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Original paper

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APPLICATIONS OF UV-LIGA AND GRAYSCALE LITHOGRAPHY FOR DISPLAY TECHNOLOGIES

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Abstract. In the article MEMS technologies for display production and application presented. UV-LIGA and greyscale lithography based on SU-8 resist approaches were shown. Methods, technologies and structures of heterogeneous materials with soft magnetic properties, pros and cons are discussed. Unique specific parameters of soft magnetic composite material were achieved: magnetic induction of saturation – 2,1 T, working frequency range – up to 1 MHz, permeability – up to 3000, total loss – 8 W/kg, Curie temperature – above 800 ºC. Electroplating allows deposition of soft magnetic alloys on the conductive substrate. Metals like Fe, Ni, Co with additives like B, P were used to get the best soft magnetic properties. Special codeposition process was developed to allow insertion of soft magnetic composite powder filaments into soft magnetic matrix formed during. It allows developing magnetic micromotors for display production. Simulation of the hybrid step micromotors was carried out in Ansys Maxwell 19. It was demonstrated that it is possible to get 10 mN m tourqe under 25 μm rotor-stator air gap. Only presented microtechnologies can provide such accuracy of the mciromotors elements. As for greyscale photolithography, special grey mask were developed and it was demonstrated the possibility to produce controllable real 3D relief on the SU-8 photoresist. Thus, microtechnologies should be integrated into display technology to provide cost effective production and advanced properties of final products.

Keywords: microelectronics, MEMS, UV-LIGA, grayscale lithography, photolithography, display production.

Conflict of interests. The authors declare no conflict of interests.

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Introduction

The fourth revolution of the industry is powered by a wide range breakthrough, new technology, innovative ideas and creative activities. All these things were naturally born, mostly, by the interdisciplinary science and technology. Soft magnetic composites (SMC) are the bright example of the different technologies integration to get final commercial technologies and to get the final products with enhanced properties. Micro displacement and micro positioning became a very important factor for new display technologies such as ink jet, 3D printing, nanoimprint. New generation of technologies allows increasing productivity and improving quality. MEMS micromotors are the core of such instruments for display production.

Moreover, micromachining based on MEMS technologies allows creation miniature and complex elements and systems, such as microoptical components (microlens arrays, filters), microcompressors, accelerometers, microactuators, microchannels, microsystems connectors, etc.

In order to obtain microstructures with geometry varying in three directions, there are many technological approaches. They differ in complexity, minimal dimensions of produced element, element size tolerances, materials suitable for processing, etc. In this regard, it is relevant to develop manufacturing technologies for 3D MEMS elements based on polymer micromold production with subsequent deposition of functional material into the mold.

The formation of functional structures at the micro and nano level is achieved through the use of MEMS technologies. LIGA, UV-LIGA technologies are referred as MEMS technologies, because they allow producing extremely complex MEMS elements with high aspect ratio.

LIGA technology has been successfully applied in various research projects [1–3]. The name of LIGA-technology process comes from the main stages of this manufacturing process: X-ray lithography (Lithographie), electroplating (Galvanoformung), and molding (Abformung) [4, 5]. In UV-LIGA technology one of the most promising materials for making microforms is the negative thick film photoresist SU-8 by MicroChem company (USA). SU-8 demonstrates excellent mechanical properties, waterproofness, uniformity and high chemical resistance. Its widespread use for MEMS production is due to such characteristics as large layer thickness (up to 1000 μm), high chemical resistance, optical transparency, high adhesion to almost any substrates, high aspect ratio.

For some application real 3D microstructures should be developed. Gray scale SU-8 based lithography is characterized by the use of differentiated light transmission photomasks [6, 7]. Patterns on photomasks contain dark and light pixels regions allow to get the UV light intensity distribution with gradient changes. This effect is used to produce various real 3D microstructures.

The most promising method of depositing metal materials on conductive surfaces and filling polymer microforms is electrochemical deposition from the electrolyte under the influence of electric current.

Soft magnetic composite for MEMS micromotors

In general, to produce MEMS micromotors, core materials should be formed with high accuracy and have high magnetic properties. To get the precise shape of rotors and stators UV-LIGA technology was developed for molds. As for materials for magnetic rotors and stators composite codeposition of the SMC powder and soft magnetic matrix were used.

To meet the requirements to electric machines and micromotors, magnetic materials should provide more power and has less cost. From the point view of the magnetic core properties they should have low losses, high magnetic induction and permeability, low coercivity.

The energy loss in magnetic material is caused by eddy currents (for an electrically conductive magnetic material) and magnetic hysteresis, also some anomalous effects. Energy loss occurs by converting the energy of the magnetic field into heat, which heats the magnetic material. Total power loss (core losses) is calculated from Steinmetz's [8] empirical equation. This equation is used to calculate losses per unit volume of magnetic materials inside of which magnetic flux is changing sinusoidally:

$$P_t = P_h + P_b + P_a, \quad (1)$$

where $P_h = k_h B^{1,75} f$ – hysteresis loss (core magnetization and demagnetization loss) which occurs as current flows in the forward and reverse directions, $P_e = k_e B^2 f^2$ – eddy current losses when a motor core is rotated in a magnetic field, a voltage, or EMF, is induced in the coils, $P_a = k_a (f B)^{1,5}$ – anomalous loss is caused by heterogeneous distributions of flux density. In the equations B – magnetic induction, f – frequency, k_h, k_e, k_a – empirical coefficients. It means that when magnetic field and frequency are increased the losses increased significantly and contribution of the eddy current loss comes to the fore.

Technology of reactive deposition of insulating nanocoatings from the gas phase in vacuum at temperature of 150–200 °C on the surface was developed (Fig. 1). Iron powder of ASC 100,29 by Hoganas (Sweeden) was used to produce SMC-LF powder with modified surface.

The final magnetic details are produced by technology of powder metallurgy with macro and micro molds. Unique specific parameters of a soft magnetic composite material were achieved: magnetic induction of saturation – 2,1 T, working frequency range – up to 1 MHz, permeability – up to 3000, total loss – 8 W/kg, Curie temperature – above 800 ºC. These allow producing electric machines with the large number of poles and high frequency of switching, thus improving specific mass and size parameters. UV-LIGA MEMS technology combined with electroplating was developed to produce hybrid stepper micromotor based on soft magnetic composites.

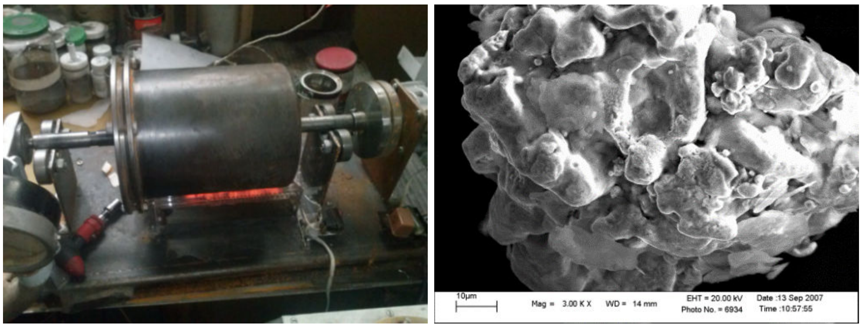


Fig. 1. Reactor for nanocoating deposition and treated particle

Microforming technology

The LIGA-like technology was successfully tested with two types of thick film photoresists: SU-8 liquid photoresist (electroplating forms are reusable up to 10 times), dry film photoresist PF-SSHCH (provides cheap and scalable production). Photoresist film thickness was 50–1000 µm. Glass high resolution photomask or affordable polymer flexible film photomask are both applicable for this technology.

The technology of microstructures formation by LIGA-like technology consists of six successive technological operations (Fig. 2):

- substrate preparation;
- application of SU-8 photoresist;
- exposure of the photoresist by the UV radiation through the photomask with a given topology;
- development of SU-8 photoresist;
- electrochemical deposition of metal into the resulting microforms (electroplating);
- removal of the photoresist mold and release the element (rotor).

Electroplating allows deposition of soft magnetic alloys on the conductive substrate. Metals like *Fe*, *Ni*, *Co* with additives like *B*, *P* were used to get the best magnetic properties. Special process was developed to allow insertion of SMC powder filaments into soft magnetic matrix formed by plating. Special surface chemical treatment is used to reduce adhesion of electrodeposited part to substrate. It provides easy removal of rotors or stators from conductive substrate without photoresist-based micromold destruction.

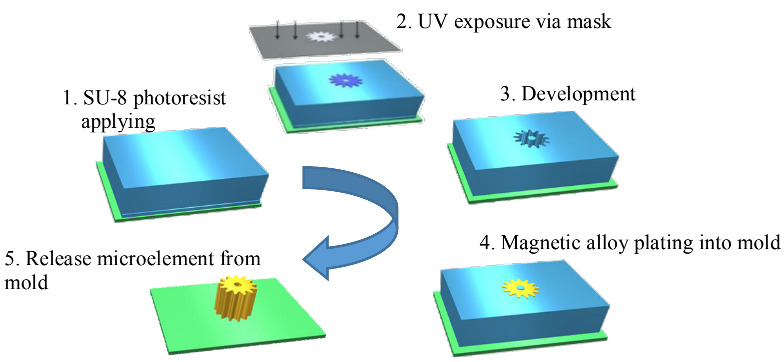


Fig. 2. Technology flow of UV-LIGA-like process

Gray scale lithography

The technology based on gray scale lithography of SU-8 resist is developed. Geometry of the final microstructure at a given point depends on the light transmission of the gray-scale photomask. To adjust the light transmission pixel size and pitch should be changed. The technique allows to produce microstructures with free real 3D shapes, for example, microlenses, including aspherical, optical filters, Fresnel lenses and so on. The technology consists on the following steps (Fig. 3):

– simulation and ray tracing of lens with Trace Pro CAD;
– design and fabrication of gray-scale photomask for various 3D lens shape using e-LiNe plus system;
– gray-scale photolithography, press forming or casting;
– testing and measurement of received lens parameters using the SMS 10c Goniophotometer by Goniophotometer and Spectroradiometric Testing System.

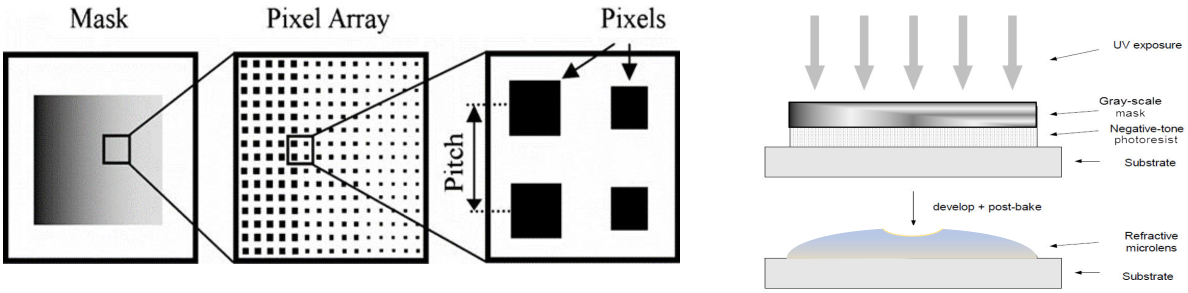


Fig. 3. Gray-scale lithography approach

Discussion of the results

Soft magnetic materials obtained by developed method have the following properties: $\rho = 10^{-3}$–10^{-4} Ohm m for the metal state, $\rho = 10^{3}$–10^{4} Ohm m for the dielectric state (resistivity is determined by the thickness of the insulating layer on the magnetic particles), maximum magnetic permeability varies from μ = 2500–3000 for the metal state and μ = 300–500 for the dielectric state. Magnetic induction B = 2,1–2,2 T for metal state and B = 1,7–1,8 T for dielectric state at field strength H = 20 kA/m. The obtained parameters of soft magnetic composite allows to use it for manufacturing of transformers and magnetic chokes operating in the frequency range of 10 kHz–1 MHz, stator-rotor systems and parts of high-efficiency and high-power electric machines operating in the frequency range of 50 Hz–20 kHz (Fig. 4).

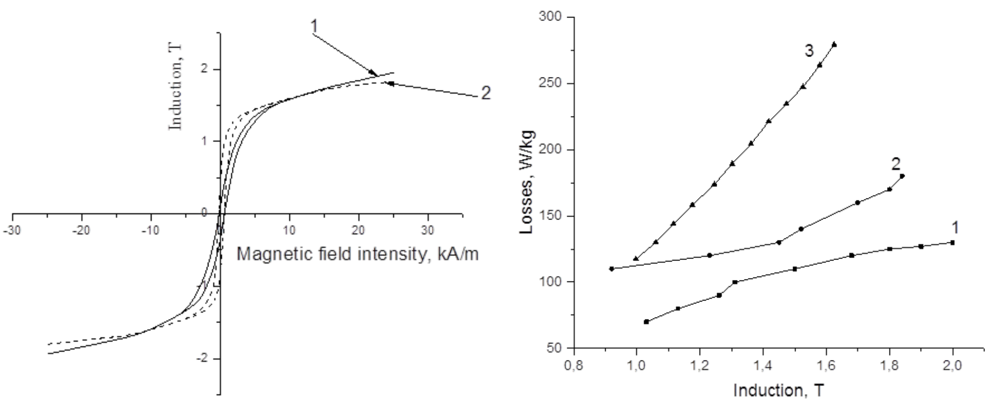
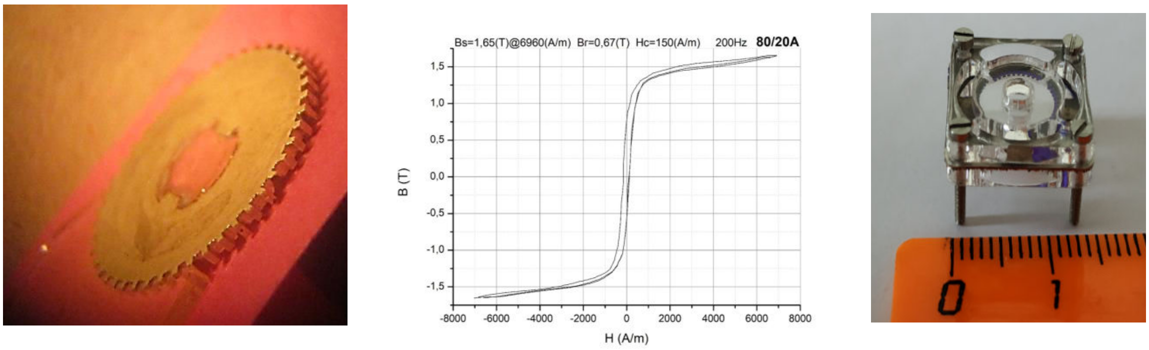


Fig. 4. Hysteresis loop and total losses for SMC-LF (1), electric steel 3412 (2) and Somaloy-700 (3) by Hoganas

The technology of codeposition of SMC powder and soft magnetic matrix allows getting the final heterogeneous materials with improved magnetic properties.

a *b* *c*

Fig. 5. Schematic (*a*) and real (*b*, *c*) images of codeposited magnetic material



a *b* *c*

Fig. 6. Rotor of micromotor with 4 mm diameter and 120 µm tooth (*a*) and hysteresis loop (*b*), micromotor prototype (*c*) based on UV-LIGA and coodeposited soft magnetic materials

Simulation of the hybrid step micromotors was carried out in Ansys Maxwell 19 (Fig. 7).

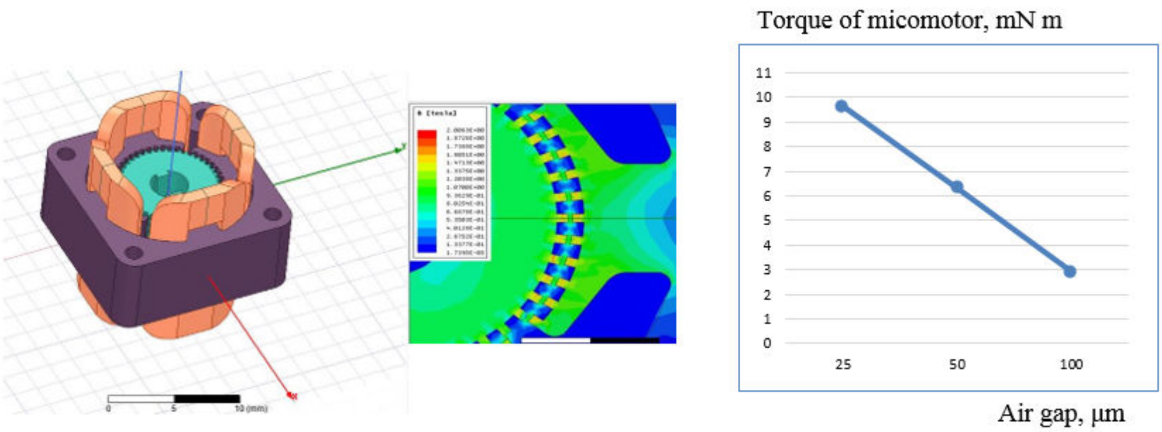
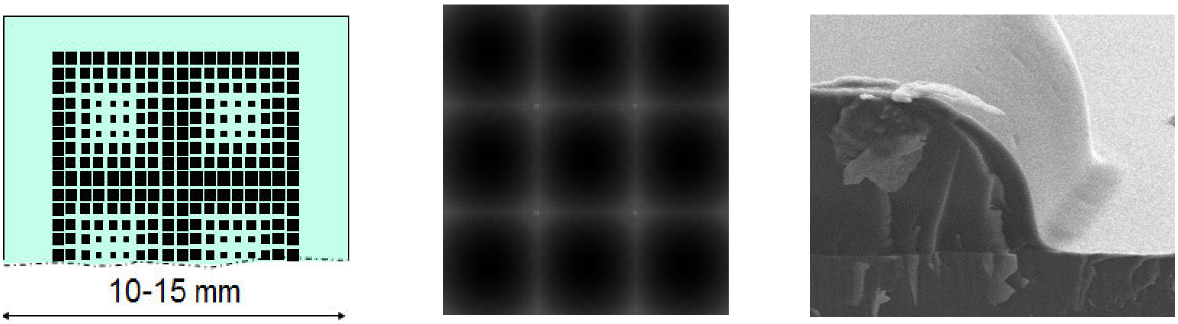


Fig. 7. Hybrid micromotors model for simulation and distribution of the magnetic field

The parameters for simulation were as follows: stator diameter – 7,5 mm, rotor diameter – 4 mm, rotor-stator gap – 0,025–0,1 mm, thickness of the soft magnetic core – 6 5 mm, thickness of the permanent magnet – 2 mm, type of permanent magnet – NdFeB N30. The simulation shows that the torque is extremely determined by the air gap between rotor and stator teeth. The only LIGA technology can provide the narrow gap and increase power of the micromotor.

As for greyscale photolithography, special grey mask were developed and it was demonstrated the possibility to produce controllable relief on the SU-8 photoresist.



a *b* *c*

Fig. 8. Photomask (*a*) and ideal dose distribution (*b*) for lenses production, SEM image of the profile (*c*)

Conclusion

Described technologies are suitable for the following applications for optical elements and display production equipment:

– manufacturing of microforms for micropressing technology;

– mechanical parts manufacturing for micropositioning – gears, racks etc;

– magnetic cores manufacturing;

– stators and rotors for BLDC and stepper motors (including linear). Combination of soft and hard magnetic materials in one process/design;

– production of microlenses arrays, filters.

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Authors contribution

Timoshkov I.V. made UV-LIGA and grayscale lithography adaptation for display technologies.

Khanko A.V. developed grayscale lithography concept and tested it.

Kurmashev V.I. developed of basic technology for magnetic materials codeposition.

Grapov D.V. produced of micromotor prototype, made simulation.
Kastevitch A.A. made simulation of micromotors in Ansys Maxwell 19 softrawe.
Govor G. A. developed SMC concept.
Vetcher A.K. produced SMC powders and made measurements.

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