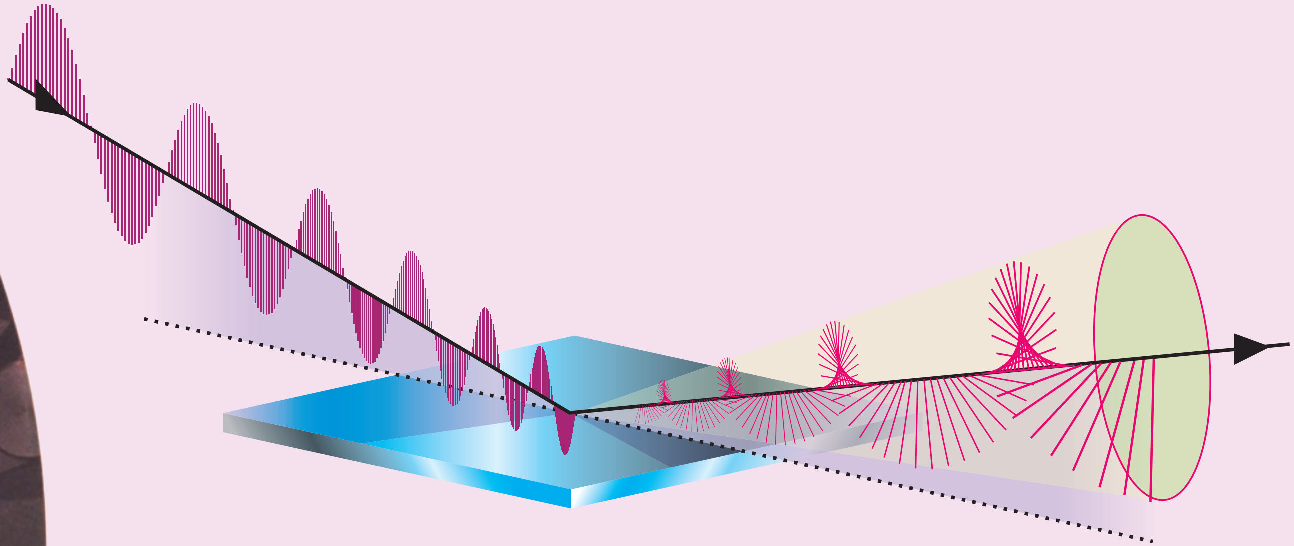

Thermal expansion of thin dielectric layers

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 can be very different. Temperature dependent ellipsometry offers the possibility to measure thermal expansion of thin layers. In addition, it provides information about water absorption behaviour of these samples. This enables a faster route for device optimisation, since these properties are vital to reliability of devices.

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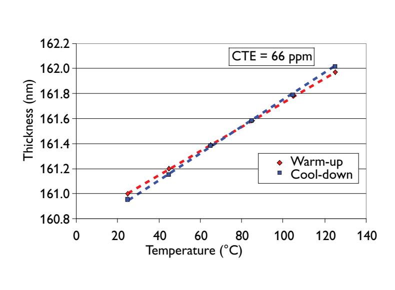

Fig. 1: Determination of the coefficient of thermal expansion for an exemplary low-k sample.

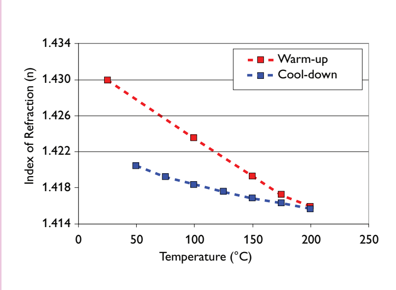

Fig. 2: Change of index of refraction of a thin film of low-k material after a heating cycle.

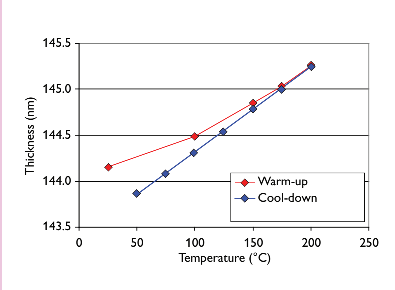

Fig. 3: Variations in thickness of a thin film of low-k material during a heating cycle.

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Ellipsometry

Ellipsometry, a 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 (see picture on the cover). 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 behaviour. This enables identification of possible irreversible changes in the film thickness or constitution. One data set at a given temperature takes about 10–15 minutes. A certain temperature range is covered with subsequent temperature steps.

Coefficient of thermal expansion

The CTE of different porous low-k dielectrics varies quite a lot. Actually measured CTE values range between 20 and 180 ppm. In general, samples with a large amount 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 could be optimised.

Refractive index

The refractive index (n) obtained at different temperatures, gives also 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 behaviour 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 in the warm-up period. The index 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 being present. Following the thickness variation of these samples during a warm-up and cool-down cycle, the graph in figure 3 is obtained. Without water being present we see a straight line for both curves. The observation of shrinkage (as in figure 3) implies evaporation of absorbed water.

Summary

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

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