Silicon Nitride Surface Preparation to Prevent Photoresist Blister Defects

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Abstract

Preparation of silicon nitride (SiN) surface prior to photoresist coating is primarily performed to improve the resist adhesion to SiN and/or to clean the SiN surface. Common industry practices include using oxygen plasma clean or priming the SiN surface with Hexamethyldisilazane (HMDS). The state of the SiN surface has been observed to be a factor in the formation of blisters in the photoresist (PR) following exposure with ultra-violet (UV) light. The PR blister defects may impact visual yield by as much as 30%. Hydrogen plasma and methane plasma were found to be the most effective SiN surface treatments to prevent the formation of PR blister defects. In this paper, the theory for the formation of the PR blister defect will be presented. Alternative SiN surface preparation methods to prevent blister defects will also be discussed.

INTRODUCTION

Silicon nitride is widely used in the compound semiconductor industry for surface passivation, as an etch mask, and as a dielectric layer. Oxygen plasma descum may be employed to clean the SiN surface to remove organic residues prior to PR coating. However, the descum step reduces the adhesion of a thin positive-type photoresist to the SiN surface, which later causes PR blisters during UV exposure. When PR is exposed under the UV light, the photoactive compounds in the PR will generate nitrogen gas [1]. If the amount of nitrogen gas generated is greater than the amount of gas released, PR blisters will form (shown in Figure 1) [2]. We define the photoresist blister as the portion of the PR that bubbled and broke away from the substrate during UV exposure. The blister defects may not be a serious problem when the positive-type resist is used as positive tone. However, if the positive-type resist is used as a negative tone resist with further resist treatment (e.g. Image Reversal), the blister defects will become a serious manufacturing yield issue. Applying HMDS to the oxygen descumed SiN surface prior to coating PR will improve the resist adhesion by changing the SiN surface property from hydrophilic to hydrophobic. However, PR blisters are still observed when light-field exposure mask is applied on positive resist with less than 3µm thickness. PR blister defects are not noticeable on thicker resist.

We believe oxygen plasma descum will create negative ion charges on the shallow SiN surface and cause PR blisters. This study will focus on altering the SiN surface charges by different SiN surface treatments to prevent PR blister defects.

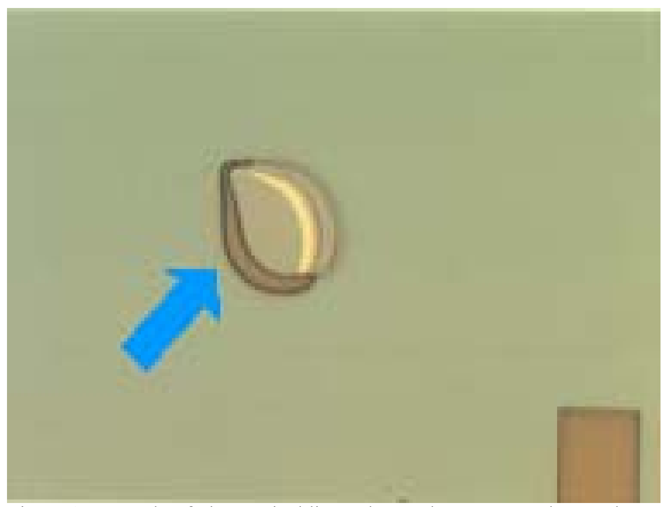

Figure 1. Example of photoresist blister observed on oxygen plasma cleaned silicon nitride surface after UV exposure in the photo stepper.

EXPERIMENTS AND RESULTS

Photoresist adhesion depends on surface roughness, surface cleanliness, substrate material, polymer type in resist, and the concentration of photoactive compound. In the designed experiment, the ionic charges on the surface was found to be the main effect on poor PR adhesion on oxygen plasma descumed SiN surface.

Experimental wafers were first deposited with 500Å thick SiN by reacting ammonia gas, silane gas, and nitrogen in the plasma enhanced chemical vapor deposition chamber at 250°C. A short oxygen plasma descum was then used to simulated the cleaning process on SiN. Next, the SiN was treated at room temperature in an inductive coupled plasma chamber for a short time with one of the following types of gases: argon, hydrogen, methane, and oxygen. After surface treatment, the wafers were coated with 1um positive resist and UV exposed in a stepper with a light field. The exposure dose was set at 3800J/m^2. The wafers were then examined for PR blister defects using a microscope.

The SiN surface treated with argon plasma showed the most PR blister defects with approximately 1000 blisters randomly scattered over the wafer. Blisters observed were approximately 50um in diameter. The surface treated with oxygen plasma was found to have about 800 PR blisters on the entire wafer. No blister was observed on wafers treated with hydrogen plasma or methane plasma.

The reason argon plasma treatment resulted in the most PR blisters is most likely due to the fact that argon plasma behaves similarly with ion milling and smoothes the SiN surface. The RMS value of the surface roughness measurement obtained from AFM on argon plasma treated surface was 0.25nm while the oxygen plasma treated surface was 0.35nm. The polished surface decreased the total interfacing area between the PR and the SiN and thus reduced the PR adhesion.

Silicon nitride treated with oxygen plasma is believed to trap with a large amount of negative ionic charges on surface. The negative charges will attract water molecules in the atmosphere and prevent it from forming close contact with the PR, thus reducing the PR adhesion. This is confirmed by using the contact angle measurement. The oxygen plasma treated surface is hydrophilic and the contact angle measured is 27.5°. In contrast, the hydrogen plasma treated surfaces is hydrophobic and has a contact angle of 65.5°. The higher the contact angle the less water molecules adsorb on the surface. The dehydration bake helps to reduce the amount of water molecules on the wafer; however, the cooling step following the dehydration bake will reintroduce the water molecules onto the wafer.

Both hydrogen plasma and methane plasma treated surfaces showed no PR blister defects. This is possibly due to the negatively charged SiN surface being neutralized with the positively charged hydrogen ions during the plasma treatment. The hydrogen ions changed the SiN surface property from hydrophilic to hydrophobic and enhanced the PR adhesion. The drawback of using methane plasma treatment is that a thin film of polymer will deposit on the SiN surface.

Hydrogen plasma was believed to induce more hydrogen bonds on the SiN surface. This is similar in function to HMDS. Experiments showed that the HMDS priming step did not improve PR adhesion on the SiN treated with hydrogen plasma. Thus, it could be skipped whenever hydrogen plasma surface treatment was employed.

Ammonia gas treatment was also used in this study to evaluate its effect on PR blister formation. The results showed that ammonia plasma treated SiN surface yielded similar amount of PR blisters as the oxygen plasma treated surface. The negative charges on the SiN surface did not get neutralized by the ammonia plasma because insufficient hydrogen ions were created in the plasma.

Wet chemistry surface treatments using ammonia hydroxide and hydrochloric acid rinse were also investigated. Neither the ammonia hydroxide nor the hydrochloric acid rinse showed consistent results in reducing the amount of PR blister defects.

CONCLUSION

Photoresist blister defects were observed on silicon nitride surface after a thin film of positive PR was UV exposed in a stepper with a light field. After running a series of experiments, the data showed that the PR blister problem was most likely caused by the negative ionic charges trapped in the silicon nitride surface. Surface Preparations using wet and dry plasma treatments prior to coating a thin film of positive resist on wafer were studied. The wet chemistry surface treatments using either ammonia hydroxide rinse or hydrophobic acid rinse failed to yield consistent results in term of reducing the amount of blister defects. Therefore, they were considered to be ineffective. Surface treatments using either hydrogen plasma or methane plasma showed promising results in preventing the PR blister defects. Thus, they are proposed for use to improve the PR adhesion on oxide plasma treated SiN surface.

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ACRONYMS

AFM: Atomic Force Microscope
HMDS: Hexamethyldisilazane
PR: Photoresist
RMS: Root mean square
SiN: Silicon Nitride
UV: Ultra Violet