A-8-03

Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp79-80

Enhancement of spin orbit interaction in nitrogen doped Cu thin films

Ryoto Enoki[1], Hiromu Gamou[1], Shutaro Karube[1, 2], Makoto Kohda[1, 2], Yoji Kunihashi[3], Haruki Sanada[3], and Junsaku Nitta[1, 2]

[1] Material Science and engineering, Tohoku University, Sendai 980-8579, Japan
[2] Center for Spintronics Research Network, Tohoku University, 980-8577, Japan
[3] NTT Basic Research Laboratory, Atsugi 243-0198, Japan

Abstract

We report the strength of spin-orbit interaction (SOI) in nitrogen doped Cu (Cu(N)) thin films fabricated by reactive sputtering method. Spin relaxation affected by nitrogen doping has been investigated on the basis of quantum interference effect. Evaluated spin relaxation length is more than 20 times shorter for Cu(N) films than that for pure Cu films. Thus, we have demonstrated the enhancement of spin-orbit interaction in Cu(N) thin films. Furthermore, we have measured spin transfer torque ferromagnetic resonance (STT-FMR) in Cu(N)/Co system. According to the measured resonance line shape, clear symmetric component is observed, suggesting that Cu(N) layer generates finite damping-like torque in Co layer.

1. Introduction

It is well known that Cu is a material with very weak spin orbit interaction (SOI). However, it has been reported that SOI in Cu is enhanced by oxidation or impurity doping [1, 2]. In this research, we have demonstrated the enhancement of SOI in Cu(N) in comparison to the non-doped Cu. This approach can provide further comprehensive study for the enhancement of SOI by impurities doping in weak SOI materials. In addition, this is industrially more profitable method as enhancement of SOI due to the cheapness of Cu and N.

2. Experimental procedure

Both pure Cu (9 nm) and CuN (9.5 nm) thin films were deposited on SiO_2 substrate by radio frequency(RF) magnetron sputtering. Substrate temperatures during sputtering of Cu and Cu(N) were at RT and 100°C, respectively[3]. Cu(N) films were sputtered by varying N_2 gas pressure between 0.03 and 0.1 Pa during the sputtering. These pure Cu or Cu(N) thin films were patterned into the Hall bar structures by repeating Ar ion milling and photo lithography. The nitrogen concentration in Cu films were characterized by X-ray photoelectron spectroscopy (XPS) shown in Fig. 1. Depth profile of XPS result indicates that nitrogen impurities are homogeneously distributed inside of Cu thin film (Fig. 1). It is also confirmed that a part of the nitrogen is bounded to Cu, and it forms Cu_3N.

In order to evaluate spin relaxation length L_{so}, we focused on quantum correction of the magneto conductance (MC). The results of MCs were fitted by Hikami-Larkin-Nagaoka (HLN) formula [4]. Carrier density, which is required for the analysis in HLN formula, for each films were experimentally estimated by the Hall measurement. All of the MC measurements and Hall measurements were performed at 2 K. Cu(N)/Co sample for the STT-FMR measurement was also fabricated by the RF magnetron sputtering method, and it was patterned into the conventional waveguide device. STT-FMR measurement was performed at room temperature.

3. Results

Experimental MC results for pure Cu and Cu(N) films are shown on Fig. 2 and Fig. 3, respectively. In Fig. 2, positive MC observed for pure Cu 9 nm film represents weak SOI. On the other hand, negative MC signals (*i.e.* weak-antilocalization (WAL)) are observed in all Cu(N) thin films. The magnetic field range showing WAL is enlarged by increasing the N_2 partial pressure. This transition from positive to negative MCs shown in Figs. 2 and 3 directly indicates the enhancement of SOI by doping nitrogen impurities to Cu thin films. The relationship between L_{so} and N_2 pressure during sputtering is summarized in Fig. 4. From this figure, L_{so} becomes decreased as the nitrogen partial pressure was increased, and the minimum value of obtained L_{so} is 7.1 nm. This minimum value of L_{so} in Cu(N) is 20 times shorter than minimum value of L_{so} in pure Cu films. This result indicates that we have demonstrated that the strength of SOI in Cu(N) can be tuned by controlling partial N_2 pressure during sputtering.

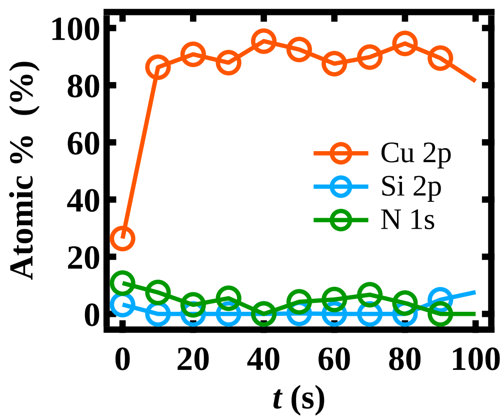

Fig 1, Depth profile of XPS. Etching time t = 0 is defined as the surface of the sample. We prepared Cu(N) 50 nm film on SiO_2 substrate for XPS measurement.

Since we observed the enhancement of spin-relaxation rate in Cu(N) by the WAL measurement method, spin-orbit torque in Cu is expected to be enhanced by doping nitrogen. STT-FMR spectra of Cu(N) (10)/Co (10) are shown on Fig. 5. In the STT-FMR measurement, we applied RF current which has 6 dBm-power and 9 to 15 GHz-frequency, 45 deg tilted in-plane field to the wire, and detected voltages by lock-in technique with AM modulation of the RF current. From this result, symmetric peak was much larger than anti-symmetric peak so that spin-torque efficiency was enhanced by nitrogen impurities. In my presentation at the conference, we will discuss more quantitative analysis for the STT-FMR result of Cu(N)/Co bilayer.

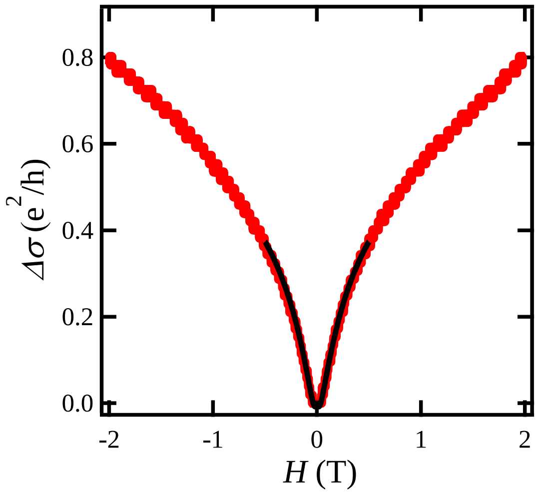

Fig. 2, MC for pure Cu (9 nm) at 2K. Red line and black line represent the raw experimental data and fitting result by HLN formula.

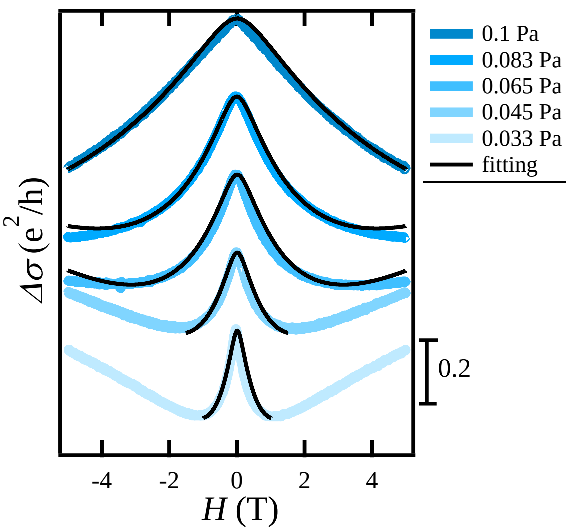

Fig. 3, N_2 partial pressure dependence of MC for Cu(N) (9.5 nm) at 2K.

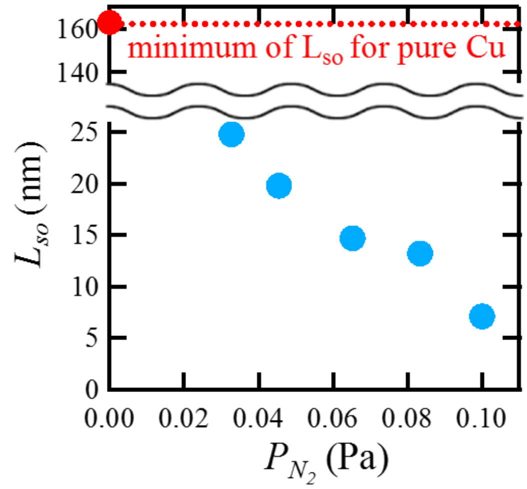

Fig. 4 The relationship between spin relaxation length and N_2 partial pressure during sputtering.

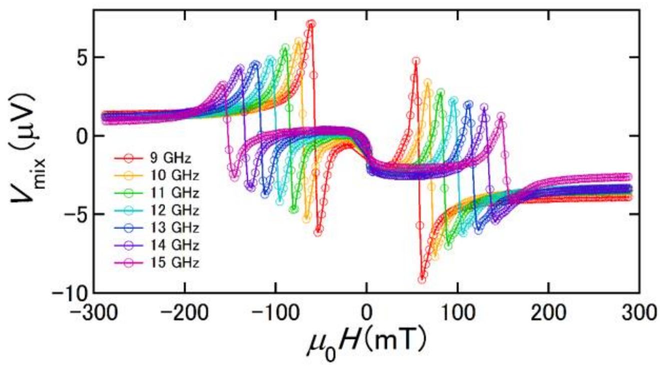

Fig. 5 STT-FMR spectra of Cu(N) (10)/Co (10) whose nitrogen partial pressure is 0.1 Pa for different RF current from 9 to 15 GHz.

4. Conclusions

We confirm the enhancement of spin orbit interaction due to nitrogen doping by two measurement methods. From the WAL analysis, it is revealed that spin relaxation rate in Cu(N) is stronger than pure Cu. Spin relaxation length is more than 20 times shorter for highly nitrogen doped Cu(N) films than that for pure Cu films. In addition, spin-torque generation efficiency investigated by the STT-FMR method shows the finite spin torque efficiency in Cu(N)/Co bilayer. From STT-FMR spectra, high spin-torque generation efficiency is anticipated. The origin of this enhancement of SOI will be also discussed in the presentation.

References

[1] H. An *et al.,* Nat. Commun. 7, 13069 (2016).
[2] Y. Niimi *et al.,* Phys. Rev. Lett. 109, 156602 (2012).
[3] T. Nosaka *et al.,* Thin. Solid. Films. 348, 8 (1999).
[4] S. Hikami *et al.,* Prog. Theor. Phys. 63, 707 (1980).
[5] L. Liu *et al.,* Phys. Rev. Lett. **106**, 036601 (2011)