Extended Abstracts of the 2013 International Conference on Solid State Devices and Materials, Fukuoka, 2013, pp382-383

Fabrication of half-metallic Co_2MnSi/diamond Schottky junctions

Kenji Ueda, Masato Nishiwaki, Takashi Soumiya, Keita. Kawamoto and Hidefumi Asano

Graduate School of Engineering, Nagoya University
Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan
Phone: +81-52-789-3567 E-mail: k-ueda@numse.nagoya-u.ac.jp

Abstract

We show half-metallic Heusler Co_2MnSi (CMS) can be grown on diamond semiconductors by using ion-beam assisted sputtering (IBAS) method. Lower temperature growth below ~400°C is the key for obtaining abrupt CMS/diamond interfaces. CMS films on diamond showed negative AMR of ~0.2% at 10 K, suggesting half-metallic natures of the CMS films. Schottky junctions using the CMS/diamond heterostructures formed at 400°C showed clear rectification properties with rectification ratio of more than 10^2. Schottky barrier heights of the CMS/diamond interfaces were estimated to be ~0.8 eV with reasonable ideality factors (*n*= ~1.7). These results suggest that CMS is promising spin sources for spin injection to diamond semiconductors.

1. Introduction

One of the major challenges in the field of semiconductor spintronics is the efficient spin injection from ferromagnetic electrodes to semiconductors. However, best combination of ferromagnets and semiconductors, and fabrication method for ferromagnet/semiconductor interfaces for efficient spin injection are not well established. It is considered one of the effective methods for efficient spin injection is to use half-metallic ferromagnets, which generate fully spin-polarized carriers, as spin sources. Heusler alloys Co_2MnSi is one of promising candidates for spin sources because of its half-metallic characters and high T_c of ~985 K.

On the other hand, diamond semiconductors are promising as next-generation high-power devices because of its excellent physical properties such as high band gap, high thermal conductivity, etc. We consider diamond is also an ideal host for spin transport because it is expected to have long spin diffusion length due to its low spin-orbit interactions [1]. However, there are currently no reports on electrical spin injection to diamond. In this study, as a first step for spin injection, half-metallic Heusler Co_2MnSi (CMS) were fabricated on diamond semiconductors and their electronic and magnetic properties were investigated for the first time.

2. Experimental

B-doped homoepitaxial diamond films were grown on commercial (100) diamond substrates by microwave plasma CVD. Typical acceptor concentration and room temperature mobility was ~10^{17} cm^{-3} and ~1000 cm^2/Vs, respectively, by Hall measurements [1, 2]. CMS films (50-100 nm) were deposited on the diamond films by Ar ion-beam sputtering (IBS) or dual Ar ion-beam assisted sputtering (IBAS). Schottky diodes using CMS as ferromagnetic contacts (junction area: 100-300 μmϕ) and Ni/Ti as ohmic contacts were fabricated by using reactive ion etching (RIE) and photolithographic process.

3. Results and Discussion

XRD measurements revealed that epitaxial growth of CMS on diamond was only achieved in a narrow growth temperature range around 600°C by IBS [Fig. 1(a)]. The epitaxial relationship was CMS (001)[100]//diamond (001)[110]. CMS films formed below 550°C or above 700°C became amorphous like or polycrystal because of larger lattice mismatch between CMS and diamond (~13%). The CMS films on diamond showed ferromagnetic hysteresis at room temperature. However, the saturation magnetization (M_s) and coercive fields (H_c) was ~400 emu/cc and ~200 Oe, respectively (Fig. 2), which were inferior to those of bulk CMS (M_s: ~1100 emu/cc, H_c: ~10 Oe). Current-voltage (*I-V*) characteristics of Schottky junctions using the CMS/diamond layers showed no rectification properties (ohmic like) (Fig. 3). We consider these results are due to interfacial reaction and/or interdiffusion at the interfaces between diamond and CMS by higher temperature growth of CMS films.

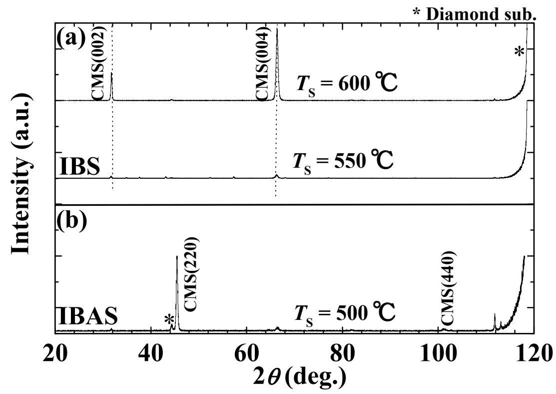

Fig. 1 (a) X-ray diffraction patterns (2θ-θ) for the Co_2MnSi films deposited on diamond at the substrate temperature (T_s) of 600°C by IBS, and (b) T_s of 400°C and 500°C with Ar ion-beam assist (IBAS).

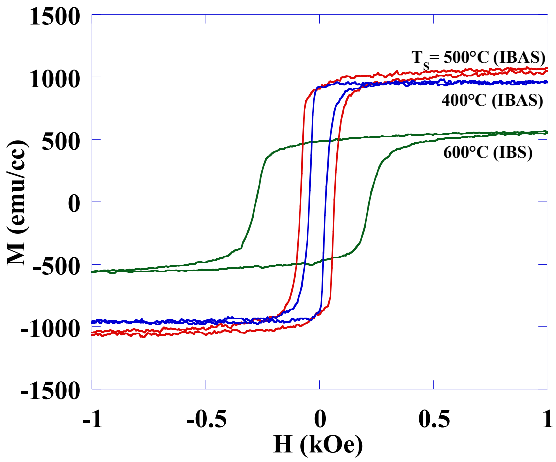

Fig. 2 Magnetic field dependence of magnetization of the Co_2MnSi films formed at T_s of 600°C by IBS, and 400°C and 500°C by IBAS measured at R. T.

To suppress interfacial reaction and/or interdiffusion, we performed lower temperature growth of CMS layers by using IBAS with Ar ion-beam assist. For IBAS method, Ar ion-beam irradiation was performed during film growth to give additional energy for film formation, and it was often used to prepare crystalline films in lower growth temperature. By optimizing ion-beam assist conditions, (110) oriented CMS films were obtained on diamond at lower growth temperature (T_s= 400~500°C) by IBAS. The M_s and H_c of the CMS films were improved and became ~1050 emu/cc and ~70 Oe, respectively (Fig. 2). These M_s and H_c values were comparable to those for bulk CMS (~1100 emu/cc, ~5 Oe).

AMR effects of the CMS films were also investigated to examine half-metallicity of the CMS films on diamond. Recently, Kokado et al. have investigated the sign of AMR of ferromagnetic materials including half-metals systematically [3]. They showed that the sign of AMR ratio was always negative for half-metallic ferromagnets such as Co_2MnSi, $La_{1-x}Sr_xMnO_3$, etc. and positive for usual ferromagnets such as Fe, Ni, etc. due to difference of the dominant s-d scattering process. This means that the sign of AMR can be used as an index of half-metallicity or non half-metallicity. The sign of AMR of our CMS films were negative with AMR ratio of ~0.2%, and two-fold structure with negative minima at φ= 0° and 180° were obtained in magnetic-field angle dependence of AMR ratio. The negative AMR ratio of ~0.2% of our CMS films is comparable to the reported values for negative AMR of high quality CMS films (~0.18%) formed by magnetron sputtering at 400°C [4]. These results indicate that the CMS films on diamond have half-metallic natures.

Schottky junctions were fabricated by using the CMS/diamond heterostructures. Schottky junctions formed at 600°C showed no clear rectification, however Schottky junctions formed at 500°C or 400°C showed rectification properties with rectification ratio of ~10 or more than 10^2, respectively (Fig. 3). The rectification ratio increased as T_s decreased. For the junctions for T_s = 400°C, the ideality factors (n) and Schottky barrier heights were obtained to be 1.7 and 0.8 eV, respectively, by the fitting of the forward *I-V* characteristics using equation for TE model. Clear rectification of *I-V* curves and lower n values suggest that the Schottky junctions for T_s = 400°C have better interfacial qualities, and interfacial reaction and/or diffusion were suppressed by lower temperature growth of CMS films by IBAS. These results suggest that high quality CMS/diamond Schottky junctions for efficient spin injection can be obtained by the method.

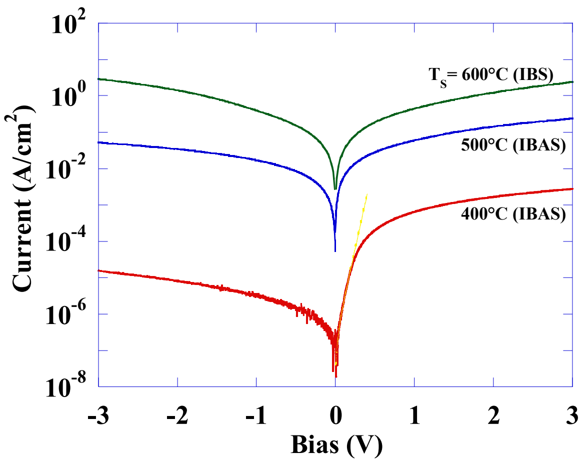

Fig. 3 Current–voltage (*I-V*) characteristics Schottky junctions fabricated by using the CMS/diamond heterostructures formed at T_s of 400°C, 500°C (IBAS) and 600°C (IBS). The dotted line shows the fitting results using TE model.

4. Conclusions

Half-metallic Co_2MnSi (CMS) was epitaxially grown on diamond semiconductors by using ion-beam sputtering method. Lower temperature growth below ~400°C is the key for obtaining abrupt interfaces between CMS and diamond. We believe that the development of this work can pave the way for operating diamond spintronic devices using the CMS/diamond interfaces as spin sources.

Acknowledgements

This work was partly supported by Grants-in-Aid for Science Research (No. 22760250, 23656214, 24560372) from the Ministry of Education, Culture, Sports, Science and Technology, Japan, the Scholar Project of Toyota Physical and Chemical Research Institute, and the Tatematsu Foundation.

References

[1] K. Ueda, T. Soumiya and H. Asano, Diamond Relat. Mater. 25 (2012) 159.

[2] K. Ueda, K. Kawamoto, T. Soumiya and H. Asano, submitted to Diamond Relat. Mater.

[3] S. Kokado, M. Tsunoda, K. Harigaya and A. Sakuma, J. Phys. Soc. Jpn. 81 (2012) 024705.

[4] F. J. Yang, Y. Sakuraba, S. Kokado, Y. Kota, A. Sakuma and K. Takanashi, Phys. Rev. B 86 (2012) 020409(R).