Novel method for fabrication of monolithic multi-cavity molds and wafer optics

Marc Wielandts and Remi Wielandts
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“Efficient and accurate diamond turning or grinding of monolithic multi-cavity molds or wafer optics” knowing the limitations of the state-of-the-art technologies...
The state-of-the-art

• Manual indexing of the part and on-axis SPDT: not feasible (setup time, pitch accuracy, balancing)

• Freeform machining of monolithic molds DMM, STS, FTS: slow processes, geometry limitations

• Molds with on-axis turned inserts: many tight tolerances, many parts
The challenge

• On-axis turning or grinding of each surface of an array

• Automatic indexing/positioning of the substrate

• Dynamic operation (spindle at constant speed)

• Maintained accurate balancing
The concept

From a cartesian substrate shift with respect to the spindle...
The concept
To a polar displacement...
The concept

To eccentric rotations…
The concept

- Two stacked eccentric rotation stages
- Each balanced on their own rotation axis

\[
\alpha = \arctan \left( \frac{2e^2 \sqrt{1 - \left( \frac{x^2 + y^2}{2e^2} - 1 \right)^2}}{x^2 + y^2} \right) + \arctan \left( \frac{x}{y} \right)
\]

\[
\beta = \arccos \left( 1 - \frac{x^2 + y^2}{2e^2} \right)
\]
Lens-to-lens registration

Different inaccuracy sources are:

• Angular positioning
• Runout
• Alignment
• Deformations

→ Compensation and calibration
• Residual unbalance
Cutting results

- Ø 6 mm, radius of curvature 9 mm, 37 lenses
- ≈ 120 nm PTV form accuracy
- < 3 nm Ra roughness
- Sub-micron repeatability in positioning of both rotation stages taken individually

Cutting parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Speed</td>
<td>350 RPM</td>
</tr>
<tr>
<td>Feed</td>
<td>1 mm/min</td>
</tr>
<tr>
<td>Tool radius</td>
<td>0.5 mm</td>
</tr>
<tr>
<td>DOC</td>
<td>3 µm</td>
</tr>
<tr>
<td></td>
<td>MLA 1000 lenslets dia 1 mm NIP</td>
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<tr>
<td>------------------</td>
<td>--------------------------------</td>
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<tr>
<td>Inserts</td>
<td>not practical because of the number</td>
</tr>
<tr>
<td>Diamond Micro Milling</td>
<td>2-4 min/lens, 30-60 h total, 200 nm p-v (compensation) 2.5-4 nm Ra</td>
</tr>
<tr>
<td>Fast Tool Servo</td>
<td>limitations on surface slopes, form, surface quality and overall lens array diameter, extremely difficult compensation</td>
</tr>
<tr>
<td>Dynamic Part Indexing</td>
<td>10-20 sec/lens, 2.5-5 h total 150 nm p-v 1-2 nm Ra</td>
</tr>
</tbody>
</table>
Conclusions

• Novel (patent pending) method using workpiece shifting to make arrays of on-axis turned features (diffractives, Fresnel, steep edge slopes, etc)

• Balancing is maintained through use of eccentric rotary tables, each balanced on their own axis

• Form accuracy and roughness comparable to traditional on-axis SPDT

• Also adapted to grinding, and ultrasonic assisted turning
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