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Laser confocal microscope noise evaluation on injection compression moulded (ICM) transparent polymer Fresnel lenses

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Abstract

The evaluation of an adequate and robust measuring strategy, for roughness assessment of polymer Fresnel lenses is put under assessment. An 'on-sample' measurement noise , is evaluated using a laser confocal microscope (OLYMPUS © Lext) . Secondly, the lowest-noise roughness measuring procedure, on an injection compression moulded (ICM) Fresnel lens, is defined. A set of two different objectives is considered, i.e. a standard series (SO), against a long working distance one (LWD); two different magnifications objectives, 50x and 100x and the use or not of a dark environment. The noise evaluation is performed by comparing 'on-sample' noise with the one calculated on an optical flat. Noise is investigated by means of established methods, i.e. subtraction and averaging methods. Afterwards, the lowest-noise analysis is structured following a 2^3 full factorial experimental planning, whose factors are measuring working distance, objective magnification and room lighting. The result confirms a strong difference of noise, using the considered objectives. The most interesting result is that the performance of SO 50x objective is better than LWD 100x.

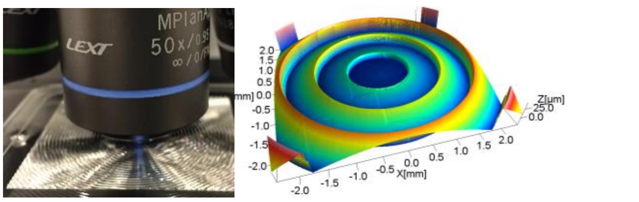
Noise evaluation, laser scanning confocal microscope, Fresnel lens, Injection compression moulding

1. Introduction

Fresnel lenses are particular optics with reduced dimensions and enhanced light gathering properties. Considering a strong demand of Fresnel lenses in mobile flashlights, automotive, indoor/outdoor lighting systems and in general in many others optical applications, the study of more precise, accurate and repeatable moulding processes is a key step to reduce costs and improve quality of these products. Injection Compression Moulding (ICM) is the leading process technology for the mass manufacturing of high precision polymer optics. Remarkably, an important milestone in the process optimization, is represented by the definition of a cost effective and robust metrological routine. For the case of ICM polymer Fresnel lenses, any measuring strategy requires suitable optical microscopes with possibility to detect transparent, micro structured objects. One of the most demanding aspects links to the lens geometry (Figure 1). Moreover, when the replication quality addresses to the roughness scale, it is interesting to evaluate the instrument noise. The aim of this scope, is to validate an 'on-sample' noise evaluation procedure to ensure an adequate, lowest noise measuring strategy.

2. Instrumentation and methodologies

The noise evaluation is performed on Olympus©Lext laser scanning confocal microscope. The flexibility and limitations of the instrumentation have been investigated [1] [2]. To do so, different objectives were utilized keeping constant for each condition the measuring time and vertical range. The use of averaging and subtraction methods are well established for evaluating measurement noise [3]. Both the methods involve the use of *Sq* [4].



(a) *(b)*

Figure 3. (a) Measuring the Fresnel lens and (b) 3D image of its central area sampled with a 5x magnification objective

2.1. Noise evaluation

In the case of subtraction method (see Eq.1), Sq_{noise} is evaluated on the residual of two subsequent topographies: the result of their difference.

$$S_{q_{noise,subtraction}} = \frac{S_q}{\sqrt{2}} \qquad (1)$$

In the case of averaging method (see Eq. 2), Sq_{noise} is determined in two steps. Firstly, the topographies of n repeated measurements are averaged. The associated *Sq* index is called Sq_n. Secondly, calculating *Sq* on one non averaged topography, noise can be calculated. The stronger assumption of this method is the reduction of noise by increase the number of replicates (*n*).

$$S_{q_{noise,averaging}} = \sqrt{\frac{n}{n-1}\left(S_q^2 - S_{q_n}^2\right)} \qquad (2)$$

For both the methods, the maximum values from a total of replicates (n = 10), have been preferred. The measurement noise was measured by an optical flat with a calibrated Sz value of 5.3 nm and declared expanded uncertainty of 10.3 nm (confidence interval of 95 %). Using this particular sample ensures that the measurement is not affected by possible workpiece -laser interactions.

3. Validation of an 'on-sample' noise evaluation procedure

Noise evaluation was performed on Fresnel lens surface topography, using average and subtraction method. The evaluation resulted in an Sq_{noise} of 10 nm. The same evaluation was conducted on an optical flat and showed the same result of Sq_{noise} 10 nm (see Figure 2). This proves that it was possible to measure the noise directly on the topography of the Fresnel lens. Furthermore, past measurements with an atomic force microscope of a tool insert, made with the same manufacturing technology of the one used for the Fresnel lens, stated a surface roughness *Sa* less than 15 nm [5] [6]. This justifies the possibility to have similar surface roughness on the Fresnel lens. This suggests the possibility to use the 'on-sample' procedure, even though the noise estimation is comparable with the specimen surface roughness.

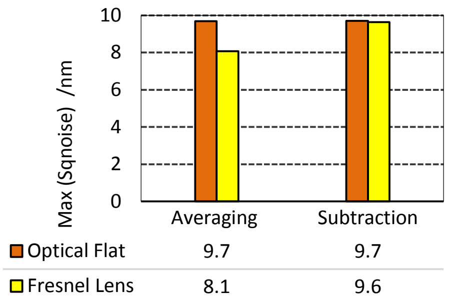


Figure 2. Noise evaluation Sq_{noise} comparison Optical Flat Vs Fresnel lens – 50x objective.

4. Identification of the lowest noise measuring strategy

The selection of the optimal procedure, has been identified with the help of a 2^3 full factorial design of experiments (DOE). The design layout is schematize in (Table 1).

Objective series	Objective Magnificatio n	Room Illuminatio n	Objective properties	
			A_N	*WD* / mm
SO	50x	ON	0.95	0.35
SO	50x	DARK	0.95	0.35
SO	100x	ON	0.95	0.35
SO	100x	DARK	0.95	0.35
LWD	50x	ON	0.5	10.60
LWD	50x	DARK	0.5	10.60
LWD	100x	ON	0.8	3.40
LWD	100x	DARK	0.8	3.40

Table 1. Experimental plan to identify the lowest-noise condition – long working distance objectives *LWD*, Standard objectives *SO*, numerical aperture A_N, working distance *WD*

Using *LWD instead of SO*, the vertical pitch between two z position at which the confocal microscope works reduces passing from 0.4 µm to 0.06 µm for 50x objective and 0.2 µm to 0.06 µm for 100x objective. This allows a faster measure if the vertical range is the same. Moreover, LWD reduced possibility to fail into inconvenient workpiece/objective collisions. On the contrary, for a coherent source, the lateral resolution, can be defined accordingly to the optical resolution R_l of the objective and calculated by the Sparrow's diffraction limit (see Eq. 3) [7]. The wavelength (λ) can be approximated with the instrument laser source (510 nm) and treat as a constant. Dark room conditions could on the other hand reduce possible laser-ambient light interactions, decreasing the noise evaluation.

$$\mathrm{R}_l = 0.73\,\frac{\lambda}{A_N} \tag{3}$$

4.1 Results

The data plot in (Figure 3) shows, a strong difference in terms of total noise between *SO* and *LWD*, especially in the case of 50x magnification objectives. Sq_{noise} passes from 10 nm of standard lens, to 65 nm of the long working distance ones. Using 100x, standard objectives, the increment goes from 10 nm to 15 nm.. Considering the presence of many disturbances on the topographies, particularly for the case of 50x *LWD* objective and in reduced scale for 100x *LWD,* it is suspected, that the different optical path of the *LWD* objectives in a system adapted to the use of standard ones produces multiple reflections.

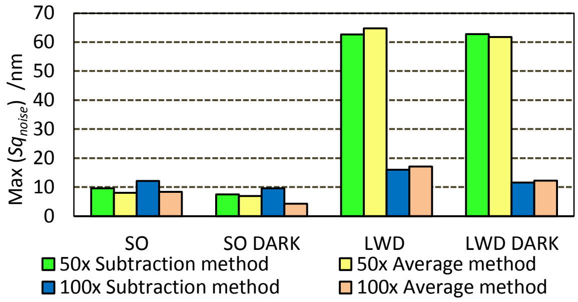


Figure 3. Noise estimation Sq_{noise} on Fresnel lens

5. Conclusions

This study shows the possibility to evaluate measurement noise directly 'on-sample' when the specimen surface roughness *Sq*, and the noise evaluation, have similar values. This is validated evaluating the same $Sq_{noise,}$ of 10 nm on-sample and on an optical flat. The lowest-noise measuring strategy is identified in the cases of maximum $A_{N,}$ in absence of measurement disturbances. Moreover noise estimation with 50x SO results lower than 100x LWD objectives, in the first case 10 nm against 15 nm.

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