MICROMACHINED INDUCTORS FOR MEMS APPLICATIONS

Stephanus Büttgenbach and Volker Seidemann
Institute for Microtechnology, Technical University of Braunschweig,
Langer Kamp 8, D-38106 Braunschweig, Germany

Abstract
This paper presents technologies for fabricating high aspect ratio multilayer micro coils with integrated magnetic flux guiding structures. They are based on new types of low-cost UV photo resists. The established technologies have been used to develop inductive micro sensors and electromagnetic micro actuators.

INTRODUCTION

Due to the development of new technologies for fabricating micro coils electromagnetic components are gaining increasing significance in micro electro mechanical systems. Besides their application as driving systems in electromagnetic micro actuators, micro coils can be used as inductive components in electronic circuits and as transfer elements in inductive sensors and telemetric devices.

To build up electromagnetic micro actuators soft magnetic flux guiding structures have to be integrated into the coils. In order to minimize the electric resistance as well as the reluctance the current and flux carrying structures should feature large cross sections. Inductive sensors benefit from enlarged conductor cross sections as well due to the resulting lower DC resistance and higher Q value. In addition, large cross sections of the soft magnetic structures lead to improved sensor sensitivities, and allow the realization of high performance magnetic field sensors.

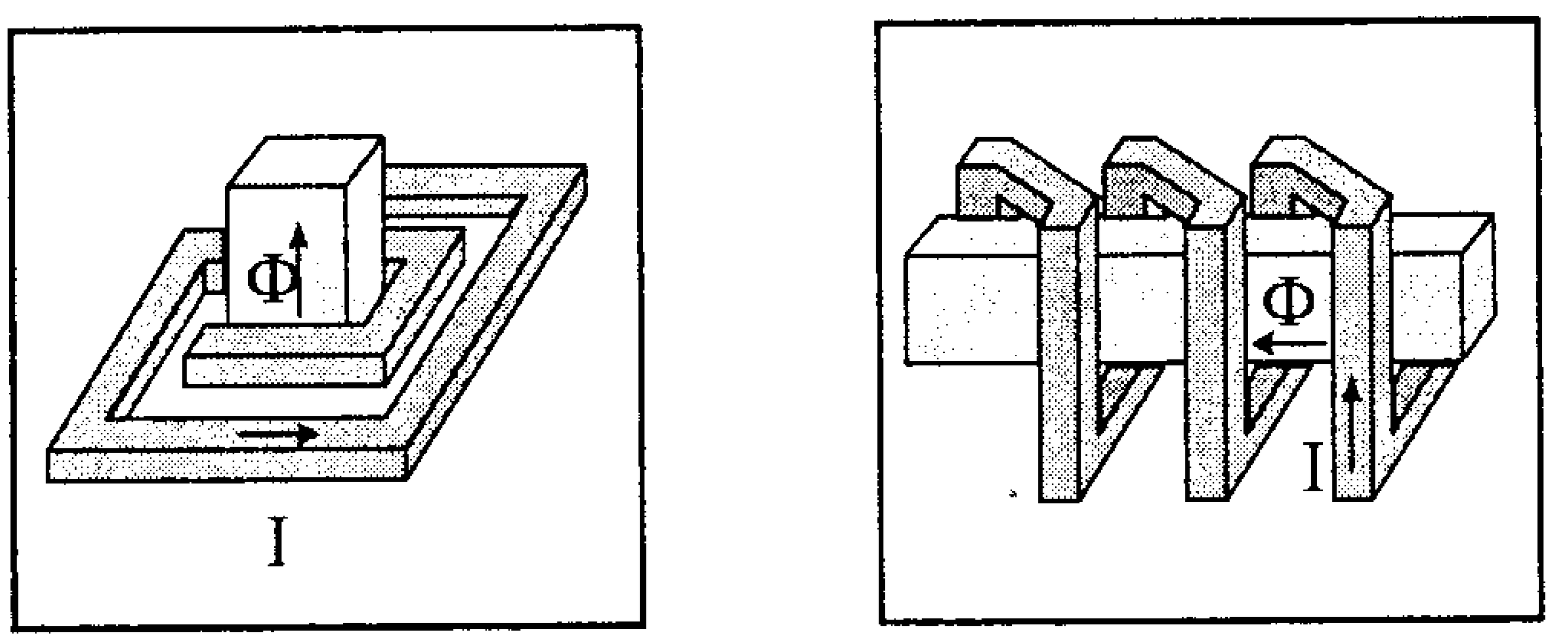

Fig. 1. Schematic of basic micro coil designs: Planar spiral coil (left) and 3D helix coil (right).

Therefore, technologies for fabricating high aspect ratio multilayer micro coils with integrated magnetic flux guiding structures are presently being developed in many laboratories [1]-[3]. Contrary to thin film technology, which allows the deposition of only few microns thick layers, the application of additive processes using UV depth lithography and electroplating results in micro structures of several ten microns height.

In principle, the possible micro coil geometries can be classified into two categories: planar spiral coils with a single or multilayer design for vertical flux generation, and 3D helical or meander coils for horizontal flux generation (fig. 1). The fabrication process presented in this paper includes successive steps of UV depth lithography, electroplating of copper and nickel iron for the coil conductor and core structures, respectively, as well as polymeric insulation and planarization as intermediate layers.

TECHNOLOGY

New types of photo resists allowing UV exposure of a thick layer of resist have been developed recently [4]-[6]. We investigated the new Novolak based positive resist AZ9260 by Clariant for fabricating high aspect ratio micromolds as well as the epoxy based negative working resist SU8 for insulation and planarization purposes.

The highly viscous DNQ/Novolak resist AZ9260 was optimized to be used for precise electroforming of up to 100 μm thickness at high resolution. An average angle of 92° between side wall and substrate was achieved. The extreme steep side wall characteristic enables an aspect ratio of up to 9 (fig. 2). So far, this result is only surpassed by the negative resist SU8.

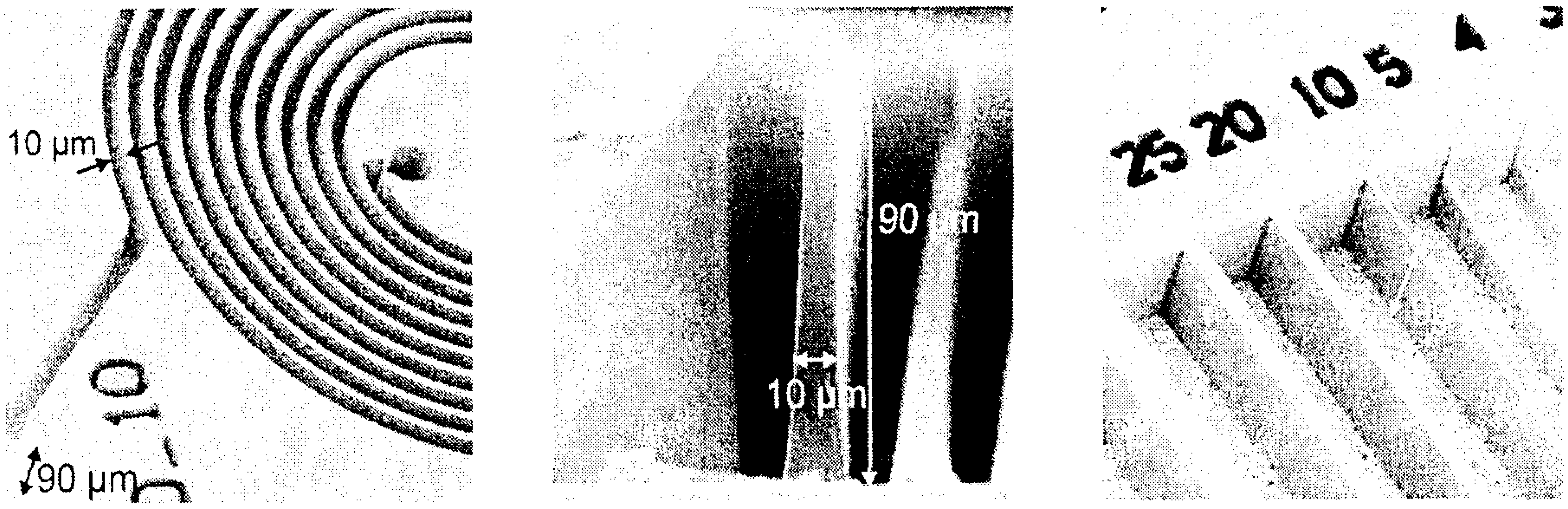

Fig. 2. Depth lithography using DNQ/Novolak based resist AZ9260: Coil structure with a minimal spacing of 10 μm at a height of 90 μm (left), cross section of a resist line (middle), test structure for the determination of resolution and the angle between side wall and substrate (right).

Concerning SU8, we developed a process for film thicknesses between 300 and 400 μm. Almost vertical sidewalls and aspect ratios of up to 36 could be achieved (fig. 3).

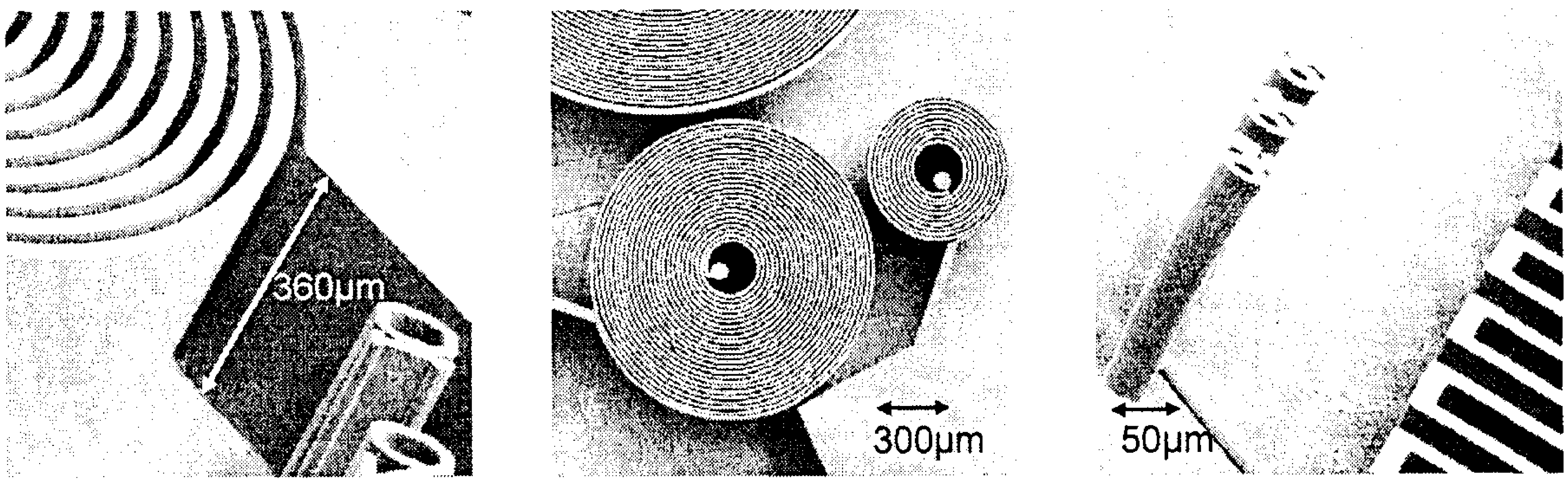

Fig. 3. Depth lithography using epoxy based SU8: Structures with a minimal feature size of 10 μm at a height of 360 μm.

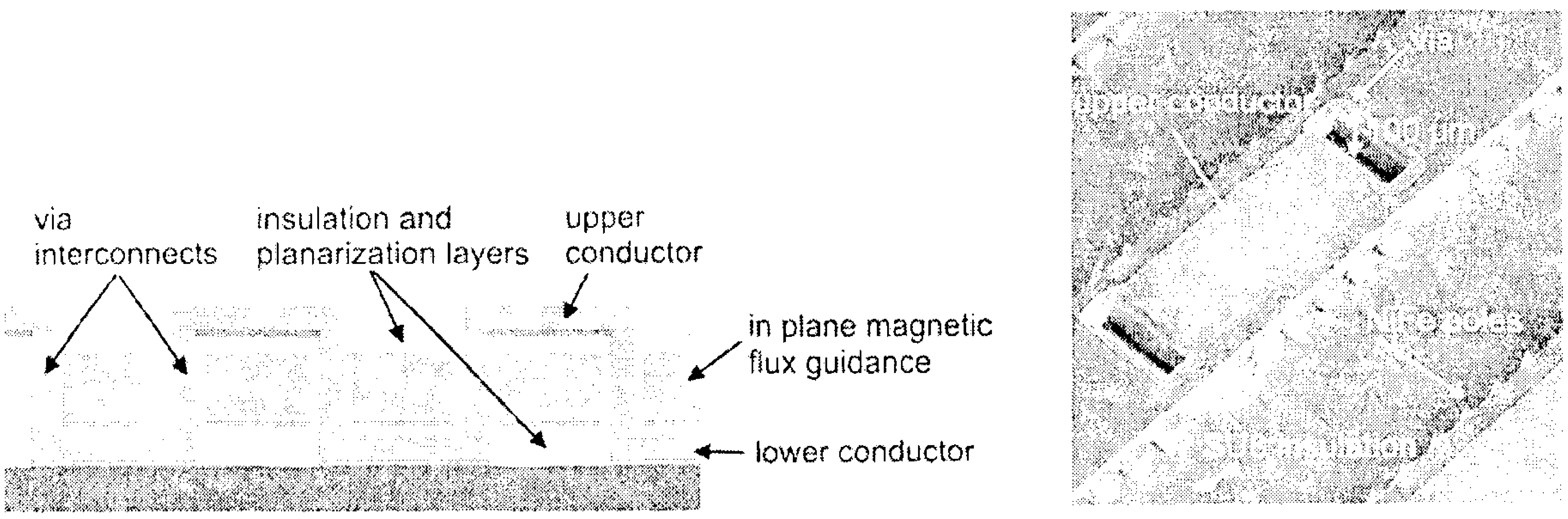

Fig. 4. Cross sectional schematic (left) and SEM micrograph (right) of an out of plane meander coil.

Optimized process sequences were developed for the fabrication of both the spiral and the helix coils. In both cases, magnetic yokes and poles were integrated in patterned coil dielectric. As an example of a helix type coil fig. 4 shows the cross sectional schematic and an SEM micrograph of an out of plane meander shaped coil. Wound around the in plane stator poles, the coils consist of many lower and upper conductors connected by vias through several dielectric layers [7]. The fabrication sequence consists of UV depth lithography for high aspect ratio electroforming molds using AZ9260, electroforming of copper and nickel iron for electrical and magnetic structures, respectively, and application of SU8 for insulation, embedding, and microforming of high aspect ratio interconnects.

INDUCTIVE MICROSENSORS

The planar spiral coil technology was applied to several sensor principles. As an example, the eddy current proximity sensor displayed in fig. 5 [8] consists of nested excitation and sensing coils. The nearly identical and concentric geometry of the two coils results in high coupling of the two coils and a magnetic flux toroidally out of plane. If a conductive object is approached the coupling is damped by eddy currents resulting in an amplitude change and phase shift. Precise distance measurement was achieved over a range up to several millimeters. The sensitivity could be significantly increased by adding a soft magnetic core despite additional eddy current losses in the conductive soft magnetic permalloy. The sensitivity increase of geometrically identical sensors without and with core is demonstrated in fig. 5.

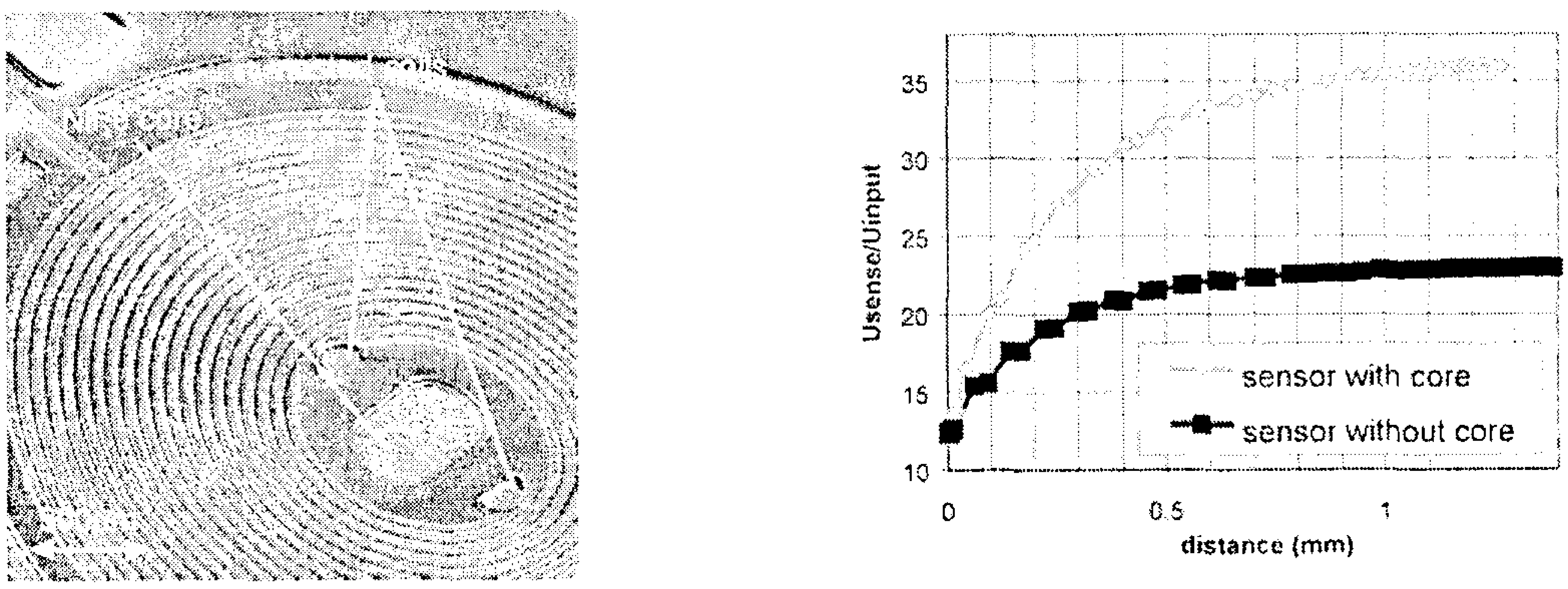

Fig. 5. Eddy current proximity sensor based on two nested transformer coils: SEM micrograph (left), sensitivity increase due to a soft magnetic core (right).

LINEAR MICRO MOTOR

The 3D meander coil technology was applied to an electromagnetic micro actuator, namely a variable reluctance linear micro motor with freely movable traveler supported by guide rails. In order to overcome the high friction forces typical for such motors, if the magnetic flux is guided vertically towards the overlying traveler, we developed a motor concept demonstrated in fig. 6 [9]. It makes use of complementary force generation onto the traveler through an even number of gaps ideally not producing any additional friction force but only thrust. This is achieved by forming the coil structures in shape of an out of plane meander wound around the in plane stator poles, thus producing a horizontal flux. The traveler consists of a guided traverse with comb shaped poles that extend in between the two stator poles. The horizontal flux attracts the traveler poles from both sides. The stator was mounted with the traveler resulting in motor dimensions of 8 x 7 mm^2. For friction reduction a ruby ball bearing was incorporated into the design (fig. 6).

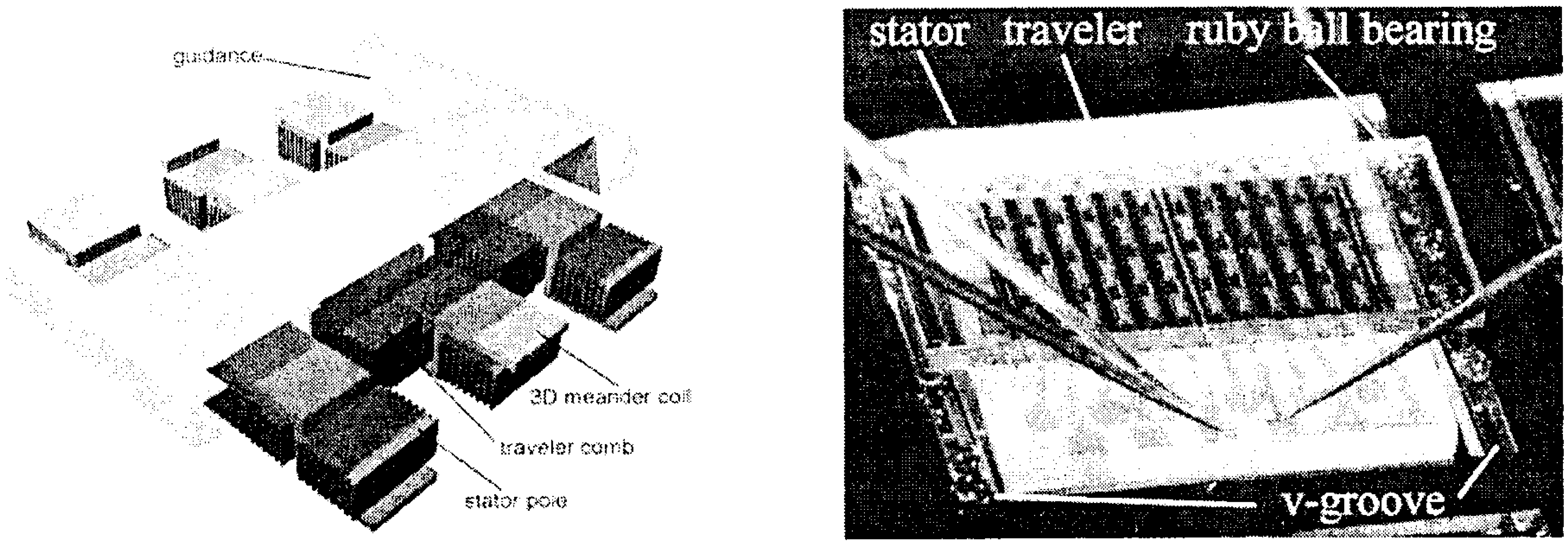

Fig. 6. Linear variable reluctance micro motor with horizontal flux guidance: Concept (left), micrograph (right).

CONCLUSION

A complete process technology for the fabrication of high aspect ratio micro components was developed. It is based on the new types of low-cost UV photo resists AZ9260 and SU8. This technology was used to fabricate micro coils featuring large cross sections of the current and magnetic flux carrying structures. The high potential for micro sensor and micro actuator applications was demonstrated with the help of two examples: an eddy current proximity sensor and a variable reluctance micro motor.

ACKNOWLEDGEMENT

This work has been supported by the Deutsche Forschungsgemeinschaft within the framework of the Collaborative Research Center "Design and Fabrication of Active Microsystems".

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