

Topography and Refractive Index Measurement
of a Sub- μm Transparent Film on an Electronic Chip
by Correlation of Scanning Electron and Confocal Microscopy



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Author: Matthias Vaupel, Hans Zimmermann
Carl Zeiss Microscopy GmbH

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Sample: Mobile phone chip, letter printed as a gold layer
on silicon surface. All covered by polymer passivation
layer.

Instrumentation

1. Confocal Microscope, e.g. LSM 700 on Axio Imager.Z2m with software ConfoMap
2. Electron Microscope: FIB-SEM Auriga
3. Sample holder CorrMic Mat, to mark and relocate a particular position with different microscopes

Tasks

- Measure the topographic map of a metal layer through the polymer passivation layer fast and non-destructively with high optical lateral resolution
- Determine the refractive index of the polymer passivation layer – Determine the layer thickness by FIB-SEM

Introduction

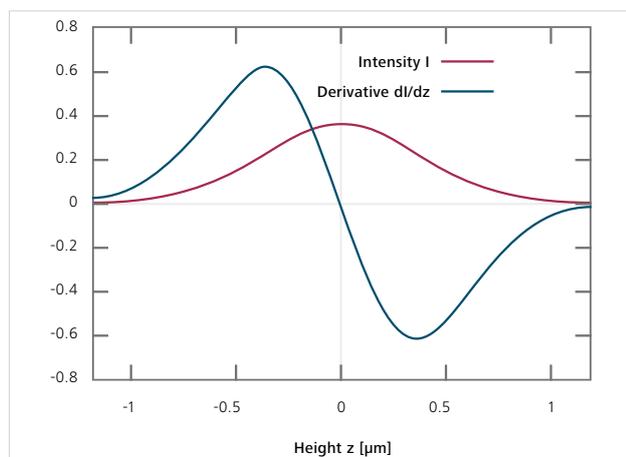
Fast and non-destructive 3D-topographic measurements are frequently done optically, i.e. by white light interferometry [1], total interference contrast microscopy (TIC) [2], and laser scanning confocal microscopy (LSCM) [3]. Disadvantage of white light interferometry is the 3 times worse lateral resolution in comparison with the other methods due to the use of Mireau-objectives. TIC overcomes this disadvantage, but it only provides topographic line scans but no 3D-topography yet. Consequently LSCM has been used for this task so far. LSCM records a z-stack of confocal images. The working distance (defined from objective to sample), which has the maximum of intensity along the z-coordinate (fig. 1a, bare substrate), defines the measured height at the measured position on the sample. In case of a surface coated with a film thicker than the depth of focus (fig. 1b), two distinct relative maxima are observed in the position with a

measured distance d' in between. In this case a simple relation is used to calculate the real thickness h

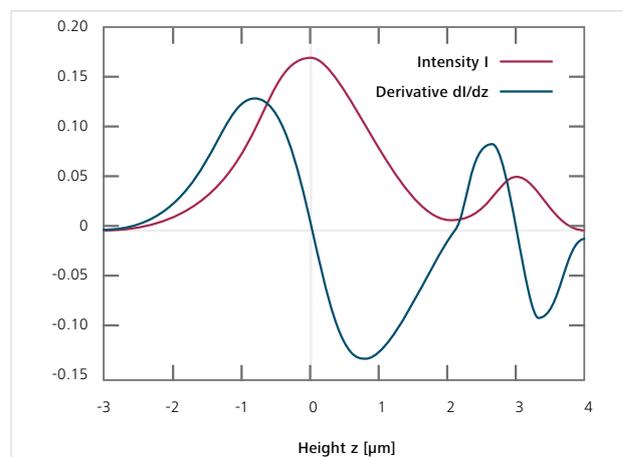
$$(1) \quad h(h',n)=h' \cdot n$$

from the measured thickness h' and the refractive index n of a thick transparent film (fig. 1b).

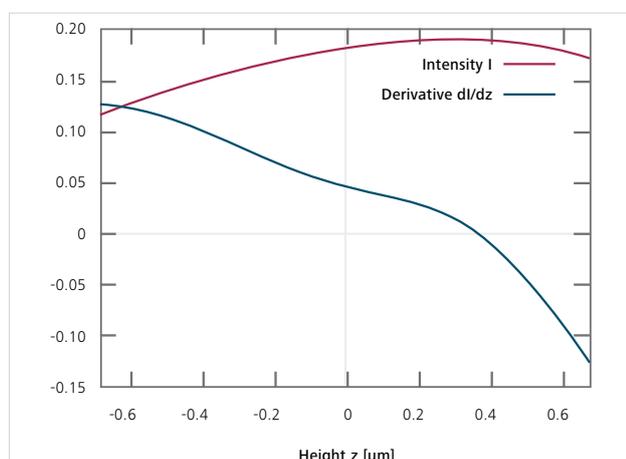
If the film thickness is below the depth of focus only one maximum exists in each position (fig. 1c, d) and relation (1) does not hold anymore. The film thickness can still be measured near the edge of the coating by the difference of the positions of the maximum on the film and the maximum on the bare substrate, where both maxima are measured at different positions. Let us assume for simplicity, that the height of the bare substrate is at zero. The real height of the coating can still be obtained from the measured thickness h'



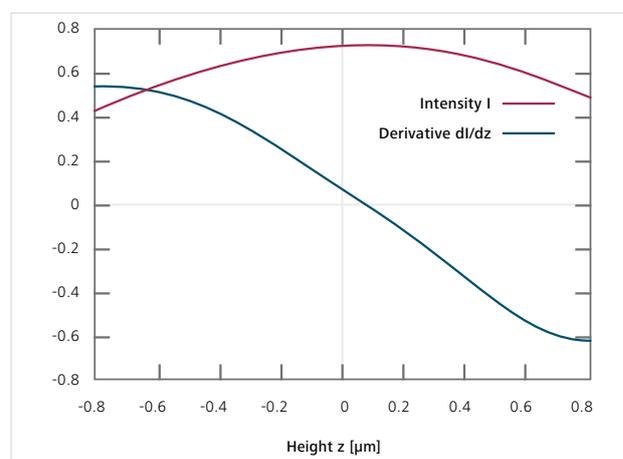
a) Bare silicon substrate



b) 3 μm thick polymer film on silicon substrate



c) 0.68 μm thin polymer film on silicon substrate



d) 0.54 μm thin polymer film on gold substrate

Figure 1 Confocal (with closed pinhole) detected intensity vs. height above the substrate's surface; intensity reflected of each interface is calculated by a Gaussian function with Fresnel reflection coefficient as amplitude. Maxima of the intensity are made visible by the zeros of the derivative of intensity. The polymer's refractive index is assumed $n = 1.6$, and its film thickness is measured by the z -distance of the maxima of the intensity in b). If the film thickness is below the width of the Gaussian function only one maximum exists in c). The z -position of this maximum depends on the optical parameters of the sample. I.e. it depends besides the film thickness also on the amplitudes of the Gaussian functions, which are given by the Fresnel reflection coefficients or by the complex refractive indices. The real film thickness can be obtained from the measured z -position of the maximum by inversion of the optical model of the sample. In the case of a highly reflective substrate, i.e. gold in d), the measured film thickness can be much smaller than the real film thickness

(z -position of the maximum) by inversion of the optical model of the sample. Instead of relation (1) in this case the measured thickness h' is a function of the complex refractive indices of coating and substrate. The function d' can be numerically evaluated by the following approach of *Sung et al 2004* [3]: add the intensity functions $I(z)$ ("peaks") of each interface in the layer stack incoherently. The functions $I(z)$ can be approximated by a Gaussian function with the depth of focus as width and the Fresnel reflection coefficient as amplitude. The Fresnel coefficients are defined by the complex refractive index $N = n + ik$. The z -coordinate of the measured

maximum of intensity is simulated by the zero of the derivative of the sum of intensities of all intensity peaks. The real film height h is obtained from the measured height h' by numerical inversion of the optical model: The difference of calculated and measured film height is minimized as a function of one model parameter, which is e.g. the refractive index or the real thickness of the film. Ref. *Sung et al 2004* [3] has applied the optical model only with real refractive indices only in the case of distinct intensity peaks, equi-valent to thick films (fig. 1a), while here the focus is on thin films.

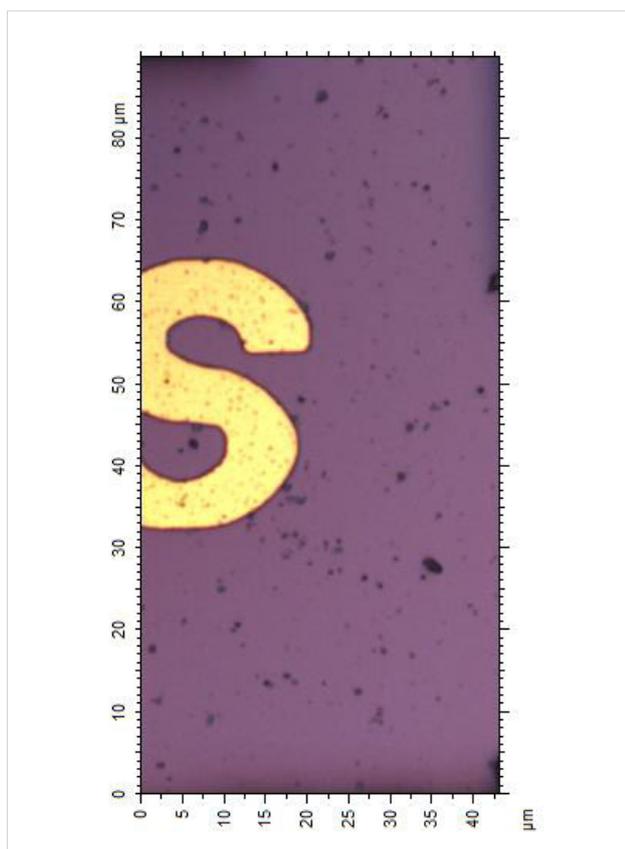


Figure 2 Brightfield micrograph of a mobile phone chip; the film thickness of the golden letter is under inspection

Measurements

The layer thickness of the gold film in shape of a letter in fig. 2 shall be mapped for quality control by LCSM. To this end a correct optical model of the sample is required. A schematic of the layer stack (fig. 4) and the model parameters, layer thicknesses of the polymer and of the gold film are obtained by the cross section in the FIB-SEM image (fig. 3). The refractive indices of gold and silicon are $N_{Au} = 0.346 + 2.731 i$ and $N_{Si} = 4.073 + 0.032 i$ respectively at 550 nm wavelength [4]. The uncorrected confocal height map (fig.5) indicates that the gold layer is about 48 nm below the silicon surface in contradiction to the schematic in fig. 4., where it is 260 nm above the silicon surface. This contradiction is resolved with the optical model. The height error, the difference of calculated and measured height, $(2) h_1'' - h_0 - h_0'' - h_2''$ with $h_0'' = 0.048 \mu\text{m}$ is plotted in fig. 6. The real refractive index of the polymer $n = 1.613$ is obtained at zero error. The z-scale of the height map (fig. 5) can be multiplied by the ratio of real (FIB-SEM-measured) height and uncorrected (confocal measured) height to obtain the real height map (fig. 7) from the confocal height map (fig. 5).

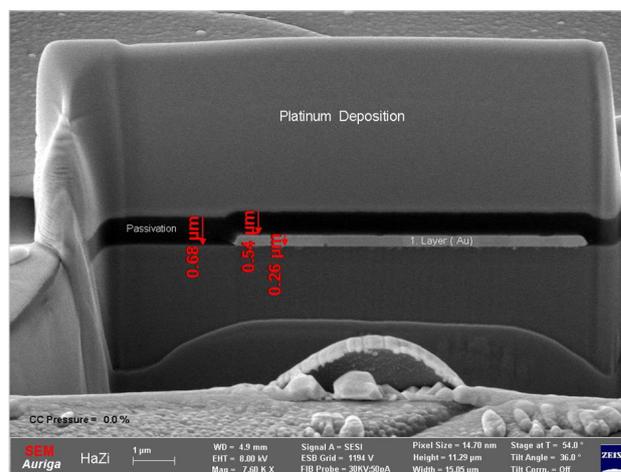


Figure 3 Golden letter, cross section with FIB-SEM Auriga, measurements of layer thickness in red annotation: $h_1 = 0.68 \mu\text{m}$, $h_2 = 0.54 \mu\text{m}$, $h_0 = 0.26 \mu\text{m}$

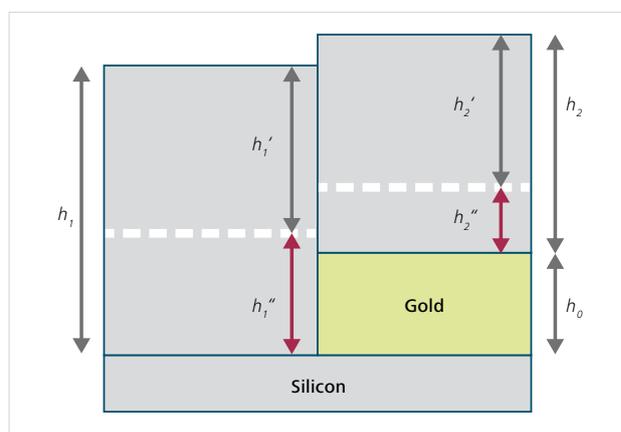


Figure 4 Schematic cross section acc. fig.3

Results

The lineshape of the intensity distribution in a confocal z-scan is calculated for different thin transparent films with given refractive index on different substrates. On thin film samples the uncorrected confocal measured height varies between 0 and 100% of the real height depending on the refractive indices and film thickness. The equation (1) is no longer valid. The incoherent superposition of reflection on surfaces must be calculated instead. Such a calculation enables to map film thickness and height of the substrate with a few nm z-resolution. Multilayer structures could be analyzed in the same approach.

The information of the layer thicknesses e.g. from FIB-SEM images enables to solve the calculation for the refractive index of the film. This information also enables to rescale the uncorrected confocal height map of the substrate under the transparent film.

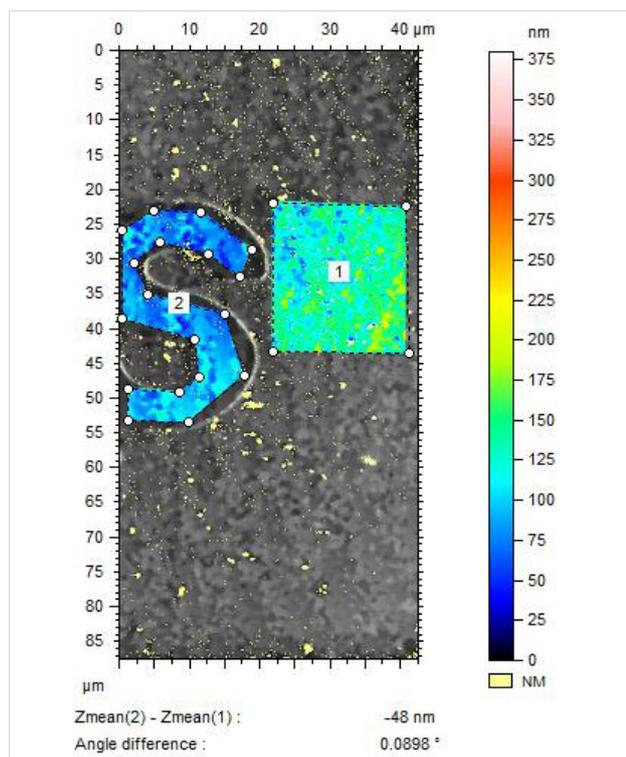


Figure 5 Raw uncorrected confocal height map with ROIs; the letter's (ROI 2) height appears negative with respect to the surrounding silicon (ROI 1) in contradiction to fig.4

Conclusion

FIB-SEM Auriga from ZEISS is an ideal tool to measure the layer thickness in the range of a few nanometers. It is desired to get the FIB-SEM measurement at the same position, where the confocal microscope measures the topography of films or of the substrate, in order to obtain correct confocal height maps on thin film coated samples. The correlative microscopy enables this result by means of its sample holder for exact location of samples in the electron and under the confocal microscope.

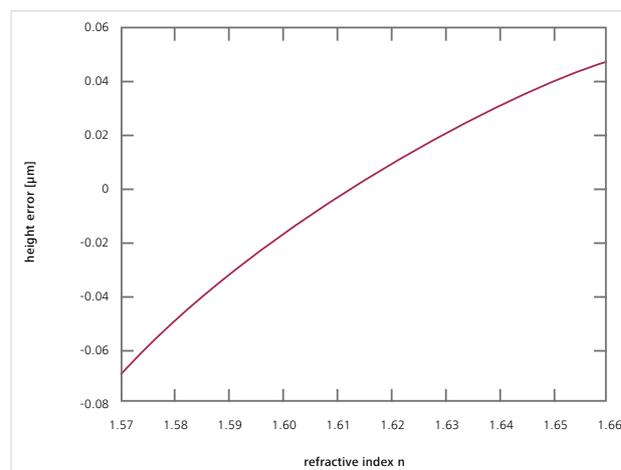


Figure 6 Height error of calculated and measured height: $+h_1 - h_2 - h_0 - 0.048 \mu\text{m}$. Zero error is obtained at refractive index $n=1.613$ of the polymer

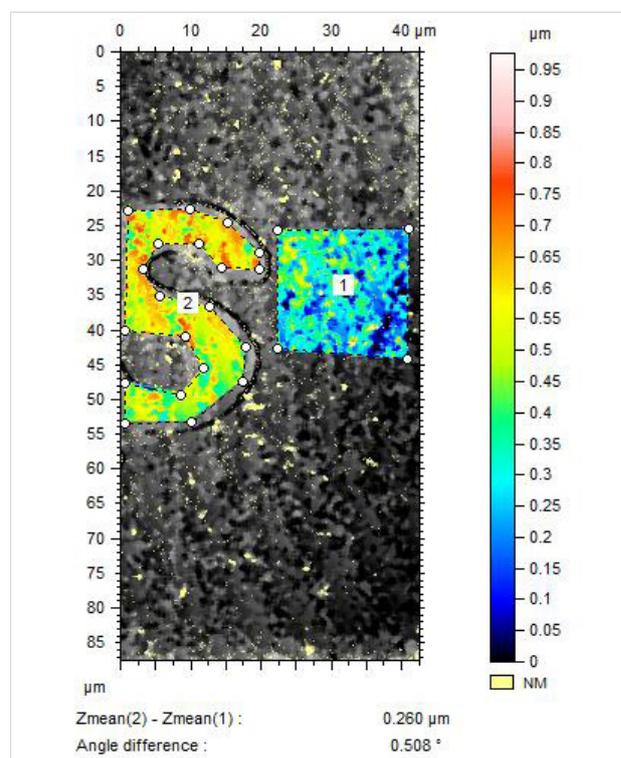


Figure 7 Height map corrected by means of the optical model. Confocal measurement of mean height between ROIs 1 and 2 yields about 260 nm gold layer thickness in agreement with the FIB-SEM cross section in fig.3

References:

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Carl Zeiss Microscopy GmbH
07745 Jena, Germany
microscopy@zeiss.com
www.zeiss.com/microscopy



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