A hybrid concept as a new approach for the micro-production of magnetic actuators

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ABSTRACT

Actuators that are widely used in industrial applications are generally based on magnetic principles. As for macroscopic actuators, the conversion of electric energy into mechanical motion is very efficient. Nevertheless, limitations arise with a decrease of the motor size. In addition, there have been many approaches to realize magnetic actuators by means of micro-technologies such as thin film technology. Hence, limiting the production processes to the use of micro-technologies implies the usage of planar technologies. In this case, the fabrication of coils with an adequate number of windings becomes very challenging. Moreover, applying precision engineering becomes limited if complex microstructures have to be processed. In order to overcome these obstacles, we developed a new approach that combines both of the macroscopic and micro-technologies. We showcase our concept by manufacturing a hearing aid. First, the coil and the flux guiding parts are manufactured using conventional coil winding processes and precision engineering. Then, the membrane and the boss structure which holds a coupling element are realized using thin film technologies. Last, the independently produced parts are merged together by means of assembly techniques. We demonstrate that this approach combines the advantages of the available technologies.

1 INTRODUCTION

The electromagnetic principle is typically applied to realize actuators to be used in industrial automation, machine tools, pick and place machines, bonding machines for the electronic production or others. The quantity of these actuators in macroscopic applications has been increased over the last decades. The advantages are that the production technologies are mature and the energy conversion is very efficient. Modern electromagnetic motors for the industrial automation reach efficiency factors of over 90 %. In case of decreasing the size of the motors to the micrometer scale the electromagnetic principle is commonly not the realization of choice. Very often piezoelectric or electrostatic principles are preferred accepting the drawback, that these techniques are depending on higher supply voltage levels. Thinking of very small motors this is understandable because the forces can scale overproportional with the characteristic dimension of these motors. But there is an interesting field of application for electromagnetic actuators with dimensions in the range of micrometers to millimeters. To produce these actuators conventional technologies have been used. The challenge is that shrinking dimensions increase the demands to reach higher precision usually accompanied with higher costs of production. There have been also many attempts to produce small motors using microtechnologies. The advantage of this approach is that the definition of micrometer structures is done by photolithography. The disadvantage has been, that the planar technology limits the easy formation of three dimensional structures. As a result the presented approach shows the combination of the two technology concepts, the conventional fabrication technique and the microtechnologies to overcome the bottlenecks.

To explain the advantages of combining the technologies the production process of a hearing aid is presented. The diagnosis of a partial or complete loss of the ability to hear has a major impact on the life of the person affected. In many cases children with reduced or lost hearing ability have problems to learn to speak and pronounce the words. To help children in an early stage implants are applied like cochlear implants. In cooperation with the Hannover Medical School different implantable hearing aids are developed. The implantable hearings aids being presented here are based on the electro-magnetic principle. The aim is to fix the coupling element of the hearing aid to a membrane of the cochlea, the so-called round window. Normally the vibration of the eardrum is transferred by a chain of middle ear bones to the oval window of the cochlea. If the original function of the ear bones is no longer given, they are replaced by the hearing aid. The hearing aid is vibrating and the vibration is transferred via the round window to the hair cells.

2 FIRST DESIGN OF THE HEARING AID – APPLICATION OF MICROTECHNOLOGIES

In figure 1 the first designed hearing aid is shown as a model. The actuator, which was designed utilizing an FEA approach [1, 2], consists of two main parts, the membrane chip and the part carrying the actuation coil. Both parts are solely processed using microtechnologies. For the substrates which are devoted to realize the membrane parts silicon is applied, the other substrate material is alumina. The coupling element is generated by dicing and is made of ceramics or silicon. To finalize the complete system the parts are assembled.

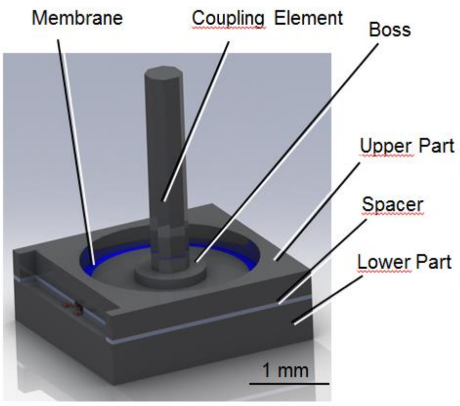

Fig. 1 Model of the hearing aid [3]

2.1 <u>FUNCTION</u>

By powering the coil with an alternating current a magnetic field and a magnetic flux are generated. The actuator is realized as a reluctance system. If the coil is powered a softmagnetic back iron is attracted towards the coil and minimizes the reluctance of the system. This softmagnetic layer has been deposited on top of the membrane and so also the membrane is deflected. Reducing the current to zero, the magnetic forces disappear and the membrane deformation also vanishes. The size of this system is 2.3 mm * 2.5 mm * 2.5 mm (plunger). The system has been presented in [4].

2.2 <u>REVIEW OF THE DESIGN APPROACH</u>

The magnetic field generated by the coil is depending on the ampere conductors. Important factors are the number of windings and the drive current. The forces attracting the back iron are on the one hand depending on the permeability difference of the softmagnetic material and air in the gap. On the other hand the force is proportional to the squared magnetic flux density. To increase the forces a scale up of the flux density respectively the magnetic field has to be generated. As a consequence the ampere conductors have to be risen. There are two possibilities to achieve this aim. On the one hand the current can be enlarged or on the other hand the number of windings has to be increased. There are limitations concerning the raise of the current. Ohmic losses caused by the current generate heat. The maximum temperature of the device has not to exeed the body temperature to prevent cell degradation, so there is only a small range to change the current. The remaining possibility to enlarge the field is to multiply the number of windings. Its implementation is technology restricted. To realize coils in planar technology they are often designed as spiral coils. Also other implementations are known, but for all of them can be reported, that the number of windings is limited and the processing of three dimensional coils using microtechnologies is very complex and expensive. Figure 2 is showing the planar coil of the first hearing aid concept. The coil consists of two layers with in total 104 windings. Figure 3 shows the membrane chip and figure 4 depicts the assembled hearing aid with plunger

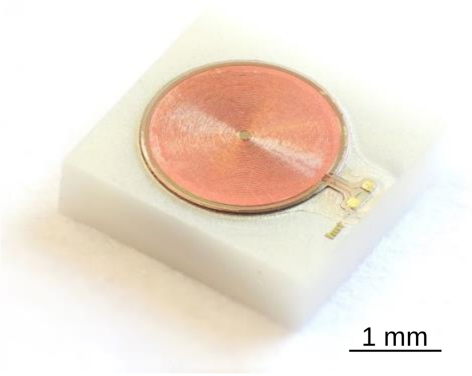

Fig. 2 Coil system

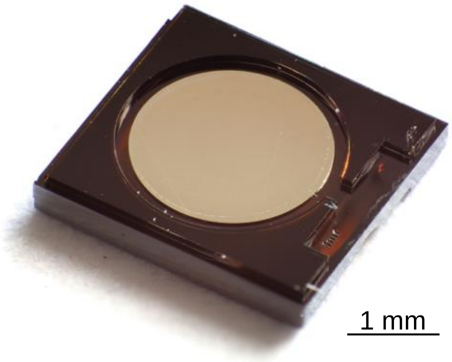

Fig. 3 Membrane chip

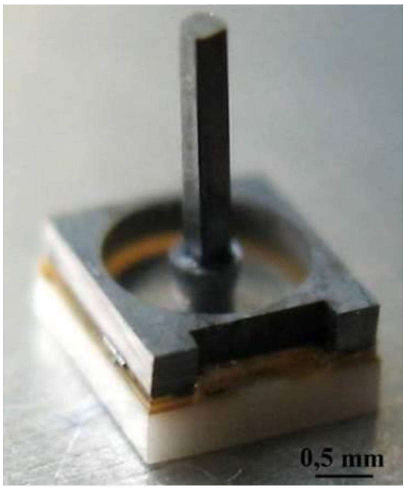

Fig. 4 Completed system of the hearing aid implant [4]

3 REDESIGN AND NEW FABRICATION CONCEPT

A redesign has been started to improve the first developed hearing aid. The following demands have been focused: The power consumption has to be further reduced and at the same time the generated magnetic field strength has to be increased. The solution to meet these requirements is to multiply the number of windings. The second goal to fulfill with the new design is to simplify the manufacturing process.

The new design concept is depicted in fig. 5. A body housing is holding a coil with magnetic core. The small housing tube is capped with two membrane chips. Powering the coil the magnetic forces deflect the polymer membrane carrying a softmagnetic back iron. The movement of the membrane is transmitted to the round window membrane of the cochlea via the movement of the coupling element.

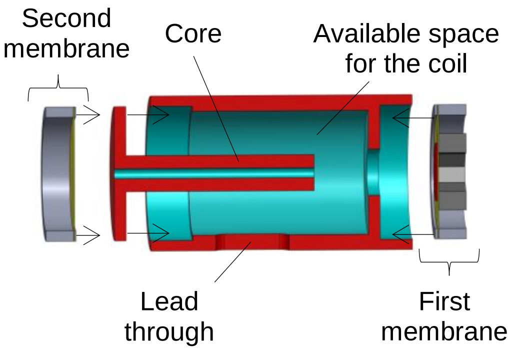

Fig. 5 The new design concept [5]

The new approach is to combine the advantages of traditional manufacturing processes with microsystem technologies.

3.1 FABRICATION OF THE HEARING AID COMPONENTS

Core and coil fabrication

As a result the soft magnetic core is produced by machining using a turning layce. The coil windings are prepared separately and afterwards attached to the prefabricated core. Figure 6 is showing the core and the coil. The coil exhibits 1000 windings and the diameter of the wire is 22 µm.

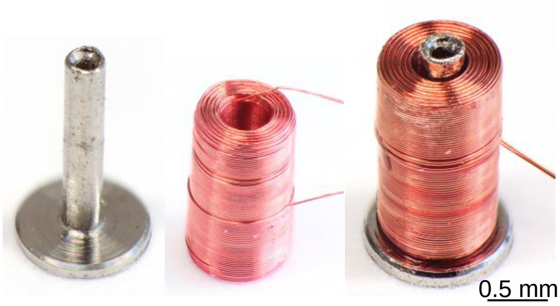

Fig. 6 Softmagnetic Core, Coil and coil attached to the core

Housing manufacturing

A body housing is produced as a package for the system components. Also this part consists of softmagnetic material and is used as a flux guide. For the fabrication of the housing a turning process again is applied. Fig 7. depicts the body housing. The housing features supports to hold the membrane chips. The package shows a lead through for the coil connects. The body housing is in the end coated with a gold layer to enlarge bio compatibility and reliability.

Fig. 7 Body housing

Fabrication of the membrane chips

The membranes are made of polymer. One of the membranes features a soft magnetic back iron and a boss structure to hold the coupling element. To manufacture this membrane microtechnology processes are applied. In the first step polyimide is spun on the surface of a silicon wafer and structured using photolithography. In the next step a seed layer is deposited by sputtering and a photoresist mold is generated by a photolithography step. The mold is used to deposit the NiFe back iron by electroplating. Afterwards photoresist is spun on the backside of the wafer, exposed and structured. This photoresist mask is used as an etching mask for the DRIE (Deep Reactive Ion Etching) process. The DRIE-process is applied to release the membrane and to form the boss structure. As a result the membrane is still fixed to the remaining silicon. In a following etch process, the membrane is thinned and structured to realize a spacer structure. This spacer allows adjusting the membrane wafer to the body housing in a well-defined distance. The process steps are shown in fig 8.

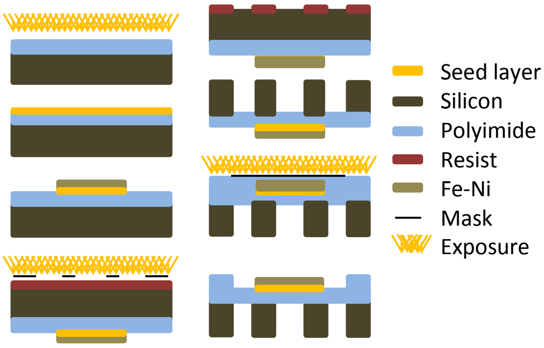

Fig. 8 Processing steps of the first membrane [5]

The second membrane is realized similar to the first, back iron and boss structure are missing. Fig. 9 shows the process steps. Both membranes are depicted in Fig. 10.

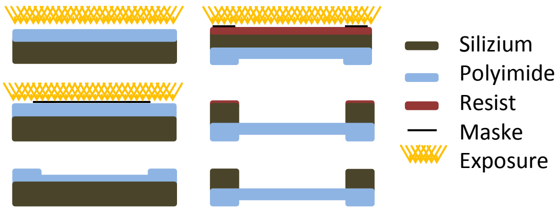

Fig. 9 Processing steps of the second membrane [5]

Fig. 10 Membrane chips: front and back sides

Plunger and Assembly

The plunger is produced by dicing. In the end the single parts are assembled and mounted. To join the single parts adhesive bonding processes are used. The components of the hearing aid are shown in fig. 11. The body housing includes the core with the coil, two membranes and the plunger.

Fig. 11 Hearing aid: components

The assembled system can be seen in figure 12.

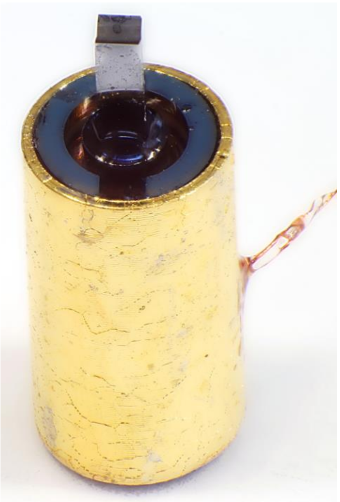

Fig. 12 assembled system

4 CONCLUSION AND FUTURE WORK

A new approach has been applied to manufacture an implantable hearing aid. The combination of a classic manufacturing process like turning with microsystem technologies allows to realize a very effective design. The designed actuator features a coil with 1000 windings of a 22 µm diameter copper wire. The air gap between back iron and core is designed to 10 µm. as a result the actuator generates forces of 0.5 mN to 2 mN.

The next step is to characterize the actuator in detail and to test the actuator to agitate a biological membrane.

5 ACKNOWLEDGMENTS

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