

# MONITORING OF Fe CONTAMINATION ON Si SURFACES USING NON-CONTACT SURFACE CHARGE PROFILER

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The SCP (Surface Charge Profiler) method is used to monitor the surface Fe concentration on p and n-type Si surfaces following immersion in DI water, SC1 and HF:H<sub>2</sub>O baths spiked with various levels of Fe. The system used provides immediate, non-contact measurements of both the surface charge and surface recombination lifetime. Wafers are also analyzed using TXRF (Total reflection X-Ray Fluorescence). It is observed that the surface charge and surface recombination lifetime are responding to the Fe concentrations in solution of less than 0.5 ppb.

## INTRODUCTION

Metal contamination on silicon wafers is a major concern in microelectronic manufacturing. Among many metals that can be found in the IC manufacturing environment, iron is the most common impurity. The adverse effect of iron is multifaceted, but most notably iron degrades gate oxide integrity (1,2) and produces charges in the gate oxide (3), as well as degrades the bulk minority carrier lifetimes (4).

It is well known that iron can be added to the silicon surface during wet cleaning operations. Potential sources of Fe contamination during wafer cleaning include chemicals, the DI water and the chemical distribution systems. The detection of iron contamination at this stage is critical for the prevention of further processing of contaminated wafers. Therefore, a method is required that would allow immediate, non-invasive, in-line monitoring of Fe contamination on the bare Si surface following wafer cleaning operations. In this work, a commercial Surface Charge Profiler (5) is evaluated as a tool to monitor the level of Fe contamination on p and n-type wafers following immersion in DI water, SC1 solution and HF:H<sub>2</sub>O bath spiked with various levels of Fe.

## EXPERIMENTAL

The SCP method used in this study is based on the generation of the ac Surface Photovoltage (SPV) by illumination of the silicon surface with a beam of chopped low intensity light, having a photon energy higher than the silicon bandgap (6). The value of the SPV is related to the density of electric charge accumulated on the illuminated surface. From the magnitude of this signal, the system determines the depletion width and hence, the surface charge. Because low intensity illumination is used in this method, the perturbation of the surface potential barrier during measurement is kept well below room temperature thermal energy, and hence, the surface charge measurement in this case is non-invasive. A schematic diagram of the measurement setup is shown in Fig. 1.

Both p-type (CZ, <100>, 6-9  $\Omega\text{cm}$ , 100 mm diameter) and n-type (CZ, <100>, 1.32-1.98  $\Omega\text{cm}$ , 100 mm diameter) silicon wafers were used in this study. Using a commercial cleaning bench, three different solutions were used to add Fe to the wafer surfaces: SC1 (0.2:1:5, 60°C), DI H<sub>2</sub>O (45°C) and HF(1):H<sub>2</sub>O(100) (25°C). Wafers were dipped in baths that had been spiked with varying amounts of an ICP-MS standard Fe solution to vary the Fe concentration. The Fe concentration in solution was varied from 0 to 30 ppb. Depositions were carried out with a dipping time of 7 min and a DI water rinse time of 2 min, followed by air drying. Immediately after drying, SCP measurements were taken and then wafers were subjected to TXRF analysis.

## RESULTS AND DISCUSSION

### Iron Contamination from SC1

First, the deposition behavior of Fe in SC1 solution was determined. It was found to be similar to that reported in the literature (Fig. 2). A large deposition is observed, which increases linearly with Fe concentration in solution (except at high concentrations where it saturates). In this solution, the dominant Fe specie is Fe(OH)<sub>3</sub>, which has a very low solubility limit. Therefore, the Fe precipitates and can deposit at the surface of the substrates due to the effect of van der Waals forces by physical adsorption (7).

The surface charge on the p-type wafers before adding Fe to solution is positive and decreases with increasing Fe concentration in solution (Fig. 3). Significant decrease in charge is observed for very low Fe concentrations below 0.5 ppb. In SC1 solution, the silicon surface is covered with an oxide. The iron at the surface is in oxidation level III. The iron III is easily incorporated in the native oxide (8) in which Silicon is in oxidation level IV. The decrease in charge is explained by hypothesizing that the Fe<sup>3+</sup> ion is exchanged with Si<sup>4+</sup> in the native oxide, resulting in a negative charge (3). Increased concentration of Fe on the surface adds negative charge which is responsible for the gradual decrease of the overall charge density (Fig. 3). The charge on the n-type wafer shows relatively little change with Fe concentration in solution. This is due to the fact

that the n-type wafer surface is near accumulation under these conditions, regardless of the surface iron concentration, and the surface charge is near the detection limit of the measurement.

It should be noted that, using the SCP method, the detection of Fe on the silicon surface following SC1 immersion and the rinse/dry process takes place without additional heat treatment aimed at driving Fe into the silicon.

### Iron contamination from H<sub>2</sub>O

In the second part of this study, the SCP system was used to detect Fe deposited on Si surfaces in DI H<sub>2</sub>O spiked with iron. The deposition characteristics were found to be in general similar to those obtained in SC1 solution (Fig. 4). The slight difference between water and SC1 is explained by the difference in ionic strength of these two mixtures. Iron III (Fe<sup>3+</sup>) precipitates in these media. At first, the precipitated molecules are isolated and neutral, and so can deposit on the silicon surface, which in solution remains negatively charged. But they can flocculate and give negatively charged particles in both of these mixtures (7). Therefore, there is electrostatic repulsion between the particles and substrate. The deposition is higher in SC1 where ionic strength is large, decreasing this electrostatic repulsion.

The surface charge results are also similar to those obtained in SC1 (Fig 5). As in the SC1, the surface charge on the p-type wafer is initially positive and decreases with increasing Fe concentration in solution. Again, the silicon surface is covered with an oxide and this added negative charge is due to deposited Iron III, Fe<sup>3+</sup> which is exchanged with Si<sup>4+</sup> in the native oxide. The charge on the n-type wafer shows more pronounced change with Fe concentration in solution because of the initially less negative surface charge in the case of DI H<sub>2</sub>O immersion.

### Iron contamination from HF:H<sub>2</sub>O 1:100

For p-type Si immersed in the HF:H<sub>2</sub>O mixture, only two Fe concentrations in solution were studied (0 and 30 ppb). No Fe deposition was detected at these concentrations. In this mixture, the silicon surface is passivated by Si-H functions which are only slightly reactive except electrochemically (7). Iron is reduced to oxidation level II, but does not deposit as it is stable in Fe<sup>2+</sup> form which does not precipitate in HF in the studied concentration range.

The surface charge on the p-type wafer has a large positive value and, in agreement with the above observation, remains independent of the Fe concentration in solution (Fig. 6). This result validates results presented above, and further confirms the reliability of the SCP method in the detection of very small amounts of Fe added to the Si surface in cleaning solutions.

## SUMMARY

The detection of iron on the Si surface using the Surface Charge Profiler was investigated. The surface charge on the p-type wafers following immersion responds to the very small Fe concentrations in solution (<0.5 ppb) for both SC1 and water. The surface charge remains unchanged by Fe added to solution in HF where no Fe deposition takes place. Therefore, the SCP method can be used effectively for the monitoring of Fe contamination on the Si surfaces inflicted during wet cleaning operations. Due to the features of the SCP method, the monitoring can be carried out in-line on the product wafers. The Fe detection capability of the SCP method at lower surface iron concentrations remains to be determined.

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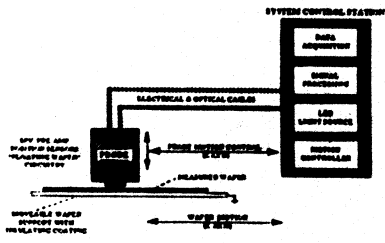


Figure 1 Schematic diagram of the SCP system

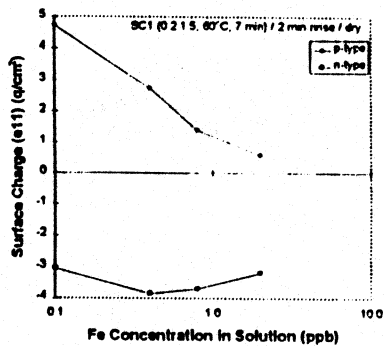


Figure 3 Surface charge vs Fe concentration in SC1 solution for p and n-type Si

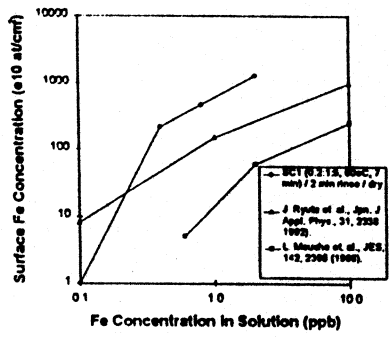


Figure 2 Surface Fe concentration vs Fe concentration in SC1 solution

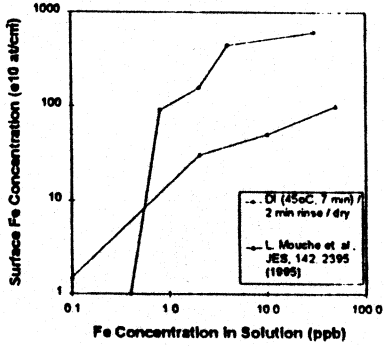


Figure 4 Surface Fe concentration vs Fe concentration in DI water

