

Use of immersion liquids in Digital Holographic Microscopy

DHM™ T1000, used in conjunction with immersion liquids, provides a versatile instrument to metrology and quality control with the following features:

- ↳ **Non-contact**
- ↳ **Real-time 3D topography of high aspect-ratio samples**
- ↳ **Refractive index determination**
- ↳ **Suppression of unwanted one-side structure**

It is illustrated by the investigation in transmission mode of high aspect-ratio corner cubes and both-sides-structured samples.

High aspect-ratio samples are common samples to be characterized in micro- and nanotechnology. Their shape, quality, roughness,... often have to be measured to certify the sample specifications. Typical technologies for imaging these kind of structures relied on Scanning Electron Microscopy (SEM) or Scanning Probe Microscopy (SPM). The drawbacks of these techniques are the following. They are quite slow techniques because of their scanning process. SEM measurements are difficult to convert into quantitative data and SPM is based on a surface-contact that could damage sample surface. For most optical methods, height measurements in transmission configuration are impossible because the refractive index of the sample is unknown. Moreover, it is very difficult to obtain precise information from a single interface on a both-sides-structured specimen due to the effect of light propagation through the second structured interface.

DHM™ technology resolves all these difficulties. DHM™ systems capture holograms instead of intensity images as do conventional microscopes. The holograms are then digitally interpreted to reconstruct an image of intensity and another of phase. The phase contrast in transmission mode is a result of the optical path length (OPL)

differences in the distance travelled by the light beam and also the refractive indices of the different mediums encountered. DHM™ T1000 has the following intrinsic features:

- Non-contact measurements
- Real-time optical path length measurement with nanometric resolution
- Lateral resolution down to 300nm

Used in conjunction with immersion liquids, the DHM™ T1000 offers other important advantages:

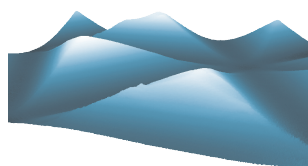
- High aspect-ratio specimen measurements
- One-side structure suppression
- Refractive index determination

Matching the refractive index of the immersion liquid to that of the sample allows the suppression of the interface structure in contact with the liquid, leaving only the second one to provide phase contrast information. This technique permits measurements of a single surface in transmission configuration.

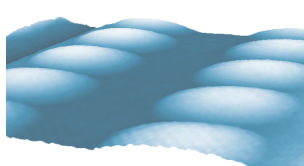
In addition to the conventional DHM™ 3D optical topographic measurements, immersion liquids allow sample refractive index

determination. By changing the refractive index of the medium between two acquisitions, the average refractive index over the vertical axis of the sample can be calculated.

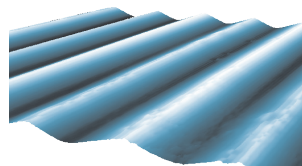
The patented method of the adjustment of the medium refractive index extends the DHM™ T1000 application field to hitherto hardly characterizable high aspect-ratio samples.



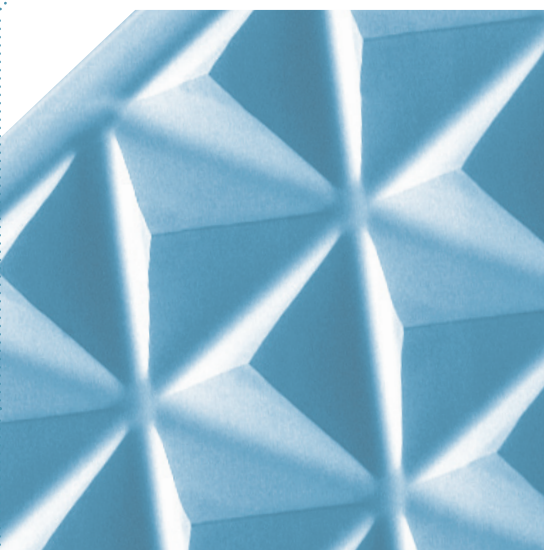
Corner cubes
base: 25µm, ratio: 1:1.4



Micro-lenses
diameter: 200µm, height: 50µm



Grating
period: 46µm, height: 25µm



SEM image of micro corner cubes. Aspect-ratio 1:1.4. Height: 50µm

Phase contrast imaging

The phase contrast image ϕ results of the optical path length (OPL) differences induced by the shape and refractive index of the sample (Fig.1):

$$\begin{aligned} \phi(x,y) &= 2\pi/\lambda \text{ OPL}(x,y) \\ &= 2\pi/\lambda [(n_s(x,y)-n_m) d(x,y) + n_m H] \end{aligned}$$

where λ is the wavelength, n_s and n_m the sample (resp. medium) refractive index, d the height of the sample and H its maximum size along the observation direction. H and n_m are constant over the image and they contribute as a phase constant.

High aspect-ratio

The ability to measure high aspect-ratio samples is conditioned by the assumption that the 2π ambiguity (phase jumps), well known in interferometric methods, induced by the OPL through the object are resolved laterally. A critical parameter is the lateral resolution, limited by the numerical aperture (NA) of the microscope objective (MO). A phase jump should not occur between two points laterally separated by a distance smaller than the Airy disc radius, otherwise it won't be resolved by the MO.

Even with a high NA objective, many samples present slopes that are too steep. To reduce the phase jumps, an immersion medium with a calibrated refractive index may be used. By

selecting one whose refractive index is near to the one of the sample, the phase delay is reduced. The knowledge of the medium refractive index allows retrieval of the quantitative topological information in the same way as in air, in reflection and transmission imaging.

The samples investigated are transparent UV copies of the metal shim of micro corner cubes arrays of 25 μ m base dimension. Used as retro reflectors, these structures present an aspect-ratio of more than 1:1.4.

Figure 2 shows the result of measurements (a) without and (b) with immersion liquid. The attenuation of the refractive index difference between the medium and the sample reduces the phase contrast. The apparent slope is thus less steep and may be imaged.

Refractive index determination

For quantitative height measurements in transmission imaging, the refractive index of the

sample has to be precisely known. This is not the case with these corner cubes. A procedure using two different immersion liquids is performed. The first medium used is a certified immersion liquid solution ($n_{M1} = 1.405$) and the second one distilled water ($n_{M2} = 1.332$). The two equations obtained enables the calculation of the sample refractive index. It is determined as $n_s = 1.517$.

One-side structure suppression

Adjusting the medium refractive index that of the sample ($n_m = n_s$) allows the cancellation of the interface in contact with the liquid. It allows the observation of the other surface only and detect its defects (Fig. 3). This technique is also useful to suppress the roughness or defects on one side of the sample in transmission configuration.

Conclusion

The DHM™ T1000 has been used to measure, with different immersion liquids, high aspect-ratio corner cubes and determine their refractive index. The technique also allows the suppression of the effect of light propagation through one interface in order to characterize only the other surface.

References

J. Kühn et al., "Measurements of corner cubes microstructures by high magnification digital holographic microscopy", *Photonics Europe 2006, Strasbourg, France*

<http://www.lynceetec.com/downloads/>

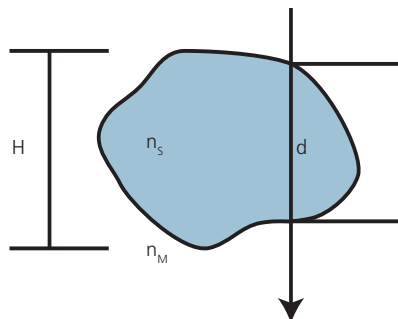


Figure 1: Schema for the OPL determination.

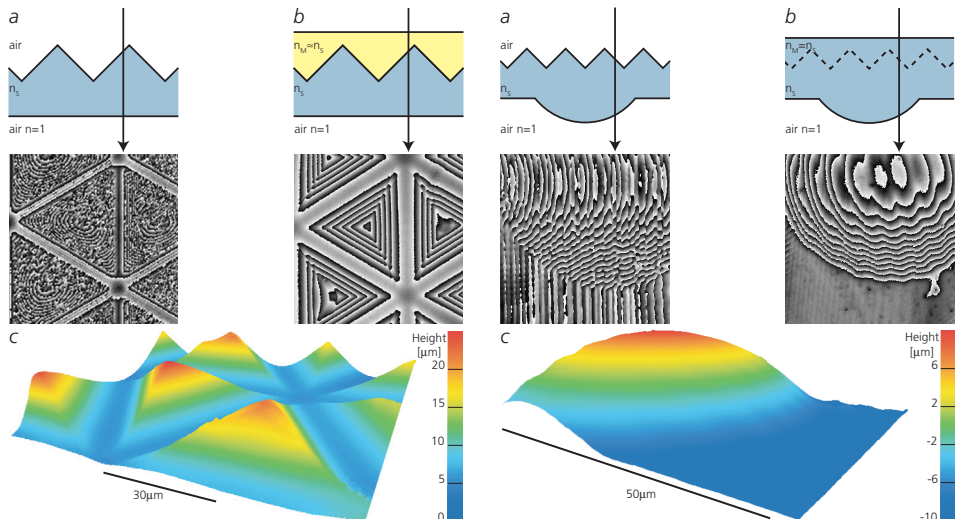


Figure 2: High aspect-ratio measurements on 25 μ m base corner cubes: (a) without immersion liquid, (b) with immersion liquid of refractive index close to that of the sample, and (c) its resulting 3D view.

Figure 3: Interface suppression on a both-sides-structured sample: (a) without immersion liquid, (b) with immersion liquid of refractive index equal to that of the sample, and (c) its resulting 3D view.