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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 SiO_x 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 standart 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 SiO_x 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/SiO_2 (20 mm × 20 mm, thickness of thermal SiO_2 film – 0.8 μm). Preparation procedure of the fused silica imprint mould included: chemical and RF (13.56 MHz) O_2 plasma cleaning of the substrates, electron beam evaporation of the auxiliary Al film (thickness 100 nm), conventional optical litography, plasma etching (RF 13.56 MHz) of a fused silica substrate using an Al masking layer ($CF_4 + O_2$ chemistry plasma at 0.75 W/cm^2 power density), removal of the Al layer in $Cr_2O_3 : NH_4F : H_2O$ 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, SF_6 chemistry plasma at 0.25 W/cm^2 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/SiO_2 imprint moulds were prepared using plasma etching (RF 13.56 MHz, $CF_4 + O_2$ chemistry plasma at 0.75 W/cm^2 power density) of the SiO_2 film using an Al masking layer. The height of imprint profile of the Si/SiO_2 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.

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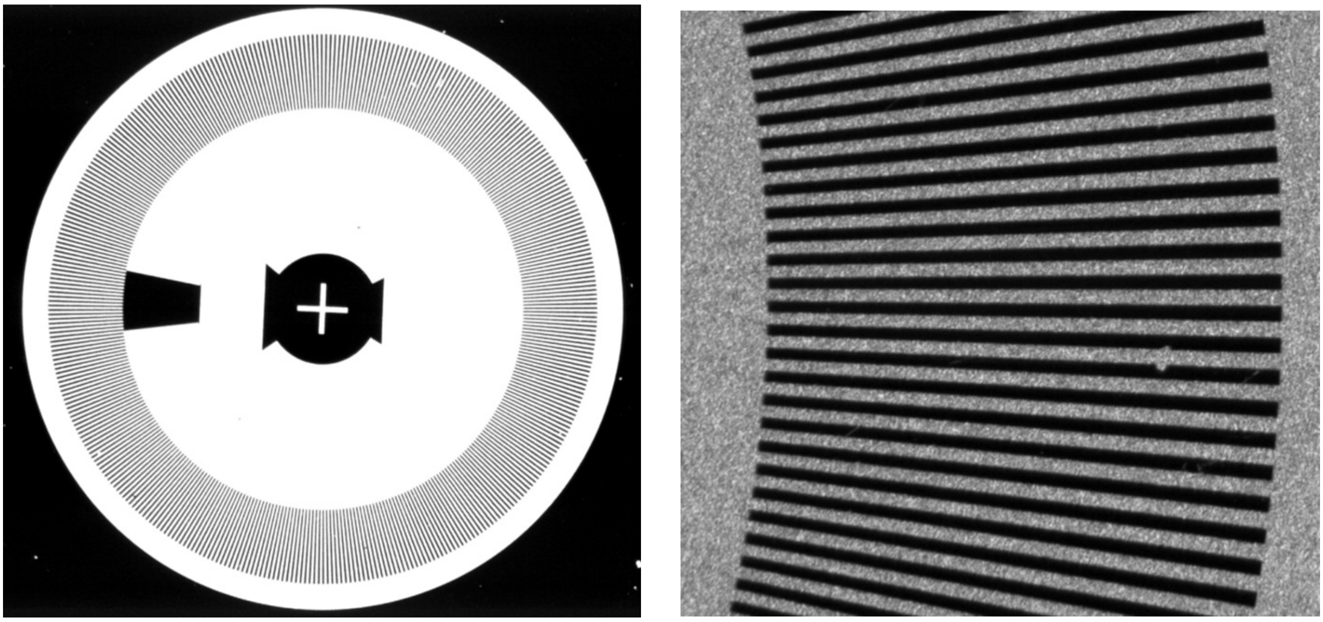


Fig. 1. Optical microscope view of the silicon imprint mould of the angular encoder (dimensions of the central cross are 0.5×0.5 mm, the width of the cross line is 20 μm), and detail of the scale (length of lines is 0.75 mm, scale pitch in the center of lines is 20 μm)

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

Table 1. Parameters of the DLC films deposition process

Reagents	$C_6H_{18}Si_2O+H_2$ $C_6H_{18}Si_2O+C_2H_2$
Base pressure	$(2 \cdot 10^{-4})$ Pa
Work pressure	$(2 \cdot 10^{-2})$ Pa
Ion beam energy	0.8 keV
Deposition temperature	293 K (room temperature)
Ion beam current density	(0.12 ± 0.01) mA/cm^2

Two types of DLC films were used on the imprint moulds: 1) ion beam deposited from acetylene gas – undoped DLC film ($E = 800$ eV, $j_s = 100$ μA/cm^2); 2) ion beam deposited from hexamethyldisiloxane vapour and hydrogen gas mixture SiO_x – doped DLC film ($E = 800$ eV, $j_s = 100$ μA/cm^2). 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 × 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

Parameter	Undoped DLC film	SiO_x – doped DLC film
Thickness, nm	10	10
Refraction index	1.5	1.5
Contact angle with water	72^0	75^0

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 O_2^+ ion beam using multicell cold hollow-cathode DC ion beam source (O_2^+ ion energy 300 eV, ion beam current 0.2 mA/cm^2, pressure 7×10^{-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 ($K_3[Fe(CN)_6]$) and sodium hydroxide (NaOH). Etching time varried from 15 min to 20 min.

The imprinted samples were investigated by scanning electron microscope Jeol JSM-IC25S (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.

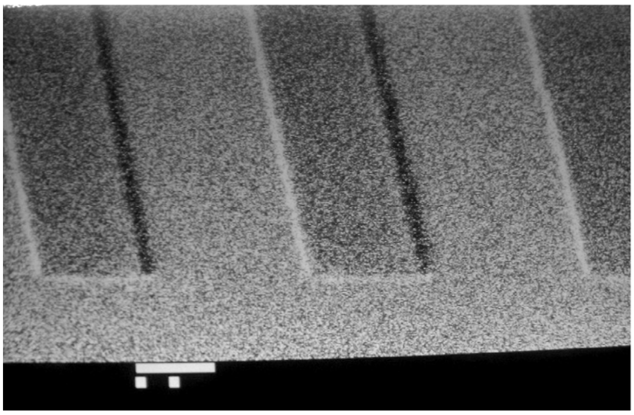
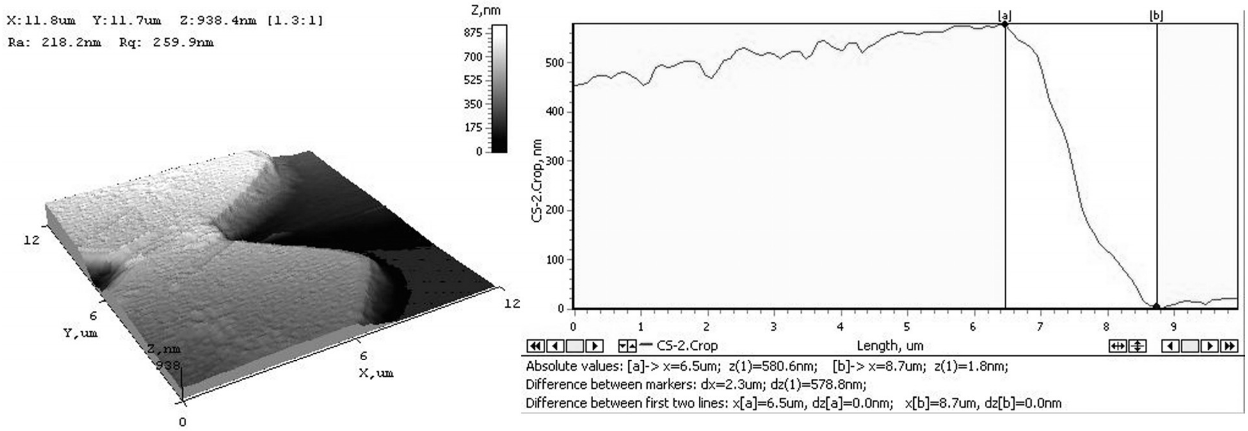


Fig. 2. SEM view of the imprinted resist film with SiO_x – doped DLC film mould. Mark size 10 μm

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_x – doped DLC film and fused silica mould. Typical sample of the imprinted resist film with SiO_x – doped DLC film mould is shown in Fig. 2.

Fig. 3 shows imprint profile of the resist film using the SiO_x – undoped DLC film coated mold and Fig. 4 shows imprint profile of the resist film using the SiO_x – doped DLC film coated mold. From the AFM view the surface is clearly less smooth in the case of imprint with SiO_x – undoped DLC film coated mold ($R_a = 218.2$ nm, $R_q = 259.9$ nm) in comparison with SiO_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_x facilitates the mold separation after imprint and leads to the improvement of the antisticking properties.



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Absolute values: [a]-> x=6.5um; z(1)=580.6nm;   [b]-> x=8.7um; z(1)=1.8nm;
Difference between markers: dx=2.3um; dz(1)=578.8nm;
Difference between first two lines: x[a]=6.5um, dz[a]=0.0nm;  x[b]=8.7um, dz[b]=0.0nm
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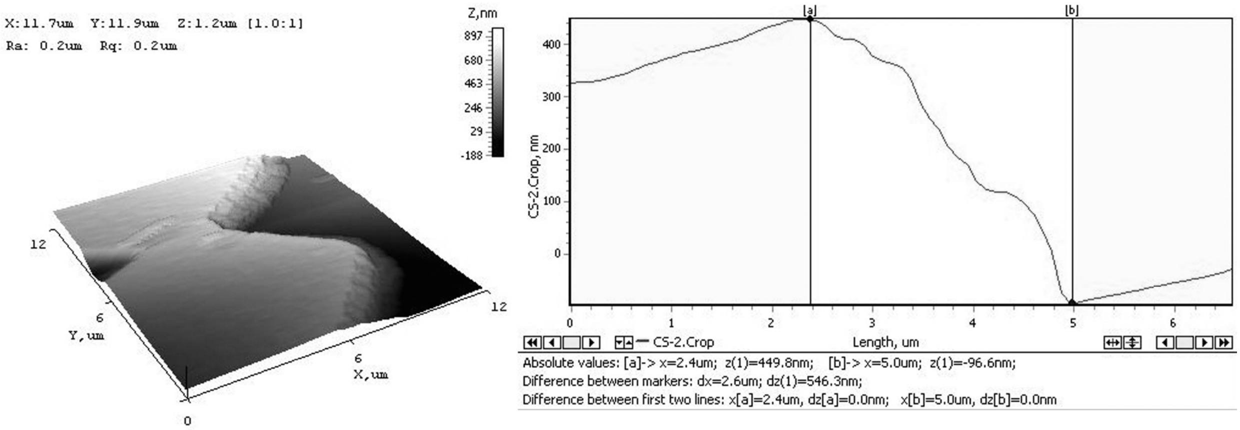
Fig. 3. AFM view of the imprint profile of the resist film using the SiO_x – undoped DLC film coated mold



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Absolute values: [a]-> x=2.4um; z(1)=449.8nm;   [b]-> x=5.0um; z(1)=-96.6nm;
Difference between markers: dx=2.6um; dz(1)=546.3nm;
Difference between first two lines: x[a]=2.4um, dz[a]=0.0nm;  x[b]=5.0um, dz[b]=0.0nm
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Fig. 4. AFM view of the imprint profile of the resist film using the SiO_x – doped DLC film coated mold

After removal of the residual resist layer by O_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_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 μm 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).

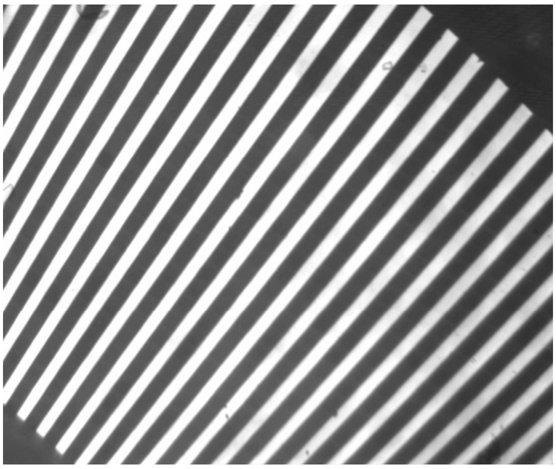

Fig. 5. Optical microscope view (light transmission mode) of the fabricated by imprint lithography angular encoder (length of lines is 0.75 mm, scale pitch in the center of lines is 20 μm)

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

1. **Merino, S., Retolaza, A., Lizuain, I.** Linear Optical Encoders Manufactured by Imprint Lithography *Microelectronic Engineering* 83 2006: pp. 897 – 901.
2. **Chou, S. Y., Krauss, P. R.** Imprint Lithography with Sub-10 nm Feature Size and High Throughput *Microelectronic Engineering* 35 (1 – 4) 1997: pp. 237 – 240.
3. **Guo, L., Krauss, P. R., Chou, S. Y.** Nanoscale Silicon Field Effect Transistors Fabricated Using Imprint Lithography *Appl. Phys. Lett.* 71 (13) 1997: pp. 1881 – 1883.
4. **Li, Mingtao, Wang, Jian, Zhuang, Lei, Chou, S. Y.** Fabrication of Circular Optical Structures with a 20 nm Minimum Feature Size Using Nanoimprint Lithography *Appl. Phys. Lett.* 76 (6) 2000: pp. 673 – 675.
5. **Martini, I., Eisert, D., Kamp, M., Worschech, L., Forchel, A.** Quantum Point Contacts Fabricated by Nanoimprint Lithography *Appl. Phys. Lett.* 77 (14) 2000: pp. 2237 – 2239.
6. **Plachetka, U., Bender, M., Fuchs, A., Vratzov, B., Glinsner, T., Lindner, F., Kurz, H.** Wafer Scale Patterning by Soft UV-Nanoimprint Lithography *Microelectronic Engineering* 73 – 74 2004: pp. 167 – 171.
7. **Choon-Gi, Choi, Chul-Sik, Kee, Schift, Helmut.** Fabrication of Polymer Photonic Crystal Slabs Using Nanoimprint Lithography *Current Applied Physics* 6 (1) 2006: pp. 8 – 11.
8. **Meskinis, S., Kopustinskas, V., Slapikas, K., Tamulevicius, S., Guobiene, A., Gudaitis, R., Grigaliunas, V.** Ion Beam Synthesis of the Diamond Like Carbon Films for Nanoimprint Lithography Applications *Thin Solid Films* 515 (2) 2006: pp. 636 – 639.
9. **Jaszewski, R. W., Schift, H., Schnyder, B., Schneuwly, A., Groning, P.** The Deposition of Anti-adhesive Ultra-thin Teflon-Like Films and Their Interaction with Polymers During Hot Embossing *Applied Surface Science* 143 1999: pp. 301 – 308.
10. **Soo-Beom Jo, Min-Woo Lee, Se-Geun Park, Jung-Keun Suh, Beom-Hoan O.** Fabrication and Surface Treatment of Silicon Mold for Polymer Microarray *Surface & Coatings Technology* 188 – 189 2004: pp. 452 – 458.
11. **Schift, H., Saxer, S., Park, S., Padeste, C., Pieles, U., Gobrecht, J.** Controlled Co-Evaporation of Silanes for Nanoimprint Stamps *Nanotechnology* 16 2005: pp. S171 – S175.
12. **Park, S., Schift, H. H., Padeste, C., Schnyder, B., Kötz, R., Gobrecht, J.** Anti-Adhesive Layers on Nickel Stamps for Nanoimprint Lithography *Microelectronic Engineering* 73 – 74 2004: pp. 196 – 201.
13. **Watanabe, K., Morita, T., Kometani, R., Hoshino, T., Kondo, K., Kaito, T., Fujita, J., Ishida, M., Ochiai, Y., Tajima, T., Matsui, S.** Nanoimprint Using Three-Dimensional Microlens Mold Made by Focused-Ion-Beam Chemical Vapor Deposition *J. Vac. Sci. Technol. B: Microelectrinics and Nanometer Structures* January 2004: pp. 22 – 26.
14. **Morita, T., Watanabe, K., Kometani, R.** Three-Dimensional Nanoimprint Mold Fabrication by Focused-Ion-Beam Chemical Vapor Deposition *Jap. J. Appl. Phys.* Part 1 42 2003: pp. 3874 – 3876.

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