研　究　速　報

特　集　2
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Micromachined Active Magnetic Bearing

能動制御型マイクロ磁気軸受

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1. Introduction, Earlier Prototype

Mechanical friction and wear are among the major difficulties in micro mechanical devices. Contact-free levitation of parts is therefore of special interest for micro machines. Among all possible levitation principles active electromagnetic levitation has dominated the practical applications for various reasons.

An important point speaking for an actively controlled system is the inherent possibility of high precision position control, a necessary feature for many applications.

A first system with 7.9 mm disc-shaped rotors has been described earlier 1, 2, 3). In this earlier version, the stator was not yet miniaturized, it was a "conventional" 12 pole stator with two windings of 100 and 20 turns on each pole, made by hand. Rotor thickness was between 1 mm and 0.5 mm, the system could be operated with several different rotors.

Rotors and stator were machined by electro discharge machining (EDM). The 7.9mm rotor has 8 poles for operation as a stepping motor. The stator has 8.1 mm inner and 80 mm outer diameter and is used as a bearing for two actively controlled radial degrees of freedom and a stepping motor at the same time.

The other degrees of freedom, the two tilt angles and the axial (thrust) direction, are passive, i.e. the rotor is "pulled in" by the magnetic field without control.

This system was operated successfully up to 3000 rpm. Control of the contact-free levitation is with a digital signal processor at a control bandwidth of about 5 kHz. The levitation is robust, several different rotors could be inserted without problems.

2. Basic Setup of the Micromachined Magnetic Bearing System

The new system should now advance to the true micromachine world. For the second prototype, rotor and stator are miniaturized. Lithographic fabrication processes combined with electroplating are applied for manufacturing of rotor and stator.

The configuration of the first system has been successful, so it is retained for the new system. One important point has to be altered. In order to simplify the production process of the stator, the 12-pole configuration with 24 windings has been reduced to 8 poles with just four windings. The stator consists of four horse-shoe type magnets in a plane. The rotor has no poles. This means that reluctance-type motor such as the stepping motor operation is no longer possible. The new system will have to combine magnetic bearing and inductance motor.

The rotor has a diameter of 3 mm and less than 15 μm thickness. The whole system including the four stator electromagnets, fits on a 7×7 mm square. The magnets have a horse-shoe shaped core of permalloy and 36 turns of copper conductors grown by electroplating to about 2 μm thickness. The rotor and the magnet cores are of permalloy (Ni:Fe 80:20) also grown by electroplating. The thickness of

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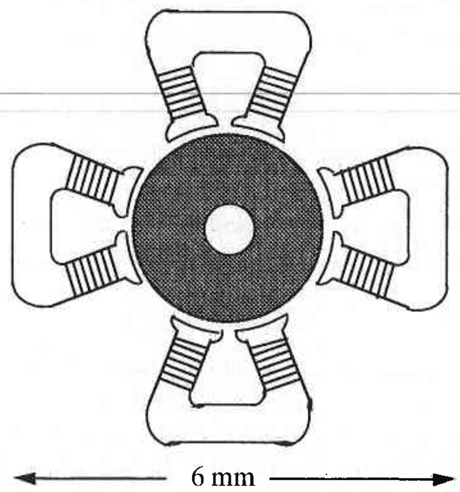

Fig. 1 Layout of rotor and stator. The rotor diameter is 3 mm.

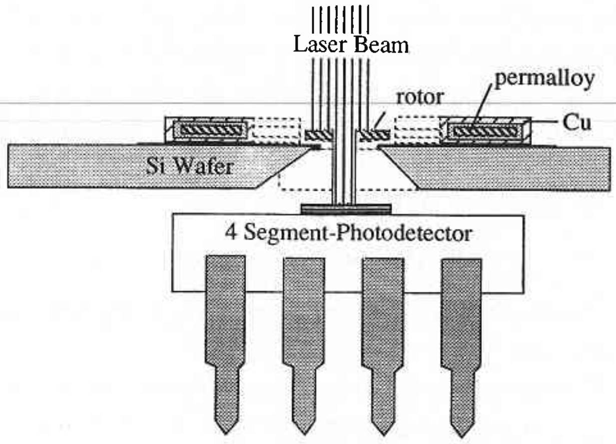

Fig. 2 Cross section of the micromachined electromagnetic bearing system. The rotor and the magnet core are of electroplated permalloy (Ni:FE 80:20) of about 10 μm thickness. The winding is of electroplated copper (about 2 μm thick), core and winding are isolated by a 2 μm thick layer of resist. The surface of the silicon wafer has an oxide layer of 0.5μm thickness. The photodetector is roughly drawn to size. It is a DIP-casing with 1.27 mm pitch pins, i.e. half-pitch.

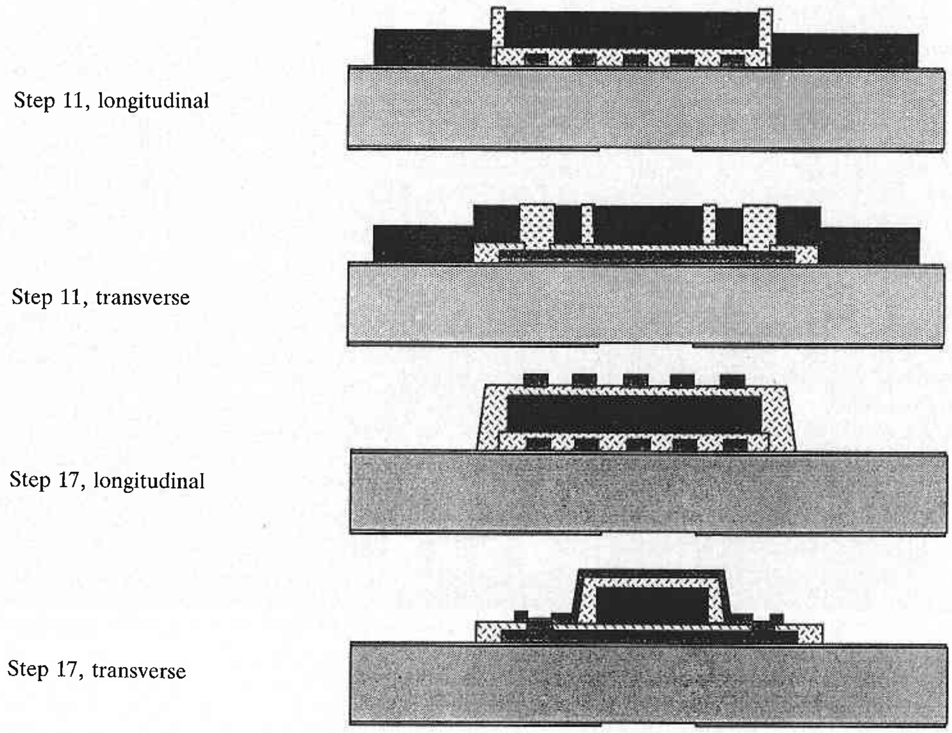

Fig. 3 Longitudinal and transverse cross sections of the coil for process step 11 (electroplating of 10 μm of permalloy) and 17 (electroplating of the last layer of copper). Horizontal and vertical dimensions not to scale.

the permalloy is about 10 μm. Initial calculations show that levitation should be achieved at about 30 mA current.

Figure 2 shows a cross section through the system including the photosensor (in a standard 6-pin DIP package) and the laser beam coming from the top. Fig. 4 shows a photograph.

3. Optical Sensor System

The sensor system is basically the same as for the previous rotor, this time using smaller photocells.

Displacement in the horizontal x-and y-directions is done by a four-segment photodiode below the rotor and by directing light from the top through a hole in the center of the rotor. The basic arrangement of the sensor system is shown in Fig. 2, along with the stator. Since a differential measurement principle is used, a precision of the 0.1 μm order or better can be achieved with such sensors.

In the next figure (3), some intermediate stages of the machining are shown. Ten masks are necessary. The stator process flow consists of 17 steps and the rotor process flow of 9.

The fabrication is done in California at the Caltech Micromachining Laboratory. Our task at Seiken will be to build the electronics (sensor, controller and amplifiers) around the system and to operate it. Results are excpected this summer.

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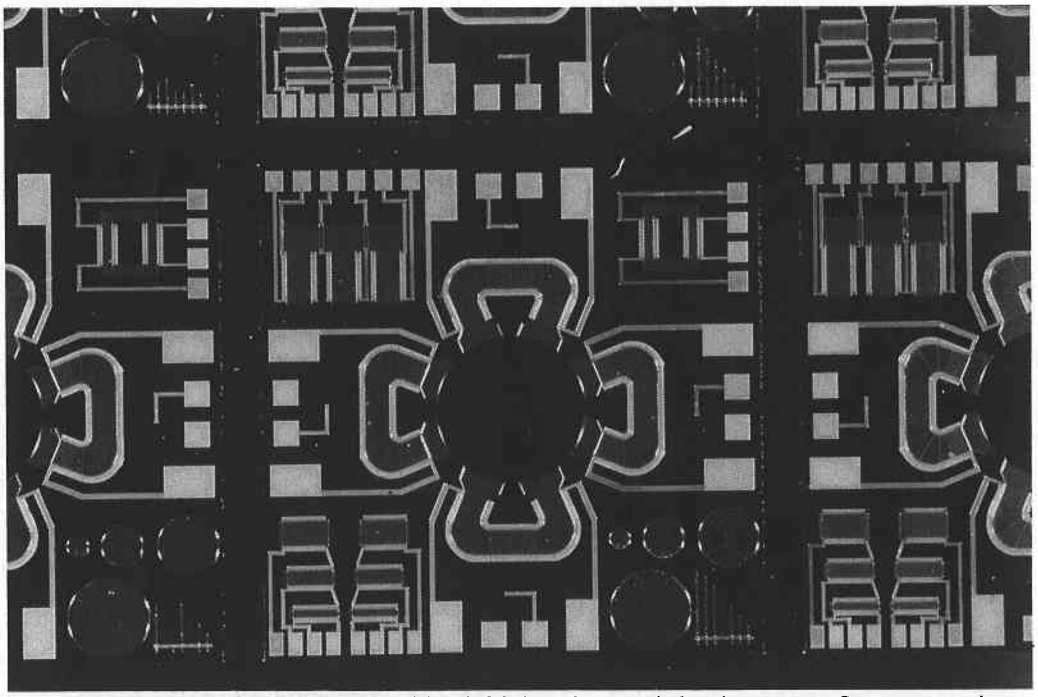

Fig. 4 Photograph of the micromachined batch-fabricated magnetic bearing system. One square unit measures 1 cm×1 cm.