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DEVELOPMENT OF MEGASONIC CLEANING FOR SILICON WAFERS

Quarterly Report No. 2

By
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October 1, 1979

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SECTION I

ABSTRACT

The Megasonic cleaning system was integrated and debugged. The system consists of the Megasonic cleaning sink, a rinse station, an air dryer, and an inspection station equipped with a laser scanner for the detection of light-scattering centers on a wafer. The recirculation-filtration system is operating satisfactorily. The preliminary data on wafer cleaning and rinsing indicate that the design criteria of cleaning ability, chemicals usage, ease of operation, and safety have been largely met. Further work on production rate is needed.

The air dryer has been demonstrated to function. Its true throughput can be evaluated only when the belt drive has been installed. The long delivery time will cause some delay in moving the system to the RCA Mountaintop location for production evaluation.

SECTION II

TECHNICAL DISCUSSION

A. MEGASONIC CLEANING STATION

1. Megasonic Tank, Transducers, and Power Supplies

During this phase a number of problems cropped up, but none that are major: the belt drive sprocket required retapping, and one of the power supplies appears to overheat after about 1.5 hours' continuous operation. Fluorocarbon Company is cooperating with us to solve this problem, probably by providing extra vent holes. The 2.4-MHz piezoelectric material was made into a pick-up transducer but not fully evaluated as a power monitoring device. For the time being we assume that the power input is proportional to the output. All tests have been made with maximum power of 310-320 W per supply. Each supply drives two transducers, nominally 2.5 in. in diameter, equivalent to an input of about 5 W/cm^2 .

A belt speed of about 4.0 cm/min was used to evaluate background cleanliness, such as particles that may be picked up from the hood or the rinse or transfer through the dryer to the silicon-wafer laser scanner. With the present experimental platen and the 3/16-in.-spaced carriers this corresponds to about 700 wafers per hour (Fig. 1.).

It is expected that a considerable increase in rate can be obtained by optimizing platen width, increasing the belt speed, and possibly reducing the spacing in the carriers to 3/32 in.

2. Rinse Tank

The best indication that the rinse and drying systems are reasonably clean is deduced from the observation that the treated wafers show no streaks, either under diffuse illumination or under the laser scanner. The incoming specially filtered inhouse-deionized (DI) water has a resistivity at the generation site of $16 \text{ M}\Omega\cdot\text{cm}$ and, at the point-of-use, of over $8.5 \text{ M}\Omega\cdot\text{cm}$, a value judged adequate for device production. Although the introduction of

Figure 1. Comparison of megasonic cleaning and drying rates. Assumptions: Megasonic cleaning - three carriers/platen, each platen 23 cm long. Air dryer - 35.5 cm active drying length $\equiv$ 61 production wafers; 3/16-in.-spaced carriers, 24 wafers each, plus one control wafer; 14-cm-long carriers.

special point-of-use ion exchangers would make it possible to further increase the resistivity, this is thought to add an unnecessary cost burden because the main contaminant is likely to be carbon dioxide. The ultimate judgment will, of course, be based on solar-cell performance. Also, no particle count increase was noted when clean wafers were circulated through the system.

3. Recirculation System

The circulating pump has been fitted with an electric motor in place of the compressed-air motor, and operates well in the on-off mode. The preferred recirculation rate is about one tankful per hour. As the overflow plumbing has a rather small bore, it can return a flow of only about 0.2 L/min. The system was therefore replumbed so that the liquid now returns from the bottom of the tank to the storage vessel and is then pumped through the filter and delivered to the top of the Megasonic tank. The maximum pump rate is about 7.0 L/min. When the level drops to a predetermined position, a float with a magnet activates a reed switch. The pump then starts and delivers solution until the float activates the upper-limit switch (Fig. 2). The system is capable of 2.3 changes/hour. Although several solution changes and extra particle burdens imposed by the various debugging operations must have added much more than the usual operations burden to this system, no problem has

Figure 2. Cleaning solution recirculation system.

been experienced in its operation. Also, the 0.2- μ m filter continues to function; one indication for this is the relatively slow decomposition of the peroxide.

4. Standard Clean Solution (SC-1)

Our experience over many years has taught us that the composition of SC-1 may vary considerably without impairing its ability to clean. The usual composition range is 4-5 parts of water to 1 part of 30% hydrogen peroxide solution and 1 part of (29.7% nominal) ammonium hydroxide solution. Actual analyses of the starting SC-1 solution in the Megasonic system averaged 27.9 g/L of ammonia and 36.9 g/L of hydrogen peroxide.

Analytical data on the solution, even without Megasonic power use, make it clear that the ammonia volatilizes relatively quickly over the first 20 hours to about half the initial concentration, then more slowly to about 10 g/L in a little over 80 hours. If these data are confirmed with power "on" over prolonged periods, it will be more economic to lower the starting concentration of ammonia and install means to maintain it at some preferred level, say between 15 and 10 g/L, by the addition of anhydrous ammonia gas. Under mass production conditions, the loss of liquid due to drag-out may be sufficient to maintain an ammonia level of that concentration range by the addition of concentrated ammonia solution.

The function of the hydrogen peroxide is to maintain a redox potential high enough to oxidize the thin organic surface films usually acquired on solar-cell wafers during handling and storage, and to prevent the attack of ammonia on silicon. In the absence of peroxide, silicon is pitted rapidly and unpredictably by ammonia; even small concentrations of peroxide, however, on the order of 5 g/L, are sufficient to inhibit this effect. When the hydrogen peroxide solution is allowed to stand in the system without circulation and in the absence of power, it drops to the 10 g/L level in about 60 hours.

A test was run with power on continuously for six hours; in that time the concentration of peroxide dropped to 35 g/L. With power on for 7.5 out of

24 hours, the peroxide dropped to 22 g/L and the ammonia to 17 g/L. There is therefore, a good possibility that the chemicals savings originally postulated will be achievable.

B. AIR DRYING SYSTEM

1. System

During the second half of this quarter the major effort was devoted to determining design parameters for the tunnel and conveyor system that connects the Megasonic system, via the dryer, to the silicon laser scanner, i.e. the inspection station.

The tunnel has been fabricated and fitted to the dryer. Because the latter had to be shortened, the opening became longer (35.5 cm) and wider. Panels of polypropylene were fitted to the side; these can be adjusted to fit all the different carriers being tested. Figure 3 shows the present arrangement.

2. Tunnel and Conveyor

At present the carriers are being pushed through the tunnel manually. Tests showed that it is necessary to provide panels on the side of the quartz carriers to channel the air over the wafers. This result and the different geometries of plastic and quartz carriers led to the design of the conveyor shown in Figs. 4 and 5. The order for this has been placed with Fluorocarbon Company for delivery in 10 weeks, completing the design and ordering phase for this contract.

3. Experimental Work

Drying tests were carried out in standard, straight-sided polytetrafluoroethylene (PTFE) carriers with 3/16-in. spacing. The grooves are 0.06 in. wide at the tip and have a taper of approximately 20°. Best drying time observed was 3.5 minutes. With properly cleaned, hydrophilic wafers, the center area dries first, then come the edges in the carrier grooves, and the last to dry are two small drops on either side of the support rod.

Figure 3. Drying-tunnel arrangement.

Figure 4. Top view of conveyor (concept).

Figure 5. Cross section of conveyor (concept).

As can be seen from the graph in Fig. 1., with the present geometry this drying time corresponds to about 1200 wafers per hour. Thus, to achieve the target rate of 2500 wafers per hour it will be necessary to either increase the number of wafers per unit length or double the effective path. Carriers with 3/32-in. spacing are on order to test the first possibility. Adding another dryer module is probably a good solution too because this part of the system is relatively inexpensive, costing on the order of only 15% more, and provides extra flexibility. The effect of ambient air relative humidity (rh) and temperature is an unknown. We have recently installed a temperature-rh recorder and will make observations regarding these variables.

The drying tests showed clearly that some induced wafer motion was necessary to displace the water in the grooves, especially when wafers leaned toward each other. A simple solution was to insert a roof-shaped deflector into the mouth of the dryer duct so that the air in front is deflected in one direction, and the air on the back surface in the other direction. This also serves to ensure that the gaps between wafers are kept constant.

C. WAFER CARRIERS

1. Quartz Carriers

To accommodate the plastic as well as the quartz carriers on the same basic belt mechanism it was necessary to modify the design of the quartz carrier slightly by adding a support on each of the four corners. This is shown in Fig. 6.

The first four carriers received had the 3/16-in. spacing. When these were first tried out, drying times of over 5 minutes were required. The main problem is the narrowness of the grooves. The carriers received had grooves only 0.016 in. wide at the tip, resulting in capillary trapping of liquid. An attempt to etch them out showed that they etched very slowly near the tip, widening to 0.018 in. in 40 minutes in concentrated hydrofluoric acid. An attempt will be made to change the groove design of the 3/32-in.-spaced carriers.

Figure 6. Quartz wafer carrier.

It is interesting to note that the entire wafer surface dried rapidly, including the area near the support rod.

2. Polysulfone Carriers

An order was placed to have three carriers machined from solid stock. These were due for delivery in mid-September.

3. PTFE Carriers

Straight-sided 25-wafer carriers made by Emerson Plastronics, Bronx, NY, with 3/16-in. spacing and grooves that are 0.06 in. wide at the tip, have been used for most of the initial experimental work. As described above (see Section II.B.3), drying times of 3.5 minutes were achieved, and the main difficulty was posed by two liquid drops on either side of the support rod.

The drying experiments have shown that the design of the carrier is critically important and that the parameters to be related are the hydrophilic/hydrophobic character of the carrier material with the capillarity due to the wafer-groove spacing.

Although only a small number of tests has been made, it appears that the straight-grooved carrier design does not impede Megasonic cleaning ability.

D. SILICON-WAFER LASER SCANNER

The instrument is performing well. Routine operating instructions have been devised. At the expense of not obtaining accurate counts above 3000, the sensitivity of the scanner can be set permanently. The operation then consists of loading the wafer onto the chuck and taking the scan, viewing the distribution of scattered-light sites on the storage oscilloscope, and recording the digital count. The whole operation takes about 40-45 seconds and is thus suitable for control purposes.

Preliminary studies, with the aid of dark-field microscopy at a magnification of 100X and inspection under collimated bright light, indicate that the number of scattering sites recorded by the scanner is greater than any

observed by the other methods. The best of the polished, carefully cleaned wafers have shown counts of 0 to 5, normal production wafers run between 25 and 250, and the experimentally contaminated wafers that had been dipped in a slurry of 2.5 g of 0.3- μ m-diam alumina per liter of water have counts far in excess of 25,000.

The ridges left on sawed-etched wafers used for the large-scale solar-cell array act as scattering centers and, due to the presence of particles, totally obscure scatter sites. It therefore becomes necessary to use a polished control wafer to evaluate Megasonic cleaning. Although the production rate is reduced by this arrangement, it is no different from the rate that obtains when product wafers are checked, because these would have to be cleaned after scanning anyway. At present we are checking 4% of the wafers. Eventually, in production it is probable that this number can be substantially reduced, based on experience and on the assumption that the reliability of the Megasonic system is high. With a little experience it is possible to diagnose the nature of a problem from the shape and distribution of scatter sites. Scratches and tweezer marks are obvious, as are crystal defects like slip. Rinse water problems show up as streaks, and drying problems as water spots on the edges. Figure 7 illustrates some of these aspects.

E. MEGASONIC CLEANING ABILITY

The purpose of this work is to determine the factors controlling the rate of cleaning Megasonically. So far, the major effort has been devoted to integrating the various parts of the system and to debugging it. Only preliminary data that bear on cleaning rate are as yet available. All tests have been made with the 3/16-in.-spaced PTFE carriers, and with one power supply for each pair of transducers. Both pairs were run at maximum power, equal to an input of 310-320 W.

The belt speed was varied from 4 to 14.5 cm/min. The wafers were polished on one side and deep etched on the other. Standard 0.015-in.-thick wafers were more readily available than 0.009-in.- to 0.011-in.-thick solar-

(a)

(b)

Figure 7. Silicon wafer (3 in.); typical scatter-point count = 100.

cell wafers and were used most of the time. The only difference this might make is in a need for a longer drying time as a result of smaller groove clearances.

The standard tests consist of using an aqueous slurry of 2.5 g/L of 0.3- μ m-diam alumina, followed by rinsing in deionized (DI) water, to clean fingerprinted wafers and deliberately contaminated wafers. Fingerprints are removed even at the fastest belt speed tested (14.5 cm/min). In preliminary tests at this speed, the deliberately contaminated wafers, with particle counts of over 25,000, could be cleaned to less than 300 counts. At 4 cm/min the average count was reduced to about 150. The major residual contamination appears to be within about 6 mm from the edge.

The plan is to examine the relationship between system geometry, exposure time, and power input.

SECTION III

PROBLEMS

1. Due to the long delivery time for the belt drive that will move the carriers from the Megasonic station under the dryer into the inspection station, the transfer of the system to Mountaintop may have to be delayed for 6-8 weeks.
2. The breakdown of the ion-implanter at Somerville has resulted in a serious backlog and delay in the production of solar-cell structures. This has held up the tests bearing on the conversion efficiency of cells cleaned by Megasonic power by about four weeks.

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

1. Feasibility of continuously cleaning solar-cell silicon wafers Megasonically has been demonstrated. The basic design of the station is satisfactory.
2. The air drying system was shown to be effective.
3. The laser scanner is an excellent tool for providing feedback and control over the cleaning system.
4. While the present rate of cleaning by use of 3/16-in.-spaced carriers does not meet the design objective, it can be increased by better platen design, closer spacing of wafers in the carriers, and faster belt speeds. It remains to be determined whether extra power or another pair of transducers is required to increase the rate to 2500/hour.
5. The drying rate with the present equipment is likely to be on the order of 1500 wafers/hour. If that is so, the recommendation will be to increase the active dryer length proportionally to the rate requirement.
6. The recirculation and filtration system is functioning as designed. The first indications are that the chemicals can be preserved in an active state for a considerable amount of time, and will probably meet the design objectives.

It is recommended to continue the program as planned but to delay the move to Mountaintop until after delivery of the belt drive and sufficient time to ensure that it functions properly.