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Magnetostrictive type inductive sensing pressure sensor

Heng-Chung Chang[a], Sheng-Chieh Liao[b], Hsieh-Shen Hsieh[a], Jung-Hung Wen[c], Chih-Huang Lai[b], Weileun Fang[a,c,*]

[a] Power Mechanical Engineering, National Tsing Hua University, Hsinchu, Taiwan
[b] Materials Science & Engineering, National Tsing Hua University, Hsinchu, Taiwan
[c] Institute of NanoEngineering and MicroSystems, National Tsing Hua University, Hsinchu, Taiwan

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ABSTRACT

This study presents a magnetostrictive type inductive sensing pressure sensor which consisted of a planar coil, CoFeB magnetic films, and a Si diaphragm. As the Si diaphragm deformed by a pressure load, the inverse-magnetostriction effect would cause permeability changes of the CoFeB magnetic films. Thus, the permeability changes as well as the pressure load can be detected by the inductance change of a planar inductor. To demonstrate the feasibility of the proposed pressure sensor, the planar inductor designs of different coil turns and in-plane patterns of magnetic films are fabricated and tested. Preliminary measurements show that the pressure sensors with 6 and 12 coil turns have sensitivities of 0.079 %/kPa and 0.064 %/kPa, respectively. In addition, based on the in-plane pattern design of the magnetic films, the gauge factor could be tuned from 55 to 852.

1. Introduction

The demand of pressure sensors has been continuously increasing recently, for instance, pressure sensors have been extensively exploited for the tire pressure and blood pressure monitoring, and also the altimeter for the personal navigation. In general, the sensing approaches of pressure sensors can be categorized as: piezoresistive, capacitive, and piezoelectric [1,2]. The piezoresistive sensing element is the most popular approach for the silicon pressure sensor [2,3]. By using existing process technologies and materials, piezoresistors are implemented and integrated with a sensing diaphragm. The gauge factor of the silicon-based piezoresistive type pressure sensor is around 70–110 [4]. The gauge factor can be improved by reducing the doping concentration of the piezoresistor, however the temperature stability of the sensor is decreased [5].

The inverse-magnetostriction effect (Villari effect) has been investigated and reported in [6–8]. The investigations indicate that permeability of a magnetic material can be changed by an external load. The Villari effect has been exploited to develop the magnetic tunnel junction (MTJ) devices for the applications of gauge or pressure sensors [9–12]. Typically, the CoFeB film used in these MTJ devices has advantages of high gauge factor and excellent temperature stability [13,14]. However, unique facilities are required to prepare an additional pinning film during the process. The inductive sensing mechanism is also employed for a better sensitivity. The inductance variation could be read out by an inductive voltage or an oscillator circuit which converts the inductance of a coil to the frequency [15,16]. The inductance sensing could also enable the wireless transmission of sensing signals. The wireless transmission could bring a positive impact for some medical applications, such as the intraocular pressure monitoring [17,18]. Nevertheless, the bulky inductive sensing module is still a concern for various applications.

This study proposes a pressure sensor consisted of a planar coil with magnetic films to couple the inverse-magnetostrictive effect and the inductive sensing. In this design, a pressure load will change the permeability of the magnetic films due to the inverse-magnetostriction effect. As a result, the inductance of the planar coil disposed between the magnetic films will be changed and thus the pressure load can be measured by the inductance variation. The special equipment for the pinning layer of the MTJ device is not required for the proposed design. Moreover, a compact inductive sensing device can be achieved via the vertical integration of the planar coil and the magnetic films. Based on this sensing mechanism, the magnetostrictive type inductive sensing pressure sensors with various planar inductor designs are investigated. The gauge factor could be further modified by design parameters of the planar inductor, including the coil turns and the in-plane patterns of

* Corresponding author at: Power Mechanical Engineering, National Tsing Hua University, Hsinchu, Taiwan. Tel: +886 3 5742923; fax: +886 3 5739372.
E-mail address: fang@pme.nthu.edu.tw (W. Fang).

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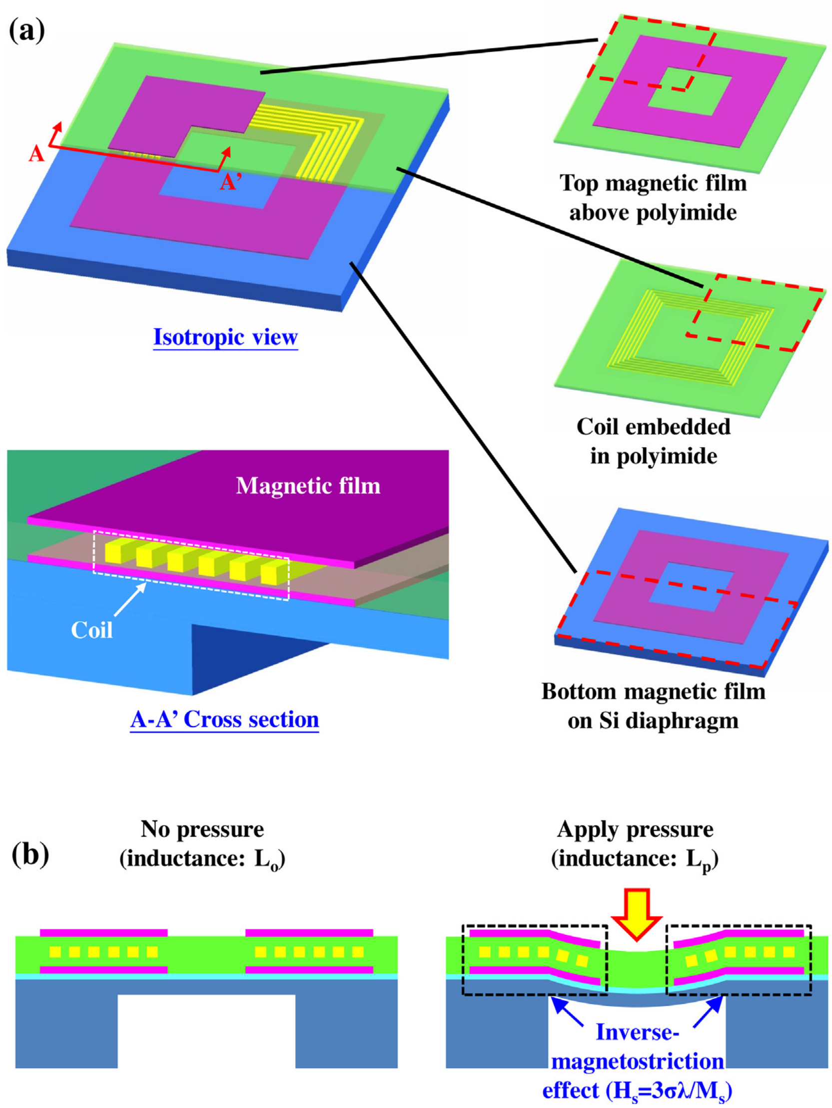

Fig. 1. The design concept of the magnetostrictive type pressure sensor, (a) structure schema, (b) sensing mechanism.

the magnetic films. Thus, the proposed designs can be implemented using the existing micro fabrication processes.

2. Concept and design

Fig. 1 illustrates the pressure sensor design formed by the proposed magnetic sensing unit on top of a deformable diaphragm. As depicted in Fig. 1(a), the proposed magnetic sensing unit mainly consists of a planar coil and two magnetic films (CoFeB film is employed in this study). The planar coil is sandwiched between these two magnetic films. The polyimide is employed as a filling material between the coil and the CoFeB films for an electrical isolation. By the integration of the planar coil, two magnetic films, and the polyimide layer, a planar inductor is constructed. The number of coil turns defined by the photolithography could modulate the initial inductance L_o of the planar inductor. Fig. 1(b) further illustrates the sensing principle of the proposed pressure sensor. As shown in the left illustration, the sensor has an initial inductance of L_o before applying a pressure load. As depicted in the right illustration, the diaphragm of sensor is deformed after applying the pressure load. The CoFeB magnetic films on the deformed diaphragm are then under a stress σ . According to the inverse-magnetostriction effect [13], the magnetic anisotropy field H_s of the CoFeB film induced by the stress σ can be expressed as,

$$H_s = \frac{3\sigma\lambda}{M_s} \tag{1}$$

where λ and M_s are respectively the magnetostriction constant and the saturation magnetization (in emu/cm^3) of the CoFeB film. In addition, the permeability μ of the magnetic film is expressed as [19],

$$\mu = \frac{4\pi M_s}{H_o - H_s} \tag{2}$$

where H_o is the anisotropy field of the magnetic film before the stress σ applying on the film. The parameter H_o could be controlled by the deposition process or in-plane pattern designs of the magnetic films. By combining Eqs. (1) and (2), the relation between the permeability μ and the stress σ on the magnetic film is expressed as,

$$\mu = \frac{4\pi {M_s}^2}{M_s H_o - 3\sigma\lambda} \tag{3}$$