Characterization of Oxidation Induced Substrate Loss

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Abstract

Post implant resist strip for sub-65 nm high-dose implant (HDI) poses challenges with regard to Si substrate loss due to oxidation. In order to ensure the desired device characteristics, this loss must be kept to a minimum, typically less than 4Å loss per strip/wet clean cycle. Conventional metrology techniques such as Ellipsometry, XPS and EOT (effective oxide thickness measurements using capacitance) have difficulty in measuring substrate loss as they make a measurement of native oxide thickness rather than substrate loss. Additionally quantitative measurements such as spectrophotometry and ICPMS measure dissolved silicon and are limited to wet clean process steps only. This paper reports on wafer mass loss as a direct linear measurement technique to quantify substrate loss. Mass loss measurement displays the ability to differentiate with a high degree of resolution mass loss in the sequential ash / clean / anneal process.

Introduction:

Although there is some interest in wet strip only processing the challenges related to resist residue prevent this approach in the main stream. Limitations are also placed on plasma chemistries, driven by the need for zero substrate and dopant loss [1]. Continuing high-dose (>2E15) but shallow implants of multiple species, combine to make dry strip a significant challenge [2]. Work using multiple process steps with controlled temperature settings and unique chemistries along with the use of soft (low-energy) ion bombardment allow many of these challenges to be overcome for a commercially-successful ash tool. In this paper, we discuss how mass metrology is used to quantify substrate mass loss at 65 nm allowing migration to 45 nm and below.

Experiment;

Product wafers are processed with a photoresist mask which defines the area to receive and not receive an implant dose. During a high energy implant dose the resist will develop a skin which makes subsequent resist strip more difficult. The challenge of HDI strip is the removal of this ‘crust’ layer without inducing ‘popping’, which occurs due to volatilisation of remaining solvent or bound N2 in the bulk resist [2]. This must be achieved with minimal substrate loss.

Fig.1
Figure 1: Schematic diagram of RF Ion-Assisted microwave plasma reactor

In this work post Implant the resist is stripped using an AxcelisRdS320i Asher. The optimum gas mixture is energized by the microwave power generator to form a plasma discharge that flows into the plenum created between the
chamber lid and the baffle plates. An aluminum baffle plate, evenly distributes the plasma across the surface of the wafer. The wafer itself is placed in the chamber on two quartz pins and a thermocouple, and is heated by halogen lamps placed below the process chamber. The thermocouple (not shown in the figure), which is in contact with the wafer, is used to maintain active temperature control of the wafer by providing a feedback loop to the lamp’s controller. However during the resist ash, there is the potential to oxidize the substrate and making it more chemically reactive. High-dose ion implantation significantly modifies the photoresist, resulting in a highly-carbonized layer on top of virgin resist while damaging the substrate and making it more chemically reactive.

For the case of a blanket silicon substrate, the loss in mass due to ash induced oxide growth and clean is described in **Figure 4a**. The wafer starts with an initial mass (M1), which includes the mass of substrate and native oxide on both sides of the wafer. Oxidative plasma ash will induce the growth of oxide on the wafer top side. While a bulk clean process (e.g. dHF) will remove native oxide from both wafer surfaces, the native oxide will regrow at the expense of some Si consumption. If this post process mass is termed M2, then the amount of Si mass loss due to ash induced oxide growth and post clean re-growth of native oxide on both sides is equal to M1-M2. **Figure 4b** illustrates a second example where blanket implanted wafers are ashed and cleaned using a front side SEZ process. In this case M1-M2 equals the Si mass consumed for ash induced oxide and native oxide from the top surface.

The loss from any type of substrate including SiGe, TiN, BPSG, Poly-Si can easily be easily quantified using mass so that the optimum chemistry/processes regime.

In this paper we present results for such blanket Silicon wafer processing as described above. Wafers are measured for mass before processing (M1) and after processing is complete (M2). Blanket Si wafers were chosen as a proof of concept due to ease of using other metrology to corroborate techniques such as Ellipsometry and XPS to mass.

Implanted and non-implanted wafers were used to distinguish the impact of the Implant on ash induced oxide growth. The mass loss due to wet clean and subsequent native oxide re-growth can be calculated using this approach. The Si lost in the wet clean is directly related to the mass loss. The results of the splits are shown in **Table 1**.

<table>
<thead>
<tr>
<th>Implant Reactions at Process</th>
<th>Non-Implanted</th>
<th>Implanted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon (Si)</td>
<td>18.26 Å</td>
<td>15.24 Å</td>
</tr>
<tr>
<td>Ash induced Si</td>
<td>1.50 Å</td>
<td>1.50 Å</td>
</tr>
<tr>
<td>Ash induced SiO2</td>
<td>1.50 Å</td>
<td>1.50 Å</td>
</tr>
<tr>
<td>Ash induced SiO2 (subtract wet clean amount)</td>
<td>6.10 Å</td>
<td>6.10 Å</td>
</tr>
</tbody>
</table>

**Table 1**
**Results:**

Mass loss was capable of distinguishing the following groups;
1) Implanted vs. non Implanted
2) Forming Gas (FG) vs FG + O2.

Also, as expected, greatest Si loss was observed with CF4 only. It can be seen that in all cases the splits (a) no Ash, (b) FG (c) Std O2 the implanted wafers lose more mass as compared to the non-implanted wafers. This is due to Si lattice damaged by implant and hence more prone to oxidation and removal by clean.

The bar chart (Figure 6) shows the oxide thicknesses post ash as measured by ellipsometry. This shows good agreement between multiple techniques (1) XPS (SiO2 thickness) (2) Ellipsometry (SiO2 thickness) and (3) Mass(Si mass) all agreeing on the ranking process conditions from least to most substrate loss.

**Conclusion:**

The advantages of using mass change to monitor substrate loss avoid the complexity associated with other techniques, particularly when working with different substrate materials. These advantages extend to both the process development phase along with high sample rate in-line monitoring on product.

This method is applicable to a wide range of product types where the substrate material / integration scheme do not easily lend them selves to other techniques.

**Acknowledgements:**

**References:**