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APPLICATION NOTE

Thermal expansion of thin dielectric layers

Using Spectroscopic Ellipsometry

State-of the-art integrated circuits require a low dielectric constant (low-k) material. Porosity of these new materials further reduces the k value. Since interesting porous materials are combinations of organic and inorganic components, expansion of the individual components can be very different.
Temperature dependent ellipsometry offers the possibility to measure thermal expansion of thin layers. In addition, it can provide information about water absorption behavior of these samples. This enables a faster route for device optimization, since these properties are vital to the reliability of devices.

Ellipsometry

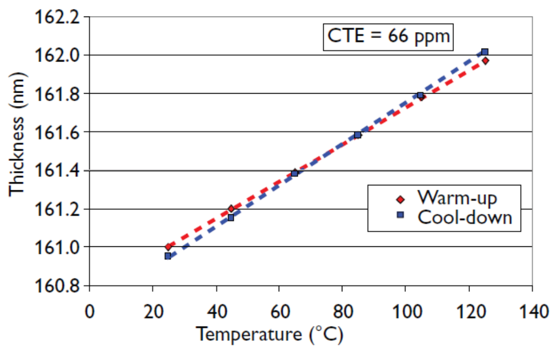
Ellipsometry, a non-contact and non-destructive optical technique, is widely used for the determination of film thickness and optical constants. The technique measures the polarization state of reflected light after interaction with a sample. By acquiring data at a range of temperatures, extremely small differences in thickness and optical properties can be detected. This unique quality is used to determine the coefficient of thermal expansion (CTE) of 100 – 500 nm thick low dielectric constant layers for microelectronics.

Measurements

Measurements as a function of temperature are always performed on one and the same spot (to exclude lateral inhomogeneity as a source of error), and with monitoring both the warm-up and the cool-down behavior. This enables identification of possible irreversible changes in the sample. Data collection at one temperature takes about 10–15 minutes. Total analysis time will depend on the number of temperatures chosen to cover the selected range.

Coefficient of thermal expansion

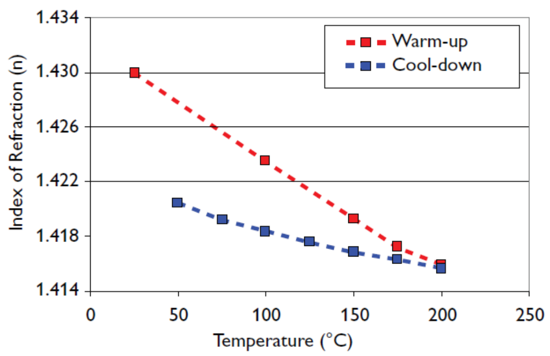
The CTE of porous low-k dielectrics can vary widely. Actually, measured CTE values range between 20 and 180 ppm. In general, samples with a large fraction of organic polymer show the highest CTE-values. A typical low-k material warm-up / cool-down cycle is presented in Figure 1.



By systematic CTE studies of a series of materials with different compositions, the selection of low-k dielectrics with desired properties can be optimized.

Refractive index

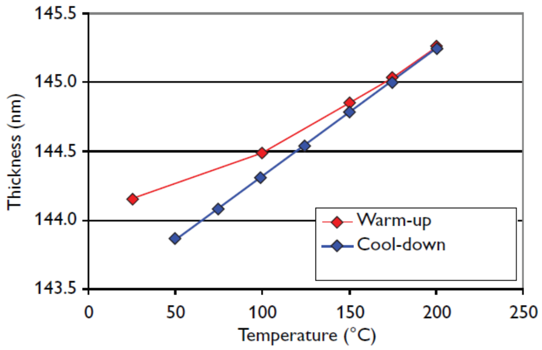
The refractive index (n) obtained at different temperatures also gives valuable information about further details of the layer (see Figure 2).



If the index of the dense material (or the index of material with a known porosity) is available, the porosity of the layer under investigation can be calculated.

Absorbed water

Another aspect is the water absorption behavior of porous thin layers. Figure 2 shows the variation of the index of refraction at different temperature steps. The fact that the warm-up and cool-down lines are not identical implies that water is evaporated from the pores of the sample during warm-up. The index of refraction changes, because water (n = 1.33) is replaced by air (n = 1.00) in the voids. The cool-down line shows the change of the index, without water present. The thickness variation of these samples during a warm-up and cool-down cycle is shown in Figure 3.



Summary

One of the intrinsic strengths of the ellipsometry studies presented here is the precision of the experimental data. By taking these data in a quasi in-situ experiment, at a range of temperatures, extremely small differences in thickness can be detected, as is evident from the figures. This unique quality was used to determine the thermal expansion coefficient and the water content of low dielectric constant layers. These data provided valuable input for device optimization.