Effluent Management for Non-Oxidizing Plasma Strip Processes

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This paper reports on the techniques employed to control the re-deposition of the partially dissociated organic photoresist (PR) by-products in advanced non-oxidizing strip processes developed to meet the PR removal requirements of future technology nodes. System features, such as the design of heated process chamber walls and an on-board, RF-based oxygen plasma effluent abatement system are described in detail. The performance of these features to prevent or eliminate hydrocarbon buildup and manage effluent with non-oxidizing strip processes is also presented and discussed.

Introduction

Continuously shrinking device nodes employ ultra shallow junction and high-*K*/metal gate stack technologies in order to fabricate high speed transistors. Optimization of the PR and residue removal process step after high-dose-implantation has become essential in order to preserve proper dopant activation and to avoid substrate loss and/or gate stack material modifications (1, 2). As a result the industry has started to utilize non-oxidizing strip chemistries for these critical PR and residue removal steps, in replacement of the traditional oxidizing chemistries (3, 4). However, the non-oxidizing chemistries, such as Forming gas (N_2:H_2), lack the oxidizing species to efficiently remove the long chain polymers of the PR. A non-oxidizing plasma only partially dissociates the resist into short-chain hydrocarbon by-products, as opposed to an oxidizing plasma that converts the PR into gaseous by-products such as CO_2, CO, H_2O or the like. These non-oxidizing strip by-products tend to condense on cold surfaces such as chamber walls, vacuum lines, valves, pumping lines, pumps, and exhaust lines. As more and more wafers are processed, this condensation leads to buildup of hydrocarbons. This buildup on the surface inside of the process chamber is a potential source of particulate contaminants to wafers in the process chamber. Having the buildup occur inside of valves, pumps and pumping lines, etc can cause pre-mature pump and valve failure, require frequent maintenance and might even pose a safety hazard. Conventional process chamber cleaning and system maintenance are done "off-line" and the strip tool is unavailable for production use, lowering the utilization of the tool. For this reason, there is a need to reduce the buildup and the frequency of maintenance, and the prevention and control of organic byproduct re-condensation has become a critical feature for the implementation of non-oxidizing strip chemistries.

In this paper two techniques are investigated and employed to reduce the re-condensation of the partially dissociated PR by-products of non-oxidizing strip processes. Elimination or reduction of hydrocarbon buildup in the process chamber is done by

heating the chamber wall. An afterburner where a secondary RF-based oxygen plasma is formed downstream of the process chamber converts the short-chain hydrocarbons to gaseous by-products, which can be pumped out and eliminate the buildup on surfaces of any components downstream.

Experimental

All studies shown in this work were carried out on a 300mm, three-module, six-chamber Axcelis IntegraES dry-strip system, with a microwave-driven, remote plasma source and a load-locked platform design which incorporates active wafer cooling. The IntegraES is designed specifically for non-oxidizing PR plasma strip processes which enables "zero" metal and substrate oxidation and loss. Figure 1 shows a schematic diagram of the features designed to control non-oxidizing ashing effluent and by-product buildup.

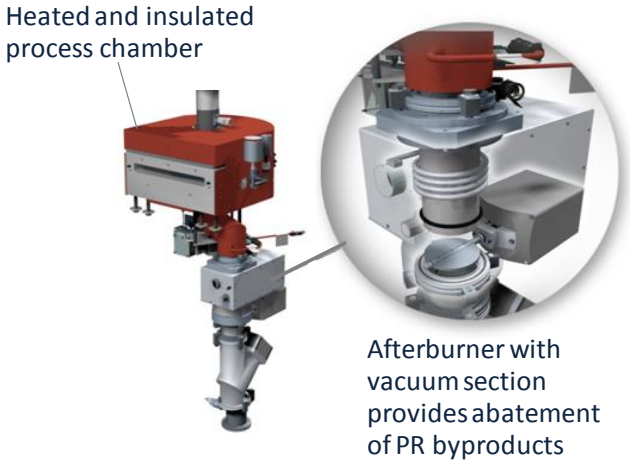

Figure 1. Schematic of heated chamber and afterburner.

The heating element increases chamber interior surface temperature to greater than 60°C during wafer processing. For safety reasons the chamber is thermally insulated to prevent burns when servicing. In addition, thermal insulation reduces the cost-of-ownership of the tool by reducing the power needed to maintain an elevated temperature within the chamber. To control the effluent downstream, an afterburner assembly is coupled to the exhaust conduit, wherein the exhaust conduit comprises a gas port intermediate to the process chamber and the afterburner assembly. A secondary RF plasma is formed inside afterburner, where oxygen is injected to abate any ashing effluent into gaseous by-products. An important element in operation of the afterburner is to keep the injected oxygen from back-streaming into the process chamber. This is achieved by keeping a sufficient pressure in the region above the afterburner (so that the gas flow is in the viscous or transition flow regime) and keeping process gas flow sufficiently high to prevent the back-streaming of the injected oxygen. The portion of the exhaust conduit between the chamber and afterburner is also heated to prevent hydrocarbon buildup at this location.

Three non-oxidizing strip chemistries, which include Forming gas-only (FG-only, N_2:H_2) and two Axcelis proprietary non-oxidizing chemistries (COD-01, COD-02), were

tested with the features described above. Multiple resist wafers were stripped with these chemistries and the performance of process chambers (ash rate, particle adders) was examined to determine the efficacy of chamber wall heating to reduce/eliminate re-condensation and the proper chamber wall temperature needed. Resist hydrocarbon buildup downstream of afterburner was monitored at several locations along the exhaust line by measuring deposition on Si wafers coupons taped at these locations. Inner surfaces of process chamber and exhaust line parts were also visually examined for resist buildup after marathon tests, in which hundreds of resist wafers were stripped to simulate the IC manufacturing environment.

Experimental Results and Discussion

The objective of this work is to provide a method to eliminate the non-oxidizing strip PR by-product buildup inside the process chamber wall, which could cause particulate contamination. Figure 2 shows the chamber wall pre and post stripping ten 1.8µm blanket I-line resist wafers with FG-only process in a cold-wall chamber. A visible resist buildup occurred even after ashing only ten resist wafers with non-oxidizing FG-only process. Similar buildup inside the chamber was observed when COD-01 and COD-02 were used to strip resist wafers in a cold-wall chamber.

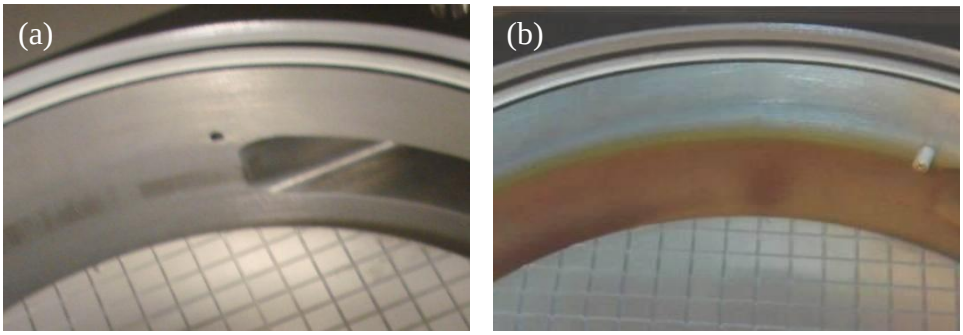

Figure 2. Photographs of chamber wall: (a) pre and (b) post FG-only strip in cold-wall process chamber.

Several techniques were tested to eliminate/reduce the re-condensation of PR by-product on a cold chamber wall. The results demonstrated that heating of the chamber wall is an effective way to achieve this goal. When the process chamber wall was heated to greater than 60°C, the PR hydrocarbon buildup was substantially reduced. However, in order to completely eliminate the buildup within the interior of the process chamber, the wall temperature should be maintained at 140°C or higher. Figure 3 shows small amount of buildup with 120°C chamber walls, but completely no buildup at 140°C chamber walls with the FG-only process. For COD-01 and COD-02 processes, there was no buildup at 140°C chamber walls as well.

Since resist buildup inside the chamber would lead to chamber performance shift and particle issues, the heated chamber configuration was also evaluated during extensive marathon testing by checking resist ash rate (AR) and particle adders on wafers, with some of the data being shown in Figure 4. In Figure 4 (a), particle adders were measured after increasing number of blanket coated 2.8µm I-line resist wafers (up to 1525) that were processed to endpoint with a FG-only plasma. All data points, except for one, fell in

the tool particle specification. Figure 4 (b) shows AR and ash non-uniformity (NU), which were regularly checked during the marathon testing in which 500 blanket coated 2.8µm I-line resist wafers were stripped with the COD-02 process. Throughout the marathon test, both AR and NU were consistent and well within tool specification. In both tests, the process chamber wall was visually checked and showed no resist buildup.

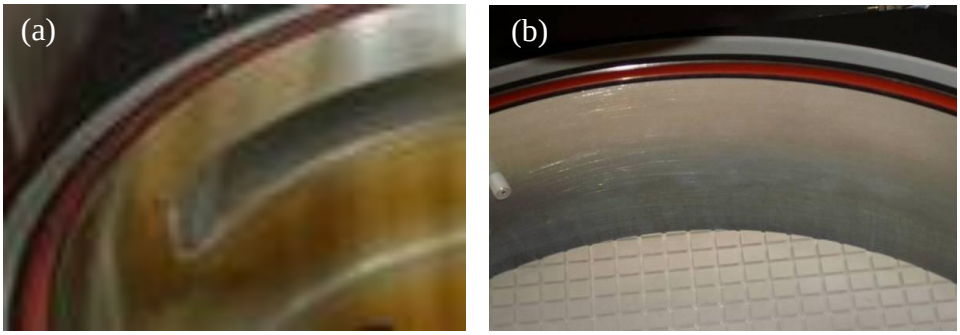

Figure 3. Photographs of chamber wall: (a) after striping 100 2.8µm resist wafers with 120°C chamber wall, (b) after striping 500 2.8µm resist wafers with 140°C chamber.

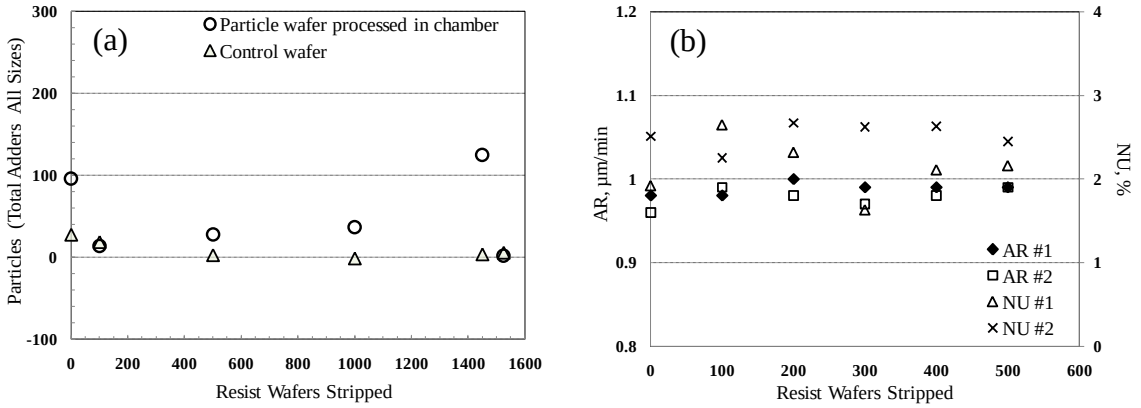

Figure 4. Performance tracking of 140°C chamber wall marathon testing: (a) particle adders of FG-only process, (b) AR and NU of COD-02 process.

Another important goal is to reduce the ashing byproduct buildup in the exhaust lines. While there are other techniques besides utilizing an afterburner assembly which can control the effluent, such as cold trap and heating of vacuum and exhaust lines, the afterburner has proven to be the best solution due to its efficiency and low cost. To verify the efficiency of the afterburner, several silicon chips were placed on a wire mesh which was then installed in the vacuum line downstream of the afterburner. After stripping ten blanket 2.8µm I-line resist wafers in a 140°C chamber with the FG-only process, the vacuum lines were opened to check for deposition on the silicon pieces. Figure 5 shows resist deposition on silicon pieces with the afterburner turned off, while no resist deposition was found on the chips with the afterburner on. Up to 21,000Å resist deposited on Si-chips was measured with the afterburner off.

Several marathon tests were conducted with the afterburner turned on and tuned for different non-oxidizing processes which were used to cycle blanket resist wafers in 140°C process chamber. The vacuum and exhaust lines were opened and checked at the end of each test. Figure 6 shows some pictures of the exhaust line and parts which clearly demonstrated that, with the effluent abatement in the afterburner, the downstream

hydrocarbon byproduct buildup was completely eliminated. Tool particle and AR performances with afterburner on were also monitored. The data shown in Figure 4 above were all collected with the afterburner on, which indicated no interference of afterburner to the tool performance.

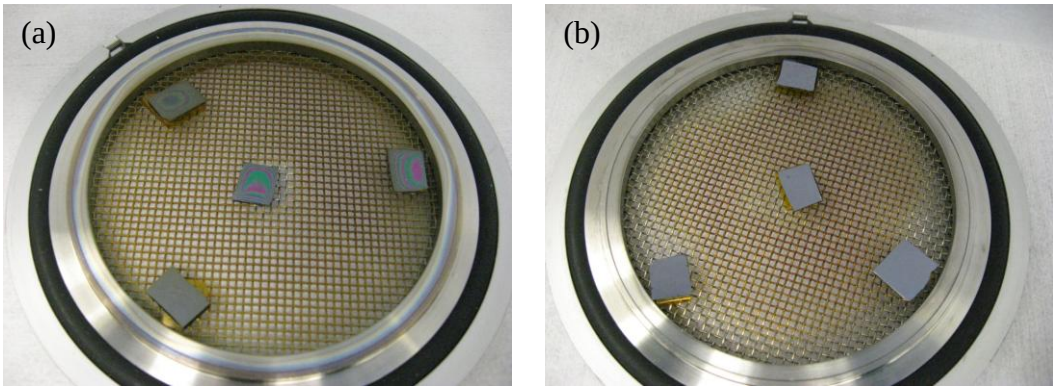

Figure 5. Resist strip byproduct buildup in vacuum line: (a) visible buildup with the afterburner off, (b) no buildup with the afterburner on.

(a) (b) (c) (d)

Figure 6. Photographs of exhaust line downstream of afterburner: (a) after cycling 8000 resist wafers with FG-only process, (b) after cycling 1000 resist wafers with COD-01 process, (c) after cycling of 500 resist wafers with COD-02 process, and (d) heavy buildup with no afterburner.

Conclusions

Two features to control the buildup of resist strip by-products in non-oxidizing strip processes were designed and investigated. Heating the process chamber wall >60°C reduced the hydrocarbon buildup inside chamber, while temperature >120°C completely eliminated the buildup. The afterburner assembly showed good efficacy to break down the ashing effluent and significantly reduced the re-deposition on surfaces of exhaust line parts. These two techniques make the non-oxidizing strip processes feasible to meet the requirements of wafer cleaning of the 28nm technology node and beyond.

Acknowledgments

The authors would like to thank Armin Huseinovic, Patrick Mayfield and James DeLuca of Axcelis Technologies, Inc. for their valuable work in system designing and data collecting.

References

1. F. Arnaud, H. Bernard, A. Beverina, R. El-Farhane, B. Duriez, K. Barla, and D.Levy1, *Solid State Phenomena*, **103-104**, UCPSS 2004.
2. S. Garaud, R. Vos, D. Shamiryan, V. Paraschiv, P. Mertens, J. Fransaer, and S. De Gendt, *Solid State Phenomena*, **145-146**, UCPSS 2008.
3. I. Berry, C. Waldfried, K. Han, S. Luo, R. Sonnemans, and M. Ameen: *IEEE Junction Technology*, IWJT 2008.
4. S. Luo, O. Escorcia, C. Waldfried, D. Roh, and I. Berry III, *Study of Alternative Plasma Strip Techniques for Advanced Photoresist Removal*, ECS Trans.-CSTIC 2010.