E-5-01 (Invited) Extended Abstracts of the 2019 International Conference on Solid State Devices and Materials, Nagoya, 2019, pp237-238

Flexible spintronics devices for mechanical sensing

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Abstract

To endow spintronic devices with a stretchability is expected to expand further a possibility for application. In this talk, I will show our recent experimental results obtained using flexible giant or tunnel magnetoresistive devices formed on a flexible substrate.

1. Introduction

Flexible spintronics is an novel electronics area that can endow mechanical functions to conventional spintronics devices [1-7]. Spintronics, however, have been developed so far without paying attention to its stretchability. For example, magnetic tunnel junctions (MTJs) [8-12] formed on rigid semiconducting substrate is one of representative device, which have been widely used as a memory element in solid-state magnetic random access memory (MRAM) and as a read head in a hard disk drive.

Owing to the magnetoelastic effect, a magnetization direction of ferromagnetic materials can be changed by the application of strain. Using a combination of this effect and the giant magnetoresistive (GMR) or tunnel magnetoresistive (TMR) effect, a strain measurement has been experimentally demonstrated [13-20]. The stretchability of both the substrate and thin ferromagnetic layers enables strain sensing on a wide range of arbitrary-shaped surfaces, which is not easy when using devices formed on a rigid semiconductor substrate. Furthermore, these stretchable and miniaturized strain sensors will be of increasing importance for the trillion sensor universe as well as for wearable devices, from the perspective of structural or human health monitoring, body mechanics, and robotics.

2. Spintronics mechanical sensors

In addition to sensing the strain "magnitude", we have recently achieved strain "direction" sensing using a GMR-based pseudo spin valve (SV) formed on a flexible substrate [7] (Fig. 1(a)). Using the fact that a NiFe/FeMn exchange-biased bilayer is insensitive to strain, a strain direction sensing without resorting to an external magnetic field assistance has also been achieved [21]. This flexible exchange-biased GMR-SV can realize the detection of the human body (fingers) motion (Fig. 1(b)). In addition to the demonstrations in the flexible GMR sensors, we have also successfully fabricated a CoFeB/MgO-based MTJ directly on the organic flexible substrate (Fig. 2(a)). Much larger TMR ratio (~100%) has been realized in our MTJ (Fig. 2(b)) compared to the previously reported Al_2O_3 barrier MTJs formed on flexible substrates [22,23].

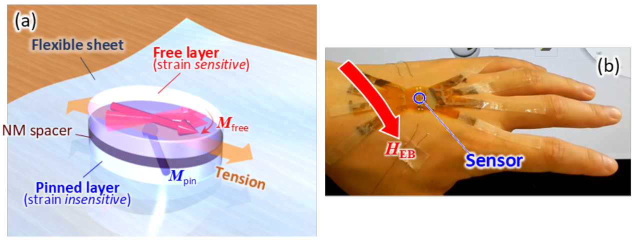

Fig. 1 (a) Schematic illustration of a flexible GMR strain direction sensor. (b) Photograph of the finger motion sensor made of the flexible exchange-biased SV attached on the back of a human hand.

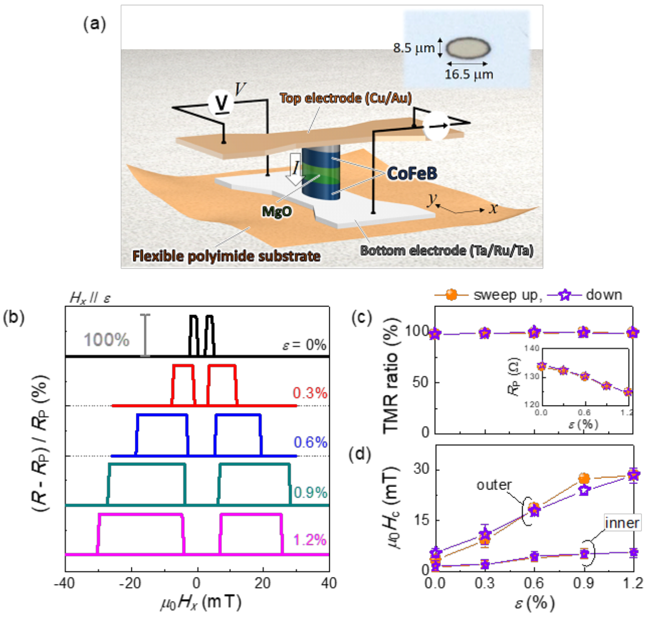

Fig. 2 (a)The schematic illustration of the MTJ formed on a flexible substrate and measurement configuration. The inset shows a top view of the MTJ pillar before lift-off process taken by a microscope. (b) The MR curves measured under various tensile strains ε. An in-plane magnetic field H_x is applied parallel to the stretched direction. (c) The TMR ratio as a function of ε. The inset shows the ε dependence of RP. (d) The inner and outer coercivity ($\mu_0 H_c$) of the MR curves as a function of ε.

3. Conclusions

Because the spintronic device is easily integrated as in the case of non-volatile memory applications, complex strain distribution, *e.g.*, that on a human skin or in civil infrastructure, may become detectable in the future using an integrated flexible spintronic sensor sheet. In addition, our flexible MgO barrier MTJ can be fabricated as in the case of conventional MTJs on rigid Si substrates and is robust against unwanted heating and stress. These facts are highly desirable for future high-sensitive flexible IoT sensors, and non-volatile memories that can be equipped around various flexible devices.

Acknowledgements

The authors thank S. Ota, A. Ando, H. Matsumoto, M. Ono, K. Ochi, R. Asai, T. Koyama, H. Awano, T. Namazu, T. Takenobu, and T. Sekitani for their useful discussion and technical help. This work was partly supported by Murata Manufacturing Co., Ltd., JSPS KAKENHI from JSPS.

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