Optimization of Cleanliness and Oxidation in Plasma Doped Photoresist Strip

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Abstract. TEM and SEM were used to characterize the behavior of plasma doped photoresist when exposed to three plasma strip chemistries. This methodology coupled with further investigation was used to propose a candidate for minimizing post plasma doping strip residues and increasing device yield while minimizing silicon and metals oxidation.

Keywords: plasma doping, plasma strip, residue mitigation, dopant retention, non-oxidizing.
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INTRODUCTION

Like high-dose ion implantation in a beam-line ion implanter, Plasma doping will also modify the patterned photoresist material. The plasma doped photoresist presents the added challenge of forming a ceramic like deposition layer on top of the hydrogen-depleted crust layer [1]. Also, the near surface proximity of the dopant makes plasma doped devices highly sensitive to the plasma chemistry used to remove the photoresist mask [2].

Conventional oxidizing chemistries have been shown to undercut the photoresist crust, causing residues to fall onto the hot substrate where they harden and cause defects [3]. Aggressive wet cleans can remove these defects but conventional oxygen based ash chemistries are not compatible with USJ applications due to Si and metal consumption in oxidation. Traditionally H2:N2 forming gas is used for beam-line high dose implant photoresist strip because the H2:N2 offers improved selectivity of the crust to the bulk photoresist [4]. In this study, the H2:N2 proved to have too low of a removal rate to present a viable process, perhaps due to an inability to etch the ceramic-like deposition on top of the carbonized photoresist crust.

An Axcelis proprietary chemistry was characterized in this study which provides excellent wafer cleanliness, low silicon oxidation, low metals oxidation and a reasonable process time. This chemistry has been successfully tested with integrated product test wafers.

EXPERIMENTAL

All studies in this work were carried out on a six-chamber Axcelis IntegraES plasma-strip system. This tool uses a microwave-driven, downstream plasma source and a load-locked platform design which incorporates inert, active wafer cooling to prevent post-process oxidation. Patterned photoresist, bare silicon and tungsten wafers were plasma doped and provided by SK hynix Semiconductor Inc. The doping conditions are provided in **Table 1**. The Photoresist strip characteristics of three plasma chemistries were characterized with SEM evaluation and the impact of the best chemistry on silicon oxidation, tungsten oxidation and dopant retention was then characterized with ellipsometry, TEM and SIMS.

TABLE 1. Plasma Doping Conditions

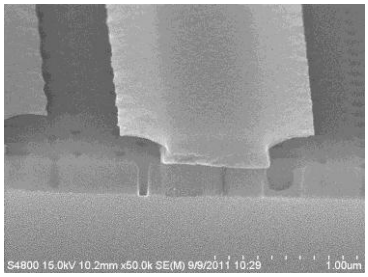
Condition	Plasma	Wafer Bias	Dose
1	PhH_3	4.0kV	2.00E+16
2	PhH_3	10.0kV	4.00E+16
3	AsH_3	7.0kV	2.00E+16
4	AsH_3	10.0kV	4.00E+16

Patterned Photoresist, blanket tungsten and bare Si wafers were supplied with each doping condition.

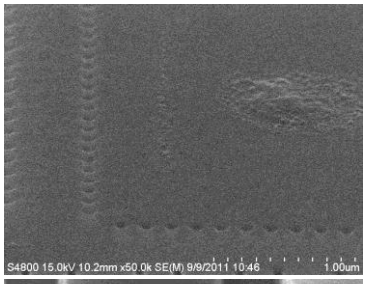
Results and Discussion

A comparison was done using a conventional O_2/N_2:H_2 chemistry, an oxygen-free N_2:H_2 chemistries and an Axcelis proprietary Controlled Oxygen Diffusion (COD) chemistry.

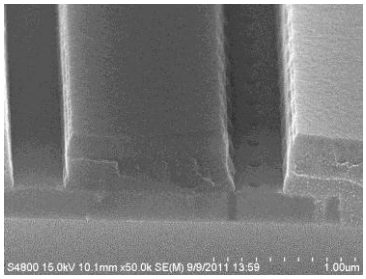
The plasma doped Photoresist samples were examined with SEM at 30 second intervals into the partial strip. **Figure 1** shows the progression of Photoresist removal for each process.



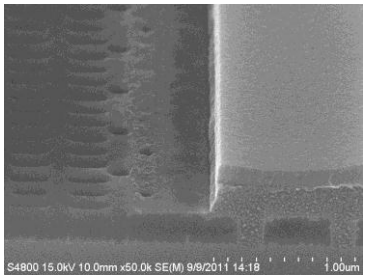
30sec O2/H2:N2



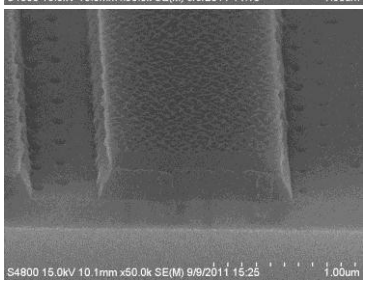
90sec O2/H2:N2



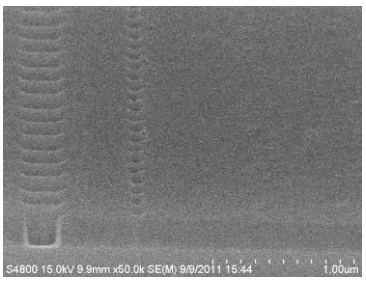
30sec H2:N2



90sec H2:N2



30sec COD



90sec COD

FIGURE 1. SEM images of partially striped resist with the three chemistries.

Figure 1 confirms the undercut of the ceramic-like deposition and the carbonized crust that is also observed in beam-line high dose implant strip with oxidizing chemistries. The H_2:N_2 chemistry undercuts the ceramic-like top layer of the fine structure but cannot penetrate that layer to ash the broad features. Only the COD chemistry can remove both the fine and broad features without undercutting the top layer and leaving heavy residues on the wafer.

The COD process was optimized for temperature and time to achieve the lowest possible defectivity. Including a 50% overash the complete process was 150 seconds long. The wafer cleanliness after plasma strip and the SK hynix proprietary R-Clean wet clean is shown below in **Figure 2.**

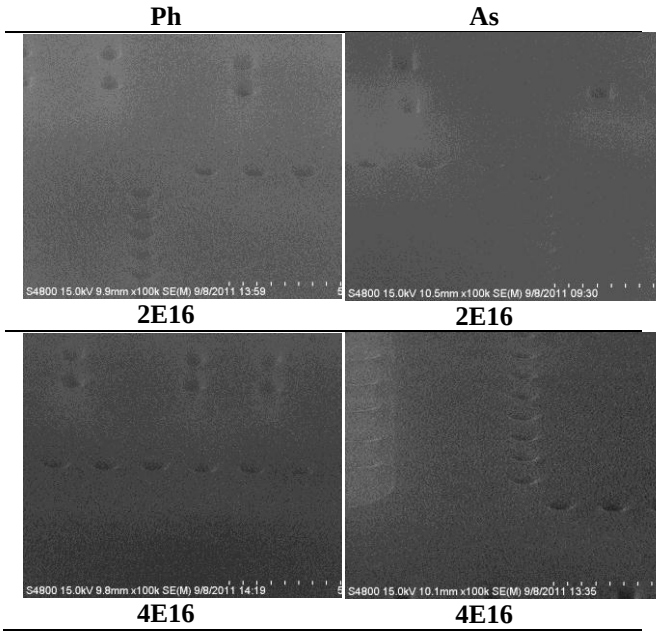


FIGURE 2. SEM inspection of clean plasma doped samples after plasma strip and R-Clean.

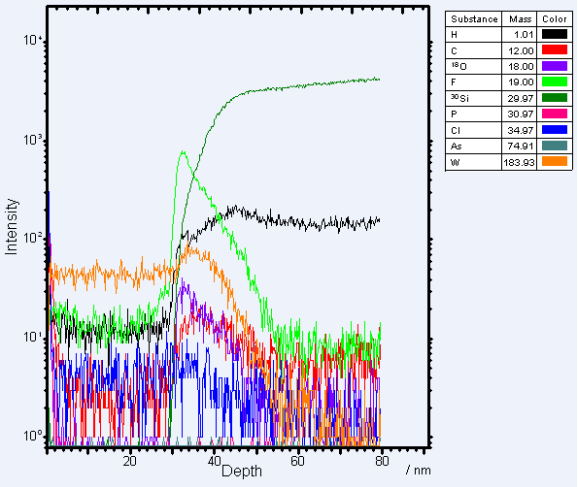
Bare silicon wafers with an initial native oxide thickness of ~10Å were used to evaluate the silicon

lost to oxidation during this COD process. The silicon loss was calculated from the oxide growth measured by ellipsometry. **Table 2** gives the silicon loss with the COD, H_2:N_2 and O_2/H_2:N_2 chemistries; the results are normalized to the H_2N_2 silicon loss.

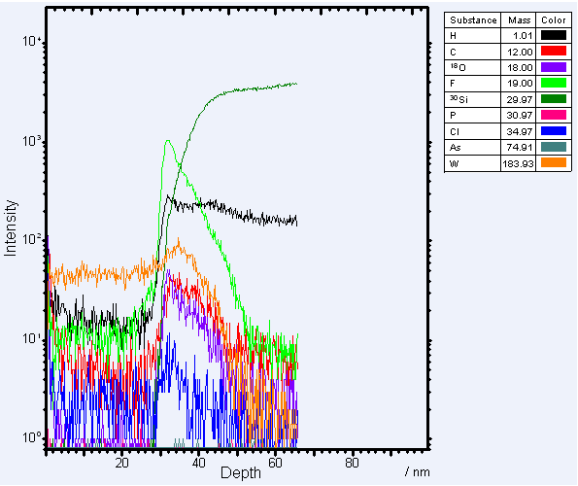
TABLE 2. Si Loss Through Oxidation

Condition	120 sec H_2:N_2	120 sec COD	120 sec O_2/H_2:N_2
Si Loss	1	1.35	2.16

The impact of the COD process coupled with the R-Clean process was evaluated by TEM and AES at SK hynix for tungsten loss to oxidation or etching. Cross-section TEM inspection of the tungsten film after COD plasma strip and R-Clean showed minimal thickness change. **Figure 3** shows the AES results of the blanket tungsten wafer analysis.



Ph, 10kV, 4E16



As, 10kV, 4E16

FIGURE 3. AES surface analysis blanket tungsten wafers.

The unchanged tungsten thickness in the TEM inspection and the unchanged tungsten composition, particularly the lack of an oxygen peak at the tungsten surface, confirms that the COD chemistry is a leading candidate for plasma doped photoresist strip even over high-K gate materials such as tungsten.

Dopant retention is always a concern in the development of a process to remove a mask over a substrate with an USJ. Dopant loss of up to 70% has been reported for conventional plasma strip used in plasma doped applications similar to the one discussed in this study [5]. SIMS inspection was done at SK hynix on a bare Si wafer that had been plasma doped with 2E16 Ph and on a bare Si wafer that had been plasma doped with 2E16 Ph and exposed to the complete COD plasma strip process. **Figure 4** shows close alignment of the SIMS profiles for the Ph as implanted and after plasma strip.

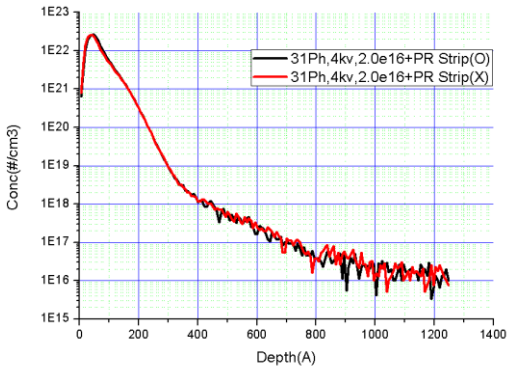


FIGURE 4. SIMS depth profiles for phosphorus doped samples with and without COD plasma strip.

CONCLUSIONS

Oxidizing plasma strip chemistries limit the potential of plasma doping by leaving residues and consuming too much of the substrate surface where the dopant concentration is the highest. The H_2:N_2 oxygen free chemistry cannot be extended from beam-line high dose implant strip to cover plasma doped photoresist strip applications because it cannot remove the ceramic-like top layer formed in plasma doping. The COD chemistry can strip the ceramic-like top layer, the carbonized crust and the bulk photoresist with minimal undercut and residues. The COD chemistry also offers excellent silicon and metals oxidation results and superior dopant retention making this chemistry a leading candidate for meeting the advanced requirements of ultra shallow junction formation.

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