Application Note: 50635

Infrared Evaluation of Fluorine – Containing Silicon Dioxide Dielectric Films

Ross Boyle, Thermo Fisher Scientific, Madison, WI, USA

Key Words

- Dielectrics
- ECO
- FT-IR
- FSG
- Low-K Films
- Semiconductor Metrology

Introduction

As dimensions of semiconductor device features continue to get smaller, there is an ongoing need to identify and develop new materials that accommodate these new designs. The family of materials used as dielectric layers in semiconductor devices are of extreme importance in the process design, and materials are always being sought that will allow the next generation of devices to be fabricated. Chemical vapor deposition (CVD) films are ideal applications for infrared analysis, and this technique has been used for many years to control the composition and consistency of these materials.

Examples of how Fourier Transform Infrared (FT-IR) spectroscopy is employed in the quality control of CVD films are abundant in the literature, and one of the more common applications is the analysis of boron and phosphorus in borophosphosilicate glass (BPSG). The success of this application and others has allowed FT-IR metrology systems to become common tools in the fab. Infrared analysis is well suited to this environment due to its ability to probe these samples in a non-destructive and non-contaminating fashion. It also yields very detailed information to confirm that the process parameters are within specification limits.

Given the flexibility of this technique, new applications can be rapidly developed as they become necessary. One of the more interesting groups of materials to be developed is the fluorinated dielectrics, specifically fluorosilicate glass (FSG). These films show great promise in being the dielectric layer for the next generation of devices, due to some very favorable material properties they possess.

Current dielectric films applied to smaller device features have limitations in the filling of narrow gaps in high-aspect ratio structures. These films also do not efficiently address propagation delay due to the capacitance between adjacent metal lines. Intermetallic dielectric films incorporating SiOF applied with standard CVD processes have demonstrated excellent gap-fill properties with low dielectric constants. These films show promise in meeting the requirements of next generation devices, but concerns with film stability remain and are the focus of intense materials research.

This technical note addresses the rapid development of the infrared method to monitor some of the material properties in these films and other low-k films. Also shown is how infrared can be used to evaluate these properties in a semi-quantitative fashion, allowing for a variety of useful information to be obtained with little external information available.

Detail

The films submitted for evaluation were deposited in a CVD system using $Si\text{-}F_4$ and N_2O. Film thickness ranged from 4000 Å to 8000 Å, and no further information was available on the samples. All films were deposited on 200 mm wafers, with resistivities of 10 Ω-cm or higher.

All measurements were made at 4 cm^{-1} resolution, using 32 co-added scans per point on a Thermo Scientific ECO™ 1000 FT-IR metrology tool. The measurement mode was in transmission, which then yielded spectra of both the film and the supporting wafer. Multiple point diameters were measured on each sample to determine the uniformity of the deposition. Each film was evaluated for:

1. Fluorine content as Si-O-F in the film
2. Hydroxide content as measured by the moisture peak
3. Hydrogen content as Si-H

All spectral data were evaluated using the Thermo Scientific ECO software and Thermo Scientific TQ Analyst™ software for quantitative analysis.

Figure 1 shows a typical spectrum obtained from these films. The normal features usually assigned to the presence of hydrogen in the film are absent, which suggests these films are free of this contaminant. In films deposited using silane ($Si\text{-}H_4$), hydrogen is present.

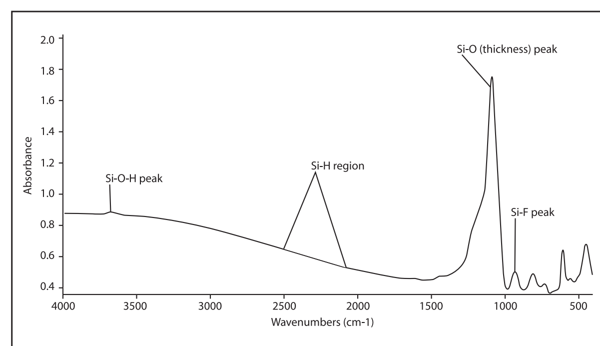

Figure 1: Typical spectrum obtained from Si-O-F film on wafer

The sample profiles were done at 90 degrees to the notch, and consisted of points separated by 5 mm for a total of 37 points per wafer. Figure 2 shows a typical pair of spectra collected from the center and near the edge of the wafer. The change in the 937 cm^{-1} peak implies an increase in the amount of fluorine in these samples toward the edge of the deposition. The change in the peak near 3650 cm^{-1} implies a reduction in the relative amount of moisture in these films. The film thickness can also be seen to change on these samples as indicated by the peak at

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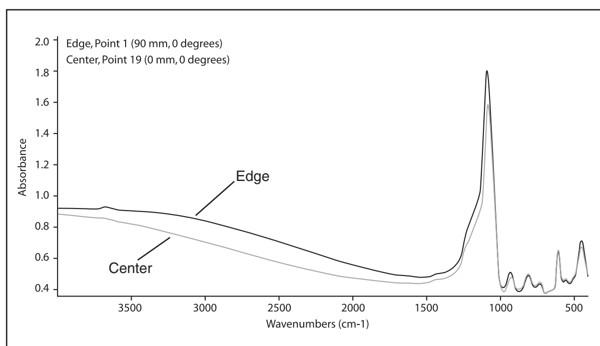

Figure 2: Showing the difference from the center to the edge of the film on a sample

1095 cm^{-1}. All the samples showed the film to be about 5-10 percent thinner in the center than near the edge of the wafer.

Figures 3 and 4 show the peak areas of these components at specific positions across the wafer. These areas were normalized for thickness in both cases and calculated relative to local baselines. The integration limits were optimized by viewing the data, and they remained consistent for all the samples evaluated.

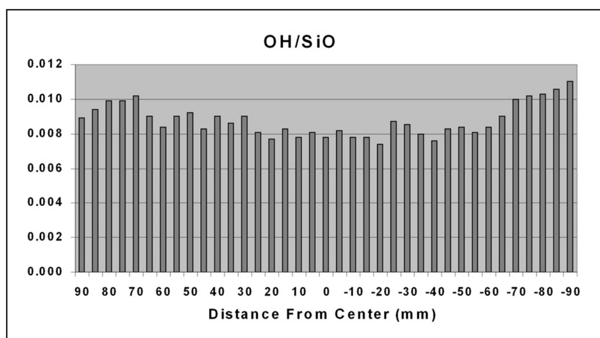

Figure 3: Variations of -OH across a sample

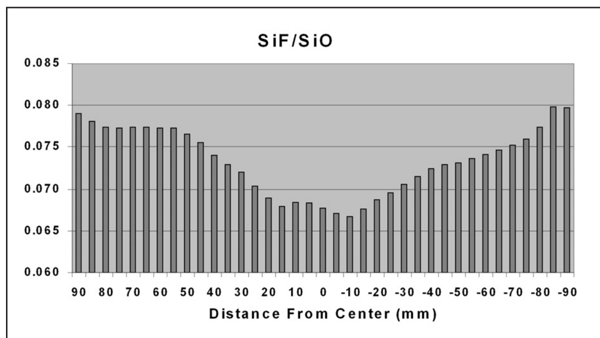

Figure 4: Variations of Si-F across a sample

Conclusions

FT-IR can be a very useful tool in determining the chemical composition of thin films even when an external calibration is not available. In the absence of real quantitative information, composition changes can be visualized by relying on pure spectroscopic features as indications of variation in the films. In this example, the spectral feature attributed to fluorine concentration in the film at 937 cm^{-1} was measured and normalized for film thickness and presented as a concentration cross section. In a likewise manner, the normalized -OH content was plotted as sampled across the wafer diameter. The tendency for higher fluorine concentrations in the film to be observed with higher absorbed moisture levels is consistent with other reports in the literature, and this instability remains one of the greatest challenges to the widespread adoption of this class of dielectric films.

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