Using polymer deposition to control contact hole distortion at ≤65nm

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ABSTRACT

Contact-hole distortion results from low mask selectivity and poor mask surface quality (roughness, striation, pitting, or pin holes) before and after etching. Thinner, softer ArF resists are particularly susceptible to these defects, giving rise to the need for additional steps in the etch sequence to mitigate pattern deformation. Experimentation with a polymer deposition process shows that by adding this step before, after, or before and after the bottom anti-reflective coat (BARC) open step, mask quality is much improved and contact profiles can be well controlled.

For 65nm geometries and beyond, one of the most challenging aspects of etching densely patterned (tight pitch) small contact holes is achieving vertical, undistorted profiles. This is made more difficult by the higher resolution ArF (or carbon-rich) resists used at these geometries. Depth-of-field limitations necessitate thinner layers of these resists that are also softer than their predecessors and, therefore, pose greater surface degradation control and etch selectivity challenges [1, 2]. While conventional BARC etch conditions can control contact hole profiles [3, 4], improvement of the etch process itself is necessary to prevent surface degradation that leads to distortion of the contact holes. Acting as an additional hard mask layer, polymer deposition is a mechanism by which both to prevent this distortion and to control contact hole critical dimension during the etch sequence. Achieving the desired balance between distortion and profile control involves optimizing the length of the polymer deposition process (PDP) as distortion is reduced by a longer PDP, but profiles are best preserved with a short PDP. Therefore, PDP time offers an effective control knob for contact hole distortion and profile.

The PDP consists of a various polymer rich chemistries, such as C_xF_y, CHF_x, etc., the gas ratios of which affect the degree of distortion of the contact holes: the richer the chemistry, the less the distortion. Process sequence also exerts an influence, the degree of distortion varying depending on whether the PDP precedes or follows the BARC open step. Experiments were conducted using an advanced dielectric etcher configured with high frequency source power and dual frequency bias powers. Both ArF and carbon-rich photoresist (PR) films were evaluated.

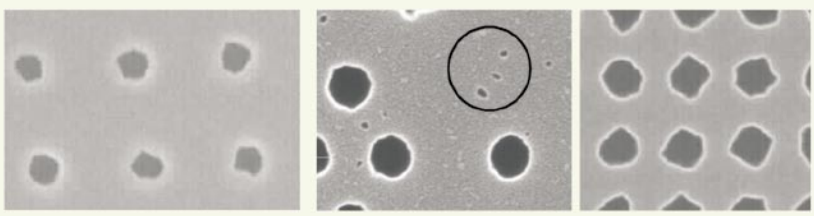

Figure 1. Distortion arises from pre-etch mask deformation (left), pin holes in the mask (center), or striation (right).

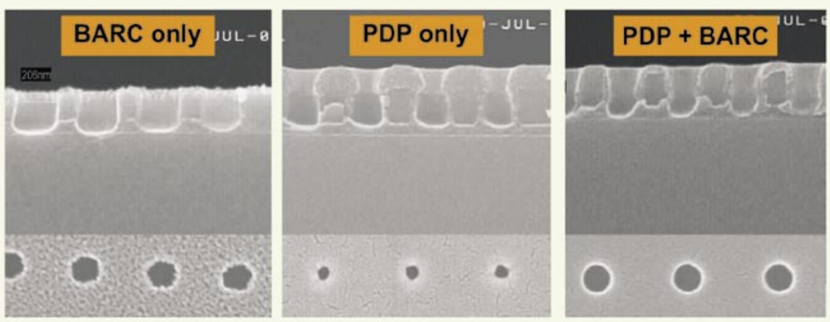

Figure 2. The combined PDP-BARC open process produced better results than either BARC or PDP chemistries alone.

PDP chemistry selection

Distortion occurs for the following three reasons: pre-etch mask damage, pin holes during processing, and mask striation after processing (Figure 1). A non-ideal mask surface is the result of either low mask selectivity or mask roughness and often cannot be solved by the chemistry used for the BARC open step.

This study initially investigated different BARC processes in an attempt to improve mask selectivity, but even a modified, polymer-rich chemistry like CF_x/CH_xF_y fell short of the necessary improvement. Therefore, a PDP step was investigated as a means of compensating for poor mask selectivity. Figure 2 illustrates results from three tests: A BARC-only process showed large bottom CD, low selectivity, and a rough surface; a PDP-only process improved selectivity by adding to the thickness of the mask but the etch rate was too low; and a PDP-plus-BARC open process showed good selectivity, tight bottom CD control, and less top striation.

To optimize the PDP chemistry, comparative runs were made on an in-house wafer patterned with an ArF PR. Combining C_xF_y and CH_xF resulted in less striation than C_xF_y-only or CH_xF-only processes. Performance also improved when carbon monoxide was used as the

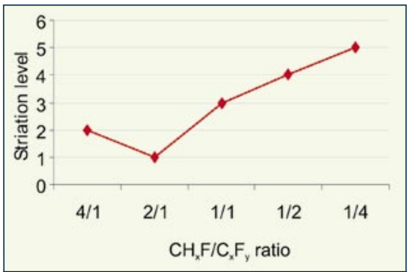

Figure 3. A 2:1 CH_xF/C_xF_y ratio produced the least striation with full etch.

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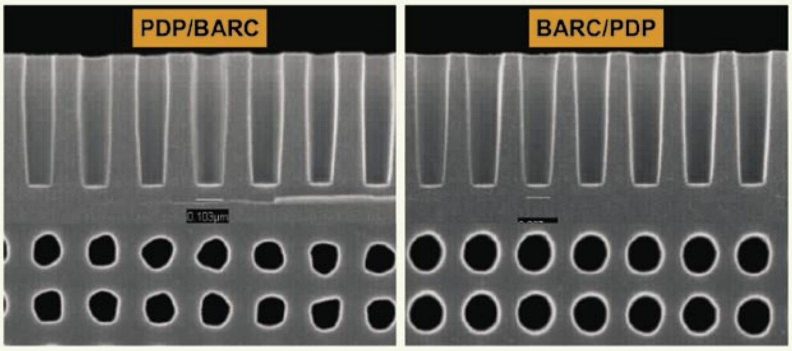

Figure 4. The process sequence affects the degree of contact-hole distortion.

dilutant rather than oxygen. To investigate the effect of gas ratio on striation, CH_xF/C_xF_y ratios from 1/4 to 4/1 were tested, with 2/1 producing the least surface striation (Figure 3). Based on these results, a $CH_xF/C_xFy/CO$ chemistry with a CH_xF/C_xFy flow ratio of 2:1 was used as the PDP baseline recipe for the remainder of this work.

Effect of process sequence

Two case studies of the PDP process compared profiles and surface roughness when the PDP preceded the BARC open step or followed it. Generally, when

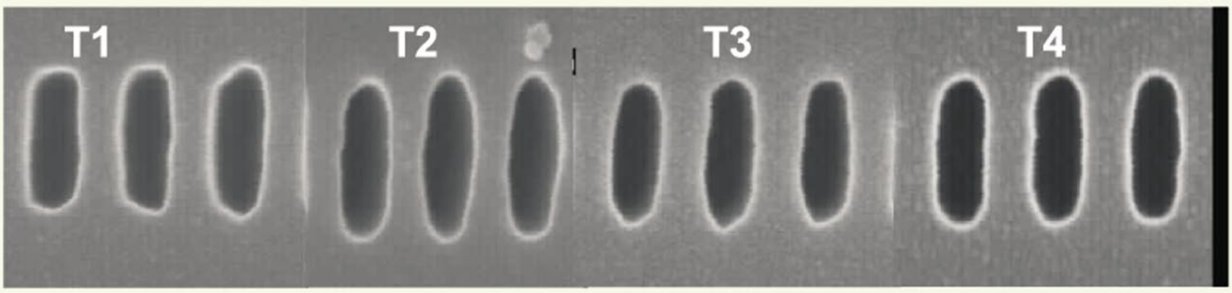

Figure 5. Oxide surface distortion lessens with longer PDP time.

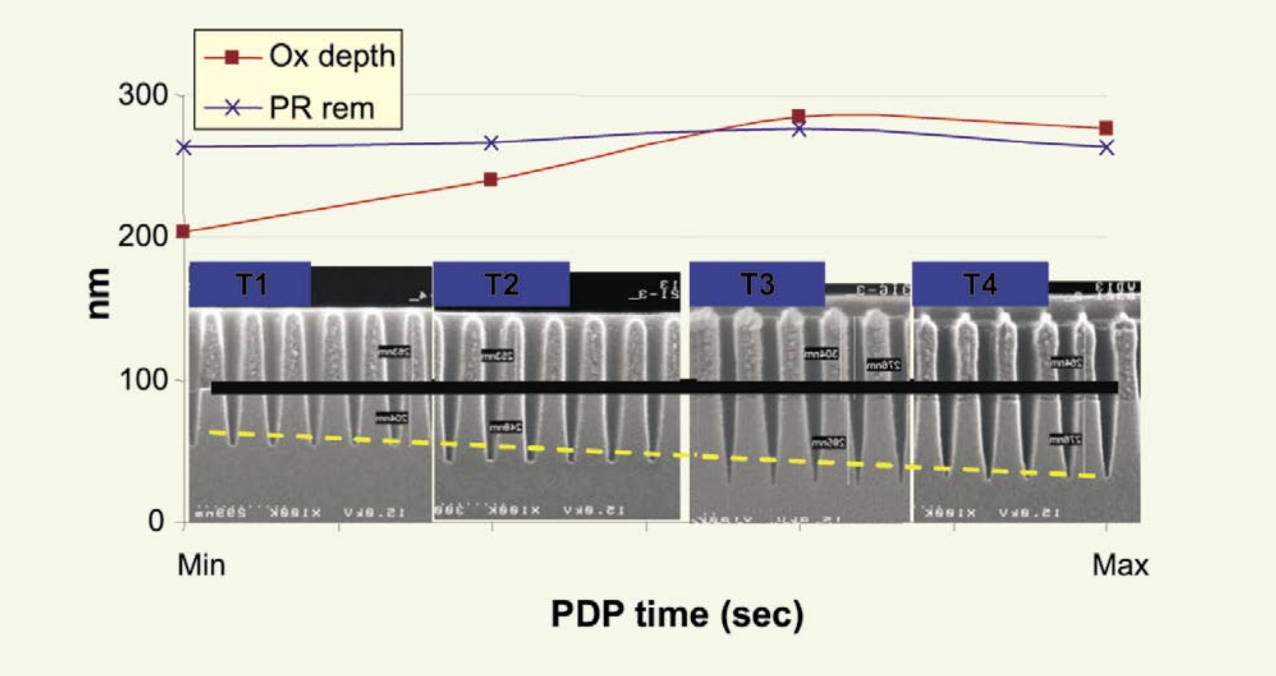

Figure 6. Trends in oxide etch depth and mask remaining established the optimum PDP step time.

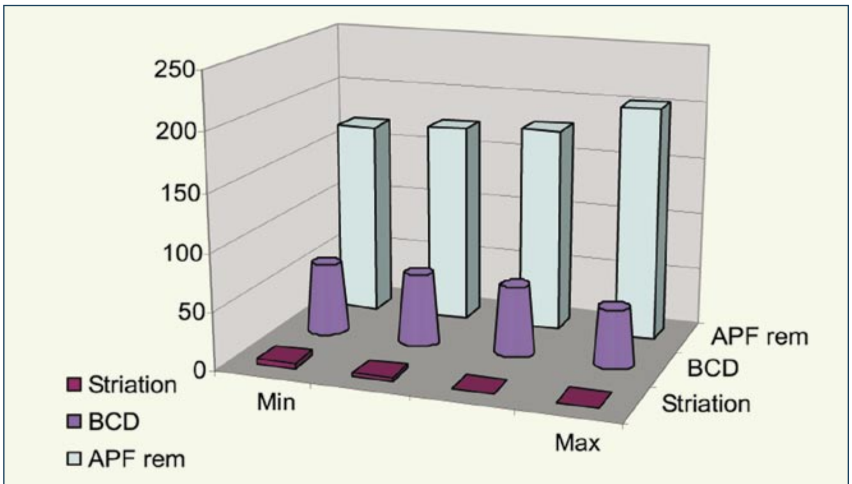

Figure 7. Remaining mask thickness, striation, and bottom CD for different pre-BARC PDP step times.

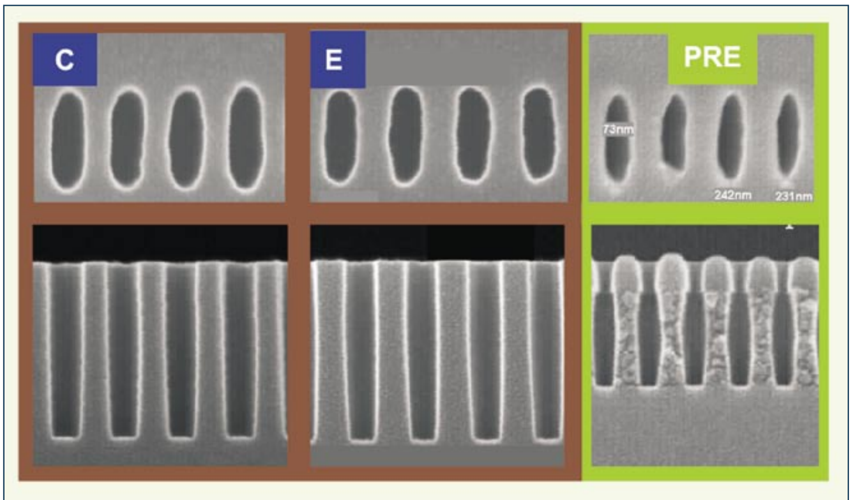

Figure 8. Pre- and post-etch comparison of contact etch process at center and edge of the wafer.

surface roughness is slight the PDP step can be used before BARC open, but in cases of pronounced roughness, it should follow BARC open or possibly be used before *and* after that step.

When the PDP preceded BARC open, the deposited polymer shrank the top CD and resulted in overall small top and bottom CD during the oxide etch. When BARC open preceded the PDP, the mask top CD blew out during BARC open, although this flaring was reduced during the PDP step as polymer adhered to the sidewalls of the BARC openings.

The difference in hole distortion between the two cases can be explained by the difference in the chemistry etching the top polymer (Figure 4). When PDP precedes BARC open, it deposits a layer of polymer on top of the mask. During BARC-open, the CF_x chemistry etches the polymer as well as the BARC. Thus, less polymer is left to protect the top of the mask from degradation during the oxide etch and greater mask deformation results. When the PDP step follows BARC open, less of the polymer is etched by the polymer-rich oxide etch chemistry; hence, a thicker mask layer remains that protects the surface from damage and reduces distortion of the contact holes during the etching process.

Effect of PDP step time

The study demonstrated that PDP step time was the key factor in controlling

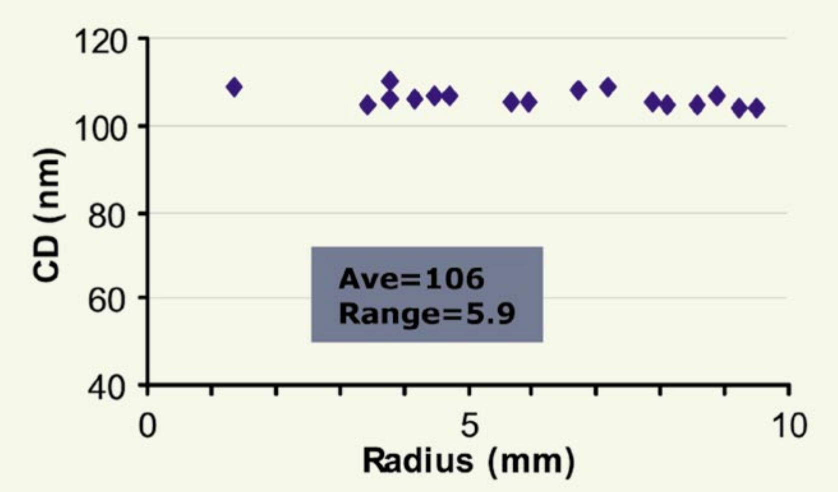

Figure 9. PDP effectiveness was demonstrated by good post-oxide-etch uniformity in mask top CD.

surface roughness as well as contact hole profile. Figure 5 shows a progression of lessening distortion of the contact hole in the oxide layer as PDP step time increases. This improvement derived from the thickening of the mask layer by the PDP, which enhanced its selectivity and reduced surface striation.

Although distortion decreased with longer PDP step time, undesirable trends were noticed, with bottom CDs becoming smaller and profiles more tapered. Initially, the oxide etch depth increased, but beyond a certain threshold time, both etch depth and the remaining mask deteriorated (Figure 6). Figure 7 summarizes the effect of differing PDP step time on remaining mask thickness, oxide bottom CD, and oxide top roughness.

Figure 8 shows results following the entire process (optimum PDP step time, BARC open, oxide etch), with contact hole shapes and profiles noticeably improved over those seen in the pre-etch views. The data in Figure 9 confirm the degree to which a PDP step following BARC open can restore good CD. Here the process achieved less than 6nm variance in post-oxide-etch top CD in the mask layer.

Conclusion

Contact hole distortion can be reduced by using a polymer rich process before, after, or before *and* after the BARC-open step. The order in which the PDP is applied depends on the degree of surface roughness and etch process limitations. A PDP step can increase mask selectivity by depositing a layer of polymer on top of the mask and can also mitigate surface degradation by improving the quality of the mask surface. PDP step time is determined by the tradeoff between contact hole distortion and profile control.

ACKNOWLEDGEMENTS

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