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THE INTERNATIONAL MAGAZINE FOR SEMICONDUCTOR MANUFACTURING

OCTOBER 2000

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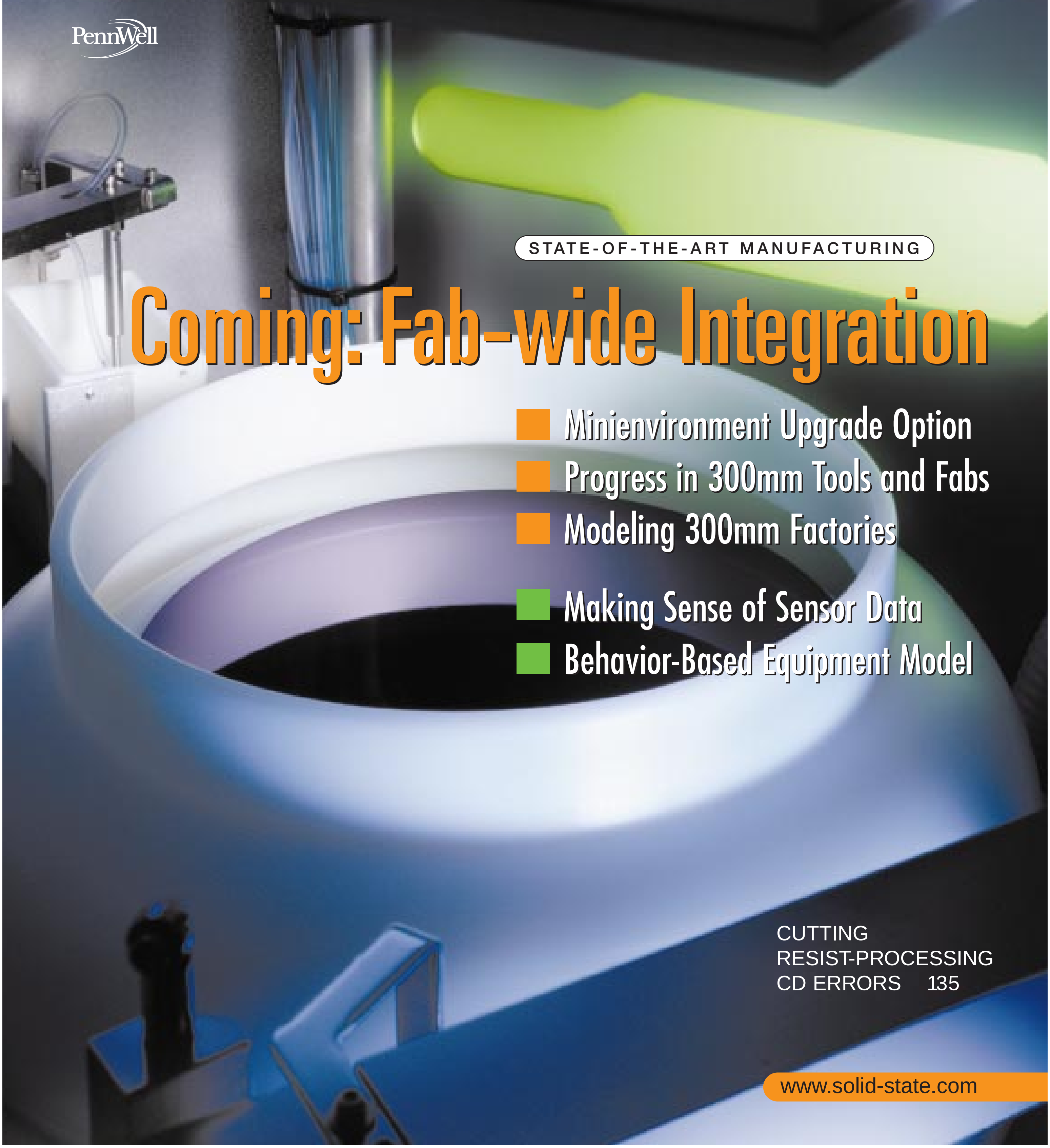

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ETCHING

An integrated wet chemical etch-strip-clean sequence

OVERVIEW An investigation was conducted to determine the source of a yield-limiting defect identified on all product types at a wafer fab. The defect was isolated to patterning operations in the frontend section of the device process where a conventional multistep sequence was used. The problem was traced to a wet chemical buffered oxide etching step and attributed to drying wafers before ashing the resist film. A novel solution was implemented using an integrated centrifugal spray process, which resulted in defect elimination, increased device yield, and fewer process steps.

Pattern transfer in the front end of device processing is especially critical because underlying active material is sensitive to potential damage from reactive ion etch radiation. A common solution to this concern is to conduct incomplete plasma etch and then follow with an aqueous etching process to complete the etch to the silicon surface. This retains the advantage of the anisotropic etch profile while reducing potential for silicon damage. On the negative side, the sequence adds a process step and its associated costs, and, in the case in question, led to increases in product defectivity.

A defectivity problem was isolated to the patterning sequence that utilizes a two-step plasma/wet etch, a resist ash,and a surface clean to form the structures. The defect, identified as a residue, was observed both optically and through scanning electron microscopy ([SEM]; Fig. 1).

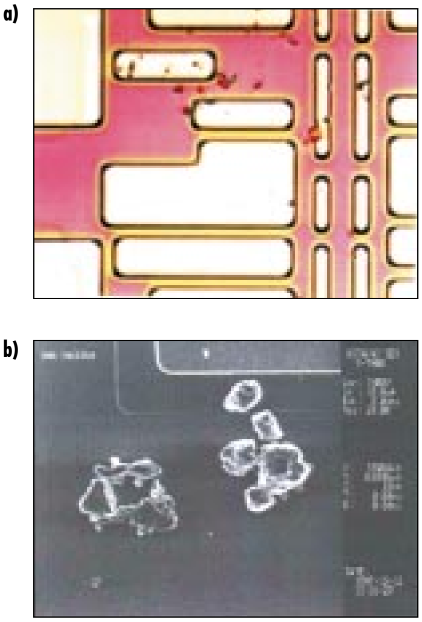

Figure 1. Residue defect as observed in **a)** optical and **b)** SEM images.

The defect was detected on all product technologies, with random lot-to-lot and wafer-to-wafer occurrence. It was found in both the periphery and memory array areas of the device. Initially, all five steps of the patterning sequence — the reactive ion etch, the BOE etch, the resist ash, the piranha strip, and the pre-diffusion clean — were suspected of generating the defect. By partitioning the process, the defect could be isolated and a formation mechanism could be proposed.

The detailed sequence of etching/strip/ clean is shown in Fig. 2. In this sequence, the reactive ion etch of the dielectric layer is stopped just short of the silicon surface. At this point, wafers are transferred to an immersion system for a buffered oxide etch (BOE) of the remaining oxide. They are then dried before moving on to the next step, removal of the resist layer using a plasma ashing process, followed by a piranha strip. Once the resist is removed, the wafers are sent through a typical RCA-based pre-diffusion clean.

Problem identification

The defects were identified immediately following the patterning sequence and appear as shown in Fig. 1. Based on past experience, the defects were recognized as typical organic residues found after plasma etching.

Normal process diagnostics compelled us to investigate the plasma etch step and the plasma ashing step as possible sources of the residue. After diagnostic tuning failed to solve the problem, the focus shifted to the wet etch step. Of particular interest was the interaction of the reactive ion etch (RIE) step, which leaves polymeric residues, and the drying of wafers after wet etching.

It was postulated that polymeric defects from the RIE step were suspended in the aqueous sequence of the BOE etch process and then subsequently attracted to the hydrophobic silicon surface when the wafers were dried. With this assumption, two solutions to the problem were considered.

The first solution was to remove the resist layer just after plasma etching and then reconstruct it with a freshly patterned resist film. This adds a lithography step and was considered a complicated and expensive solution.

The second proposed solution was to integrate the wet etch step with a wet resist strip process in a centrifugal spray processor. This had the advantage of eliminating the drying action, which was required in the original BOE process, and eliminating the need for an ashing step. This approach, if successful, had the advantage of combining two steps into one.

Process integration

The focus for the integrated process was the FSI International MERCURY surface-conditioning system. The system was in-house and capable of dispensing multiple process chemistries in several sequence possibilities. It could also incorporate the pre-diffusion clean, reducing three steps to one. The resist strip and the pre-diffusion clean processes were essentially qualified and ready to be integrated, so the focus of the work was on characterizing the BOE process.

Buffered oxide etching

Because photoresist is not attacked by chemistries with a pH >3, buffered oxide etching is preferred for patterned etching of oxides. BOE, a solution based on HF acid buffered by NH_4F, is widely used in the

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Reprinted with revisions, from the October 2000 edition of **SOLID STATE TECHNOLOGY**

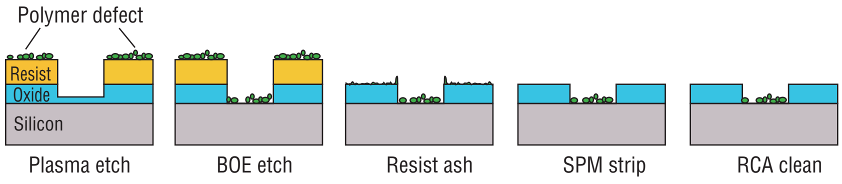

Figure 2. Pattern transfer process sequence showing all five steps.

semiconductor industry to etch oxide layers through a photoresist mask.

While IC makers recognize the benefits of buffered oxide etching, premixed BOE — which contains a large number of species, including HF, F^-, H_2F_2, HF_2^-, NH_3, NH_4^+, H_3O^+, and OH^- — is more expensive than diluted HF and is only available in a limited number of blend ratios. Often only one or two blend ratios are available at a facility.

Many works already published on the subject of etching with BOE present the behavior of doped [1–4] and undoped [2, 5] silicon dioxide etching. The mechanism of SiO_2 etching, however, is not fully understood, and many works provide different analyses [3, 4, 6].

Blended BOE

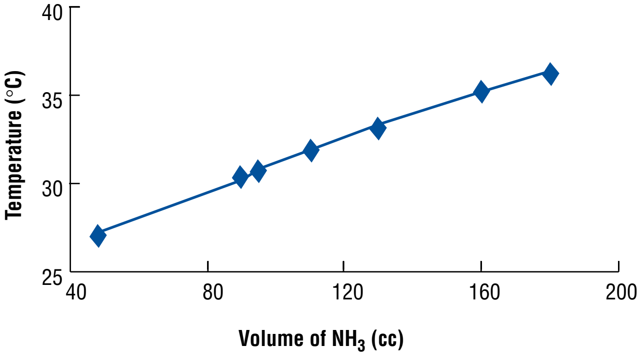

Figure 3. Exothermic reaction between HF and NH_4OH, showing temperature as a function of the volume of NH_3.

Online blending of HF and NH_4OH makes point-of-use BOE an in situ process and allows a reduction in cost and optimization of the etch process [7]. Blended BOE is a HF-based oxide etchant with added NH_4OH. The combination of HF and NH_4OH forms NH_4F in solution, which buffers the fluoride concentration. The description "BOE n/m" refers to a volumetric mixing ratio of n parts of 40 wt% NH_4F and m parts of 49 wt% HF. Research by Metron Technology and FSI International engineers solved a system of eight equations to determine the concentration of each species [8]. We were then able to choose the final experimental settings.

Characterizing the etch process

The focus in etch characterization was on removal of thin oxides (<100Å) and etch uniformity. Tests were performed using 200mm wafers. The etch uniformity data was given after nine point measurements. The experiments were optimized using predictions from the theory [8].

Figure 3 shows the exothermic reaction between HF and NH_4OH. In the experiments, the reaction of different volumes of 28% NH_4OH with 100cc of 49% HF was considered. Because NH_4OH is the limiting factor of the reaction, the volume of NH_4OH was the key parameter in controlling the exothermic reaction.

Depending on the NH_4OH volume to be used in the mixture, it was possible to optimize the process conditions and take into account the exothermic reaction. Figure 4 shows the etch rates of BOE made by online blending of HF, NH_4OH, and DI water. A large range of etch rates were available, allowing process optimization. The chart indicates the effect of varying the amount of NH_4OH for four different HF:H_2O mixtures, which were each held constant.

It was possible to get relatively low etch rates (<1Å/sec) or higher values if necessary. The amount of oxide to be etched set the basis for selecting a practical etch rate and, consequently, the blended mixture. Also, different blended mixtures can be prepared to get a similar etch rate (e.g., 2Å/sec). The final online blending conditions were selected based on optimum etch uniformity.

Figure 5 shows the on-wafer nonuniformity for different blended BOE processes. Etch nonuniformity on wafers was as low as 0.7% (1σ). A slight uniformity gradient was observed from wafers 1–24, but good cross-cassette nonuniformities (about 1%) were obtained.

It was important to avoid any damage to the photoresist during the oxide etch. Our simulations confirmed that while the BOE n/1 ratio is above 3 (pH >3), the oxide is successfully etched without any damage to the photoresist. In comparison, HF solutions that are even very diluted (200 times) still have a pH <3, making such solutions much less convenient than BOE for critical etchings.

With the blended BOE process completed in the centrifugal spray system, emphasis shifted to the resist strip and pre-diffusion clean processes. Resist stripping was accomplished using a typical piranha (H_2SO_4/H_2O_2) sequence. Pre-diffusion cleaning involved a classic RCA cleaning sequence of SC1 (NH_4OH/H_2O_2/H_2O) and SC2 (HCl/H_2O_2/H_2O). Since both processes have been previously characterized and represent mature processes, no characterization details are provided here.

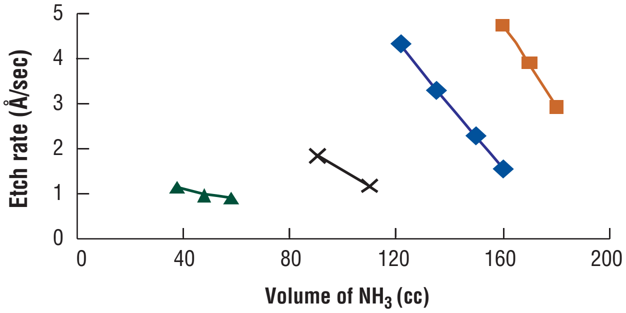

Figure 4. Etch rates obtained for different blended BOE solutions, with the lowest HF concentration on the left.

Figure 6 illustrates the new process flow taking advantage of the new integrated process sequence. The final integrated sequence of BOE etch → piranha strip → RCA clean was all conducted in the spray system with a cycle time of <50 min for 100 wafers. This reduced the overall cycle time by more than 40% when compared to the discrete method of processing, which is calculated assuming no delay in station-to-station transfer. In practical use, cycle time reductions could be even greater, and the process would also benefit from a reduction in the number of processing tools required.

Finally, device wafers split through the newly developed integrated sequence were compared for yield impact to the process of record (POR)

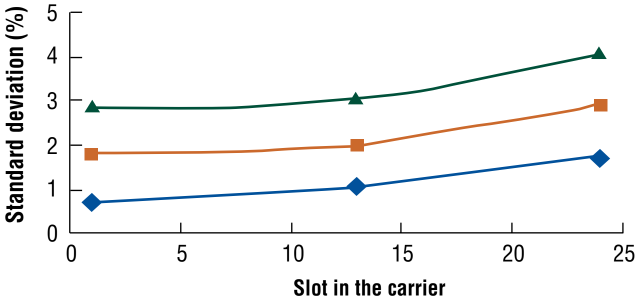

Figure 5. On-wafer nonuniformity for three different HF:H_2O mixtures, with test wafers in slots 1, 13, and 24. Lower concentrations at the bottom of the graph give the best results.

and the alternative method of double photo processing. As can be seen by the normalized data, only a modest improvement was observed using the double photo step, while a substantial increase in yield was found using the integrated process (Fig. 7).

Atmel attributes the yield improvement found with the new integrated process to the elimination of the residues found earlier. Although this process reflects a number of changes that could account for the yield improvement, the most significant is the elimination of the wet-etch-drying step. This drying step occurs when the silicon surface is especially sensitive to liquid-borne contamination that can be precipitated out during drying.

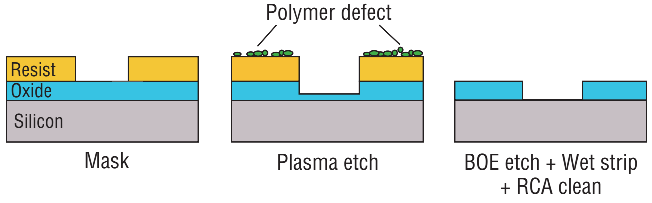

Figure 6. New process flow reflecting step consolidation.

The integrated processing method avoids this issue by transitioning from the wet-etch-rinsing step to the oxidizing step of a typical piranha resist strip, without drying. Once the surface is re-passivated by the piranha resist strip step, the wafer can then be dried without forming residue.

In addition to eliminating the residue, the flexibility of the spray tool cycle allowed the added benefit of completing the RCA clean in the same sequence. This resulted in the elimination of the ashing step and the associated queue times between wet-etch/ash/clean, leading to a more productive total solution.

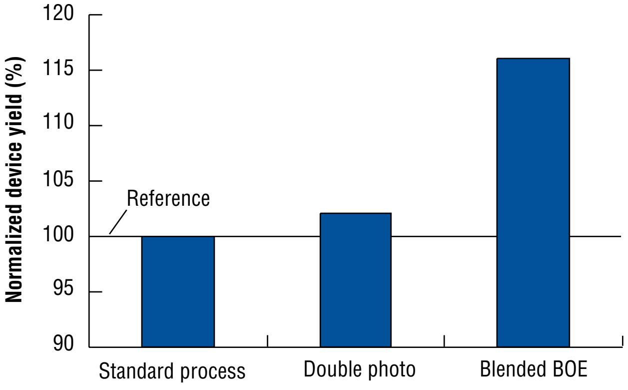

Figure 7. Yield (normalized) increase using blended BOE and the integrated centrifugal spray process.

Conclusion

An investigation that was begun to eliminate a common factory defect led to the implementation of a novel integrated centrifugal spray process. The integrated centrifugal spray process resolved the defect problem while reducing the processing steps. The step reduction obtained here multiplies its impact by reducing tool counts, footprint requirements, and operating costs through consumables. Also demonstrated was the flexibility of the blended BOE process that allows for multiple blend concentrations, and it also reduces cost by blending lower-cost chemicals. The integrated sequence including blended BOE allowed Atmel to increase the yield of its products. ■

Acknowledgments

The authors thank Jerry O'Dwyer and Christian Pizzetti of Metron Technology in Grenoble, France, and Dan Syverson of FSI International in Chaska, MN, for their contributions in developing and writing this article.

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