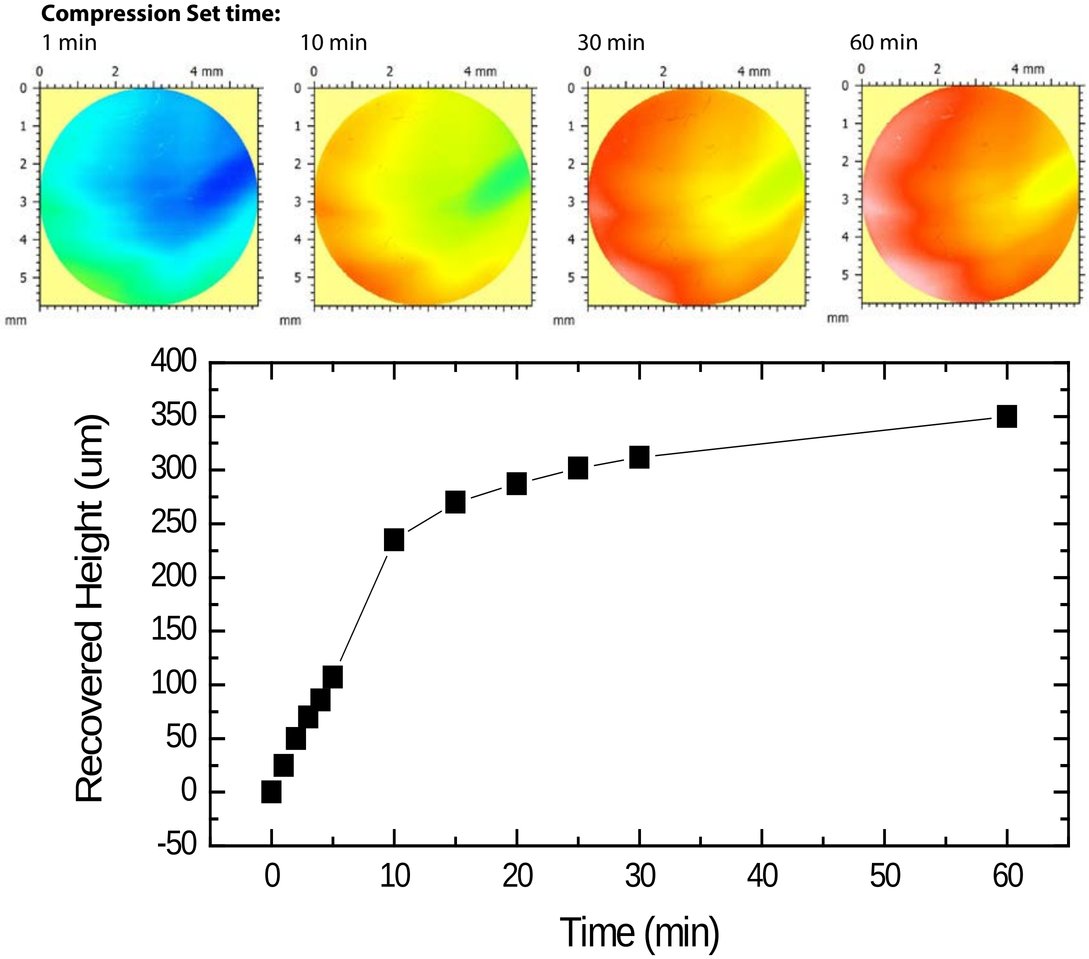
COMPRESSION SET IN SITU MEASUREMENT USING 3D PROFILOMETRY



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INTRO

The compression set of a material is the permanent deformation remaining when a previously applied compression load is removed as defined in ASTM D395[i]. Rubbers are subjected to massive compressive stresses in air or liquid media in a wide range of applications, such as machinery mountings, vibration dampers, valves, faucets and bearings. Their capacity of retaining elastic properties after long-term compressive stresses is vital to the service quality and functionality. For example, a compression faucet relies on rubber washers to seal the valve seat. The elasticity of the rubber seal washer ensures the proper function of the faucet. Leakage occurs when the rubber washers, seals or gaskets in the valve assembly wear out and lose their elasticity. Therefore, it is crucial to evaluate the compression set of the rubbers after prolonged action of compressive stresses.

IMPORTANCE OF 3D PROFILOMETER FOR COMPRESSION SET MEASUREMENT

Rubbers progressively recover their shape after the compressive stress is removed. Accurate *in situ* measurement of the shape evolution during the compression set period can provide important insight into the mechanism of material recovery. Moreover, real-time monitoring of surface morphologies is very useful in various materials applications, such as paint drying and 3D printing. The Nanovea 3D Non-Contact Profilometers measure the surface morphology of materials without touching the sample, avoiding introducing additional scratches or shape alteration which may be caused by contact technologies such as sliding stylus.

MEASUREMENT OBJECTIVE

In this application, the Nanovea ST400 non-contact profilometer equipped with a line optical sensor is used to measure the surface evolution of a rubber sample during its compression set period for 1 h. We showcases the capacity of Nanovea non-contact profilometer in providing real-time 3D profile measurement of materials with continuous shape change.

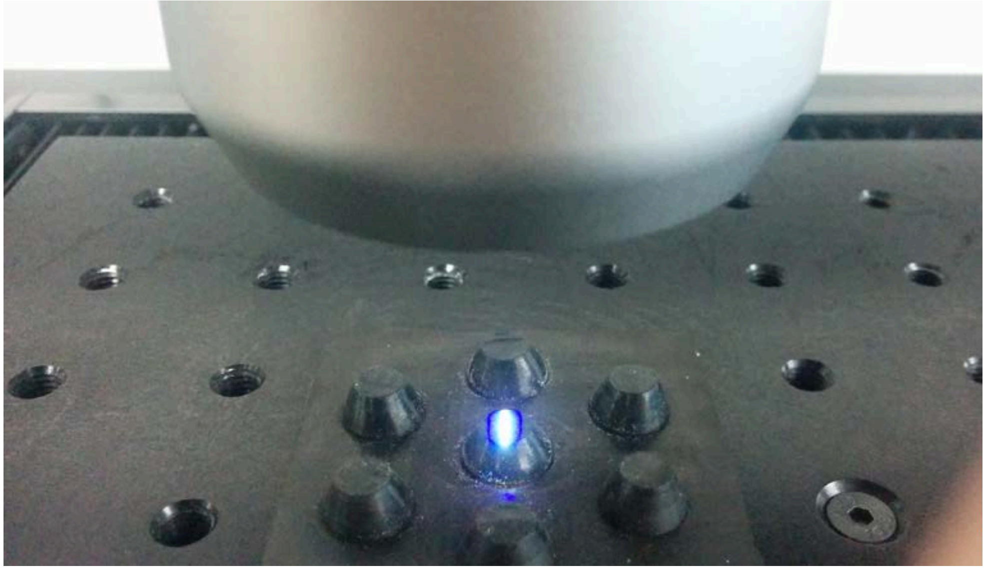


Fig. 1: Optical line sensor scanning on the surface of the rubber sample.

RESULTS AND DISCUSSION

A rubber sample was compressed by a normal load of 150 N for 24 h at room temperature. Upon removal of the weight, the 3D surface topography of its residual deformation was monitored *in situ* using Nanovea ST400 non-contact profilometer equipped with a line sensor for 1 h. A macro had been programed to automatically measure and record the 3D surface morphology at given time interval: 1, 2, 3, 4, 5, 10, 15, 20, 25, 30 and 60 min. The optical line sensor generates a bright line of 192 points, as shown in Fig. 1. These 192 points scan the sample surface at the same time, leading to significantly increase the scanning speed which allows each 3D scan to be finished in 3 s to avoid substantial deformation during the scan.

The false color view and the 3D view of the rubber surface topography at representative time are shown in Fig. 2 and Fig. 3, respectively. The false color in the images eases the detection of features that are not readily discernible. Different colors represent the height variation at different areas of the sample surface. The 3D view provides an ideal tool for users to observe the rubber sample from different angles. The rubber sample exhibits a slightly lower height on the upper right area. When the compression weight is removed, the false colors on the rubber surface changes more rapidly from the cooler tone to the warmer end during the first 10 min of the test, indicating a more drastic height increase in this period.

The average recovered height as a function of the compression set time is plotted in Fig. 4. We can observe that the sample height promptly recovers at a high rate of ~23 µm/min during the first 10 min test. Such a recovery rate progressively slows down thereafter as the time elapses during the rest of the 1 h test. In the conventional Compression Set test for rubber property, the residual deformation (the thickness) of the test specimen is only measured once by the dial micrometer 30 min after removal from the compression device. Therefore, only one point is measured at 30 min in the plot. In Fig. 4, Sample A (in Red) and Sample B (in Blue) represent the height evolution of two test samples as a function of time in hypothetical situation. Sample A has much faster height recovery at the initial stage of compression set and gets stable thereafter, while Sample B still experiences the first fast-recovery stage at 30 min. They exhibit vastly different ability to retain elastic properties after prolonged action of compressive stresses. However, according to the conventional Compression Set test method, Sample A and Sample B would possess the same residual deformation. This demonstrates the importance of monitoring the 3D sample surface change in situ, which provides more insight in the mechanism of compression set.

Table 1 summarizes the Roughness and Flatness parameters of the rubber surface at the compression set time of 1, 30 and 60 min. The average roughness Sa recovers from 37.6 to 44.7 µm from the compression during the first 30 min and it maintains this value thereafter. The rms flatness also increases from ~43 to 51 µm in the meantime.

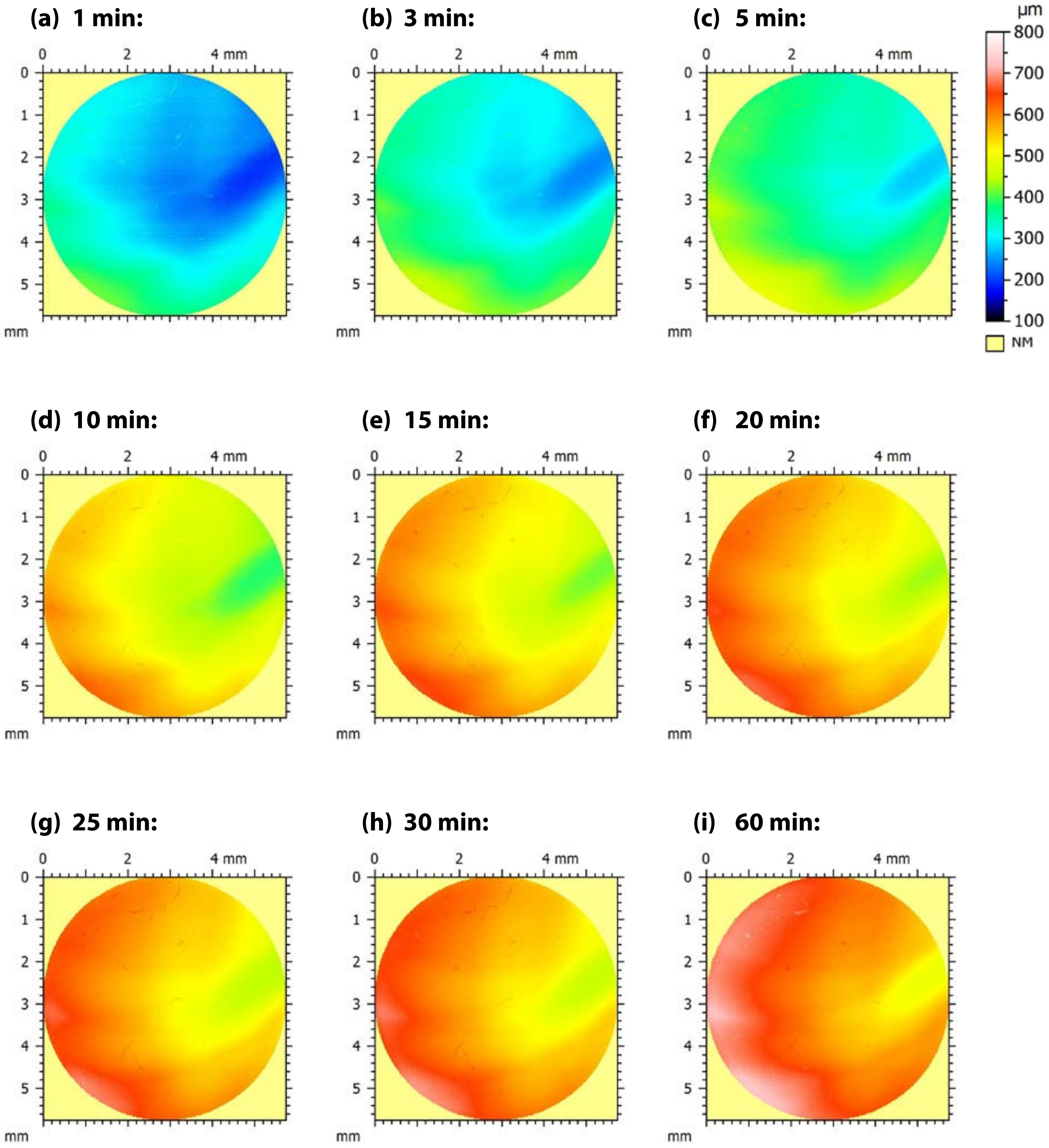
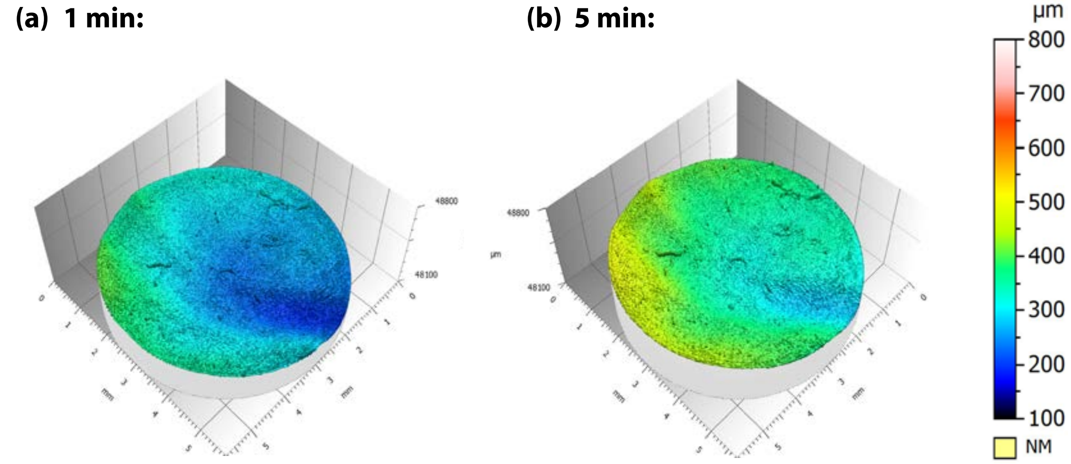
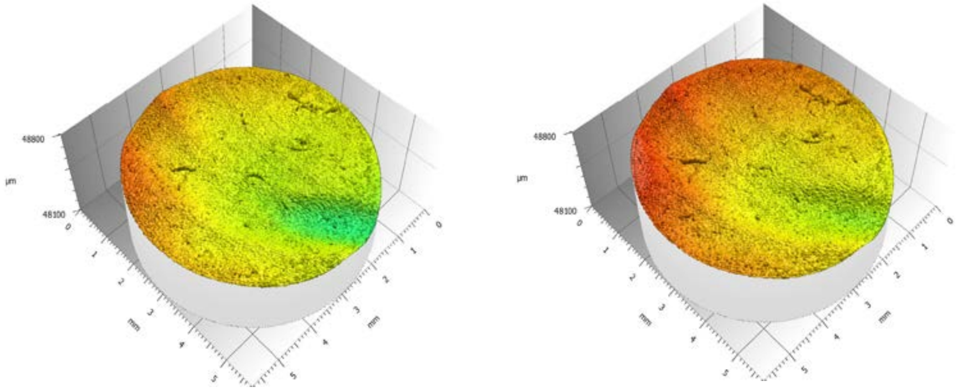


Fig. 2: Evolution of the rubber sample surface at different time.



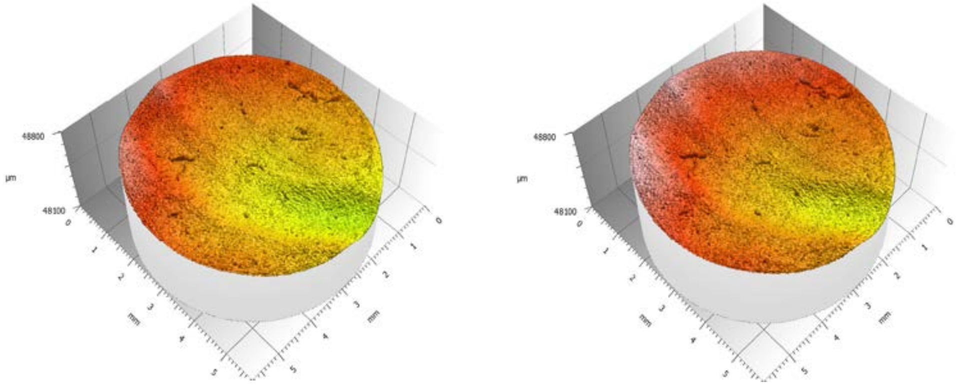
(a) 1 min:

(b) 5 min:



(c) 10 min:

(d) 20 min:



(e) 30 min:

(f) 60 min:

Fig. 3: 3D view of the rubber surface at different compression set time.

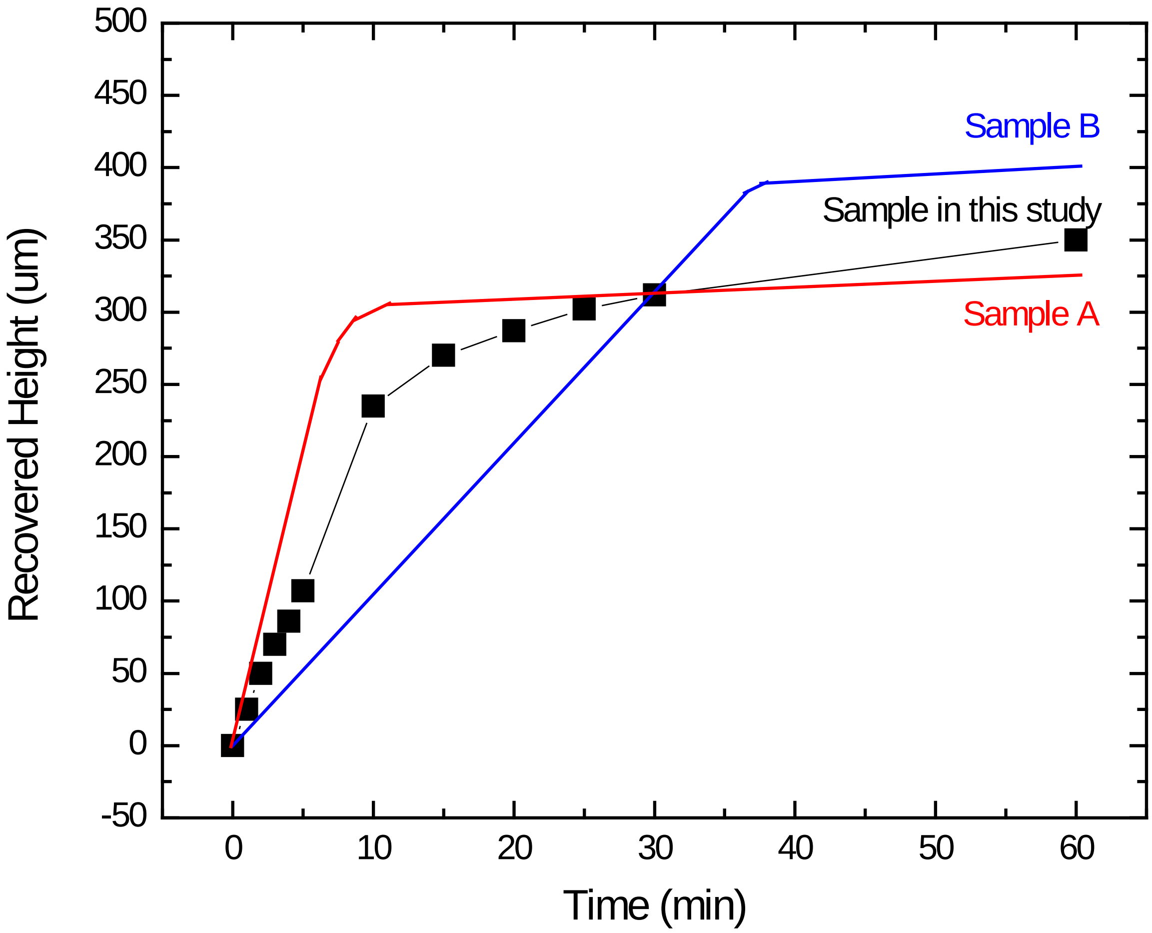


Fig. 4: Evolution of the average recovered height as a function of compression set time.

ISO 25178					
Roughness Parameters		1 min	30 min	60 min	
Sq	µm	46.3	53.9	53.8	Root-mean-square height
Ssk		0.295	-0.101	-0.135	Skewness
Sku		2.7	2.36	2.31	Kurtosis
Sp	µm	142	134	126	Maximum peak height
Sv	µm	110	127	127	Maximum pit height
Sz	µm	252	262	253	Maximum height
Sa	µm	37.6	44.7	44.7	Arithmetic mean height
ISO 12781					
Flatness Parameters					
FLTt	µm	208	229	224	Peak-to-valley flatness deviation
FLTp	µm	118	113	108	Peak-to-reference flatness deviation
FLTv	µm	89.3	117	116	Reference-to-valley flatness deviation
FLTq	µm	43.2	51	50.9	Root-mean-square flatness deviation

Table 1: Roughness and Flatness at the compression set time of 1, 30 and 60 min.

CONCLUSION

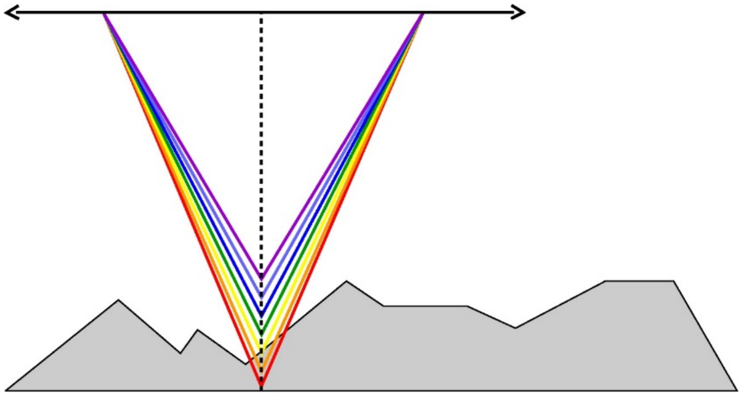
In this application, we have showcase that the Nanovea ST400 3D Non-Contact Profilometer measures the evolution of the surface of a rubber sample recovering from compression at a load of 150 N after given compression set time. The optical line sensor generates a line consisting of 192 light spots that scan the sample surface at the same time, leading to significantly increased scan speed. The macro function of the measurement software enables programing the automatic measurement time for the 3D surface morphology *in situ*. The height of the rubber continues to grow after the removal of the compression weight. It is observed that the rubber sample recovers from the high load compression at the highest speed at the beginning after stress release. Such a recovery progressively slows down as the time elapses.

The data shown here represents only a portion of the calculations available in the analysis software. Nanovea Profilometers measure virtually any surface in fields including Semiconductor, Microelectronics, Solar, Fiber Optics, Automotive, Aerospace, Metallurgy, Machining, Coatings, Pharmaceutical, Biomedical, Environmental and many others.

Learn more about the Nanovea Profilometer or Lab Services

MEASUREMENT PRINCIPLE

The axial chromatism technique uses a white light source, where light passes through an objective lens with a high degree of chromatic aberration. The refractive index of the objective lens will vary in relation to the wavelength of the light. In effect, each separate wavelength of the incident white light will re-focus at a different distance from the lens (different height). When the measured sample is within the range of possible heights, a single monochromatic point will be focalized to form the image. Due to the confocal configuration of the system, only the focused wavelength will pass through the spatial filter with high efficiency, thus causing all other wavelengths to be out of focus. The spectral analysis is done using a diffraction grating. This technique deviates each wavelength at a different position, intercepting a line of CCD, which in turn indicates the position of the maximum intensity and allows direct correspondence to the Z height position.



Nanovea optical pens have zero influence from sample reflectivity. Variations require no sample preparation and have advanced ability to measure high surface angles. Measure any material: transparent/opaque, specular/diffusive, and polished/rough.

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[i] https://www.astm.org/Standards/D395.htm