Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp884-885

Formation and Characterization of High Density FePt Nanodots on SiO_2 Induced by Remote Hydrogen

Katsunori Makihara, Yuuki Kabeya, Akio Ohta, Takeshi Kato, Satoshi Iwata and Seiichi Miyazaki

[1]Graduate School of Engineering, Nagoya University
Furo-cho, Chikusa-ku, Nagoya, 464-8603, Japan
Phone: +81-52-789-2727 E-mail: makihara@nuee.nagoya-u.ac.jp

Abstract

We successfully demonstrated formation of magnetic nanodots (NDs) made of FePt alloy by exposing a metal bi-layer stack to remote H_2 plasma and characterized their magnetization properties. The magnetic properties show that the FePt-alloy NDs exhibit a large perpendicular anisotropy with an out-of-plane coercivity of ~4.8kOe, while the in-plane and out-of-plane coercivities of the Pt/Fe bi-layer are almost zero, reflecting the small magneto-crystalline anisotropy of the Fe layer. In addition, electron conduction measured through FePt-NDs on ~1.7-nm-thick SiO_2/c-Si by using a magnetized CoPtCr-coated AFM probe at room temperature confirm a distinct anisotropic magnetoresistance reflecting the characteristic of the $L1_0$-FePt phase.

1. Introduction

Metallic nanodots (NDs) have received much attention because of their potential application to charge storage nodes.[1, 2)] The charging and discharging characteristics of metallic NDs through an ultrathin oxide layer depend on their electrostatic potentials and their magnetization properties. In the spintronic application of metallic NDs, high-density formation of magnetic NDs and control of the magnetization change are major concerns. So far, we reported that Ni- and Co-NDs with an areal density as high as ~10^{11}cm^{-2} were formed on ultrathin SiO_2 by exposure of ultrathin metal layer to remote H_2 plasma (H_2-RP) without external heating, and demonstrated their charge storage properties.[3)] More recently, we reported formation of magnetic NDs made of CoPt alloy by exposing a metal bi-layer stack to remote H_2 plasma (H_2-RP) and characterized their magnetization properties.[4)] In this work, we extended our research to form high density FePt-NDs and to study their magnetization and local I-V characteristics under external magnetic field application.

2. Experimental Procedure

After conventional wet-chemical cleaning steps of p-type Si(100) wafers, a ~1.7-nm-thick SiO_2 layer was grown at 1000˚C. A ~1.4-nm-thick Fe layer was first deposited uniformly on the SiO_2 layer by electron beam evaporation and then covered uniformly with a ~1.7-nm-thick Pt layer without air exposure. Subsequently, the Pt/Fe bi-layer stack so-prepared was exposed simply to a remote H_2 plasma without external heating. The plasma was generated by inductive coupling with an external single-turn antenna connected to a 60-MHz generator through a matching circuit. During the remote H_2 plasma exposure, gas pressure and VHF power were maintained at 13.3 Pa and 500 W, respectively. Magnetization properties were characterized by alternation gradient magnetometer (AGM) at room temperature.

3. Results and Discussion

Atomic force microscope (AFM) images for an as-evaporated ~1.1-nm-thick Pt layer on Fe/SiO_2 and after H_2-RP exposure (Fig. 1(a) and (b)). The images for the as-evaporated bi-layer stack structure showed a fairly smooth surface morphology with a root-mean-square (RMS) roughness as small as ~0.24 nm, being almost identical to that for the as-grown SiO_2 surface. The result confirms uniform surface coverage with the ultrathin Pt/Fe bi-layer. By exposing the Pt/Fe bi-layer on SiO_2 to the H_2-RP for 10 min, the RMS roughness was increased by a factor of ~6.5, and formation of NDs with an areal density as high as ~4.8×10^{11} cm^{-2} and an average height of ~8.7 nm was observed, which was determined by the dot height distribution (not shown). Considering the fact that the temperature rising up to ~400 ˚C in the case of Pt foil during H_2-RP exposure,[5)] the result of Fig. 1 (b) suggests that Pt-Fe alloying with the H_2-RP exposure was promoted with agglomeration by cohesive action of Pt and Fe atoms on the SiO_2 surface. Electrical isolation among the FePt-alloy NDs so-prepared was confirmed by changes in surface potential due to electron charging to the dots (not shown). To get an insight into the their magnetic properties, in-plane and out-of-plane hysteresis loops of the FePt-NDs with an applied magnetic field of ±15 kOe were measured at room temperature (Fig. 2). Notice that the in-plane and out-of-plane coercivities of the Pt/Fe bi-layer were almost zero, reflecting the small magneto-crystalline anisotropy of the Fe layer. In contrast, the FePt-alloy NDs exhibited in-plane and out-of plane coercivities of 0.31 and 0.52 kOe, respectively, indicating ferromagnetic characteristics at room temperature.

To evaluate the local electron transport properties of the FePt-alloy NDs, a PtCoCr- and Rh-coated Si cantilever was contact to the sample surface and kept at the same position, and the I-V characteristics were measured at room temperature. A typical I-V characteristic for a ND is shown in Fig. 3, where electrons are injected from the tip. Without any external magnetic field application, the current level slightly increased at a tip bias of over ~-3.0 V. In addition, when applying 0.5 kOe in the same direction as the initial tip magnetization by using a Nd-magnet installed under the sample (inset in Fig. 3), there was no significant change in the I-V curve from the case without a magnetic field. However, a distinct increase in the current level was

detected when a magnetic field of 0.6 kOe was applied in the same direction as the tip magnetization, namely, the threshold voltage at 1 nA decreased from -4.3 to -1.2 V. With an increase in the magnetic field over 0.6 kOe, no further changes in the I-V curve were observable, which means that the resistance decreased significantly with magnetic fields over 0.6 kOe. When using a Rh-coated Si cantilever, almost no change was detected in the I-V curve with an applied magnetic field of 4.5 kOe, irrespective of the field direction. These results indicated that an MR ratio of ~70% was obtained in the magnetic field between 0.5 and 0.6 kOe. An observed decrease in tunnel resistance is attributable to the magnetization alignment between the AFM tip and FePt-NDs. It is interesting to note that no significant change in the I-V curve was confirmed without a magnetic field after a magnetic field of 4.5 kOe was applied. The result is attributable to the coercivity of FePt-NDs. We also confirmed a remarkable decrease in the current level with 0.6 kOe in the opposite direction and an almost complete recovery in the current level with 1.5 kOe and higher in the opposite direction, as shown in Fig. 4. A reverse contrast in the MFM of a floppy disk was obtained with a tip exposed to a magnetic field of 1.5 kOe as a result of the reversal of the tip magnetization direction (Fig. 5).

3. Conclusions

We fabricated Pt-based alloy NDs with an areal density as high as ~10^{11} cm^{-2} on ultrathin SiO_2 and evaluated local I-V characteristics through individual dots under magnetic field application by using a magnetic cantilever. A clear change in the magnetoresistance depending on the magnetization of NDs was confirmed at room temperature. For the case of FePt-NDs, the high electrical conductivity obtained by the alignment in the magnetization direction between the FePt-NDs and AFM tip was stably retained, reflecting the coercivity of FePt-NDs.

Acknowledgements

This work was supported in part by Grant-in Aids for Scientific Research (A) No. 15H02239 from the Ministry of Education, Culture, Sports, Science and Technology, Japan.

References

[1] B. V. Waeyenberge et al., Nature **444** (2006) 461.
[2] K. L. Metlov et al., J. Appl. Phys. **114** (2013) 223908.
[3] K. Makihara et al., Jpn. J. Appl. Phys. **47** (2008) 3099.
[4] R. Fukuoka et al., Abst. Magn. Opt. Res. Int. Symp., 2013 (Omiya), We-P-07.
[5] K. Makihara et al., J. Optoelectro. Adv. Mater. **12** (2010) 626.

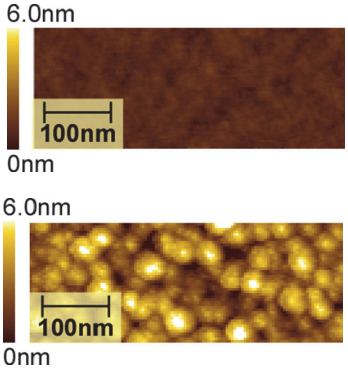

Fig. 1 Topographic images before (a) and after H_2-RP exposure (b) of Pt/Fe bi-layer stack structures on SiO_2.

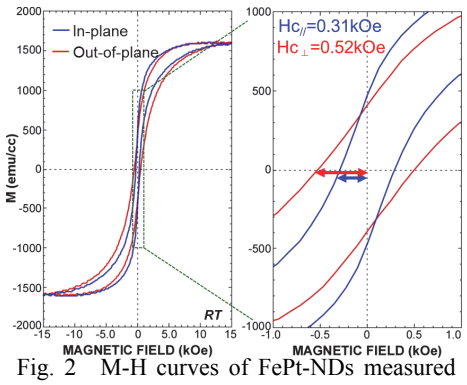

Fig. 2 M-H curves of FePt-NDs measured at room temperature. In-plane and out-of plane coercivities of 0.31 and 0.52 kOe, respectively.

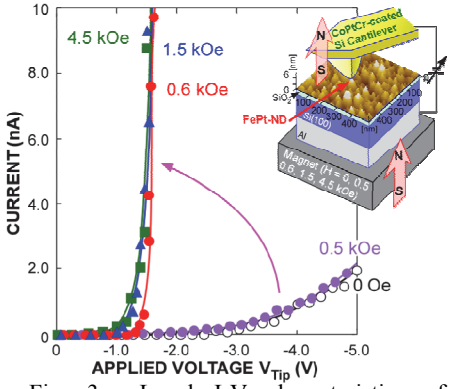

Fig. 3 Local I-V characteristics of FePt-NDs obtained with CoPtCr-coated AFM tip with and without magnetic field application in same direction as initial tip magnetization. Measurement set up shown in inset.

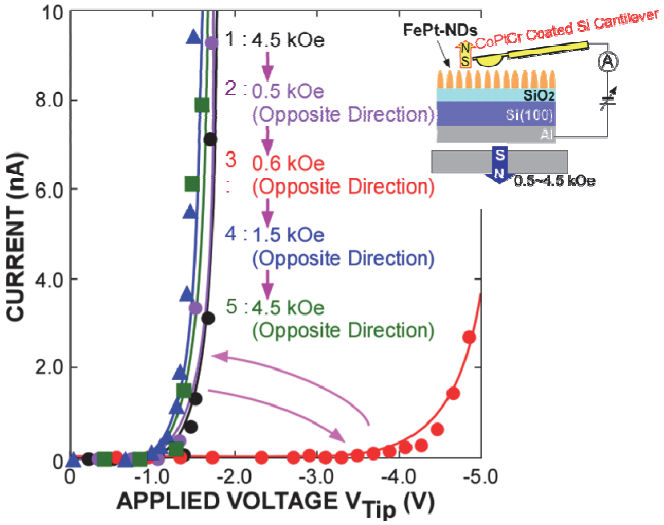

Fig. 4 Local I-V characteristics of FePt-NDs obtained with CoPtCr-coated AFM tip with magnetic field application opposite to 1st magnetization direction at 4.5 kOe.

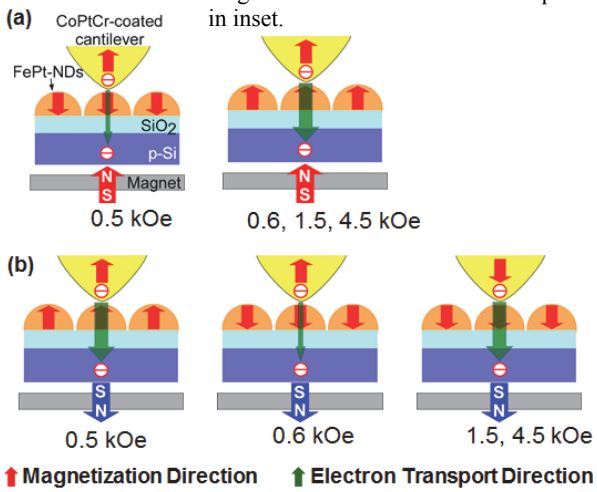

Fig. 5 Magnetization direction diagrams corresponding to local I-V characteristics of Figs. 3 and 4. Magnetic field application in same direction as initial tip magnetization (a) and opposite to initial tip magnetization (b).