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Combining Chromatic Confocal Microscopy and Spectral Interferometry into a single-shot high-precision multi-purpose measurement device

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Abstract
By combination of chromatic confocal microscopy and spectral interferometry, a hybrid system enables high-resolution single-shot topography measurements (chromatic confocal spectral interference). Using the same setup, it is also possible to measure refractive index as well as layer thickness of multi-layered specimens simultaneously in a single-shot with high lateral as well as axial resolution (chromatic confocal coherence tomography).

Metrology, Topography, Tomography, Interferometry, Chromatic Confocal, Single-shot

1. Introduction Bold, space 12pt bef., 3pt aft., 1.5 line

In industrial topography inspection, fast acquisition most often has to meet high precision. A high lateral resolution requires high Numerical Aperture (NA) objectives, which also provide axial resolution for confocal schemes. Interferometric methods like Scanning White-Light Interferometry, on the other hand, achieve axial resolution on a wavelength scale. However, most established devices need some kind of mechanic or spectral scan to operate and are therefore not suited for fast single-shot operation.

In Chromatic Confocal Microscopy (CCM), adding a chromatic focal separation to the confocal scheme allows for single-shot operation with high NA (i.e. high lateral/axial resolution), while maintaining a large axial measurement range. But confocal methods are severely affected by artefacts near steps or in case of strong local curvatures of the specimen's surface. Single-shot operation is also feasible using interferometry, which is less affected by these problems: Spectral Interferometry (SI) provides very high axial resolution, but the measurement range is limited by the depth of focus, hence the NA.

We present our recent results achieved by combining both methods, CCM and SI, in one sensor to profit from their individual advantages while evading their limitations. The method called Chromatic Confocal Spectral Interferometry (CCSI, section 2) is capable of sub-micron single-shot topography measurements, also on uncooperative specimens. Here, the results from the decoupled information channels (CCM and SI) are combined to achieve interferometric resolution in absolute topography measurements over a large axial measurement range with very few artefacts left.

This combination of decoupled information channels is also very useful in case of multi-layered or contaminated objects: In this mode, called Chromatic Confocal Coherence Tomography (CCCT, section 3), we make use of the fact, that both information channels, confocal and interferometric, are differently affected by the (probably unknown) refractive index between two surfaces. This enables for simultaneous single-shot high-resolution measurement of multi-surface topographies as well as the refractive index of the layers.

2. Chromatic Confocal Spectral Interferometry (CCSI)

The combination of CCM and SI into CCSI [1-4] to measure topographies has two main advantages: It is possible to achieve the interferometric axial resolution of SI in combination with the high lateral resolution of high aperture objectives and the large measurement range of CCM. On the other hand, the combination gains robustness from the two independent channels. Thus, artefacts and measurement errors as described in [5] are overcome.

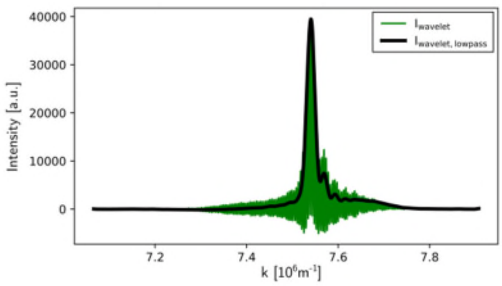

Figure 1: CCSI signal.

The signal shown in fig 1. carries its confocal information in the envelope of the peak, while the high-frequency part of the wavelet gives access to the interferometric information. The confocal value is evaluated by the centre-of-gravity of the envelope's upper half. Out of different interferometric algorithms, a lock-in like evaluation showed best results [3]. By a combination of different evaluation methods, a more robust evaluation is gained, reducing uncertainties and artefact induced errors significantly [4].

3. Chromatic Confocal Coherence Tomography (CCCT)

Interferometric measurements overestimate the geometric thickness d by the refractive index n, as they measure the optical thickness d_{int}:

$$d_{int} = d \cdot n \qquad (1)$$

On the other hand, confocal systems gain the value d_{conf}, an underestimation of d by n and a correction factor depending on the numerical aperture NA of the used objective, as can be seen from fig.2:

$$d_{conf} = \frac{d}{n} \cdot \frac{\sqrt{1-NA^2}}{\sqrt{1-\left(\frac{NA}{n}\right)^2}} \qquad (2)$$

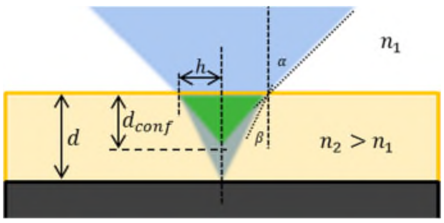

Figure 2. Refraction at semi-transparent surface. Confocal schemes underestimate the actual layer thickness.

The combination of eq. (1) and (2) gives a fourth-order polynomial, which has only one real-valued positive solution. Hence, it is possible to evaluate both, layer thickness and refractive index simultaneously, if confocal and interferometric information is available.

If the distance between two surfaces is sufficient, the confocal filtering suppresses interference of these surfaces and the acquired signal (fig.3) is dominated by two CCSI like wavelets, which can be evaluated similarly to the description above. The distance of the envelope's peaks is d_{conf}, while the difference of the frequencies under each peak gives d_{int}. Using the demonstrator described in section 4, proof-of-concept measurements where carried out on different slabs of fused silica and diamond. The results for thickness and refractive index showed a deviation of about 3% from the nominal values [6].

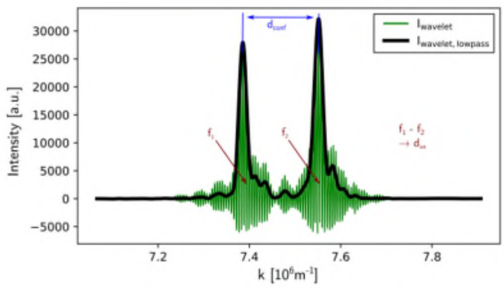

Figure 3: CCCT signal of a 50µm fused silica sample. The distance of the two envelope peaks corresponds to the thickness measured by the confocal channel, while the difference of the peaks´ respective wavelet frequencies is the interferometrically measured thickness.

4. Experimental setup

As both measurement modes described above work with the same type of signals, it is possible to decide which one to use even after the measurement. The capabilities of these methods are studied in a linnik type demonstrator setup depicted in fig.4 [5, 6]. An SLD with about 60nm Bandwidth (810..870nm) is joined via fibre to a spectrometer (resolution 0.08nm) and then coupled to the sensor head, where the single-mode fibre core acts as confocal filter.

In the object arm, a diffractive optical element generates the chromatically separated focal range. The signal from achromatic reference arm can be attenuated by neutral density filters to match the signal strength from the object.

An exemplary 20x 0.46 microscope objective yields a measurement range of about 100µm.

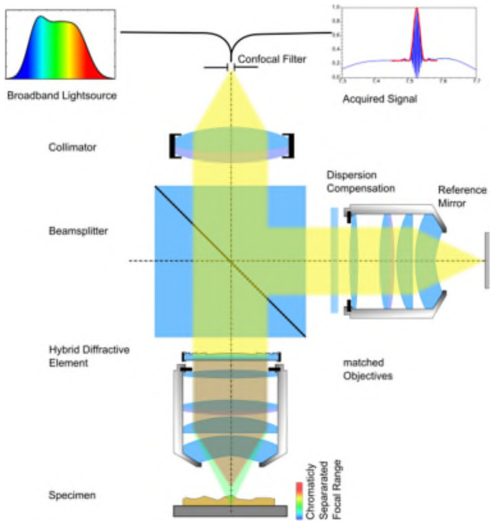

Figure 1. Schematic of multi modal demonstrator setup

5. Conclusion

By a combination of two well-known measurement principles – chromatic confocal microscopy and spectral interferometry – a multi-modal single-shot scheme is created, that has a wide range of applications. In CCSI mode, topographies can be measured with high lateral as well as axial resolution, while maintaining a large measurement range. In CCCT mode, all layers of a multi-layered specimen can be measured with nearly the same resolution as single surfaces using confocal schemes. The refractive index of each layer is simultaneously measured. However, for a correct measurement of a whole stack, each measurement point has to be traced laterally as well as axially through the measurement volume, as local curvatures act as small optical elements.

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