A New Approach to Tackle Wafer Contact Mark Contamination Issues in Marangoni Drying

Gim Chen, Dennis Nemeth and Ismail Kashkoush

NAURA Akrion Inc., 6330 Hedgewood Drive, #150, Allentown, PA 18106, USA

Contact mark contamination of Si wafers in Marangoni drying is related to water retention at the contact area between wafers and a process holder. The formation of water retention at wafer/holder contact is addressed with a conceptual model. A technical approach of capillary drainage is proposed to tackle the contact mark issue, along with experimental verification.

Introduction

In semiconductor manufacturing, silicon wafers (or other semiconductor materials) are normally treated with a series of wet chemical cleaning steps to prepare wafer surfaces for subsequent IC fabrication processes. Wafer drying is the last and most critical step, by rendering the product finished with a clean and dry surface, to make the wet wafer surface preparation processes effective. Among various wafer drying technologies, Marangoni drying is broadly employed nowadays due to its advantages in many aspects (1-5). As illustrated by figure 1a, the principle of Marangoni drying can be outlined as the following.

- Diffusion of IPA vapor into water through the gas/liquid interface
- IPA concentration at the meniscus geometry (Spot I) is greater than at the bulk surface (Spot II)
- Since IPA decreases surface tension, liquid surface tension at Spot I is lower than at Spot II
- Marangoni force from the surface tension gradient pulls liquid from Spot I to Spot II
- Slow withdrawal of the wafer out of water results in a dry and clean wafer surface

While the Marangoni process is effective in drying wafer surface well and clean, it has encountered a challenge at the contact area between the wafer and wafer-holder. To prevent the wafers from touching each other in wet processing and to facilitate the automation of wafer transfer in a wet bench, a wafer holder normally has saw-tooth like design to keep individual wafers in relatively fixed position. If the surface tension gradient generated by Marangoni effect does not fully overcome the capillary force existing at the tight geometry of the wafer/holder contact area, liquid can remain at this area and dries by evaporation, resulting in contact mark contamination issues, as shown by figure 1b and 1c. Since the inception of Marangoni drying, there is little discussion of wafer contact mark issues in the literature. NAURA Akrion has developed a Marangoni type of wafer dryers, LuCID™, to integrate with its GAMA™ wet station product line. In this paper, a new approach is proposed to tackle the contact mark problem and discussed along with experimental results.

Conceptual Model

The existence of capillary force has been attributed to intermolecular forces between the liquid and surrounding solid surfaces (6). These intermolecular forces are the combination of cohesive forces within the liquid and adhesive forces between the liquid and solid surfaces. The force becomes prominent as the distance of surrounding solid surfaces decreases. In this context, a Marangoni dryer tank may be imagined as a large cylindrical container with a drain valve at the bottom, while a wafer/comb contact with tight geometry may be deemed as a capillary tube with a much smaller diameter, as shown in figure 2a.

As outlined in figure 2b, a Marangoni drying cycle begins with water being slowly drained out of the large cylindrical container. When water surface passes the top opening of the slim tube, capillary force exerted in the tube slows down the water drainage inside the tube compared to the bulk water outside. Therefore, there is still liquid remaining in the small glass tube when the bulk water surface moves to the bottom of the tube. As the bulk water surface keeps moving lower, the surface tension of water can no longer hold the liquid continuity between the water inside the small tube and the bulk water outside. A “snapping” breakup of the liquid surface occurs, resulting in two separate liquid bodies. The water remaining in the tube ceases drainage and eventually dries by evaporation. During the process of water droplet drying on Si surfaces by evaporation, dissolved silicates precipitate and form water marks (7,8).

To prevent the water retention, we propose to introduce stronger capillary force by placing a bundle of glass tubes with even smaller diameters under the slim tube, as illustrated by figure 3. The equation of capillary force, *P*, in a simplified form based on a capillary tube, can be expressed as follows.

$$P = (2\gamma \cdot \cos\theta)/r \qquad [1]$$

where γ is surface tension of water in air, θ is contact angle of water on tube wall, and r is radius of the capillary tube. Equation [1] indicates that, without changing the gas/liquid/solid system, capillary force in a capillary tube can be increased with decreased tube radius. In the case of figure 3, the bundled tubes with much smaller radii should provide greater capillary force than the upper tube and thus keeps pulling the water out until the upper tube fully drains.

Experimental

To verify and implement the capillary drainage concept, a series of testing has been conducted in NAURA Akrion’s Applications Laboratory. Multiple medium materials were screened against a certain criterion such as contact angle, mechanical strength, chemical compatibility, structural integrity, and thermal stability. A few candidates in sheet forms were then prepared for water absorption testing. The candidate sheets were dissected to approximately 25mm × 100mm stripes and placed in an edge-on position. Using a pipette to drip water droplets on sample’s edge-on surface, a medium material that requires minimal time to fully absorb a droplet was selected for further investigation. Feasibility tests were performed to verify the drainage of water at a wafer/comb contact point. Using the selected medium to make a simple comb structure, a bare silicon wafer was vertically placed onto the comb. Water droplets were dripped onto the wafer/comb contact area to check the water absorption to verify the capillary drainage concept.

A proprietary comb assembly integrated with the capillary medium was designed and made. Batch wafer process experiments were conducted in the Apps Lab on a GAMA^{TM} wet station using a LuCID^{TM} dryer for wafer drying. The dryer was set to run a typical Marangoni process at fixed parameters, with the in-tank wafer holder as the only variable (i.e. the proprietary comb versus a regular comb). Various numbers of 200mm bare Si test wafers, sandwiched with clean dummy wafers as a full-load condition, were placed to a full pitch process carrier as a wafer batch. To ensure a consistent hydrophilic-state of Si surfaces prior to the drying process, each wafer batch was processed with an SC1/QDR/Dry instead of a Dryer Only recipe. Before and after a process run, test wafers were inspected with a KLA-Tencor SP1 at ≥100nm particle threshold with 2mm edge exclusion.

Results and Discussion

Figure 4a and 4b shows the droplet absorption tests of a capillary medium material on a flat edge-on surface and on a tight geometry of wafer/comb contact, respectively. It was observed that a ~0.05mL water droplet (i.e. ~4mm diameter globule) can be absorbed by the medium within 5 seconds, no matter if the medium is saturated with water or not. The observations have confirmed the feasibility of the capillary drainage concept.

The proprietary comb assembly was tested against a regular comb assembly with Marangoni drying for contact mark incidence. Wafer contact mark incidence was evaluated by overlapping the “pre” and “post” wafer map of each test wafer to identify the specific contact mark signature. Figure 5 shows the results by highlighting the contact mark incidence with respect to frequency and severity of contact mark events. The frequency presented by the X-axis indicates how many test wafers in a process batch show contact mark contamination, while the severity presented by the Y-axis indicates the extent of particle clustering in a contact mark. The results clearly indicate that the incidence of contact mark contamination is significantly reduced with the comb assembly using a capillary medium. Particle performance of the proprietary comb assembly was also evaluated. As shown by figure 6, particle addition inspected at ≥ 100nm with 2mm edge exclusion suggests that the dryer integrated with the capillary comb assembly is particle neutral (average particle addition = -2, with most of the total addition less than 20 particles per wafer).

Conclusion

Experiments were conducted to examine the wafer contact mark issue in a Marangoni drying process. The capillary effect holding liquid droplets at wafer/holder contact areas can be overcome by a drainage mechanism exerting stronger capillary forces. With the integration of a capillary comb assembly in the dryer tank for Marangoni process, wafer contact mark incidence is significantly reduced without the expense of particle performance.

References

1. D. C. Burkman, et. al., in *Handbook of Semiconductor Wafer Cleaning Technology*, W. Kern, Editor, p. 131, Noyes Publications, Westwood, NJ (1993).
2. G. W. Gale, et. al., in *Handbook of Silicon Wafer Cleaning Technology*, K. A. Reinhardt and W. Kern, Editors, p. 223, Elsevier Inc., Cambridge, MA (2018).
3. A. F. M. Leenaars, et. al., *Langmuir*, **6**(11), 1701, (1990).
4. K. Wolke, et. al., *Solid State Technology*, **39**(8), 87, (1996).
5. T. Vukosav, *R&D Magazine*, 7/16/2013. https://www.rdmag.com/article/2013/07/substrate-drying-using-surface-tension-gradient-technology
6. J. C. Maxwell and J. W. Strutt, in *Encyclopedia Britannica/11th Edition*, H. Chisholm, Editor, **5**, p. 256, Cambridge University Press, United Kingdom (1911).
7. Y. Cotkis and L. Kondic, presentation in *5th International Surface Cleaning Workshop*, Nov. 13-14, Boston, MA (2007).
8. G. Chen and I. Kashkoush, *Solid State Phenomena*, **134**, 15 (2008).

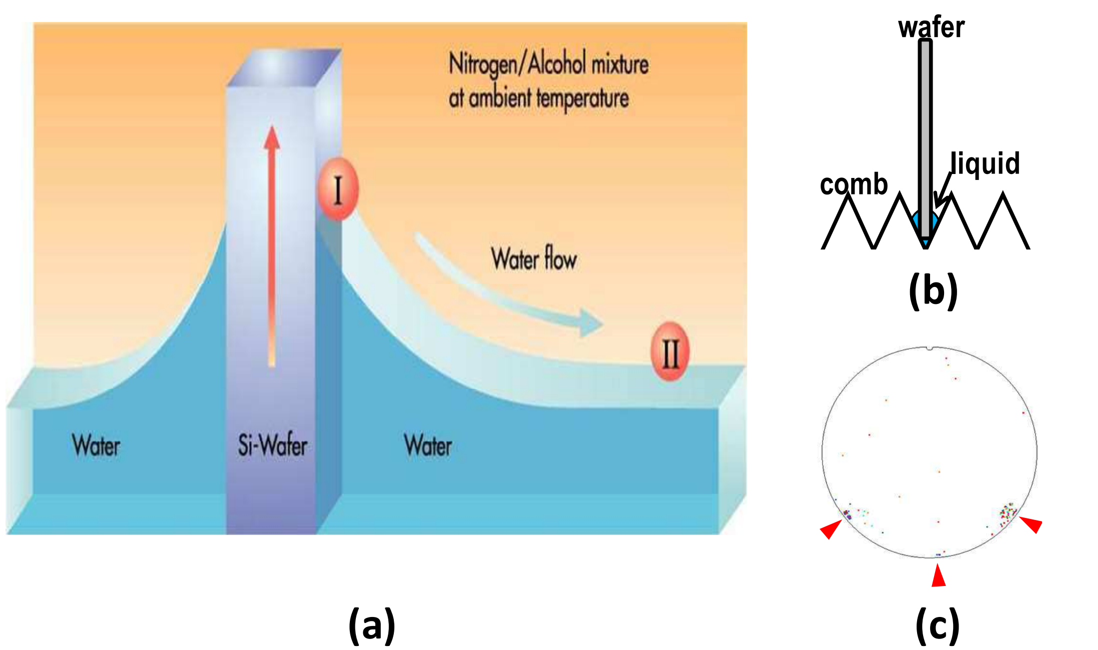

Figure 1. Marangoni wafer drying process is schematically illustrated in (a), likely inducing wafer contact mark contamination which is related to liquid retention at the wafer/holder contact area (b) and revealed by a wafer particle map (c).

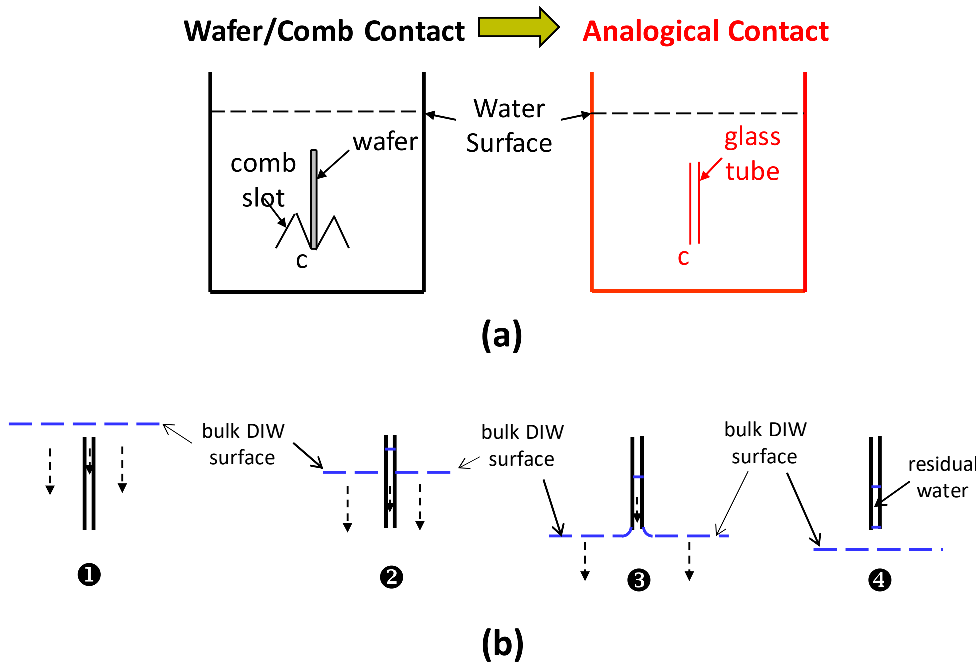

Figure 2. Schematic illustrations are used to interpret the analogy of a wafer/holder contact area (a), and how water retention at a contact area occurs in Marangoni drying (b).

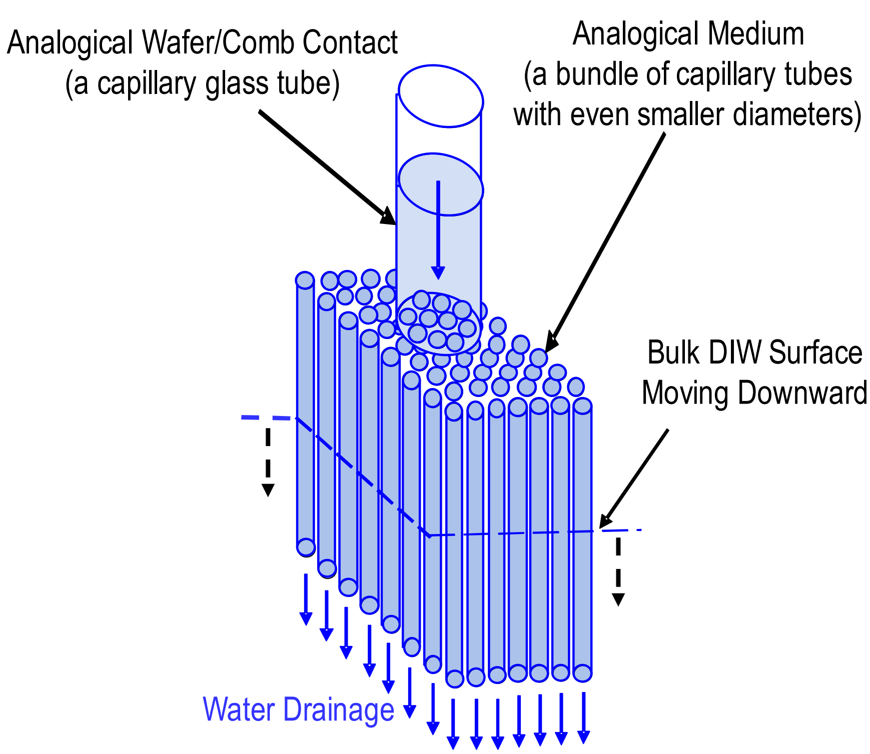

Figure 3. Conceptual modeling of a technical approach for eliminating water retention at the wafer/holder contact area.

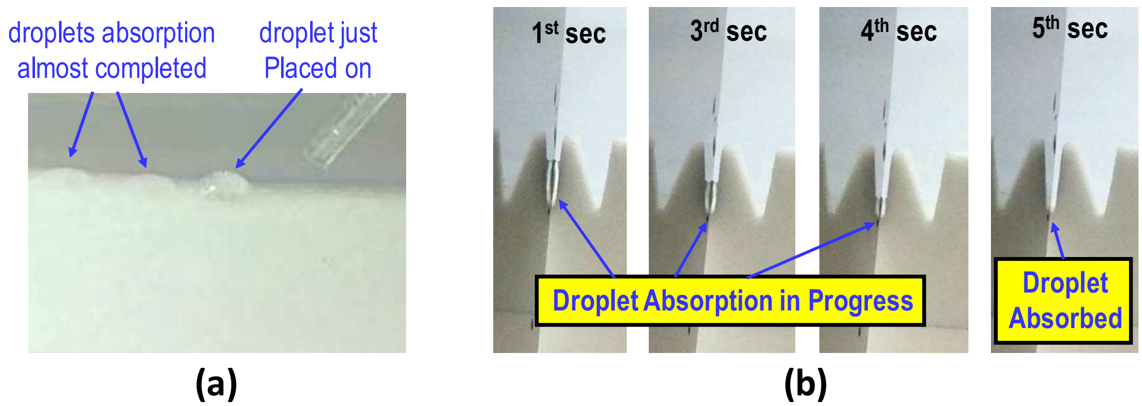

Figure 4. Water droplet absorption testing is performed on a capillary medium with a strip sample in edge-on position (a), and a Si wafer at the wafer/comb contact (b).

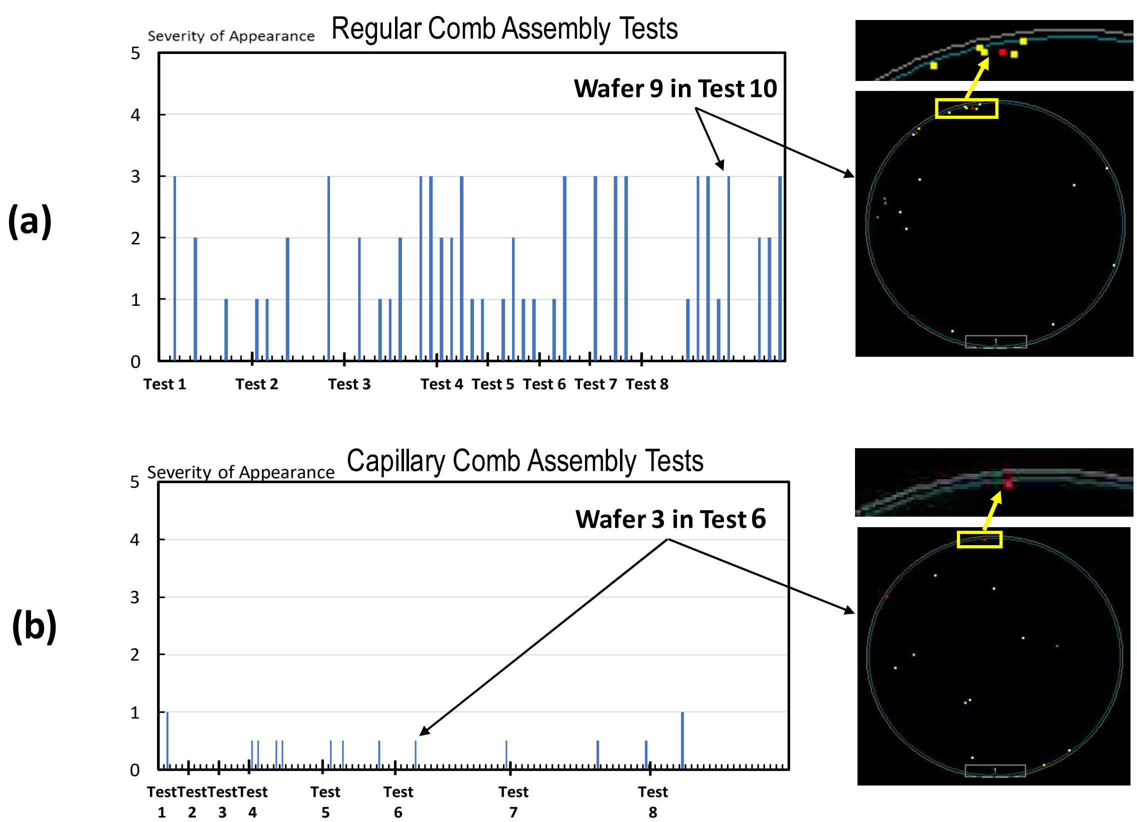

Figure 5. Comparison of contact mark incidence between the use of a regular comb assembly (a) and a capillary comb assembly (b) in a LuCID™ dryer. The severity of appearance (Y axis) is rated against particle number in a contact mark; i.e. 0.5 (one particle), 1 (two particles), 2 (3-5 particles), 3 (> 5 particles).

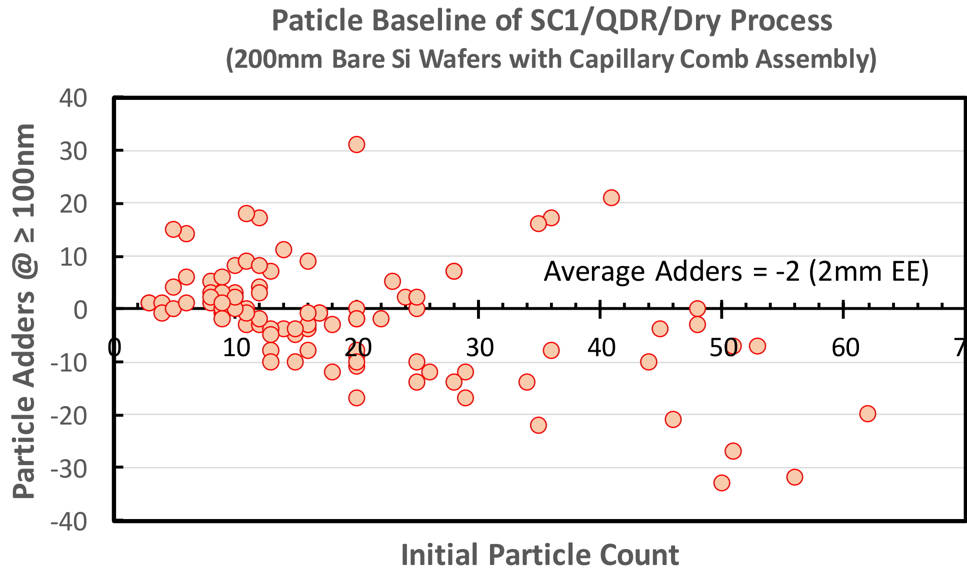

Figure 6. Particle performance of a Marangoni dryer using a capillary comb assembly.