APPLICATION NOTE

ASTRON® REMOTE PLASMA SOURCE
ATOMIC FLUORINE TRANSPORT

PROBLEM

Remote-plasma cleaning methods are the most appropriate procedures for modern deposition chambers. Most chamber cleaning processes employ atomic fluorine as the most efficient species for chamber cleaning. Proper design for the transport of the atomic fluorine flux from source to the chamber is required to minimize losses due to surface recombination. Moreover, if care is not taken with the materials present within the process chamber, the reactive fluorine will etch these surfaces along with the intended deposition layers, potentially producing high particle counts and component failure within the system.

BACKGROUND

Historically, CVD process chambers had to be frequently dismantled and cleaned. Wet chemical cleans of the dismantled components maintained the performance specification for process particle counts. This approach to system cleaning incurred significant costs in terms of system downtime, labor and safety risks. In-situ plasma cleaning, a logical extension of plasma technology for low temperature deposition and etch, was developed to avoid the need to dismantle the process tool. In-situ cleaning uses available plasma excitation and gaseous molecular precursors to create reactive chemical species. These reactants then react with wall deposits in the chamber and produce volatile products that can be pumped away. The combination of plasma-assisted deposition with in-situ plasma cleaning constituted a major advance in semiconductor manufacturing protocols, yielding significant and valuable reductions in system downtime, much reduced labor costs and enhanced procedural safety.

Modern plasma-assisted cleaning employs a variety of fluorine chemistries to produce chemical radicals within a deposition chamber. It is these short-lived and highly reactive radicals that accomplish the clean. The exact chemistry chosen for an individual tool depends on a mixture of considerations that include: the nature of the reactive chemistry; the risks incurred in storage and use of the precursor; and environmental issues associated with emissions from the cleaning procedure. Atomic fluorine is the most common cleaning agent chosen since most of the deposited materials in semiconductor tools produce volatile products on reaction with this species. Atomic fluorine radicals are created by plasma dissociation of a variety of gaseous precursor compounds, including: NF_3; F_2; CF_4; C_2F_6; ClF_3; and SF_6. Of these candidate precursors, NF_3 is preferred since it can be handled safely; it dissociates relatively easily and has no detrimental byproducts (e.g., C or S deposits).

The direct application of plasma within the deposition chamber is the simplest option for in-situ cleaning. However, direct exposure of the chamber to the plasma environment can create serious problems since plasma within the process chamber subjects the chamber walls and sensitive internal components to damaging ion bombardment. Such damage does not occur if the clean employs neutral reactive species rather than plasma-generated ions. For this reason, manufacturers have moved away from direct plasma exposure to remote plasma source cleaning in which reactive radical species are generated in a plasma chamber separate from the process chamber and transported by pumping action to the process chamber. Remote sources eliminate the presence of electric fields and ionic species within

the process chamber allowing the cleaning process to proceed by the relatively benign agency of chemical radical reactions. Remote plasma sources are also more efficient at generating radicals since higher power densities can be used inside a remote plasma source. The introduction of remote plasma sources for chamber cleaning resulted in a significant increase in the service lifetime for the expensive components within CVD process chambers. However, in remote plasma systems, the plasma source is itself subject to surface damage, and thus has a finite lifetime.

MKS Instruments produces the ASTRON® line of remote plasma sources for the production of reactive gases for use in chamber cleaning processes. ASTRON plasma sources are low-field toroidal RF plasma sources that provide high fluxes of reactive gas-phase radicals for chamber cleaning.

Effective chamber cleaning using remote plasma sources requires considerations beyond just the selection of an appropriate remote source. In particular, two key equipment/process characteristics must be addressed. First, reactions of atomic fluorine with the walls of the transport tube connecting the remote source to the process chamber may reduce the flux of fluorine radicals delivered to the process chamber. Therefore, the geometry of the transport tube must be designed to minimize such interactions. For similar reasons, the material of construction of the transport tube should be minimally reactive with fluorine radicals. Second, the materials of construction within a process chamber and other materials in the process chamber must be compatible with atomic fluorine otherwise etching of system components will occur, leading to maintenance and safety issues within the tool. This Application Note addresses these critical issues.

SOLUTION

ASTRON® REMOTE PLASMA SOURCES

Figure 1 shows an example of an ASTRON remote plasma source. They are compact and self-contained, and ASTRON plasma sources typically dissociate more than 95% of NF_3 precursor, producing a high flux of neutral atomic fluorine radicals. Radical recombination within the plasma chamber and transport tube is minimized by the combination of high gas flow rates, materials with low surface recombination coefficients, and, in one model of the ASTRON, an admixture of Ar with the gas feed. High gas flows and pumping speeds increase the gas velocity through the ASTRON source and transport lines, reducing the residence time of the reactive species, thereby maximizing the flux of reactive species available for chamber cleaning.

Figure 1 - Paragon® remote plasma source for chamber cleaning

THE TRANSPORT TUBE: THE IMPACT OF TEMPERATURE AND MATERIALS ON ATOMIC FLUORINE FLUX

MKS has explored the impact of different materials used in the interface between an ASTRON remote plasma source and a downstream process chamber. Atomic fluorine loss in transport tubes made of C-22 Hastelloy®, 304 stainless steel, 6061 aluminum and Teflon®-coated stainless steel were measured. The objective of the

experiment was to identify materials with low surface recombination rate for fluorine. The relative atomic fluorine fluxes were measured based on changes of etch rates of SiO_2 with and without the transport tubes. Figure 2 shows the measured relative etch rates. The dimensions of the transport tubes were 1 meter in length and 22-23 mm in diameter. The NF_3 flow rates were from 250 sccm to 1000 sccm. It showed that Teflon has the lowest loss for atomic fluorine, followed by aluminum, stainless steel and Hastelloy.

MKS also tested the impact of tube temperature on fluorine transport for aluminum and Teflon-lined transport tubes. Repeated tests with the aluminum tube and baseline runs showed that the etch results were repeatable to within ±2%.

Figures 3 (a) and (b) show relative fluorine transport efficiencies for the aluminum and Teflon transport tube as functions of temperature. Radical transport efficiencies were assumed to be equivalent to the observed SiO_2 etch rate divided by the SiO_2 etch rate in the baseline tests. The results showed that the transport efficiency for atomic fluorine was 71% to 93% with the aluminum tube compared to 88% to 98% in the Teflon tube. The fluorine loss decreased with increasing tube temperature, likely due to lower adsorption of fluorine atoms on the tube

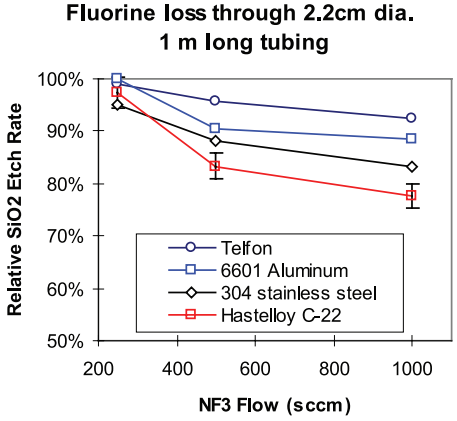

Figure 2 - Relative etch rate of thermal SiO_2 through four atomic fluorine transport tubes

surfaces at higher temperatures, reducing the probability of surface recombination. While Teflon-lined transport tubes are superior to aluminum ones in this test, both options are acceptable in most applications.

Figure 4 shows the impact of different geometries (tube diameters) on the radical flux, as measured by SiO_2 etch rate results. The observed etch rates were virtually identical for tests with the two tubes. These results showed that variations in the transport tube diameter only weakly affect the transport efficiency of fluorine radicals to the process chamber.

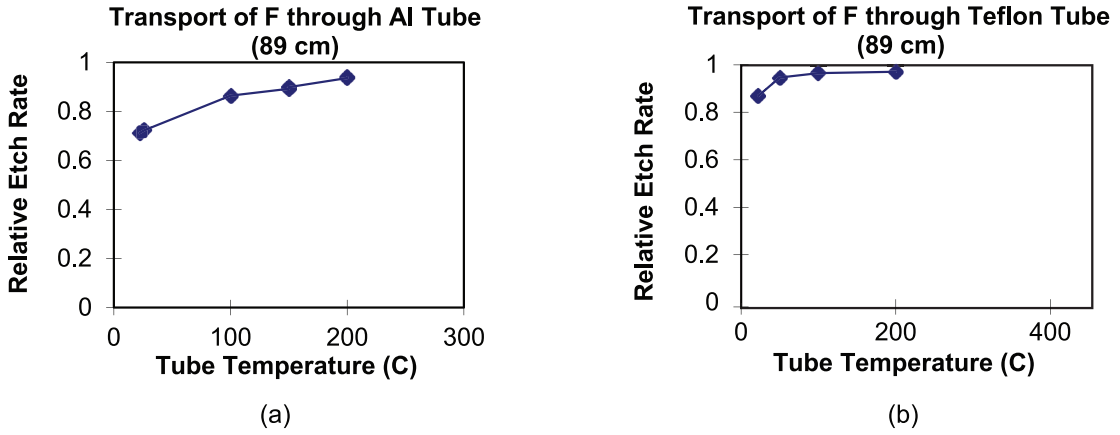

Figure 3 - (a) Transport efficiency vs. temperature for 89-cm long, 3.44-cm I.D. aluminum transport tube; (b) Transport efficiency vs. temperature for 89-cm long, 3.44-cm I.D. Teflon-coated transport tube

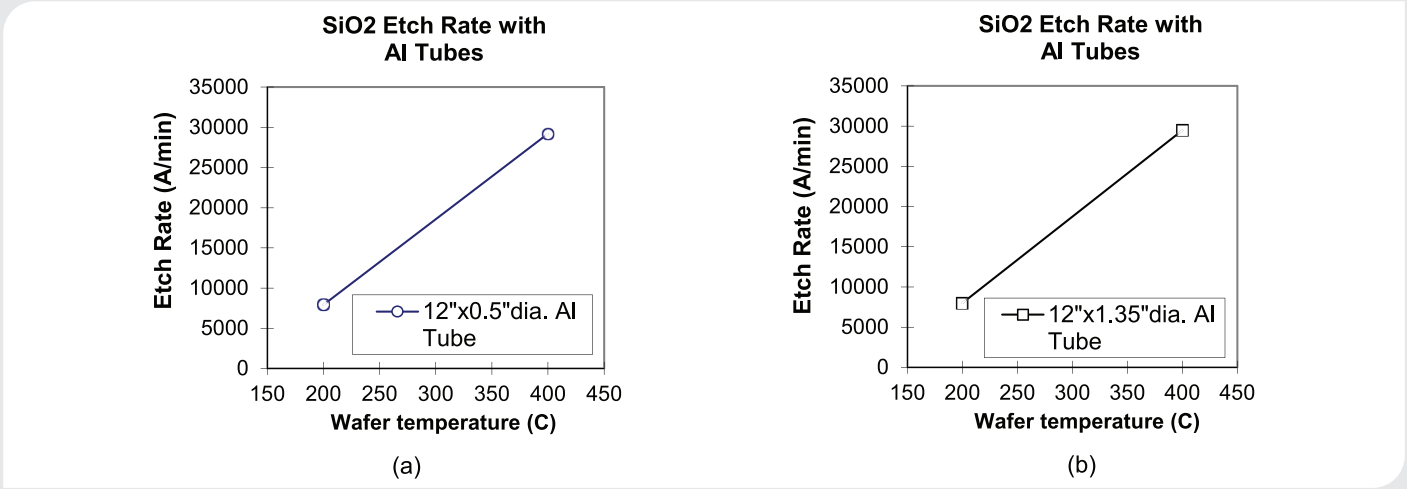

Figure 4 - Measured SiO_2 etch rates with aluminum transport tubes, (a) 0.5" diameter x 12 inches long, and (b) 1.35" diameter x 12 inches long

CONCLUSION

The data described in this Application Note provides user information for the connection geometry between ASTRON remote plasma sources and on the materials of construction of these connections. Within the limits tested, we found that connection tube diameter had little, if any, effect on the atomic fluorine flux delivered to the process chamber. Some loss in atomic fluorine flux is experienced when using aluminum rather than a Teflon-lined transport tube. This loss is minimal, however, and both materials are acceptable for transport tube construction.

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