Mechanical Design of a Spin-MEMS Microphone with a Series of Spintronic Strain-Gauge Sensors
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ABSTRACT
This paper presents the mechanical design of a novel Spintronic MEMS (Spin-MEMS) microphone that has a series of spintronic strain-gauge sensors (Spin-SGSs) with a high gauge factor. The series of Spin-SGSs is integrated onto a bulk micromachined diaphragm. We compare a circular diaphragm with a rectangular diaphragm of the same area by ANSYS simulation. As a result of applying sound pressure, the rectangular diaphragm generated a larger uniaxial strain at a constant angle in the diaphragm over a wider range. By employing a design that integrates Spin-SGSs arrays along the long edge of the rectangular diaphragm, we obtained a Spin-MEMS microphone with a signal-to-noise ratio (SNR) of 49 dBA and a mechanical resonance frequency of 72 kHz.

INTRODUCTION
New strain-gauge sensors based on spintronic technology have been reported [1]-[2]. These spintronic strain-gauge sensors (Spin-SGSs) are basically magnetic tunnel junctions (MTJs) that have a high gauge factor (GF). MTJs consist of a nonmagnetic barrier layer (BL) sandwiched between two ferromagnetic layers, called the sensing layer (SL) and the reference layer (RL). When a magnetostriuctive material is used as the SL, the MTJ acts as a strain gauge.

The Spintronic MEMS (Spin-MEMS) microphone comprises a series of Spin-SGSs and a bulk micromachined diaphragm (Fig. 1 (a)). We have successfully fabricated a Spin-SGS with a high GF of up to 5,000 (Fig. 1 (b)) [3]. When a uniaxial strain is applied to the SL at a tilted direction to the initial magnetization direction, the electrical resistance of the Spin-SGS changes. Moreover, the signal-to-noise ratio (SNR) of the Spin-SGS is improved by a factor of \( \sqrt{N} \) times when N Spin-SGSs are connected in series. Although the Spin-SGS has a high GF, in order to maximize the performance as a Spin-MEMS microphone, it is important to use the optimum diaphragm shape and integrate the series of Spin-SGSs at the proper position.

SIMULATION AND MEASUREMENT RESULTS
We compared a Si circular diaphragm with a Si rectangular diaphragm of the same area by ANSYS simulation. When sound pressure was applied to the diaphragms, the circular diaphragm deformed more than the rectangular diaphragm (Fig. 2), which would appear to indicate that a circular diaphragm is more suitable for capacitive MEMS microphones. However, the rectangular diaphragm generated a larger uniaxial strain at a constant angle over a wider range of the diaphragm. Figure 3(a)(b) show the simulation results of the principal strain vectors and Fig. 4 shows the rate of change of the strain due to sound pressure \( \frac{d(\varepsilon_x-\varepsilon_y)}{dp} \). When a uniaxial strain is applied to the SL at a tilted direction to the initial magnetization direction, the electrical resistance of the Spin-SGS changes. In addition, the SNR of the Spin-SGS can be improved by \( \sqrt{N} \) times by using N Spin-SGSs connected in series. So, for Spin-MEMS microphones, it is important that uniaxial strain is generated in the same direction over a wide range. Therefore, a rectangular diaphragm is more suitable for Spin-MEMS microphones. We fabricated two types of Spin-MEMS microphones, one with a circular diaphragm and one with a rectangular diaphragm, both having the same area, and fabricated arrays of 30 Spin-SGSs along the edges of the diaphragm connected in series electrically. The change in electrical resistance due to sound pressure was 40 \( \Omega/kPa \) for the circular diaphragm and 95 \( \Omega/kPa \) for the rectangular diaphragm. Because the orientation of the uniaxial strain was not constant in the case of the circular diaphragm, the resistance did not increase linearly with the number of devices in series.

We also simulated a larger rectangular diaphragm in which more Spin-SGSs arrays can be integrated. We placed 62 Spin-SGSs arrays and top and bottom electrodes on an Si-N rectangular diaphragm with residual stress. By integrating the Spin-SGSs arrays along the long edge of the rectangular diaphragm, all Spin-SGSs generated uniaxial strains of approximately the same magnitude and in the same direction (Fig. 5 (a)(b)). The Spin-MEMS microphone with this design had an SNR of 49 dBA and a mechanical resonance frequency of 72 kHz [4].

CONCLUSION
We showed that a rectangular diaphragm is more suitable for Spin-MEMS microphones comprising Spin-SGSs connected in series than a circular diaphragm. It is important to integrate the Spin-SGS arrays along the long edges of the rectangular diaphragm.
REFERENCES


Figure 1. (a) Schematic diagram of a Spin-MEMS microphone. In Spin-SGS, strain-induced rotation of the SL magnetization changes the magnetization configuration between the SL and RL, resulting in a change in the resistance of the MTJ. (b) Electric measurement of resistance change under uniaxial strain.

Figure 2. Simulation results of diaphragm deformation without residual stress when a sound pressure of +2 Pa is applied.

Figure 3. (a), (b) Simulation results of principal strain vectors. (c), (d) Schematics of uniaxial strain vectors along the edges of the diaphragms.

Figure 4. Simulation results of the change in the difference between y direction strain and x direction strain with sound pressure d(ε_y-ε_x)/dp. The value ε_y-ε_x is used as an index for evaluating uniaxial strain in the y-axis direction.

Figure 5. (a) Simulation result for the d(ε_y-ε_x)/dp distribution generated in the rectangular diaphragm and the Spin-SGSs. (b) Graph of d(ε_y-ε_x)/dp for each of Spin-SGSs #1 to #31 on the rectangular diaphragm.