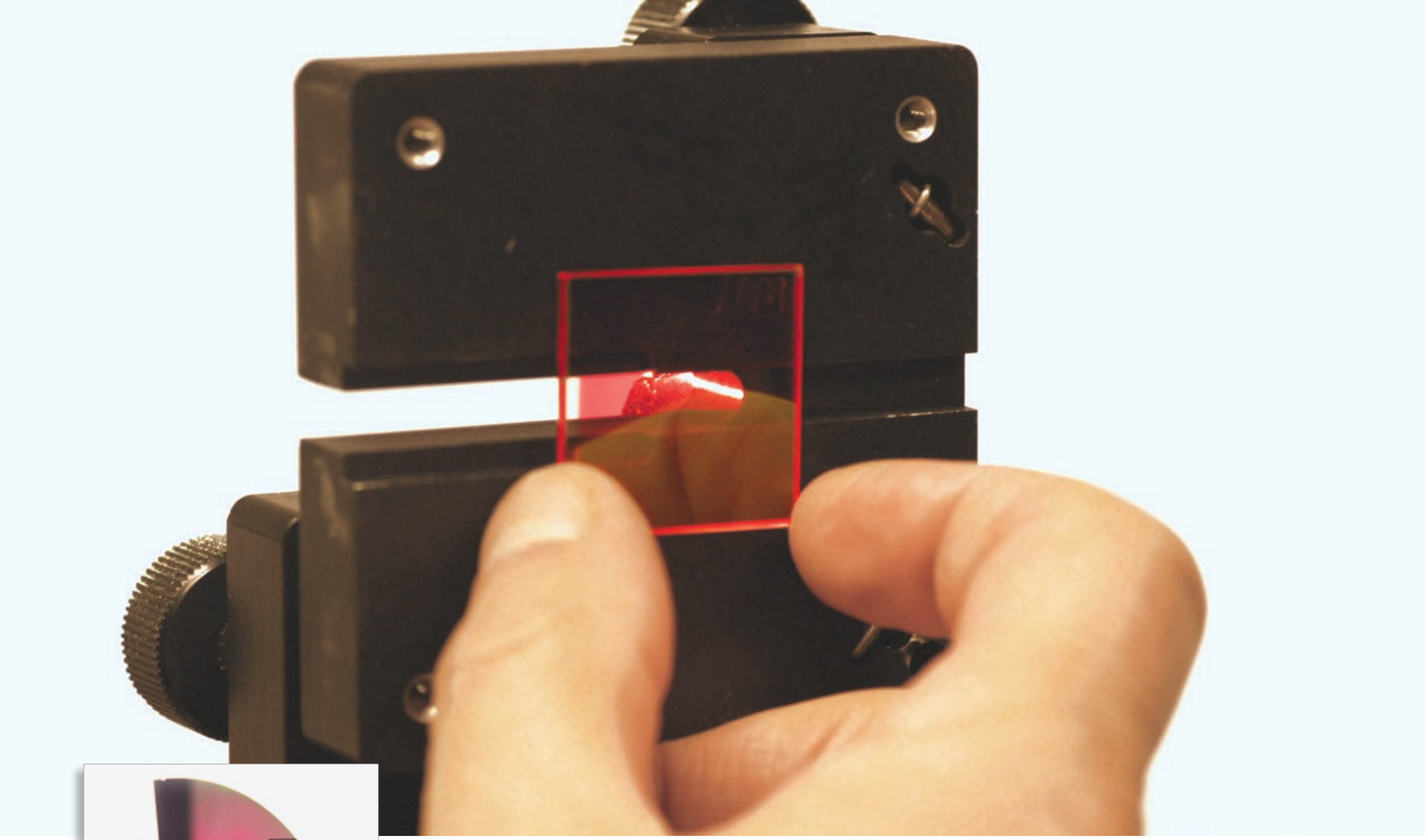

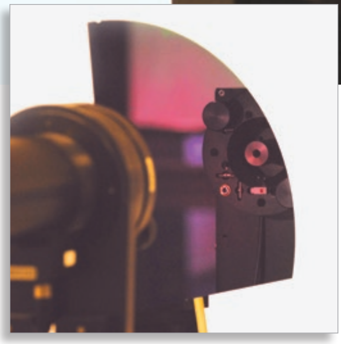

Spectroscopic Ellipsometry

- layer thickness
- refractive index
- extinction coefficient
- multi-layers
- temperature dependence

Ellipsometry is a powerful analytical tool in the characterisation of thin films in many applications, including semiconductors, dielectrics, metals and polymers. It is a non-contact, non-destructive optical technique, which measures the polarization change of reflected light after interaction with a layer. This change in polarisation is related to thin film properties like thickness and refractive index.

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Theory

Ellipsometry involves light reflecting from a surface of interest.The plane of incidence is the plane perpendicular to the surface of the sample (see Figure 1).The polarization state of the light is defined by two components, one parallel (p) to the plane of incidence and one perpendicular (s).

It is important to understand that these components reflect differently from the sample, depending on the angle of incidence. Notice the differences in reflection of the ”p” and ”s” component in the silicon example of Figure 2a. The Rs reflection increases steadily, while the Rp reflection goes through a minimum.

This angle is called the Brewster angle. Ellipsometry measurements are most sensitive to film characteristics at this Brewster angle.

As a light wave is propagating it appears to be a sinusoid from the side (Figure 3a). However, if you were to look down the z-axis with the wave coming directly into your eye, the electric field of the wave would appear to be a vertical line along the y axis as shown in Figure 3b.

The polarization of a wave can be rotated to any angle.To describe its polarization, the wave can be projected onto the X and Y axes. When a wave is defined like this, there are two electric field components, Ex and Ey. When these components are propagating in the same direction, perpendicular and in phase with each other, a linearly polarized wave results.

Elliptically polarized light is illustrated in figure 4. In this polarization state, the vectors Ex (the s component) and Ey (the p component) can take on any arbitrary phase and amplitude. The resulting concept is an ellipse propagating in space

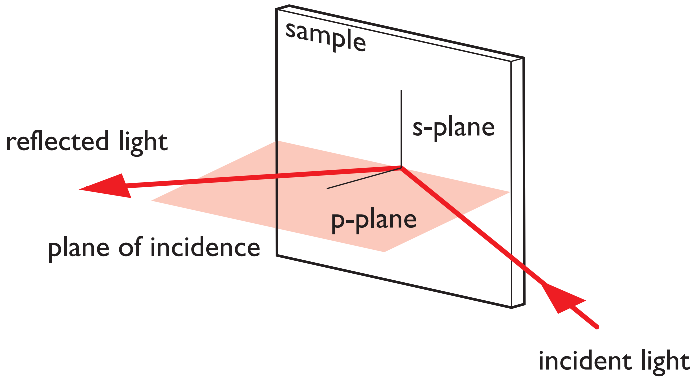


Fig. 1:The plane of incidence.

Ellipsometry

The term ellipsometry comes from measuring elliptically polarized light. Figure 1 illustrates the basic principle behind ellipsometry. First, the polarization state of incoming light is known. This incident light interacts with the sample and reflects from it.The interaction of the light with the sample causes a polarization change in the light, from linear to elliptical polarization. This change is measured by analysing the light reflected from the sample.

To describe polarization there are two parameters, orientation and ellipticity. They are related to the two ellipsometric values, Psi (Ψ) and Delta (Δ), which describe the polarization state of reflected light after interaction with a film (See Figure 2b).

Because we measure a ratio and a phase change of one and the same light beam, both parameters can be measured very accurately.

Measurements are not affected by light source intensity fluctuations.

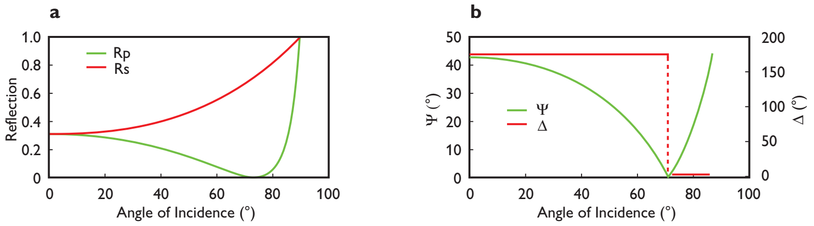


Fig. 2: a) the reflection as a function of angle of incidence for the parallel (Rp) and perpendicular (Rs) components of polarised light . b) behaviour of Psi (Ψ) and Delta (Δ), which describe the polarization state of reflected light after interaction with a film. Ψ is the Ratio of the reflected intensities Rp and Rs and Δ is the relative phase change of these two waves.

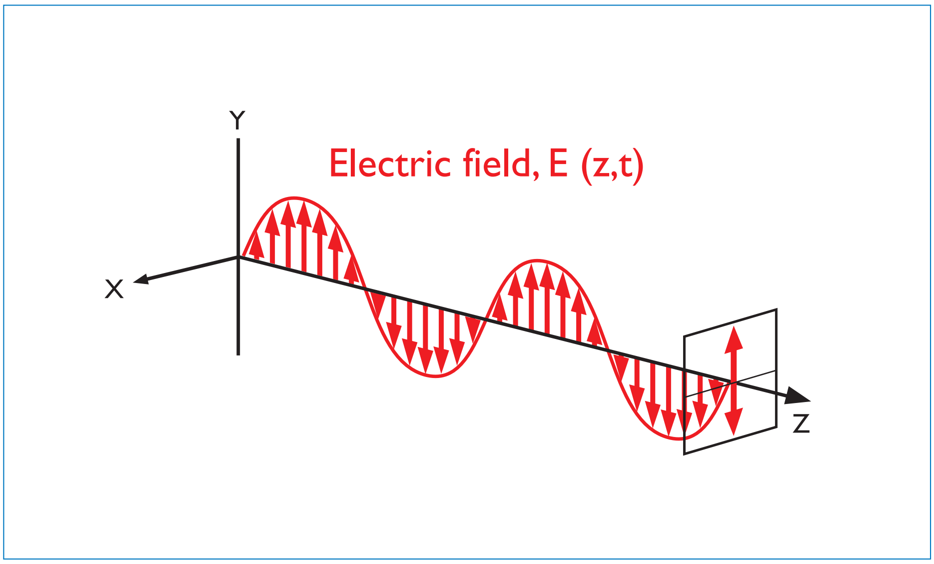


Fig. 3: Visualisation of propagating linearly polarised light.

VASE

Variable Angle Spectroscopic Ellipsometry (VASE) is used to measure at different angles of incidence and in a wavelength range of interest. This helps to ensure optimum sensitivity to any problem and determine multiple unknown parameters in difficult, multi-layer samples.

Refractive index and extinction coefficient

Ellipsometry is primarily used to measure film thickness, the refractive index (n) and the extinction coefficient (k). Both n and k are needed to describe real materials and are not constant, but vary with wavelength and temperature.

Layer thickness

When light is incident on a thin film it is reflected by both the top and bottom interfaces. Each reflected wave will have its own phase and amplitude, which causes interference in the reflected light.Thicker films will have more oscillations versus wavelength (Figure 5). This enables very accurate layer thickness measurements, both for single layer thin films (see Figure 6) as well as for multilayer stacks.

Data Analysis

Ellipsometry does not actually measure optical constants or film thickness, but Psi and Delta are functions of these characteristics.
To extract useful information about thin films, a model is constructed that describes the optical parameters of the sample. Then, the unknown parameters and the thickness are fit to obtain a best match between the theoretical response and the experimental data.

Fig. 4: Visualisation of propagating elliptically polarised light. For an elliptically polarized wave both components have arbitrary amplitude and phase.

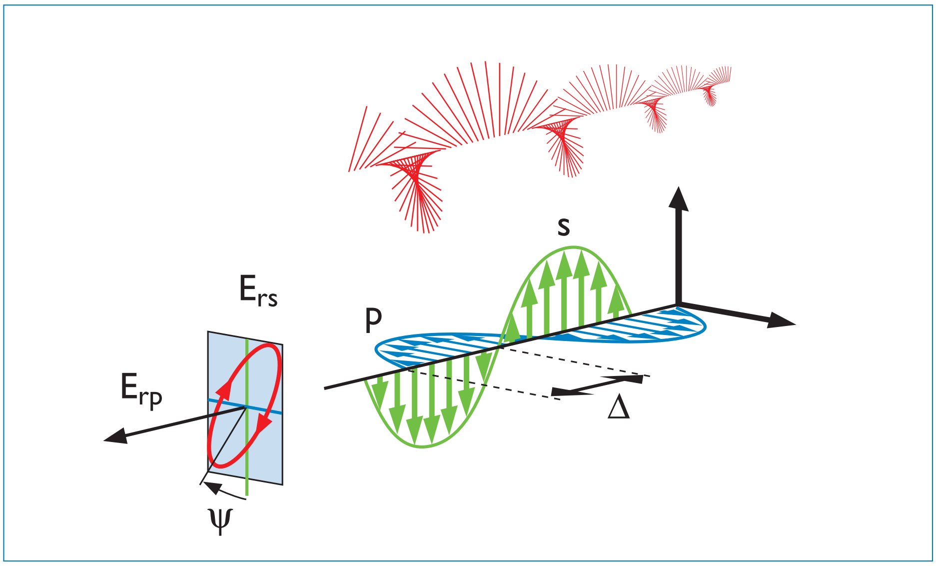
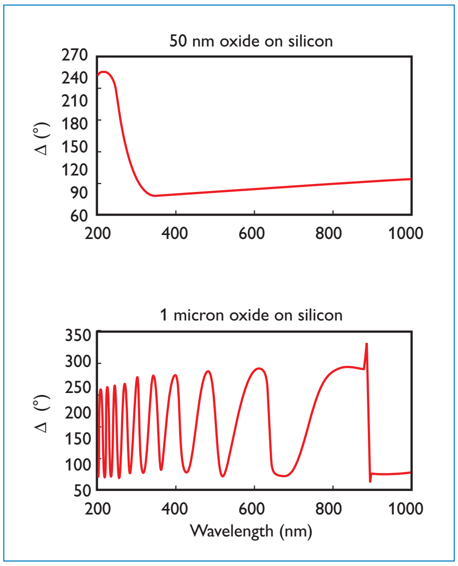


Fig. 5: Layer thickness studies: the number of oscillations is characteristic for the film thickness.



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Applications

- thickness, optical constants of organic and inorganic thin films on flat substrates
- individual layer thicknesses of complex multi-stack samples
- thermal expansion of organic and inorganic thin layers
- optical anisotropy of polymer films

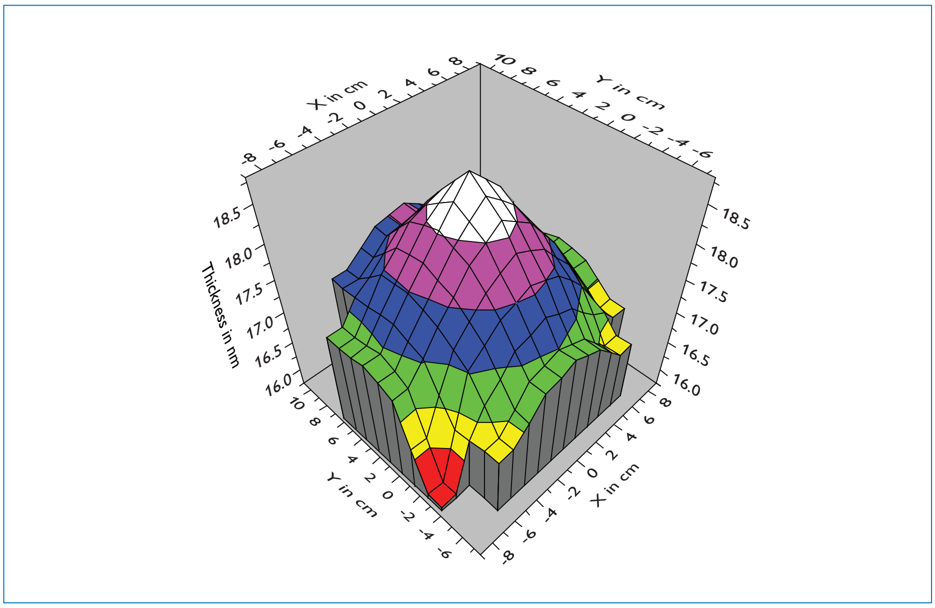

Fig. 6: Example of thickness mapping of a layer of phase change material as used as the data storage layer in DVD+RW discs.

Characteristics

Measurement

- Measurement of Psi, Delta data at different angles of incidence over a wide wavelength range (193 – 1700 nm) with a variable step-size.

Acquired data

- Reflection and transmission ellipsometric data, polarized transmission and reflection intensity, anisotropic measurements.

Lateral information

- >1 mm, depending on spot size. Automated sample translation stage (150 x 150 mm) available for mapping procedures.

Accuracy (thickness, refractive index)

- Strongly dependent on sample geometry.

Sample type & requirements

- Solids, thin layers and multilayers with optically flat substrates. Thickness from sub-monolayer coverage to µm range.

Heating experiments

- Temperature (max. 300°C) dependent measurement in different atmospheres, used for the determination of the thermal expansion of thin films.

Spot size

- 200 µm or 2 mm.

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