ADVANCED PROCESS CONTROL OF CHEMICAL CONCENTRATION FOR SOLAR CELL MANUFACTURING

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ABSTRACT: Solar cell manufacturing requires many wet cleaning steps. One of these steps is texturization. As a method for light trapping, the texturization step is very critical for high cell efficiency for cells based on both mono-crystalline and multi-crystalline silicon. In order to obtain stable and reproducible manufacturing processes, a reliable and accurate real-time measurement of the etching constituents becomes necessary. Chemical mixtures include: KOH/IPA, HF/HNO_3, HF/HCl. Other additives, e.g. surfactants are typically added to enhance the etch uniformity.

KEYWORDS: Manufacturing and Processing, Texturization, Cost reduction

1 INTRODUCTION

The continuously increasing integration of today's most advanced solar cells requires increasingly tight process control of the cell fabrication. The silicon etching and cleaning in wafer processing are standard steps for process engineers. Although numerous studies have been performed to analyze the mechanisms and kinetics of these processes, little attention, if any, has been given to monitoring and controlling the chemical concentrations in the process baths [1-4]. Chemical concentration control is becoming crucial to wafer processing in order to obtain consistency, low cost of ownership, and more environmentally sound processes [5].

For years, wet wafer processing has adopted the use of high concentration chemicals at elevated temperatures and long process times. For example, the KOH/IPA step is designed to texturize the wafers as a way to enhance the light trapping on mono-crystalline silicon. Chemicals are typically used at ranges from 1-5% and at a temperature of about 85°C for a process time of 20-30 minutes. Similarly, HF/HNO_3 is used to texturize multicrystalline silicon but at ambient or sub-ambient temperatures and shorter process times. However, a major shortcoming is that these etching solutions are typically replaced after short periods of time (4-8 hours) in order to obtain any degree of process uniformity.

Conductivity cells provide fast, cost-effective, and real-time chemical concentration control. However, they are best used in a single component system, e.g. HF/water, or KOH/water. Analytical methods available today for continuous monitoring of wet process solutions include NIR spectroscopy [1], Raman spectroscopy, [5], UV absorption spectroscopy, and a variety of electrochemical techniques, [6-8]. A major drawback of instruments based on these procedures is that they are used only on a "stand alone" basis. Compact instrumentation and full integration of these techniques into the process baths have had limited success.

The integration of these sensors into process baths has proven to be easy. In this paper, we demonstrate the use of "flow-through" NIR sensors for simultaneously monitoring and controlling the concentration of multi-component solutions. Results indicate that better process control can be obtained thus extending the bath life. Experiments also indicate that this technique can be used to control both concentrated and dilute chemical process solutions.

2 EXPERIMENTAL

Wet chemical processes were conducted on a fully-automated GAMA™ wafer etching and cleaning station. Silicon etching processes were conducted with the aid of Akrion Systems' patented in-situ chemical concentration control system (ICE-1™). Measurements of concentrations were taken using inline NIR (near Infra-Red) sensors located in the recirculation loop of the process tanks. These sensors measure light absorbance and transmit it through fiber optics to an array of detectors (spectrophotometer). The system basic set up is illustrated schematically in figure 1.

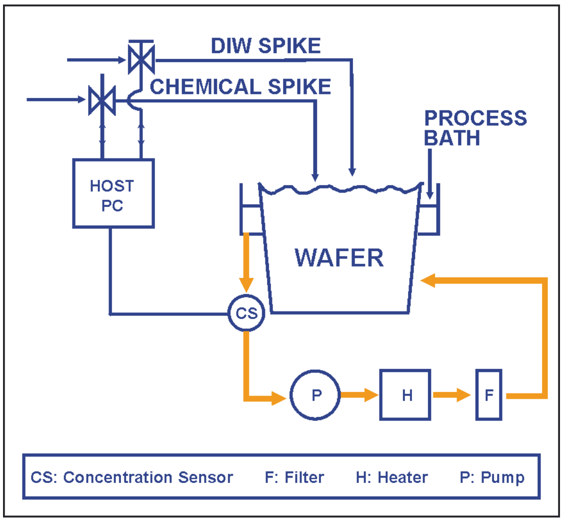

Figure 1: Basic setup of system

The light absorbance of a given specie of the solution is correlated to its concentration over a wide range of wave lengths. The signal is then reported to an amplifier that scales the response to a 4-20 mA output. This signal is subsequently fed into an analog module that scales the signal and reports directly to the system computer which controls the spiking (volumes and frequency) of chemicals to maintain concentration. A variety of chemicals e.g. HF, HNO_3, HAc and applications were also studied but only the results of KOH/IPA control will be presented here. Good correlation between measured versus predicted values for both KOH and IPA can be seen in figure 2 a and b. The concentration of chemicals in the process bath is detrimental to ensuring consistent wafer surface characteristics. As shown in figure 3, the KOH concentration can drastically change the texturization pattern if left uncontrolled. The goal was to produce consistent texturization patterns similar to those shown in figure 4 over the entire bath life.

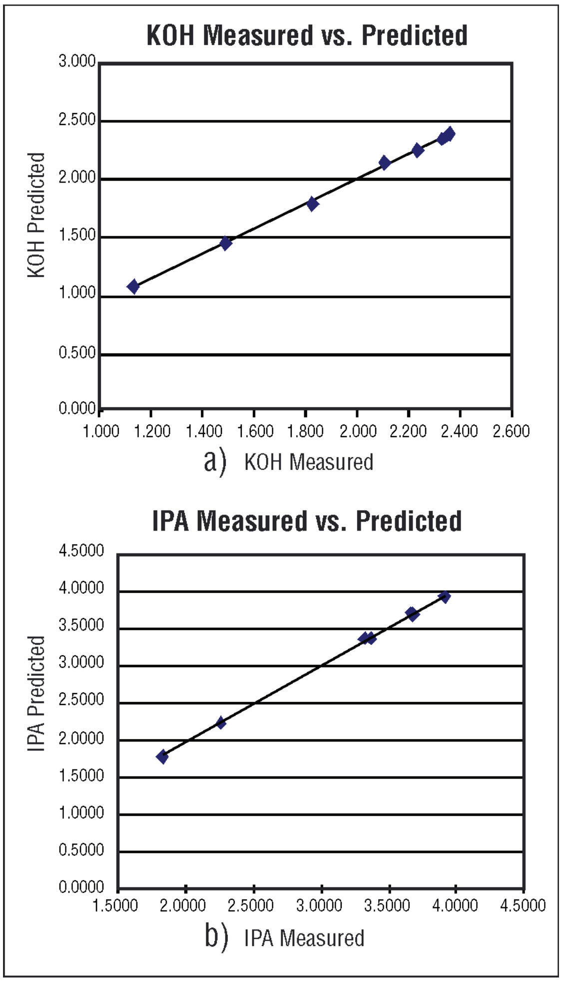

Figure 2 a) and b): Calibration curves for KOH and IPA.

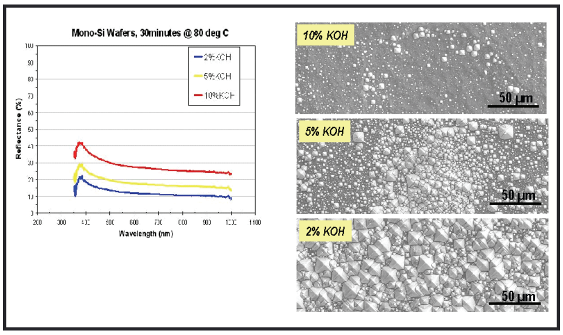

Figure 3: Texturization pattern at different KOH concentrations for a given IPA concentration.

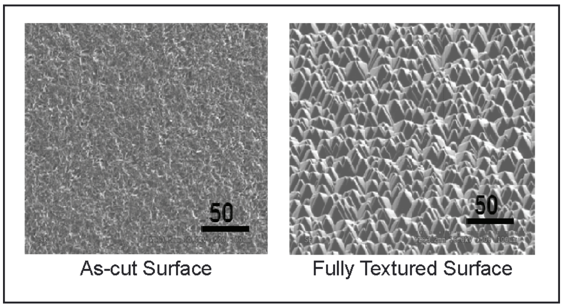

Figure 4: A sample of surface texturization at **2% wt. KOH and 4% wt. IPA** at 85°C

3 RESULTS AND DISCUSSION

This technology provides technical advantages by accurately measuring the concentration of chemicals to produce the desired process results, in this case the texturization pattern. Controlling concentration for uniform, repeatable texturization will help solar cell manufacturers reduce cost of ownership (COO) and overall cost of manufacturing by extending the usable life of the chemical bath. The technology will thus extend the up-time and overall utilization of the tool and hence lower cost of manufacturing.

Figure 5 shows that the system accurately tracks the concentration of KOH, IPA, and water over a long beriod of time. Figure 6 graphs the number of wafers processed (as measured by the amount of Si deposited in the process bath in grams). Figure 6 also shows the amount of KOH that's required to maintain a stable etch rate over time.

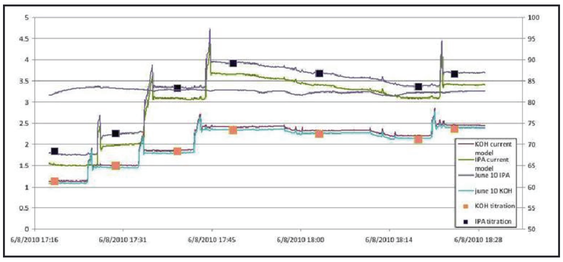

Figure 5: Measured and predicted concentrations of KOH and IPA.

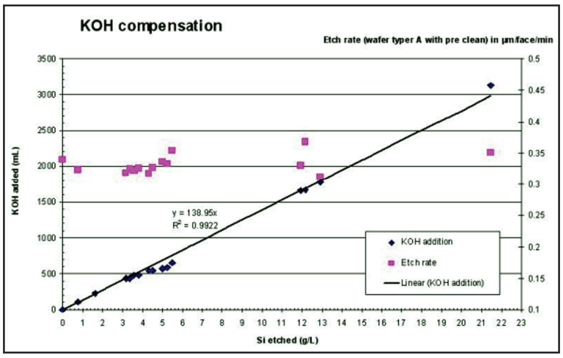

Figure 6: Volumes of KOH required to maintain a stable etch rate (ER) of Si.

As can be seen from figure 6, the volume of KOH required to maintain a constant ER is linearly related to the mass of Si etched which is predicted. The system is also calibrated to track the etch byproducts (measured as Si) as shown in figure 7. The spike signals for KOH, IPA and water are shown in real-time while wafers were processed as well as when no wafers were processed. The Si concentration is increasing while wafers were being etched while it remains constant when in the bath is left at stand-by

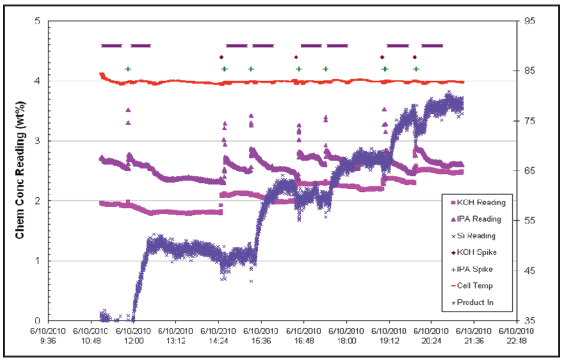

Figure 7: Concentration of KOH, IPA and Si under Real Time Processing.

With such high throughput tools, the etch-byproducts noticeably and steadily rise in the process bath. This rise of Si content will suppress the etch once the bath is saturated. For the system used here, a level of 40 gm/l can be attained after running about 4000 wafers in the case of no feed and bleed as shown linearly in the graph. Results have shown that the dissolved Si in the bath must be maintained below a threshold limit (e.g. 30 gm/l). Akrion Systems has implemented an algorithm to control Si concentration in the bath as well, so the etch rate is maintained. This algorithm allows the capability to spike known volumes of fresh chemicals and drain out old chemicals. Once the Si concentration reaches its upper limit, the system begins the feed and bleed process to maintain the desired Si values. If the system starts the feed and bleed from the beginning of the bath, the Si content will slowly rise until it eventually reaches the threshold and remains at or below the threshold. The system is simulated at a rate of 5% volume as shown in figure 8.

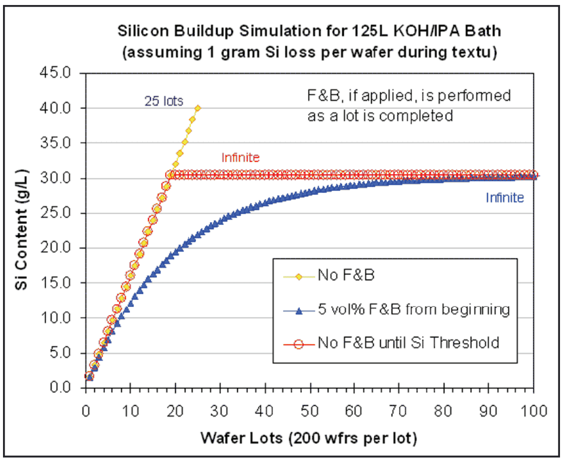

Figure 8: Design setpoint for the feed/bleed control.

Depending on the operating volume of the tank and amount of silicon etched, the user can design a setpoint for the feed and bleed volumes so that the Si content in the bath is maintained. The system now enables us to maintain the concentration of chemicals as well as the etch byproducts. As a result, consistent wafer processing, longer utilization of the bath, and lower cost of ownership is attained. Additional results are graphed in figure 9. The concentration profiles of KOH, IPA, and Si under real-time texturization conditions are shown to be steady (within the desired tolerances). For this dynamic bath, the silicon etch rate and reflectance are also shown to be within their target values of 6 and 9.8 a.u., respectively.

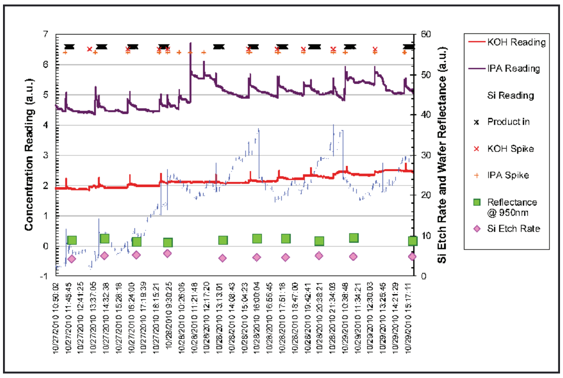

Figure 9: ICE operation under real time Si texturization process (Si content < 30 a.u.).

Similar performance is shown in figure 10 under different operating conditions where the Si content was maintained in a window of 20-40 a.u. However, the etch rate and reflectance were maintained steadily for the life of the bath of almost 5 days at 5 and 9.85 a.u., respectively.

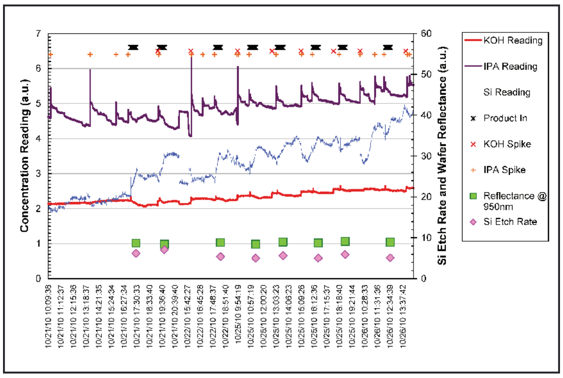

Figure 10: ICE operation under real time Si texturization process (Si content < 40 a.u.).

4 CONCLUSIONS

Today's environmental pressures mandate the reduction of chemicals used in solar manufacturing lines. In addition, most advanced solar cells require increasingly tight process control of the cell fabrication including wet etch and cleaning steps. Results show that real-time chemical concentration monitoring and control is critical and beneficial for advanced solar cell manufacturing. The technology reduces the days required for field installation by eliminating the time and resources required to dial-in the right chemicals' concentrations. With closed loop concentration control, this process no longer requires many iterations and tedious work until the results are achieved. The technology significantly reduces rework and wafer miss-processing and results in robust and less costly manufacturing.

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