ROUGHNESS METROLOGY AT NANO-SCALE

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Aceasta lucrare studiaza acuratetea aparatelor de masura si a metodelor actuale folosite pentru masurarile de rugozitate, la nivel nanometric. In lucrare se tine cont de metodele profilometriei cu contact si cele ale interferometriei in lumina alba, aplicate pentru cinci probe de rugozitate facute in laborator.

This work investigates the adequacy of present measuring devices and methods for nano-scale roughness measurements. Contact profilometry and white light interferometry methods applied to five laboratory-made roughness samples are taken into account.

Keyword: nanoscale, roughness, interferometry, profilometry

1.Introduction

Dimensional nanometrology is the science and practice of measuring the geometrical characteristics of objects (e.g. dimension, shape, roughness, separation or displacement) in the 1-100 nm range. Metrology today, as in other historical periods of industrial revolution, ensures the uniformity of measurements and mass production. This is the case of nanotechnologies as well. In order to go to mass production reproducible measurements are essential and without it the manufacturing of nano-materials and nanostructures or MEMS and MOEMS is unconceivable.

There are three geometrical parameters that describe macro-, micro- or nano-devices, namely: dimension, shape and roughness. In terms of metrology, dimension and shape are characterized by lateral and axial dimensions of the device, with roughness being a special measurement [1]. For macro- and micro-scale devices things are settled, there being hundreds of commercial devices able to measure roughness. As in the case of length, the passage from micro- to nano-

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scale was realized by translation: devices used at a scale were artificially extended to be used at the next scale. Thus the results were, predominantly, approximate. Roughness is at this moment in the same posture when researchers and engineers are using devices that are not suitable from the metrological point of view at the nanometer scale. We are referring here to contact profilometers (Fig.1) and AFM (e.g. *force* measuring) devices. Nanometer scale brings an essential difference as compared to the micrometer one, namely roughness is comparable with shape and dimensions of the object.

2.Samples

Five samples with random roughness were realized by grinding pieces of glass with various abrasives of 1.5 1.6, 3.2, 3.5, and again 1.6 micrometers. Abrasive grains have dimensions specified by the producer. Given that the grinding process, more or less, breaks the glass, the obtained roughness is correlated with the dimension of the abrasive but is not identical with it. Granulations were chosen such that to have dimensions of close values or far to each other, in order to observe correlations of the measurements with the dimension of the abrasive. 1.6 micrometer grains are from two different producers. Optical microscope (Fig. 2) made the difference but is not able to deliver metrological values.

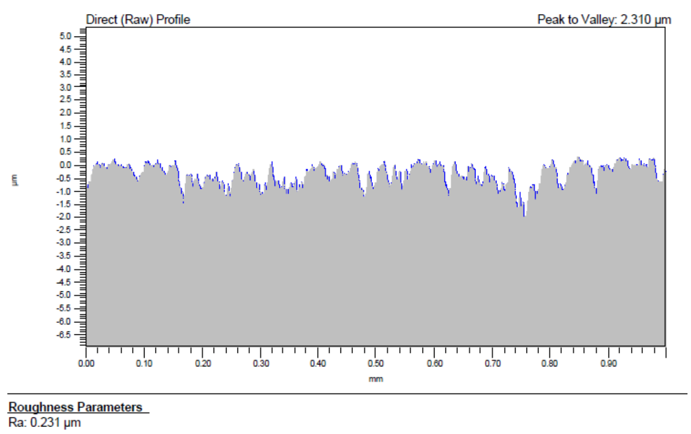


Fig.1Stylus profile of sample

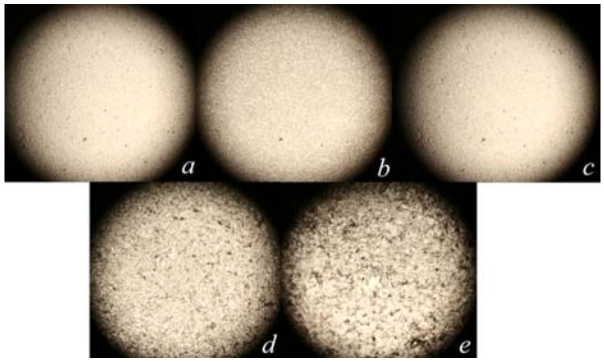


Fig. 2 Optical images of roughness sample (Zeiss AxioImager Microscope)

3. Equipment

The ideal inspection technique for surface roughness measurement (indeed, for measurements of almost any parameter) would be truly contactless, objective, reproducible, and preferably assess the full necessary area or a statistically significant fraction of it. For these reasons, white light interferometry is main category of devices that interested us. Among the devices routinely used to measure roughness, the stylus profilometer (Fig.3) is – surprisingly – the most encountered. In the first stage, we used three stylus profilometers having different brands, namely Mahr S2, XP-2 Ambios and TOKYO Seimitsu Surfcom.

From contactless category we chose white light interferometer Ambios Xi-100 having two interference systems: Michelson and Mireau.

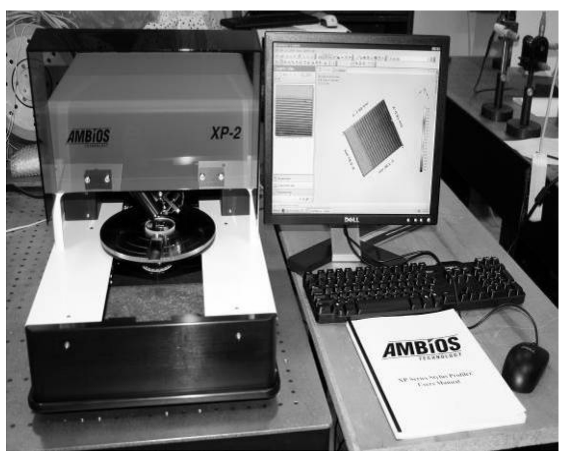


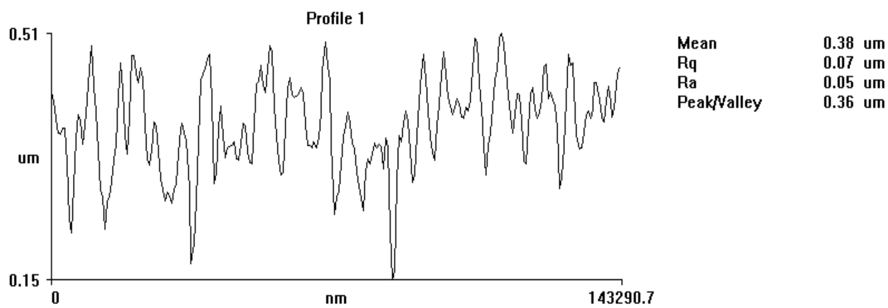
Fig.3 Ambios profilometer

Ambios profilometer is a last generation device, having the up-down tracking system identical to that of the AFM (e.g. laser and quadrant detector).

From the many parameters [2] that describe roughness, we chose the one that is the most commonly used: Ra (*average roughness*). This is the average value of the absolute profile data inside an evaluation length, divided by the total length:

$$Ra = \frac{1}{L}\int |z(x)| dx \qquad (1)$$

We recognize as more appropriate to measurements the second contactless profilometer, namely the White Light Interferometer (WLI). Scanning



interferometry or white light interferometry became increasingly important in the analysis of MEMS devices because of a variety of factors including roughness and step height analysis within a single measurement or possibility of surface coating measurement – film thickness and real surface roughness measurement.

Fig.4 Profile and roughness Ra value of a thin film obtained with WLI.

4.Results

Roughness measurements of the five surfaces are shown in Table 1. They are given for three profilometers.

Table 1.

Stylus [μm]

Nr.	Abrasive grain	Tokyo Seimitsu Surfcom	Xp-2 AMBIOS USA	Mahr
1	1.6	0.268	0.285	0.690
2	3.5	1.084	0.997	2.723
3	3.2	0.702	0.754	1.708
4	1.6	0.291	0.308	0.487
5	1.5	0.210	0.231	0.417

They all have the same 2.5 mm stylus, which is the most known and rarely specified. The stylus head is crucial when roughness results are reported in nano-sciences and technologies papers. Just observe the Fig. 4: a small head can follow the high spatial frequency surface geometry; a large one cannot.

From data analysis it is clear that the differences are extremely large hundreds, if not thousands of nanometers. Thus, the 1 nm resolution indicated by the manufacturer is useless due to the tip.

Waviness [3] is irregularities from a mean line which are of greater spacing than the roughness and integrates roughness structures. When roughness is not completely resolved by the stylus- the lateral resolution is much too small- the waviness parameter is more probable observed.

However, *it is not possible to measure with different instruments on the same spot on the surface*, so we cannot blame it all on the instruments.

Results of two variants (e.g. Michelson and Mireau) of WLI measurements are shown in Table 2. Again, the results are much too different to state any differentiating conclusion regarding the effect of the sample, measurement technique and instruments. Even though the instruments are more sophisticated, the error sources are as sophisticated too [4,5].

Various roughness ranges are normally studied in order to define the overall properties of the surface and one of the limitations to the analysis at nanometer scale is the bandwidth of the measurement method. (see the high spatial frequency surface geometry Fig.4)

Table 2.

WLI [μm]

	Abrasive grain	WLI (ob. Michelson)	WLI (ob. Mireau)
	1.6	2.06	1.46
	3.5	4.25	3.29
	3.2	3.15	3.04
	1.6	2.35	1.48
	1.5	1.55	1.55

5. Conclusions

-Surface finish gages are verified against test patches or specimens whose surface characteristics are known and certified. If gage results do not agree with the characteristics of the specimen, the instrument must be adjusted. Random grinding gages were presented.

-The difficulty is to realize standards with known roughness. We achieved these standards rather easy but they are not well characterized. An ideal gage must show the same roughness on any line on its surface;

-An open issue is that of traceability: the standard should be realized and attested by an interferometric method that relates directly to the definition of the meter. This is one of our near future goals.

-A detailed analysis of the error causes in roughness measurements at nano-scale is imposed. Such an analysis at micrometer scale is given in [6].

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