Reflectance and substrate currents of dielectric layers under vacuum ultraviolet irradiation

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The reflectance of low-*k* porous organosilicate glass (SiCOH) as a function of photon energy under synchrotron vacuum ultraviolet (VUV) radiation was measured using a nickel mesh reflectometer. The authors found that during VUV irradiation, the reflectance of SiCOH and the substrate current were inversely correlated. Thus, reflectance can be inferred from substrate current measurements and vice versa. The authors conclude that reflectance or substrate current measurements can determine the photon energies that are absorbed and, therefore, cause dielectric damage during processing. Thus, reducing the flux of deleterious photon energies in processing systems can minimize dielectric damage. © *2010 American Vacuum Society.* [DOI: 10.1116/1.3488594]

I. INTRODUCTION

Vacuum ultraviolet (VUV) photon absorption generates trapped positive charges in dielectrics.[1,2] In addition, photoabsorption can cause chemical and structural changes.[3,4] Thus, more processing-induced damage is likely to occur with an increased absorption of photons. A decrease in the reflectance implies an increase in photon absorption.[5] To reduce dielectric damage, the flux of such deleterious photons should be reduced in processing systems. Reflectance measurements can be a tool to determine those photon energies for a dielectric.

The ratio of reflected photon flux to the incident photon flux determines the reflectance at a given photon energy.[6–8] This paper reports an inexpensive and rapid method to measure the reflectance of dielectrics in the VUV range of the spectrum using synchrotron radiation and to relate the reflectance to the measured substrate current. Substrate current is easier to measure during processing as compared to reflectance. Also, substrate current measurements as a function of photon energy can be more accurate for low photon flux. Thus, if substrate current measurements can be correlated with reflectance measurements, the substrate current measurement can be an effective method to determine those photon energies that cause increased processing damage.

Photons that are not reflected are transmitted into the dielectric and absorbed.[6] Depending on the thickness of the dielectric layer, the photons may either be absorbed in the dielectric or penetrate to the substrate. We experimentally verified that for the dielectric thicknesses and photon energies used in our analysis, most of the photons are absorbed in the dielectric. Depending on the photon energy, the absorbed photons can generate electron-hole pairs in the dielectric. These electron-hole pairs can undergo photoconduction and can be photoemitted. For photoemission to occur, the generated electrons must have enough energy to overcome the band gap and electron affinity of the dielectric.[1,9]

Photoemission of electrons leads to charge imbalance in the dielectric. If the dielectric is grounded, then to maintain charge neutrality, electrons will flow from ground into the dielectric. Thus, in a steady state, a current, i.e., the substrate current, equivalent to the photoemission current, will flow into the dielectric.[1,9]

The photoemission/substrate current is a function of the photon flux transmitted into the dielectric. On the other hand, reflectance is a function of the reflected photon flux. Since transmitted flux through and reflected flux from the dielectric are complementary, we expect the substrate current to be inversely related to the reflectance of the dielectric. That is, the substrate current should increase as reflectance decreases and vice versa.

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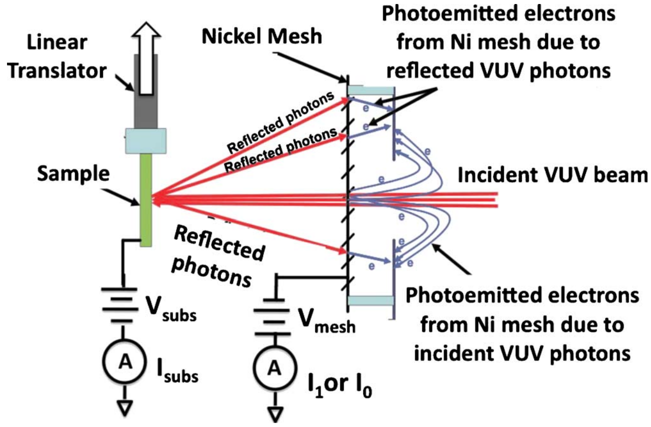

FIG. 1. (Color online) Measurement of incident and reflected photon flux with a Ni mesh and sample normal to the incident beam.

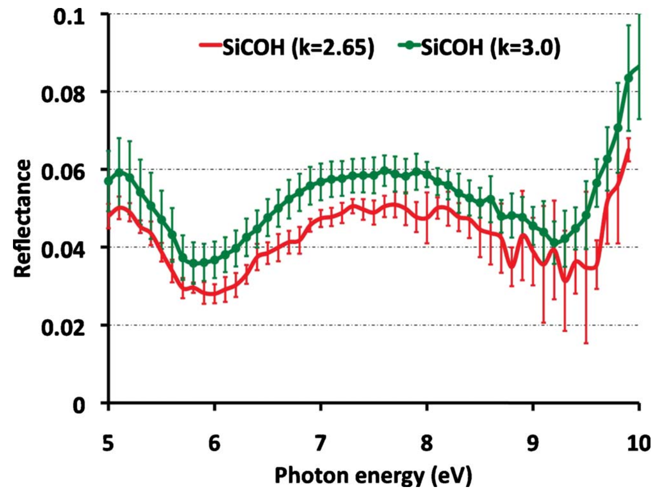

FIG. 2. (Color online) Calculated reflectance for SiCOH (k=2.65 and k=3.0) for 5–10 eV photon energies.

II. EXPERIMENT

The Synchrotron Radiation Center at UW-Madison was used as a VUV photon source for reflectance and substrate current measurements. The experimental setup shown in Fig. 1 was installed in a vacuum chamber connected to the synchrotron. To measure the reflectance, a nickel mesh with 90% transparency was placed in the path of the beam. The mesh is connected to a picoammeter (Keithley-486). The dielectric sample is mounted normal to the synchrotron beam with a separate picoammeter used to measure the substrate current.

The photons absorbed in the nickel mesh will result in photoemission. Thus, the current drawn by the nickel mesh is proportional to the total photon flux incident on the nickel mesh.[10,11]

Reflectance is calculated from the ratio of the measured reflected photon flux to the measured incident photon flux. To calculate the reflected photon flux, the nickel mesh current was measured both when the sample was present and when it was absent. When the sample is absent from the path of the VUV photons, a photon dump is used to minimize any possible reflectance. Thus, the net photon flux incident on the nickel mesh when the sample is absent is the synchrotron flux. Under these circumstances, the reading from the picoammeter (I_0) is proportional to the synchrotron flux.

When the sample is present, as shown in Fig. 1, some of the photons are reflected from the sample. Since the sample is placed normal to the VUV photon flux, the reflected photons can travel back to the nickel mesh where they also cause photoemission. The combination of normal incidence and smooth dielectric coating maximizes the normal reflectance. Thus, under these conditions, the net photoemission current (I_1) drawn by the nickel mesh is the sum of the incident synchrotron photon flux and the reflected photon flux. We calculated the reflected photon flux from the difference ($I_1 - I_0$) in the two photoemission currents. The reflectance is then calculated from the expression

$$\text{reflectance} = (I_1 - I_0)/(0.9 I_0).$$

The factor of 0.9 is needed to account for the attenuation in photon flux after passing through the nickel mesh. The substrate current, as opposed to the nickel mesh photoemission current when a sample is present, is measured with a separate picoammeter that was connected to the sample mount. To improve the accuracy of the measurements, the mesh was biased with −120 V. The bias prevents photoemitted electrons and any other electrons in the vacuum chamber from being collected by the mesh and causing incorrect current measurements.

III. DATA ANALYSIS

Reflectance measurements were made on 266 nm (k =2.65) and 458 nm (k=3.0) organosilicate glass (SiCOH) deposited on silicon using a Novellus Systems Vector Express™ system. Since SiCOH (k=3.0) is less porous than SiCOH (k=2.65), we expect the reflectance for SiCOH (k =3.0) to be higher, but since the two samples are similar materials, the basic relations between reflectance and substrate current as a function of photon energies should be similar.[12,13]

Figure 2 shows the measured reflectance for these two samples as a function of VUV photon energy between 5 and 10 eV. As expected, the change in reflectance as a function of energy is similar for the two samples with SiCOH (k=3.0) being more reflective. The reflectance measurements were found to be repeatable. However, at higher photon energies, the synchrotron photon flux decreases, which causes the mesh current to decrease. As a result, the signal-to-noise ratio decreases in the reflectance formula. Thus, the reflectance measurements resulted in larger variations in this portion of the spectrum as shown. Nevertheless, the reflectance measurements show good agreement with available data in the literature.[14–16]

The calculated reflectance showed the expected inverse correlation with the measured substrate current. Figure 3

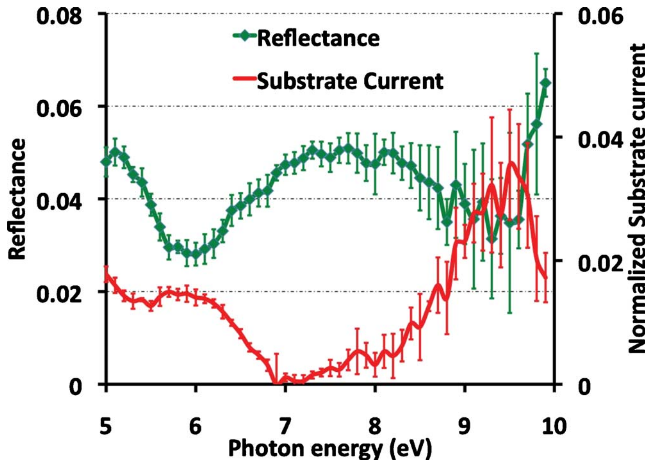

FIG. 3. (Color online) Calculated reflectance and normalized measured substrate current for SiCOH (k=2.65) for 5–10 eV photon energies.

shows the reflectance and the substrate current for SiCOH (k=2.65) as a function of VUV photon energy. This validates the hypothesis that it is possible to obtain the reflectance from substrate current measurements.

We found that calculating reflectance from the substrate current is advantageous for two reasons. First, we can use low synchrotron photon flux for substrate current measurements, since otherwise dielectric properties can be affected by VUV photon irradiation. Second, it is easier to measure the reflectance from the substrate current in this way especially for materials that have low reflectance. In addition, the substrate current measurements in comparison with the reflectance measurements have larger signal-to-noise ratios. This is because the substrate current is measured directly; whereas the reflectance is calculated as the difference of two currents. This combination of advantages and ease of measurements makes the substrate current an effective method to measure reflectance.

IV. CONCLUSIONS

In conclusion, we found that the reflectance in the VUV range of the spectrum can be measured by using a simple experimental setup that measures the reflected flux by measuring the photoemission current from a partially transparent mesh. We found that the reflectance can also be inferred from substrate current measurements for SiCOH. The reflectance and its inverse correlation with substrate current are of interest in the pursuit of reducing dielectric damage during device processing.

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