論文 / 著書情報
Article / Book Information

題目(和文)	
Title(English)	Fabrication and Application of Micro Diaphragm-type Electromagnetic Actuators Utilizing Thin Film Permanent Magnet
著者(和文)	ZHICHAO
Author(English)	Chao Zhi
出典(和文)	学位:博士（工学）, 学位授与機関:東京工業大学, 報告番号:甲第9692号, 授与年月日:2014年12月31日, 学位の種別:課程博士, 審査員:進士　忠彦,香川　利春,北條　春夫,初澤　毅,吉田　和弘
Citation(English)	Degree:, Conferring organization: Tokyo Institute of Technology, Report number:甲第9692号, Conferred date:2014/12/31, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

専攻： Department of	メカノマイクロ工学　　専攻	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of　（　工学　）
学生氏名： Student's Name	Chao ZHI	指導教員（主）： Academic Advisor(main)	進士　忠彦　教授
		指導教員（副）： Academic Advisor(sub)	北條　春夫　教授

要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

This thesis is entitled as "Fabrication and Application of Micro Diaphragm-type Electromagnetic Actuators Utilizing Thin Film Permanent Magnet". It consists of five chapters.

In chapter 1, the background of diaphragm-type electromagnetic actuators (DEMA) is introduced. Conventional DEMA consists of bulk permanent magnet bonded on polymeric diaphragm and driven by external electromagnet. The bottleneck of conventional DEMA is the use of bulk permanent magnets fabricated by sintering or casting process, which is not suitable for batch fabrication. A high performance thin film NdFeB/Ta permanent magnet (TFPM) is recently developed by MEMS-based sputtering process. Its magnetic property is same as bulk NdFeB magnet. The objective of this research is to realize a DEMA utilizing TFPM. They should have the characteristics of small size and batch fabrication. The configuration of the DEMA is also discussed.

In chapter 2, the research topic is "Micro DEMA utilizing TFPM and its application to a prototype pump". The DEMA is composed of a TFPM, a PDMS diaphragm and an electromagnet. A 3mm diameter and 20μm thick TFPM is sputtered on a 50μm thick Nb substrate and bonded with a flexible PDMS diaphragm. The electromagnet has a closed magnetic circuit. Several shapes of magnetic core are designed to concentrate the magnetic flux around the TFPM area. The DEMA generates an electromagnetic force with a coefficient of 35.75mN/A and achieves a displacement of ±500μm. The DEMA is then utilized to drive a diffuser valveless pump. The pump realizes a maximum flow rate of 50μL/min and a maximum pressure of 110Pa. The temperature of the electromagnet during the working process is also measured.

In chapter 2, three problems remain. Firstly, TFPM fabrication process with PDMS is not compatible with batch fabrication. Secondly, bulk electromagnet is selected to generate sufficient force. The coil has large size and is fabricated by mechanical wiring. Thus, it is not suitable for batch fabrication, portable application and miniaturization. Thirdly, the prototype pump is made of high stiffness material. Thus, it is not suitable for flexible application such as to attach the micro pump on human skin in drug delivery system. These problems are to be solved in chapter 3 and chapter 4.

In chapter 3, the research topic is "MEMS process integration of TFPM with flexible diaphragm". The high sputtering temperature of TFPM around 733K makes it impossible to deposit the TFPM directly onto the PDMS diaphragm without

damaging the PDMS material. The proposed process involves, firstly, sputtering the TFPM onto a silicon substrate, then coating this with PDMS, and finally etching silicon using XeF_2 gas. The high substrate temperature during the XeF_2 etching process degrades the magnetic property of the TFPM and also detaches part of the TFPM from the PDMS layer. The substrate temperature during XeF_2 etching process is measured by an infrared thermometer. The temperature can be controlled by adjusting the pressure of XeF_2 gas. After pressure control, TFPM retains its magnetic property and no detachment is observed between TFPM and PDMS. Furthermore, PDMS retains its mechanical properties. The technology developed in this chapter enables the realization of PDMS diaphragm with TFPM pattern. They are flexible and will not be damaged after bending or twisting.

In chapter 4, the research topic is "Development of high force/energy density planar micro electromagnetic actuators and their applications to a flexible MEMS pump". The force density and energy density are defined as the force and energy per unit volume with unit ampere input into the coil. Conventional planar micro electromagnetic actuators consists of film permanent magnet bonded on the diaphragm and spiral shape micro coil. The force density and energy density of these actuators are low due to the large self-demagnetization effect. To enhance the force/energy density, planar-type micro electromagnetic actuators consisting of patterned TFPM and mesh coils are proposed. Furthermore, the actuator's force performance is enhanced by covering a ferromagnetic layer of $Ni_{60}Fe_{40}$ permalloy on TFPM patterns. The electromagnetic actuators are then fabricated by fully integrated MEMS based process.

The magnetic flux densities of TFPM pattern, the generated electromagnetic force between TFPM and micro coil are evaluated by simulation and experiment. The segmented actuators can generate several times larger force than that of without segmentation when the gap between TFPM and micro coil is within 200μm. The proposed actuator attains maximum 20 times larger force density and energy density than previous research. The experimental force attains 70% to 90% of the simulated one due to the alignment error between TFPM and micro coil.

Meanwhile, in chapter 4, a flexible MEMS pump is fabricated using PDMS based pump body. The DEMA composing planar type micro electromagnetic actuators is utilized to actuate the MEMS pump. Due to the alignment error between TFPM pattern and micro coil, the MEMS pump could not work currently.

In chapter 5, the results obtained in this thesis are summarized and themes for future works are discussed. The developed technologies in this research can be applied to devices such as energy harvesting devices, tactile display devices, micro magnetic levitation devices and so on.