Characterization of trace organic contamination on silicon surfaces in semiconductor manufacturing

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As semiconductor devices continue to be highly integrated and their geometries also continue to shrink, not only particulate and metallic contamination but also trace organic contamination adsorbed on the surface of silicon wafers has an increasingly detrimental impact on the performance and yield of semiconductor devices [1].

Airborne organic volatiles leads to unintentional hydrophobization (or wettability changes) and haze generation on the surface of silicon wafers as well as degradation haze on the lenses of wafer steppers/scanners by photochemical reactions. They can also cause accelerated oxidation of silicon surfaces due to the presence of moisture generated by decomposition of organic compounds during rapid thermal oxidation. Furthermore, trace organic volatiles on silicon surfaces have an increasingly detrimental impact on the performance, yield, and reliability of ever smaller semiconductor devices. It has been shown that such organic contaminants not only have deleterious effects on the gate oxide integrity (GOI) in MOS transistors [2,3] but also give the lot-to-lot deviation of the film thickness due to variable incubation time[4] or the irregular growth of the film in chemical vapor deposition.

In order to prevent the degradation of device characteristics, an overall systematic approach, which consists of the prevention of adsorption of organic volatiles onto silicon surfaces before film growth process, the elimination of organic contaminants if they were adsorbed on silicon surfaces, and the quantitative understanding of their influence on device characteristics, is required. For the systematic approach, first, organic contaminants on silicon surfaces must be detected. Then they must be analyzed for identification. The adsorption and desorption behavior of organic contaminants on silicon surfaces must also be analyzed.

In this paper, various techniques for the detection, analysis, and identification of trace organic contamination on silicon surfaces are reviewed [5,6] along with their typical applications to silicon wafer processes. Analysis of the adsorption and desorption behavior of organic contaminants on silicon surfaces and analysis of residual carbons in device structures after thermal processing.

Several techniques have been proposed for detection of organic volatiles on silicon surfaces. Table I compares various techniques in terms of sensitivity, identification, detection of volatiles, and quantification. Attenuated Total Reflection Fourier Transformed Infrared Spectroscopy (FT-IR-ATR) is capable of detecting volatile organic compounds because the analysis is performed at ambient pressure. However, this technique gives poor identification.

In order to determine the source of organic contamination, the analytical technique should allow one to identify the organic compounds. Techniques that are better suited for the detection and identification of organic volatiles are Gas Chromatography-Mass Spectrometry following Thermal Desorption (TD-GC/MS)[5-7] and Thermal Desorption Ion Mobility Spectrometry-Mass Spectrometry (TD-IMS) [6]. TD-GC/MS, most commonly used in worldwide, has a higher identifying power compared with TD-IMS because TD-GC/MS allows better separation of complex organic compounds by using gas chromatography. Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS) which allow to directly analyze silicon surfaces can be complementarily used for the witness of organic contaminants on the surface. Thermal Desorption Atmospheric Pressure Ionization Mass Spectroscopy (TD-APIMS) does not give poor separation of complex organic contaminants but gives excellent resolution of temperature at which organic volatiles desorb from silicon surfaces. This technique is useful to analyze the behavior of organic contaminants on silicon surfaces during thermal processing because a lot of thermal processes such as oxidation or annealing take place in semiconductor manufacturing.

Table I Comparison of various techniques for the analysis of organic contamination on silicon surfaces.

	Sensitivity	Identification	Detection of Volatiles	Quantification	Direct Surface Analysis
XPS(ESCA)	△	×	×	△	○
FT-IR-ATR	△	△	○	△	○
TOF-SIMS	◎	○	△	△	○
TD-APIMS	◎	△	○	△	×
TD-IMS	◎	○	○	○	×
TD-GC/MS	○	◎	○	○	×
SIMS	○	×	×	○ ※	○ ※

◎ :Excellent, ○ :Good / Yes, △ :Poor, × :No, ※ : as carbon atoms

Lastly it should be noted that residual carbon atoms must be analyzed after a thermal process for quantitative understanding the influence of organic contamination on device characteristics. Secondary Ion Mass Spectrometry (SIMS) gives depth profiles of residual carbons in device structures. Most organic molecules on silicon surfaces can be desorbed, be decomposed and disappear during thermal processing, while residual carbons can be the origin of the degradation of device characteristics[3].

The appropriate choice of analytical techniques in each individual situations is important for providing the answer to contamination problems. More in-depth understanding of the phenomena occurring on the silicon surface using more appropriate analytical tools to directly provide molecular and bonding information on the surface of silicon wafers will be necessary.

References

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