Imprint Lithography for Large Scale Angular Encoders

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This work presents experimental results of research directed toward production of large scale angular encoders using imprint lithography instead of conventional ultraviolet lithography. Testing of the different mould materials and ion beam deposited from hexamethyldisiloxane vapour and hydrogen gas mixture film like antisticking coating shows the best action of the SiOₓ doped diamond like carbon film coated mould to transfer features of the encoder. It was revealed, that linear dimensions of elements of the fabricated angular encoders differ from the master and it was shown that producing of large scale devices requires estimation of thermal behaviour of the used materials.

Keywords: nanoimprint lithography, DLC films, glass scales and discs.

INTRODUCTION

Angular encoders are used in precision photoelectric measuring systems for instruments and machinery. They are produced in a wide range of dimensions, diameters and thickness. Manufacturing of angular encoders usually employs conventional UV-lithography suitable for exposure of micrometer range devices [1]. Sometimes it is necessary to produce angular encoders which are out of the standard equipment exposure area range. Flat or roll-based imprint lithography could be effective mean to solve this problem, because it could be not limited in dimensions for producing of encoders. On the other hand, during last period the nanoimprint lithography was applied to fabricate the nanostructures and nanodevices [2], e. g., silicon transistor [3], circular gratings with a 20 nm minimum linewidth [4], quantum point contacts [5], it was proved for the wafer scale patterning [6] and for the fabrication of photonic crystal slabs [7]. Despite of this wide application there is almost no published results on applications of imprint technique for structures with linewidth dimensions >10 μm or structures combining micrometric and milimetric features and so the first aim of this work was proving of suitability of hot imprint lithography for the fabrication of the large scale devices. The second aim of this work was devoted to the improvement of mould durability and imprinting properties using diamond like carbon (DLC) film [8]. Low surface energy fluoride films – teflon-like [9, 10], fluorinated silane [11, 12], etc. coatings have already been investigated as anti-sticking layers for the nanoimprint moulds. However, film degradation due to the fluorine mass transfer at elevated imprint temperatures was observed [8] and after certain number of imprint cycles this films should be replaced. Due to the combination of the hydrophobicity with outstanding mechanical and tribological properties DLC films can be a good choice for imprinting application. Thick DLC layers have already been reported as an efficient imprinting mould material [13, 14], and our task was comparison of antisticking properties of SiOₓ doped and undoped DLC films employed on the moulds for large scale angular encoders.

EXPERIMENTAL SETUP AND RESULTS

Three types of substrates were used for the imprint moulds: fused silica (25 mm × 25 mm, thickness – 1.5 mm), single-crystal silicon <111> (20 mm × 20 mm, thickness – 0.4 mm) and Si/SiO₂ (20 mm × 20 mm, thickness of thermal SiO₂ film – 0.8 μm). Preparation procedure of the fused silica imprint mould included: chemical and RF (13.56 MHz) O₂ plasma cleaning of the substrates, electron beam evaporation of the auxiliary Al film (thickness 100 nm), conventional optical lithography, plasma etching (RF 13.56 MHz) of a fused silica substrate using an Al masking layer (CF₄ + O₂ chemistry plasma at 0.75 W/cm² power density), removal of the Al layer in Cr₂O₃ : NH₄F : H₂O solution. The height of etched profile of the fused silica moulds was about 1.5 μm. Silicon imprint moulds were prepared by RIE (RF 13.56 MHz, SF₆ chemistry plasma at 0.25 W/cm² power density) using an Al masking layer as well. The height of etched profile of the silicon moulds was about 2.0 μm. The typical etched silicon imprint mould of the angular encoder is shown in Fig. 1.

Si/SiO₂ imprint moulds were prepared using plasma etching (RF 13.56 MHz, CF₄ + O₂ chemistry plasma at 0.75 W/cm² power density) of the SiO₂ film using an Al masking layer. The height of imprint profile of the Si/SiO₂ moulds was about 0.8 μm. Deposition of the DLC films was performed in a vacuum unit equipped with a closed drift hollow cathode electrostatic ion beam source.
Fig. 1. Optical microscope view of the silicon imprint mould of the angular encoder (dimensions of the central cross are 0.5 x 0.5 mm, the width of the cross line is 20 μm), and detail of the scale (length of lines is 0.75 mm, scale pitch in the center of lines is 20 μm).

Parameters of the DLC films deposition processes are shown in Table 1.

Table 1. Parameters of the DLC films deposition process

<table>
<thead>
<tr>
<th>Reagents</th>
<th>C₆H₁₈Si₂O+H₂</th>
<th>C₆H₁₈Si₂O+C₂H₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base pressure</td>
<td>(2.10⁻⁴) Pa</td>
<td></td>
</tr>
<tr>
<td>Work pressure</td>
<td>(2.10⁻²) Pa</td>
<td></td>
</tr>
<tr>
<td>Ion beam energy</td>
<td>0.8 keV</td>
<td></td>
</tr>
<tr>
<td>Deposition temperature</td>
<td>293 K (room temperature)</td>
<td></td>
</tr>
<tr>
<td>Ion beam current density</td>
<td>(0.12 ±0.01) mA/cm²</td>
<td></td>
</tr>
</tbody>
</table>

Two types of DLC films were used on the imprint moulds: 1) ion beam deposited from acetylene gas – undoped DLC film (E = 800 eV, j = 100 μA/cm²); 2) ion beam deposited from hexamethyldisiloxane vapour and hydrogen gas mixture SiOₓ – doped DLC film (E = 800 eV, j = 100 μA/cm²). Parameters of the deposited DLC films are presented in Table 2. Imprinting of the angular encoders was performed on the chromium coated glass substrates (30 mm x 30 mm, thickness ≈ 1.5 mm). More experimental details on deposition and properties of the DLC films can be found in [8].

Table 2. Parameters of DLC films on the imprint moulds

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Undoped DLC film</th>
<th>SiOₓ – doped DLC film</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness, nm</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Refraction index</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Contact angle with water</td>
<td>72°</td>
<td>75°</td>
</tr>
</tbody>
</table>

Hot imprinting of the angular encoders was performed using EVG®520HE Semi-Automated Hot Embossing System (automated hot embossing process, all wafer bonding processes, temp. 550 °C max., pressure up to 8,000 lbf (40 kN), accessible open chamber design). MRT-mr-I-8100E resist was used for the imprints. All imprints were performed at the same proved process conditions. Coating recipe for all imprints included: cleaning with acetone and IPA, static dispense, 3000 rpm/30 sec., bake 140 °C/2 min. Residual layer after imprinting was removed in RIBE unit (“Usi-ionic”) by O²⁻ ion beam using multicell cold hollow-cathode DC ion beam source (O²⁻ ion energy 300 eV, ion beam current 0.2 mA/cm², pressure 7 x 10⁻² Pa, etching time 8 – 12 minutes, substrate temperature 293 ±5 K). Cr etching (final fabrication of angular encoders) was performed in a water solution of potassium hexacyanoferrate (K₃[Fe(CN)₆]) and sodium hydroxide (NaOH). Etching time varied from 15 min to 20 min.

The imprinted samples were investigated by scanning electron microscope Jeol JSM-IC2SS (accelerating voltage 5 kV, tilting angle 30°) and optical microscope in light transmission mode. Surface and profile roughness of the resist film after imprint was measured by atomic force microscope Nanotop NT-206 in contact scanning mode. Metrological evaluation of the fabricated angular encoders was performed using a photoelectric microscope Hilger Watts and laser interferometer Hewlett Packard at 19.9 °C temperature. Measurement error didn’t exceed 0.2 μm.

Fig. 2. SEM view of the imprinted resist film with SiOₓ – doped DLC film mould. Mark size 10 μm.
Comparison of the antisticking action of different moulds after imprinting was done by SEM observation of imprinted resist film and surface roughness evaluation by atomic force microscope. It was revealed, that the best action provide two types of the moulds: SiO\textsubscript{x} – doped DLC film and fused silica mould. Typical sample of the imprinted resist film with SiO\textsubscript{x} – doped DLC film mould is shown in Fig. 2.

Fig. 3 shows imprint profile of the resist film using the SiO\textsubscript{x} – undoped DLC film coated mold and Fig. 4 shows imprint profile of the resist film using the SiO\textsubscript{x} – doped DLC film coated mold. From the AFM view the surface is clearly less smooth in the case of imprint with SiO\textsubscript{x} – undoped DLC film coated mold ($R_a = 218.2$ nm, $R_q = 259.9$ nm) in comparison with SiO\textsubscript{x} – doped DLC film coated mold ($R_a = 197.7$ nm, $R_q = 239.3$ nm). It can be concluded, that doping of the DLC film by SiO\textsubscript{x} facilitates the mold separation after imprint and leads to the improvement of the antisticking properties.

After removal of the residual resist layer by O\textsubscript{2}+ ion beam and chemical etching of chromium layer angular encoders were observed by optical microscope in light transmission mode (Fig. 5). Observation confirmed best action of the SiO\textsubscript{x} – doped DLC film coated mould as compared to the undoped DLC – area free of macroscopic defects as well as features of the encoder were transferred during hot imprint.

On the other hand, metrological evaluation of the fabricated angular encoders revealed, that linear dimensions of the fabricated angular encoders differ from the master and project value about 7.0 $\mu$m for the distance of 12.3 mm, i. e., linear contraction (approximately 0.057 %) of the produced macroscopic elements took place. We assume that this contraction takes place in other cases as well and it could be explained by different thermal expansion and contraction of the used materials during hot imprint procedure. This should be estimated in designing stage (especially while designing small size elements).

**Fig. 3.** AFM view of the imprint profile of the resist film using the SiO\textsubscript{x} – undoped DLC film coated mold

**Fig. 4.** AFM view of the imprint profile of the resist film using the SiO\textsubscript{x} – doped DLC film coated mold

**Fig. 5.** Optical microscope view (light transmission mode) of the fabricated by imprint lithography angular encoder (length of lines is 0.75 mm, scale pitch in the center of lines is 20 $\mu$m)
CONCLUSIONS

In conclusion, large scale angular encoders containing micrometric and milimetric features were fabricated by hot imprint lithography instead of conventional UV-lithography. SiO$_x$ doped DLC ion beam deposited film from hexamethyldisiloxane vapour and hydrogen gas mixture gives best antisticking effect in use with all types of stamps (Si, fused silica, Si/SiO$_2$). The precise producing of macroscopic elements requires estimation of the thermal expansion and contraction of the used materials during hot imprint.

Acknowledgments

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REFERENCES