Novel synchronous linear and rotatory micro motors based on polymer magnets with organic and inorganic insulation layers

M. Feldmann, A. Waldschik, S. Büttgenbach

Institute for Microtechnology, Technical University of Braunschweig,
Alte Salzdahlumerstr. 203, 38124 Braunschweig, Germany
Tel (+49) 531-391-9768, Fax (+49) 531-391-9751, E-mail: m.feldmann@tu-bs.de

ABSTRACT

In this work, we show the development of several synchronous motors with rotatory, 1D or 2D movements. The synchronous micro motors are brushless DC motors or stepper motors with electrical controlled commutation consisting of a stator and a rotor. The rotor is mounted onto the stator adjusted by an integrated guidance. Inside the stator different coil systems are realized, like double layer sector coils or special nested coils. The coil systems can be controlled by three or six phases depending on the operational modus. Furthermore, inorganic insulation layers were used, which reduced the system thickness. By this means four layers of electrical conductors can be realized especially for the 2D devices. The smallest diameter of the rotatory motor is 1 mm and could be successfully driven.

Keywords: Synchronous micro motors, 1D- and 2D linear actuators, micro coils, UV depth lithography, polymer magnets

1 INTRODUCTION

Due to the development of new technologies, more and more complex MEMS applications can be realized. Especially electromagnetic micro actuators [1, 2] have reached a growing interest in micro technology in addition to commercial applications during the last years. Their basic construction exists of electric conductors and coil systems as well as of soft-magnetic and/or hard-magnetic materials that were fabricated in additive technology via UV-depth lithography and electroplating. For UV-depth lithography photo resists like Epon SU-8, AZ9260, Intervia-3D-N and CAR44 were applied and optimized. Layer thicknesses up to 1 mm and aspect ratios over 60 were achieved (see Fig. 1). Special micro composites were developed. This allowed the fabrication of micro magnets with arbitrary shape and properties, ensuring a complete compatibility to existing process chains. With these potential technologies several synchronous motors with rotatory, 1D or 2D movements were developed. In addition inorganic insulation layers like silicon nitride or silicon oxide were used. The advantage of these inorganic insulation layers in comparison to organic insulation layers like Epon SU-8 is the reduced thickness, whereby four layers of electrical conductors can be realized especially for the 2D devices. Furthermore, for different fields of application inorganic insulation layers are more chemical or thermal resistant.

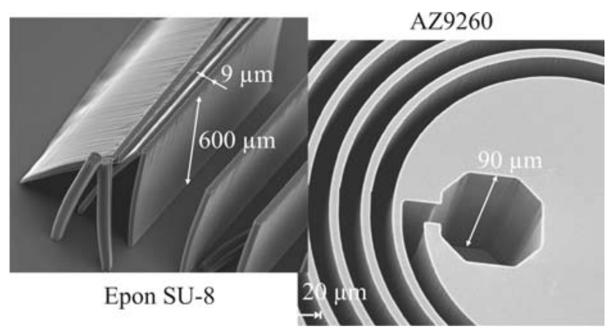

Figure 1: SEM-pictures of Epon SU-8 and AZ9260 photo resist structures.

2 CONCEPT AND DESIGN

The synchronous micro motors are brushless DC motors or stepper motors with electrically controlled commutation. In Fig. 2 the basic setup for an electric motor with disc-shaped rotor consisting of a stator and a rotor is shown. The rotor is made of a SU-8 form, which contains alternate magnets. These magnets were realized by polymer magnets [3, 4, 5] or commercial magnets. Both magnet types have an axial magnetization. The stator consists of double layer coils, which where arranged as sector coils or nested coils. The coils have 6-30 windings per phase depending on the motor size and number of poles. The arrangement of the coils and magnets allows the driving by three or six phases. For the adjustment of the rotor and the stator a centrical arranged circular guidance is integrated.

NSTI-Nanotech 2008, www.nsti.org, ISBN 978-1-4200-8505-1 Vol. 3

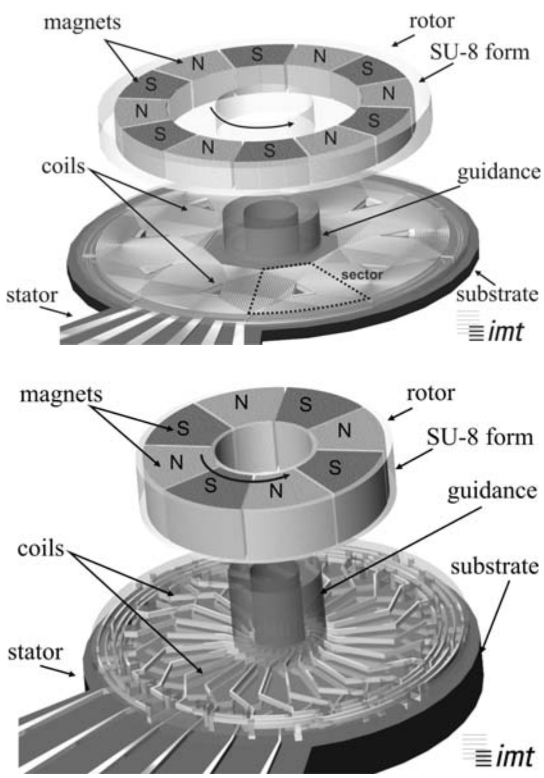

Figure 2: Concepts of rotatory synchronous motors with sector coils (top) and nested coils (bottom).

3 FABRICATION

The principle process chain for fabrication of stator and rotor consists of an iteration loop of single process steps for in layers built-up for complex 3D microstructures. The fabrication process includes UV-depth lithography using AZ9260 of electroforming and Epon SU-8 for insulation, planarization and embedding. Inorganic materials like silicon oxide and nitride where used alternatively to SU-8 for insulation of the different coil layers.

3.1 Stator

The process sequence for fabrication of the stator starts with the lower conductors of the double layer coil. A mould of AZ9260 is patterned and filled with copper by electroplating. After stripping the AZ9260 mould, a SU-8 layer is spun onto these structures as insulation layer. This layer provides openings for through connections to the upper coil layer. Both connections and upper conductors are likewise structured by copper eletrcoplating. A following second SU-8 layer serves on the one hand as insulation between upper conductors and traveler magnets and on the other hand it serves as bearing layer for the traveler. In the last step the circular or linear guidance is made by pattering a 200 µm thick SU-8 layer. The fabricated stators are shown in Fig. 3.

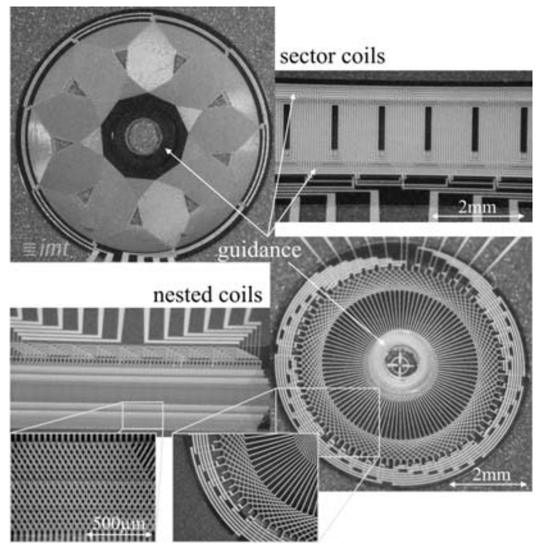

Figure 3: Photograph of different fabricated stators.

For the application of inorganic insulation layers, instead of organic SU-8, investigations with silicone oxide and silicone nitride were carried out. Both films were deposited by a PECVD process with thicknesses of 600-1000 nm for oxide and 100-200 nm for nitride respectively. These layers were masked by patterned AZ9260. Both wet and dry etch were tested. In the wet etching process large undercut could be observed. Pattering silicone nitride could be improved by using dry etching in a barrel etcher because of no undercut has occurred (see Fig. 4).

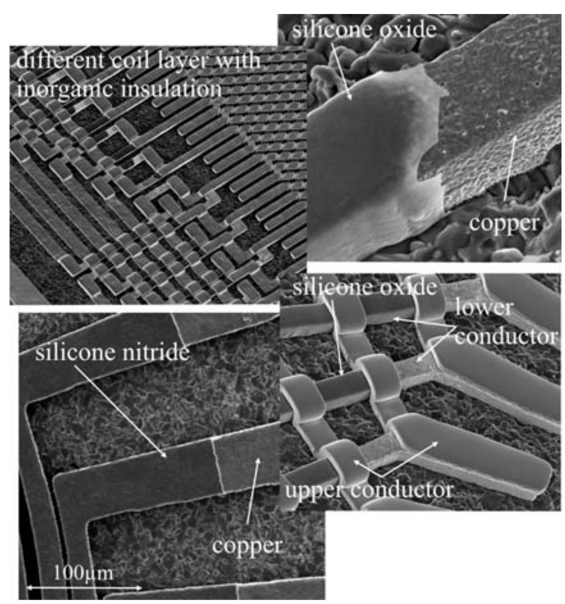

Figure 4: SEM-pictures of lower conductors covered with inorganic insulation layers.

3.2 Rotor

The rotor is realized by SU-8 creating a form for polymer magnets or commercial magnets with high precision adjustment (see Fig. 5). The commercial magnets were mounted inside of this form and hold by a fit. The polymer magnets are filled in these forms and magnetized by special developed magnetization equipment. It is mounted onto the stator adjusted by the integrated guidance.

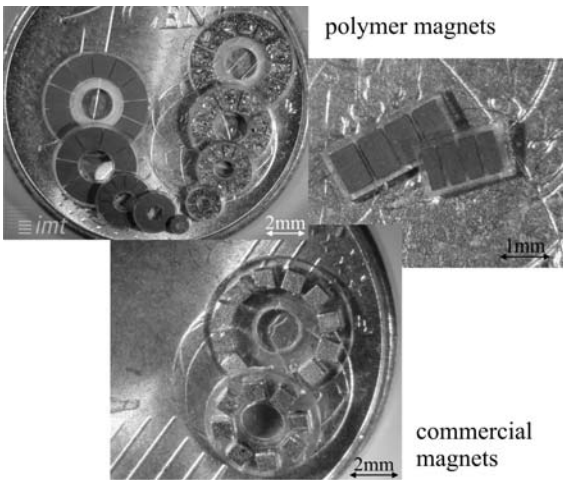

Figure 5: Photographs of different rotors and travelers with integrated polymer magnets (top) and mounted commercial magnets (bottom).

Both rotor types were fabricated to compare their influence of motor properties and performance respectively. The structured polymer magnets show comparatively less magnetic properties. However, the advantage is the flexible formation so that higher area fillings could be achieved. Furthermore, with polymer magnets smallest structures down to several tens micrometers are producible. By that, rotors with a smallest diameter of 1 mm could be realized. The following table shows the realized rotors.

Diameter [mm]	2p	Weight [mg]	Magnets
5,5	12	45	Commercial
5,5	12	24	Polymer magnet
4,5	8	30	Commercial
4,5	8	17	Polymer magnet
3,0	12	6	Polymer magnet
2,0	8	2	Polymer magnet
1,0	8	<1	Polymer magnet

Table 1: Overview of realized rotor configurations.

For the fabrication of the rotor a sacrificial copper layer is electroplated onto the substrate followed by a thin patterned SU-8 layer. After that a 400 µm high SU-8 layer is structured to provide the filling form. The polymer magnet is filled in this form and baked. After baking a polishing process follows to level the compound structure and to remove waste residuals. By etching the sacrificial layer the rotors are detached from substrate. The applied polymer magnets consist of 80wt% barium-strontium ferrite or 90wt% neodymium-iron-boron.

4 MAGNETIZATION

A special magnetization equipment was designed for apply the alternate magnetization into the polymer magnet sectors in axial direction (see Fig. 6). It consists of a ferromagnetic core with a yoke in which special magnetization adapters can be placed. At these adapters milled sectors respective stripes are located for magnetization rotors and linear travelers. A flat coil with 400 windings wound around the core serves for generating magnetic flux. For the magnetization process a rotor is inserted and oriented to the adapter (see Fig. 7) by means of a multi axis positioning stage. By the first current feed every second segment is magnetized. After that the rotor is is rotated at an angle, which corresponds to the pole pitch. By a second current feed the other segments are magnetized in the opposite direction.

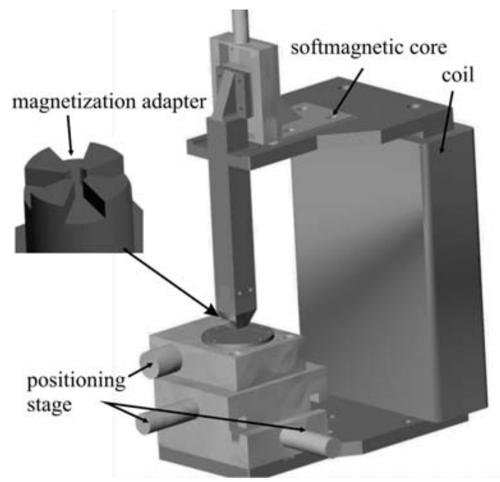

Figure 6: Magnetization equipment.

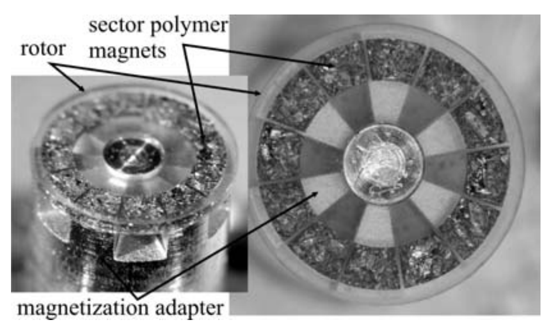

Figure 7: Magnetization adapter with polymer magnet rotor.

NSTI-Nanotech 2008, www.nsti.org, ISBN 978-1-4200-8505-1 Vol. 3

5 RESULTS

By the use of the described process sequences stators and rotors or travelers were succesfully fabricated. By means of the guidance structures the components could be mounted and first tests were carried out. The smallest diameter of the rotatory motor is 1 mm and driving currents between 50-300 mA are necessary depending on magnet type. This results in a torque up to 20 µNm and higher depending on the used magnets and size of the motor. In first test the motor could be successfully driven over a long period with a rotating speed over 7000 rpm (see Fig. 8). Generally, the motors with nested coil indicate a smoother movements due to their finer pitch.

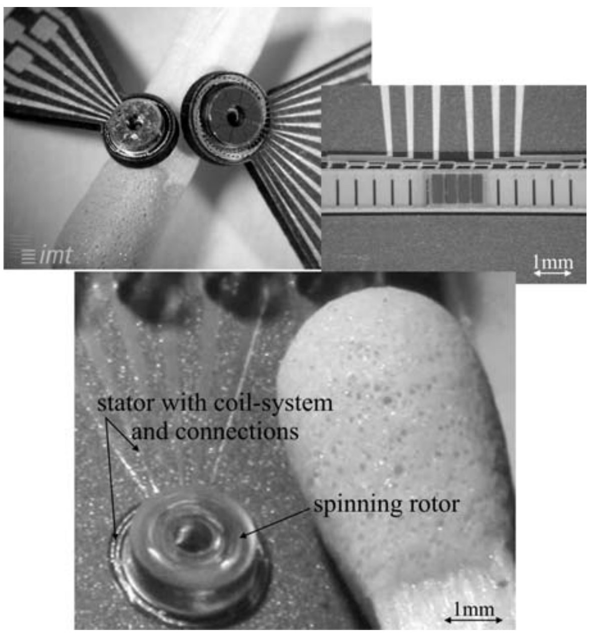

Figure 8: Photograph of different mounted synchronous motors with comparision to a match.

6 CONCLUSION

The purpose of this work was to develop linear and rotatory synchronous motors. Both motor types could be realized succesfully by means of UV-depth lithography, electroplating and by using polymer magnets. The integration of polymer magnets made it possible to miniaturize synchronous motors down to 1 mm rotor diameter. All devices are currently under further investigation to optimize and characterize the operating behavior. In addition, a special packaging is being developed. Also first concepts for integrated magnetic sensors were developed for closed loop control, which allows micro-/nano stepping and rotating. Following investigations also aims to exact measurements of magnetic flux densities generated by the polymer magnet segments.

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