Advances in micro gap creation between form molds for thin-film replication of diffractive optical elements with strong curvature

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Abstract

There is a market need for affordable diffractive optical elements (DOEs) with strong curvature, e. g. for the production of handheld spectrometers. Customers often need few different geometries in their requested optics but comparatively high quantities of each geometrical specification. Conventional production methods, such as ultraprecision machining, are intensive in cost, time and knowledge. To overcome these problems, we propose a replication process of conventionally machined DOEs with strong curvature in novel hybrid polymer materials.

It is most promising to carry out a thin-film replication process which involves two form molds: a master structure and a so-called pre-form. To obtain high quality replicas it is necessary to create a gap between the form molds. Two properties of this gap influence the replication process: width and uniformity. Since hybrid polymers shrink about 7 % in volume while curing, a smaller the gap results in less absolute shrinkage. This carries over in a more accurate transfer of the master geometry to the thin-film. However, in reality, the gap cannot be infinitely narrow. The applied liquid hybrid polymer volume still needs a gape wide enough to be able to spread evenly, covering the structures to be replicated, while allowing entrapped air to escape. Due to these constraints, a gap width of approx. 20 µm to 50 µm seems to be optimal.

The ideal gap would be absolutely uniform, viz. zero tilt, to ensure even shrinkage over the whole geometry. Ultimately, tolerances of gap width and tilt have to be determined when means to examine a significant number of replicas are available. As for now, a difference in gap width of 5 µm across the diagonals of a preform with a cross section of 25 mm by 25 mm seems passable as a starting point. The height of the blaze features of the DOEs with strong curvature depends on period and blaze angle.

Regarding available sample geometries it can range from a few hundred nanometers to 10 µm, while lower and upper limit can be regarded as extremes.

We introduce a way of implementing the thin-film replication process in an automated process chain, using conventional instrumentation. Two create the gap between form molds a group of three calibrated single point load cells is used to determine the point of first contact when closing the form molds. Due to their design, single point load cells are impervious to the position of the load orthogonal to their load axis. They are connected with a level platform onto which the preform is mounted. Mechanically, the load imposed on each load cell depends on the total load and the distance of the load cells load axis to the point of contact between form molds. A mathematical model to determine the point of contact between form molds with the load cells signals was developed and integrated as an algorithm.

The algorithm's output is interpreted by a Programmable Language Controller (PLC) which rotates the actuator plate of a hexapod onto which the master is mounted a given angle away from the point of contact. This process is repeated until the point of contact changes to the opposite edge of the form molds. Now the angle can be decreased and the process repeated. This is done until the angle is so small that the point of contact's position does no longer change significantly. This process is done subsequently for both spatial angles defining the tilt between master and pre-form.

To quantitively assess the tilt after adjustment took place a pre-form dummy with bore holes to contain three capacitive sensors as a reference system was designed (see figure 1 a). The sensors are able to detected distances to surfaces between 10 µm and 30 µm away from the sensor surface. Thus, they have to be locked in position with a screw 10 µm to 20 µm away from the pre-form surface to enable reasonable distance measurement to the master surface. Ideally, they would all be mounted in the exact same distance from the pre-form's surface. However, this is not possible manually. Hence, at the beginning of each experiment the offset from a flycut sample placed on top of the pre-form is recorded as compensation. This offset is then subtracted from further sensor readings, virtually placing them flush with the pre-form surface. Thus, a reference state of zero tilt is created (see figure 1b).

After adjusting the tilt of the mold forms with the load cells, the achieved tilt is measured with the capacitive sensors, once more using a mathematical model implemented as an algorithm to calculate the tilt from the actual sensor readings. First tests suggest that differences in gap width of smaller 5 µm across the diagonals of a 25 mm by 25 mm preform are obtainable this way.

a) b)

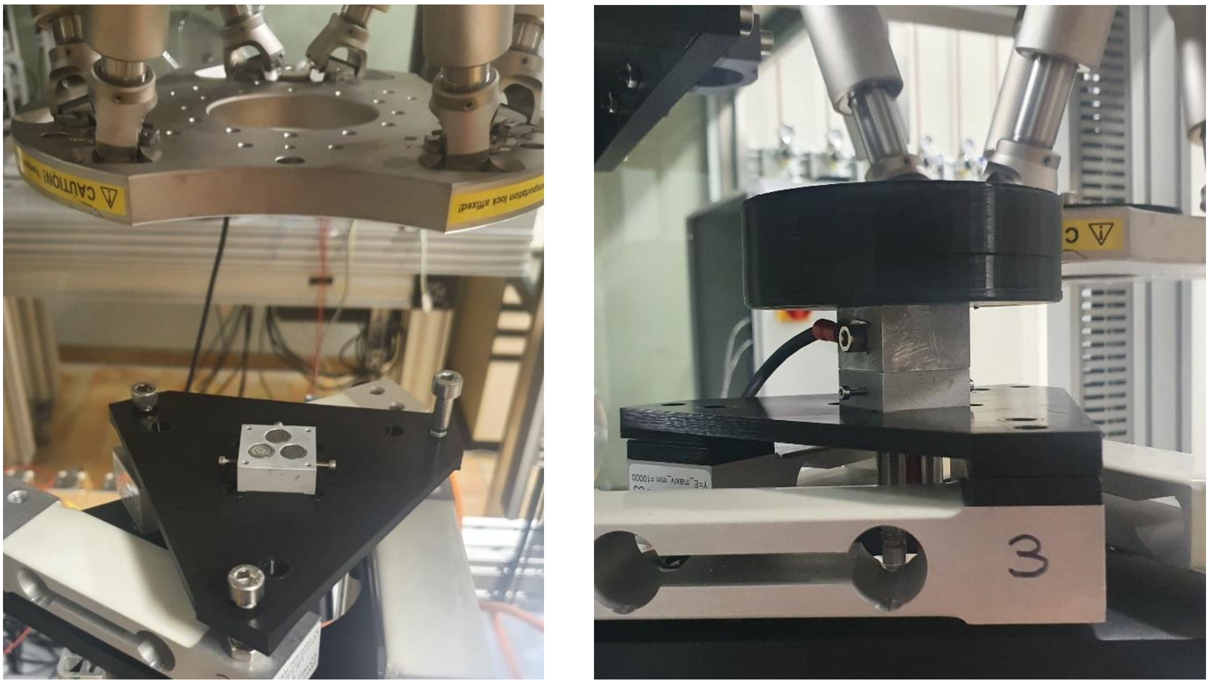

Figure 1: a) pre-form dummy with capacitive sensors

b) referencing zero tilt state