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FABRICATION OF NdFeB THIN FILM AND ITS APPLICATION IN MEMS

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ABSTRACT
The paper measures the magnetic properties of NdFeB thin films developed under the effects of magnetic field. The samples exhibited a larger residual inductance, saturation magnetization and energy product than those treated without field or with weaker field. Magnetic MEMS was introduced with application of the NdFeB film to micro device such as pumps and gear transmission system.

INTRODUCTION
This study investigates the process of fabricating NdFeB (Neodymium-Iron-Boron) thin film on a silicon substrate of micro device. The purpose of the study is demonstrating the feasibility of MEMS (Micro-Electro-Mechanical-Systems) devices driven by wireless and remote magnetic field. In order to achieve the magnetically driven MEMS devices it is first demonstrated that the magnetic material such as NdFeB may be deposited in a thin film on the silicon micro device. The study also shows that a sufficient force and torque can be generated from the coupling of the magnetic film with the external magnetic field generated by a high field permanent magnet.

Compound $Nd_2Fe_{14}B$, is considered an ideal material for magnetic MEMS due to its high B-H product. $Nd_2Fe_{14}B$ film has already found wide applications in compact recording devices, magnetic sensors, actuators and other integrated electromagnetic components. Much work has been done on the film deposition composed of this tetragonal crystalline [1,2].

The idea of using magnetic force to drive the micro-machine has several obvious advantages. One important merit is that it does not need the physical contact between the external magnets and the micro device. This study showed that the coupling of high field strength, in the order of one tesla and above, permanent magnet could create a substantial torque when the separation between the devices is within centimeters or less. In magnetic MEMS, one couple of magnets is usually driven by an external source while the other one is the magnetic film coated on the micro devices, shown as figure 1. As the driving magnet rotates, it transfers torque to the magnetic film and forces the micro device to rotate once the torque overcomes the loading drag and internal forces [3,4].

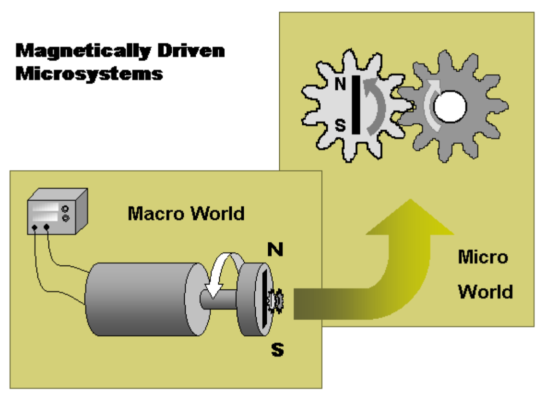
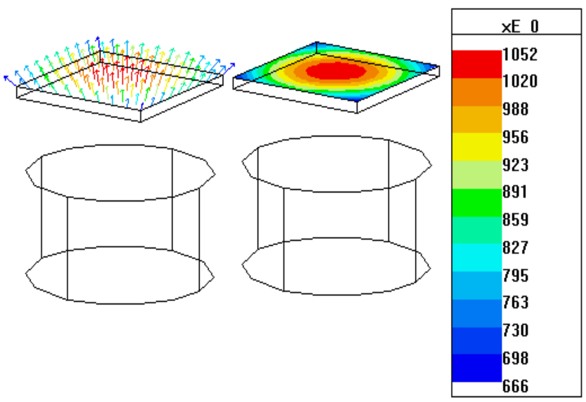


Figure 1. The schematic of Magnetic MEMS

DEPOSITION OF THE THIN UNDER THE MAGNETIC FIELD AND DISCUSSIONS
The magnetic material, film thickness, fabricating and processing methods play important roles in producing high-performance magnetic coupling. Many investigations about the effects of the different annealing temperature, target composition and processing time for different magnetic materials were reported in the past years [5,6]. In this work, we use laser-sputtering method to deposit a NdFeB thin film on the silicon substrate. We also study the properties of the film when different magnetic fields are applied on the substrate during the deposition.

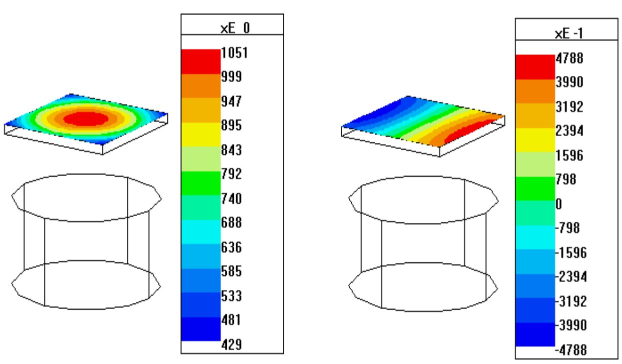
The experiment of laser-sputtering was made with the target $Nd_2Fe_{14}B$ residual induction of 11,400 Gauss, coercive force of 10,400 Oersted, and intrinsic coercive force of 13,500 Oersted. NdFeB films were grown on silicone substrates by pulsed laser deposition (PLD) employing a KrF excimer laser (λ=248 nm). The films were deposited in a vacuum chamber. The laser beam output energy is 250 mJ at a pulsed rate of 20 Hz. The separating distance between the target and substrate is 3cm. The substrate temperatures were set to 100°C. Film thickness was measured by using the profilometry and the magnetic properties of the film were obtained by SQUID. Magnetic properties of the films developed with and without magnetic fields were compared.

Samarium cobalt is used as the magnet source to create the magnetic field during the deposition. The maximum operation temperature of SmCo is 350°C. Its residual induction of 10,500 Gauss, coercive force is 9,200 Oersted, and intrinsic coercive force is 10,000 Oersted. The gap between the silicon and the top surface of the SmCo magnet is 5 mm. The experiment settings and magnetic field distributions are shown as figure 2,3,4,5 respectively. The (a) parts of figure 3,5 are the magnetic field contours that perpendicular to the substrates, (b) parts represent the magnetic field in the plane of the substrate (parallel to the surface). The Chamber vacuum of the deposition chamber maintains around 6 mtorr.



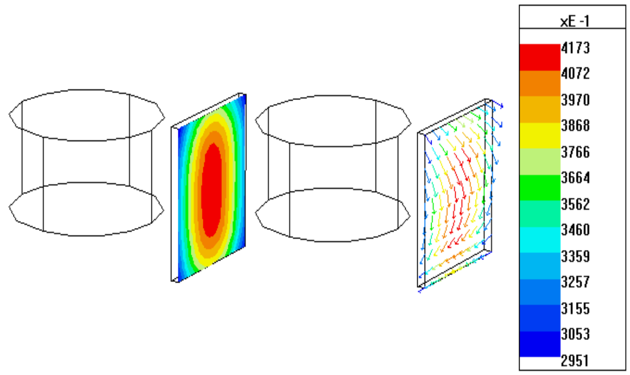
(a) (b)

Figure 2. Magnetic field distribution on the silicon surface induced by SmCo Permanent Magnet (setting 1).



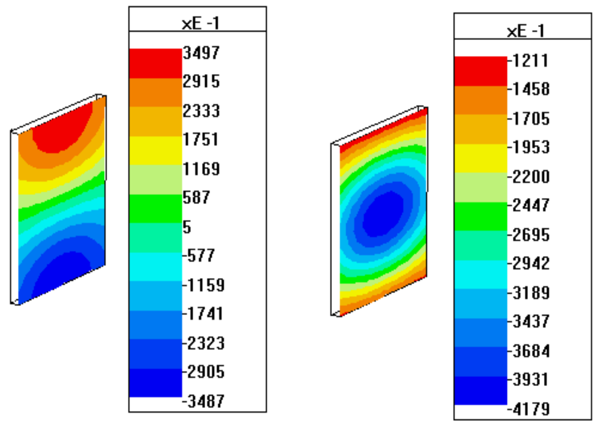
(a) (b)

Figure 3. Field distribution in normal direction and field distribution in the plane of setting 1.



(a) (b)

Figure 4. Magnetic field distribution on the silicon surface induced by SmCo Permanent Magnet (setting 2).



(a) (b)

Figure 5. Field distribution in normal direction and field distribution in the plane of setting 2.

Figure 6 shows perpendicular demagnetization hysteresis loops of the thin film deposited to the silicon substrate at 100°C. The magnetic properties of film samples measured by SQUID are cut from the middle part of the substrates. Compared the figure 3(a) and figure 5(a), The SmCo permanent magnet creates different magnetic field in normal direction in these two experiment settings. The magnetic field of former setting is larger than that of the later one in the central part of the substrate. That makes magnetized domains of the thin film easier to align the normal direction under stronger normal magnetic field than under weaker magnetic field. Similarly, figure 7 shows parallel demagnetization hysteresis loops of the thin film.

MAGNETIC MEMS

Mechanical system driven remotely by magnetic field has special advantages for certain working circumstances. In the new development of blood screw pump driven by magnet coupling [7]. The power is transmitted to the pump from an outside operating motor by magnetic coupling. The advantage of a magnetically driven pump is that the rotating part is sealed inside the pump house and self-contained. The pump works without a shaft that crosses its housing. In blood flow applications this eliminates the possibility of blood leakage through the seals. The pump can be driven remotely by magnetic coupling. This allows the pump to be designed so that it is disposable and eliminates the possibility of biocontamination. Those advantages will be kept when to apply the magnetic coupling to the micro device such as micro pumps.

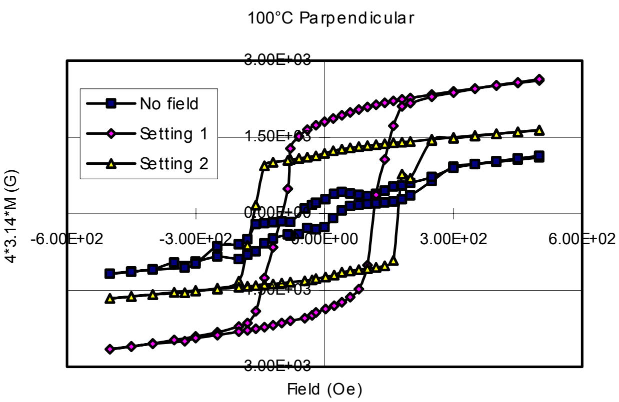


Figure 6. Hysteresis loops along the perpendicular direction of the NdFeB thin film deposited with different magnetic field conditions.

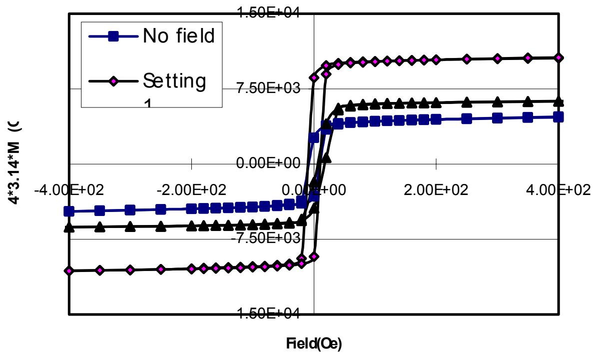


Figure 7. Hysteresis loops along the parallel direction of the NdFeB thin film deposited with different magnetic field conditions.

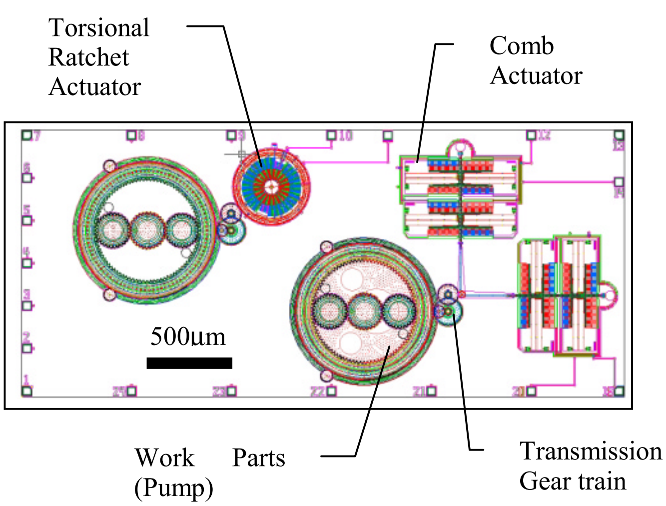


Figure 8. Typical micro engines to drive the work parts by electrostatic input.

Figure 8 shows the typical driving actuators (micro engines) for MEMS application. These designs usually need electrical wiring circuits to provide the electrical voltage or current to the micro engine for creating mechanical motion or use micro battery cell and integrated circuit (IC) to provide the energy for the MEMS. The requirement of electrostatic field for these MEMS actuators makes the construction of MEMS complicated and limits their applications. For example, in some microsurgery, it is often desirable to avoid electrical current that has electron or ionic motion and also desirable sometimes to avoid the insertional wires. The major advantage and uniqueness of the magnetic MEMS is obviously the wireless transmission of magnetic torque that replaces the complex micro mechanical design to bring the electrical motive force to the MEMS. To let the concept of magnetic MEMS be a realistic practice, the magnetic force and torque induced between the driving and driven magnetic parts must be sufficient strong to transfer the mechanical motion. The NdFeB thin film deposited under the effect of the magnetic field can provide relative strong magnetization than usual one. This property enables us to construct some magnetic MEMS such as the spiral pump shown as figure 9.

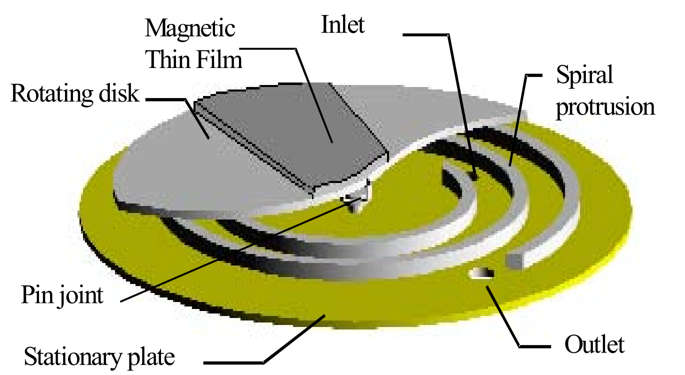


Figure 9. Spiral pump with the magnetic film on the rotating top disk.

Figure 9 illustrates a micro spiral pump works by rotating a disk over a spiral groove on a stationary plate with a close proximity. Fluid is contained in the channel created by the groove between the rotating disk and the stationary plate. Due to non-slip conditions, a velocity profile develops in the channel with fluid velocity increasing from zero at the stationary plate to the rotating plate velocity at the top. Viscous stresses on the upper and lower surfaces of the channel allow the fluid to be transported against an imposed pressure difference. Two holes at the ends of the spiral channel provide the required inlet and outlet for the pumped fluid. Combing the basic mciro fabrication technology such as mask pattern, deposition and etching, The NdFeB can be deposited on the top of the rotating disk. Outside the micro system, put two permanent magnets with the motor, then we can transfer the torque to micro spiral pump to overcome the viscous force and fluid head pressure. The scale-up model shows this design is applicable.

CONCLUSIONS

This paper shows the magnetic properties of NdFeB thin film get to be improved under the effect of magnetic field. A way to drive the micro device by magnetic coupling is introduced and discussed. The advantages of the remote driving system by magnetic coupling are indicated. The idea and the practice of using the magnetic thin film to the MEMS design are verified to be applicable and valuable.

ACKNOWLEDGMENTS

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