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Design and fabrication of sputtered AlOx/CVD SiNx/sputtered AlOx diaphragm for Spin-MEMS microphones

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Abstract

In this study, we investigated the mechanical film properties of SiOx and AlOx deposited by sputtering in order to design a MEMS diaphragm for microphone devices combining spintronic strain gauge sensors (Spin-SGSs) and MEMS. Based on the result that sputtered AlOx films have relatively low residual stress and high process resistance, we fabricated a diaphragm formed by laminating the sputtered AlOx films and a CVD-SiNx film. As a result of measuring the resonance frequency of the fabricated diaphragm using a laser Doppler velocimeter (LDV), we confirmed that the vibration behavior measured by LDV corresponded to that calculated by the residual stress of the fabricated diaphargm. This study suggested that sputtered AlOx films have a high affinity for the fabrication processes of spintronic MEMS (Spin-MEMS) sensor devices.

1. Introduction

New strain gauge sensors based on spintronic technology have been reported recently [1]. These spintronic strain gauge sensors (Spin-SGSs) are basically the magnetic tunnel junctions (MTJs) used as magnetic sensors for hard disk drive (HDD) heads, with the MTJs functioning as strain gauge sensors by using a magnetostrictive material as a sensing layer. We previously reported that Spin-SGSs employing a high magnetostrictive sensing layer exhibit a large gauge factor of 5000, which exceeds that of a poly Si piezo-resistor. Devices that combine such highly sensitive Spin-SGSs and MEMS are promising for new devices for high-sensitivity detection of various physical quantities.

MTJ elements are current-perpendicular-to-the-plane type elements, as shown in Fig. 1. Since the device properties of MTJ elements are strongly affected by damage in the side walls of the MTJ elements, the elements for HDD heads are generally fabricated by a lift-off process to avoid this damage. In this process, after the MTJ film is patterned and etched into an element by photolithography and ion milling, an insulating film is deposited around the element before removing the photoresist. In many cases, this insulating film is deposited at room temperature by a sputtering method because this film deposition is performed while the photoresist remains on the element, as shown in Fig. 1 [2].

However, when Spin-SGSs are integrated on MEMS sensors consisting of thin diaphragm structures such as microphones, it is important to design the MEMS diaphragms by taking into consideration the mechanical properties of the insulating film, because the thickness of insulating film around the MTJ element is not so thin that it can be ignored with respect to the total thickness of the diaphragm, as shown in Fig. 2.

In this study, we investigated the mechanical properties of sputtered SiOx and AlOx films, which have been used as insulating films for embedding MTJ elements. Based on the results, we designed and fabricated the MEMS diaphragm shown in Fig. 2, which has a laminated structure consisting of a sputtered AlOx film and CVD-SiNx to create a novel spintronic MEMS (Spin-MEMS) microphone in which Spin-SGSs are integrated on the MEMS diaphragm.

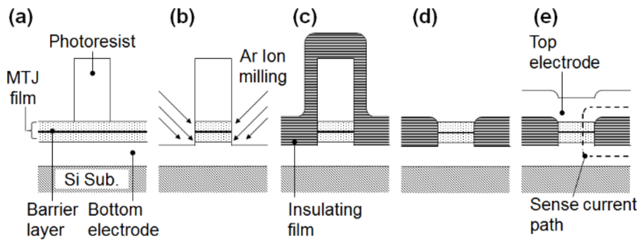

Fig. 1. Schematic diagram of fabrication process of the MTJ element. (a) Patterning of photoresist by photolithography on MTJ film. (b) Etching of MTJ film by ion milling. (c) Deposition of insulating film. (d) Removal of photoresist. (e) Deposition of top electrode film.

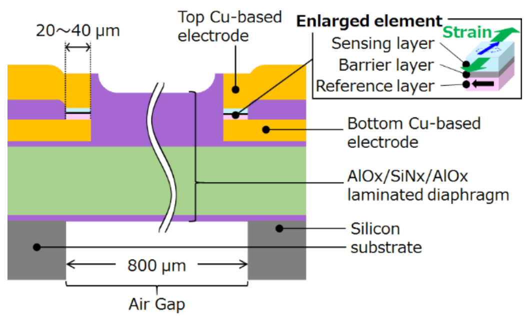

Fig. 2. Cross-sectional view of a typical Spin-MEMS microphone device.

2. Results and Discussion

Figure 3(a) shows the residual stresses, which are an important property related to the characteristics of devices with sputtered SiOx and AlOx films. Because the residual stresses are correlated with the sputtering gas pressure, the SiOx and AlOx films were deposited on silicon substrates using various sputtering gas pressures from 0.2 to 1.0 Pa by radio-frequency magnetron sputtering. Both SiOx and AlOx films exhibited compressive stresses. The absolute values of the residual stresses were lower in the AlOx films than in the SiOx films.

In the case of diaphragms for microphone devices, the residual stress of the diaphragm should be tensile because a diaphragm in compressive stress causes the buckling phenomenon. Given that SiOx and AlOx exhibit compressive stress (Fig. 3 (a)), it is necessary to laminate these insulating films with a base film in tensile stress for the diaphragm film. For example, CVD SiNx films, which have been used for MEMS devices, can be used as a base film with tensile stress. Considering the theory of composite materials, the composite stress of an entire diaphragm is affected not only by the residual stress of each layer, but also by the film thickness of each layer. Therefore, we investigated the etching rates of SiOx and AlOx.

The ion milling rate of AlOx was lower than that of Cu, which is used in electrode materials, lower than that of Ru and Co-Fe alloys, which are used in MTJ elements, and lower than that of SiOx (Fig. 3 (b)). This result means that the final thickness variation of the AlOx film, which is caused by over-etching when MTJ films or electrode films are patterned by ion milling, is smaller than that of the SiOx film. The deep reactive ion etching (D-RIE) selectivity of SiOx and AlOx against Si were 175 and 1130. This means that sputtered AlOx films can be used as D-RIE stopper layers (Fig. 3 (c)).

From the above results, we employed an AlOx/CVD SiNx/AlOx laminated structure as the diaphragm for a Spin-MEMS microphone. Figure 4 (a) shows the typical structure of the fabricated Spin-MEMS microphones. The residual stress of the entire diaphragm (σ_{dia}) is correlated with the resonance frequency of the diaphragm (f_{dia}). The f_{dia} of rectangular diaphragms, as shown in Fig. 4 (a), is defined by the following equation.

$$f_{dia} = \frac{1}{2} \cdot \sqrt{\frac{1}{{L_{sa}}^2} + \frac{1}{{L_{la}}^2}} \cdot \sqrt{\frac{\sigma_{dia}}{\rho_{dia}}} \qquad (1)$$

where L_{sa} is the short axis length, L_{la} is the long axis length, and ρdia is the composite density of the entire diaphragm. As shown in Fig. 4 (a), σ_{dia} of the diaphragm was set to realize the target values of f_{dia} and the residual stresses of each layer were set to satisfy the set σ_{dia} based on the theory of composite materials. ρ_{dia} was also estimated from the density of the etch layer measured by using an x-ray reflectivity method.

To confirm the vibrational behavior of the fabricated diaphragms, we measured their resonance frequency by using a laser Doppler velocimeter (LDV). As shown in Fig. 4 (a), the measured resonance frequency of the diaphragms was 73.5 kHz, which corresponds reasonably well to the target f_{dia} of 71.5 kHz. We carried out the same experiment for an AlOx/SiNx/AlOx diaphragm with different design of σ_{dia} and the shape. As can be seen in Fig. 4 (b), the measured resonance frequencies for various samples were relatively close to the target values of f_{dia}.

By employing the sputtered AlOx/CVD SiNx/sputtered AlOx laminated diaphragm proposed in this study, we successfully fabricated Spin-MEMS microphones with a signal-to-noise ratio of 49 dB(A) and a mechanical resonance frequency of 74 kHz [3].

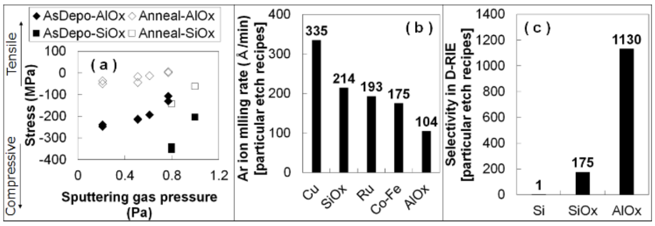

Fig. 3. (a) Comparison of residual stress as a function of sputtering gas pressure for as-deposited and annealed SiOx and AlOx films. Both films were annealed at 360 °C in a vacuum. (b) Argon ion milling rate of various kinds of materials. (c) D-RIE selectivity of sputtered SiOx and AlOx against Si.

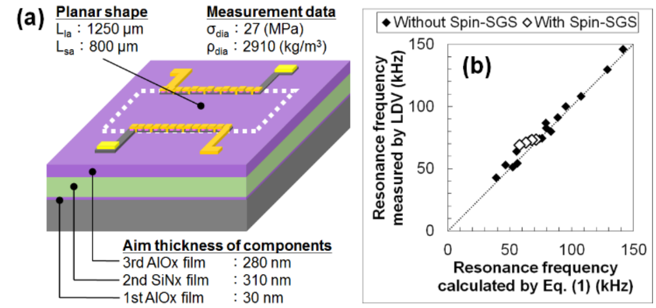

Fig. 4. (a) Schematics and process parameters of AlOx/SiNx/AlOx diaphragm for Spin-MEMS microphone. (b) Measured resonance frequency obtained by LDV versus resonance frequency calculated by using Eq. (1).

3. Conclusions

By comparing the residual stresses and process resistance of the sputtered SiOx and AlOx films, we designed and fabricated an AlOx/SiNx/AlOx diaphragm for a novel Spin-MEMS microphone. The resonance frequency of the fabricated AlOx/SiNx/AlOx diaphragms corresponded reasonably well to the target resonance frequency calculated from the residual stresses of whole diaphragms, indicating that the sputtered AlOx films have a high affinity for fabricating Spin-MEMS and are applicable for not only microphones but also other MEMS sensor devices.

Acknowledgements

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