDS Analysis Results (Right)

Fig. 3 shows the relationship of SiO_2/Ru selectivity and residue.The horizontal axis is SiO_2, but not Si. That is because, based on the assumption that Si in the uppermost layer has likely deteriorated into a natural oxide film, the etch rate was measured on a SiO_2 sample. Also note that the term "residue" here refers to the etching residue that remains on the quartz substrate after having etched to multilayer. If the mixed layer is etched under the condition of SiO_2/Ru selectivity = 6, for example, Si in the mixed layer will be selectively etched and the Ru film will remain in an island pattern. If the island-pattern Ru is left as is and the multilayer is etched, the remaining Ru will form a micro-mask and consequently multilayer will generate residue. To prevent this residue, it is desirable to etch the mixed layer at SiO_2/Ru selectivity < 3 as revealed by the experiment.

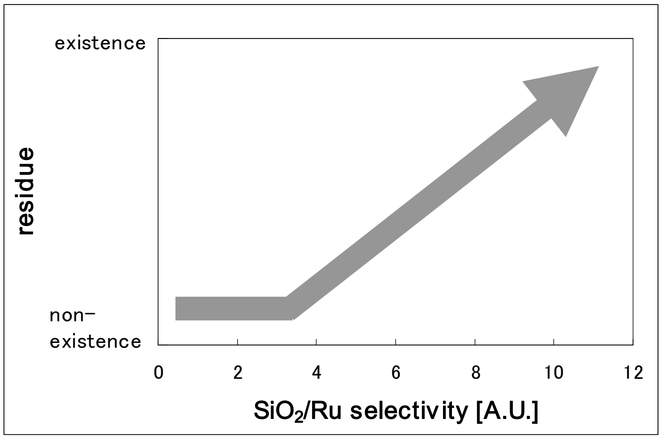


Fig. 3 Relationship of Residue and SiO_2/Ru Selectivity

3.2 Etching of Multilayer

Next, the method to etch a multilayer is described. Multilayer is etched with gas chemistry including Cl_2 and O_2. Chlorine gas is used primarily to etch the Si layer, but since the Mo layer cannot be etched using Cl_2 gas, O_2 gas is added. Fig. 4 shows the relationship of O_2 gas ratio and Mo/Si etch rate. O_2 gas must be added because the Mo layer cannot be etched without O_2 gas. On the other hand, however, adding a greater amount of O_2 gas causes the Si layer to oxidize and thereby inhibits the etching of the Si layer.

Multilayer consists of 40 pairs of Si and Mo layers. To vertically process this multilayer consisting of as many as 40 pairs, ideally etching must be performed at Si/Mo selectivity = 1. However, adjusting the O_2 gas ratio alone as shown in Fig. 4 for the purpose of achieving Si/Mo selectivity = 1 will trigger local oxidization of Si and cause oxidized Si to form a micro-mask. Consequently, etching residue will generate. To solve this problem, we optimized the Si/Mo selectivity according to the O_2 gas ratio when etching multilayer; increased the ion energy; and thus successfully prevented the locally oxidized Si from forming a micro-mask.

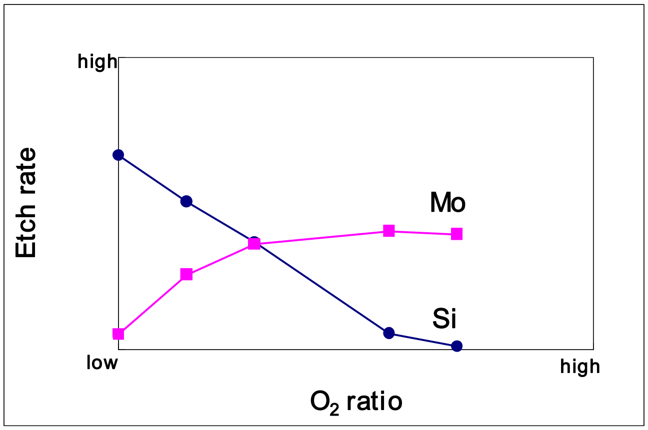


Fig. 4 Relationship of O_2 Gas Ratio and Mo/Si Etch Rate

Fig. 5 shows SEM micrographs of the conditions of residue on quartz substrates after etching at low bias power and high bias power, respectively, following an optimization of Si/Mo selectivity. When the bias power was low, the Si layer in multilayer was locally oxidized and formed a micro-mask, as mentioned earlier, and therefore etching progressed in a column pattern and residue generated. When the bias power was high, on the other hand, high ion energy provided assistive etching with physical sputters and residue-free etching could be achieved.

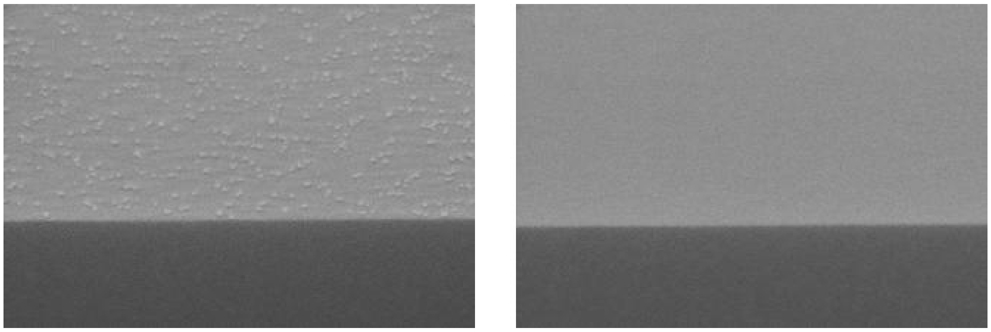


Fig. 5 Residue on Quarts Substrate after Etching at Low Bias Power (Left) and Absence of Residue on Quarts Substrate after Etching at High Bias Power (Right)

3.3 OES (Optical Emission Spectroscopy)

One important process performance is repeatability. To ensure repeatability, the ARES is equipped with a unique OES. Fig. 6 shows the OES signal during etching of multilayer. In the left graph of Fig. 6, the OES signal represents etching of a Ru/Si mixed layer between t1 and t2, and the signal change at t3 indicates that etching of Mo in the top layer of multilayer has started. The right graph shows how the OES signal changes while multilayer is etched, and also captures the change corresponding to "etch off" of multilayer. Here, OES signal detection used a unique algorithm.

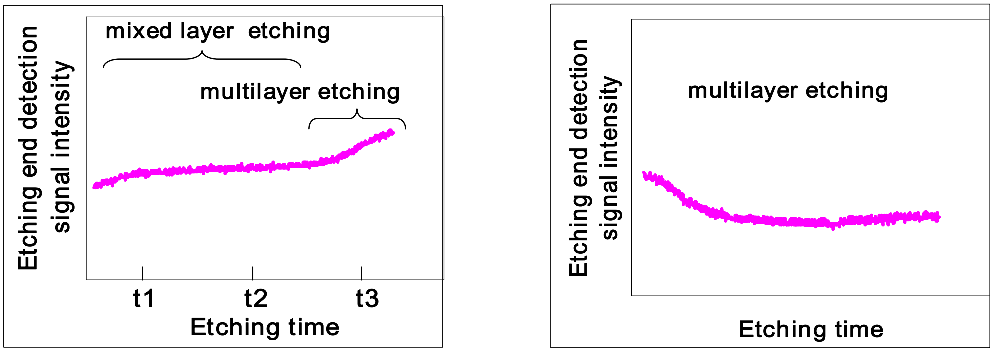


Fig. 6 OES Signal during Mixed-layer Etching until Start of multilayer Etching (Left) and OES Signal during multilayer Etching (Right)

4. CONCLUSIONS

The results in Fig. 7 were obtained by applying the aforementioned etching process mechanism to etch multilayer. Fig. 7 provides cross-sectional SEM micrographs showing desired etching results in cases where only multilayer was etched and where the absorber layer on top of multilayer was etched together using the same resist mask. Moreover, desired etching was resulted on both blank-A and blank-B.

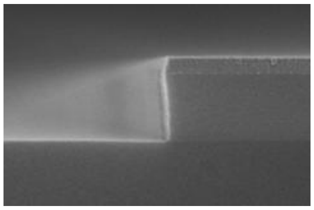
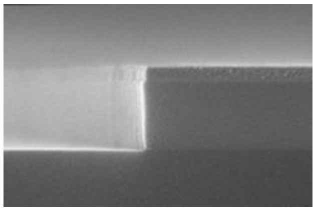
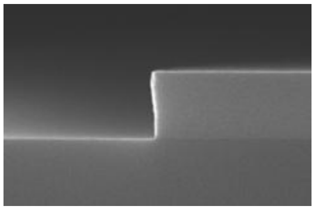
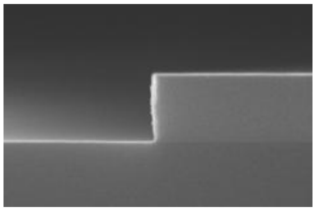
	blank- A	**blank-B**
Ta/Ru/ML		
Ru/ML		

Fig.7 Results of multilayer etch performance

The above reported multilayer etching process. According to the knowledge we have gained, residue-free etching of a Ru/Si mixed layer can be achieved by etching the mixed layer at SiO_2/Ru selectivity < 3, while residue-free etching of multilayer can be achieved by etching at Si/M selectivity = 1, ideally, and also giving ion energy of a specified level or higher.

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