Fabrication and Interface Electrical Properties of Fe_3O_4/MgO/GaAs(100) Spin Contacts

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In previous experiments we have demonstrated the growth of a fully epitaxial Fe_3O_4/MgO/GaAs(100) structure by molecular beam epitaxy [1]. The aim of the present investigation is to study and compare the interface electrical properties of Fe_3O_4/GaAs(100) and Fe_3O_4/MgO/GaAs(100) epitaxial spin contacts as well as to discuss the respective electronic transport mechanisms involved in these hybrid materials at room temperature (RT).

The preparations of Fe_3O_4/GaAs(100) and Fe_3O_4/MgO/GaAs(100) have been described elsewhere [1,2]. In brief, moderately doped *n*-GaAs(100) substrates ($n = 5 \times 10^{17}$ cm^{-3}) with In Ohmic back contacts were annealed in the growth chamber with a base pressure of 1×10^{-8} mbar for 60 min at 830 K prior to the film stack growth. MgO layer was then grown by *e*-beam evaporation at a rate of 2 Åmin^{-1} while the substrates were kept at 673 K, followed by postgrowth annealing of a 3.0 nm thick epitaxial Fe at 500 K in an O_2 partial pressure of 5×10^{-5} mbar for 10 min. As for Fe_3O_4/GaAs(100), the tunneling barrier deposition was skipped. The epitaxial spin contacts were *ex situ* characterized by current-voltage (*I–V*) measurements. The junction size ranges from 25 to 200 μm square and were patterned by standard photolithography and wet etching using a 50 nm thick thermally evaporated Au layer as an etch mask.

Fig. 1 shows the result of a typical *I–V* measurement of one of the spin contacts to the GaAs at RT with the MgO barrier thickness $t_{MgO} = 3.0$ nm. The measurement for Fe_3O_4/GaAs(100) is also illustrated in order to compare the electrical properties of the two structures. The Fe_3O_4/GaAs(100) contact is clearly asymmetric, indicating a diode-like behavior which is typical for Schottky barriers as expected. Accordingly electron transport across the Fe_3O_4/GaAs(100) interface at elevated temperature is governed by thermionic emission due to the presence of depletion region which is commonly observed at the metal-semiconductor interface. By fitting with the thermionic theory, the Schottky barrier height has been determined as 0.31 eV. In contrast, the Fe_3O_4/MgO/GaAs(100) spin contact exhibits a less asymmetric *I–V* with a current density two to three orders of magnitude smaller than that of the Fe_3O_4/GaAs(100) counterpart. Such behavior which is distinctly different from the observation by Le Breton *et al*. appears surprising because it implies that the Schottky barrier height of the spin contact is substantially suppressed compared with the contact without the MgO layer [3]. This may be partially related to a change in the surface state density at the vicinity of the Schottky interfaces, which requires further verification.

We found from the numerical fit that the tunneling barrier height and width are 3.6 nm and 1.0 eV, respectively. The fitted barrier height is comparable to the values reported for magnetic tunnel junctions with MgO barriers deposited by various techniques [4,5]. Yet recent ballistic electron emission microscopy experiments on MgO/GaAs(100) suggested that oxygen deficiency

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in the MgO barrier introduces electronic defect states at the upper part of the MgO bandgap, which in turn act as conduction channels for the electrons [6]. The rather low barrier height obtained in our characterization is very likely to be originated from such defect states as well. Detailed elaborations will be given in the full manuscript.

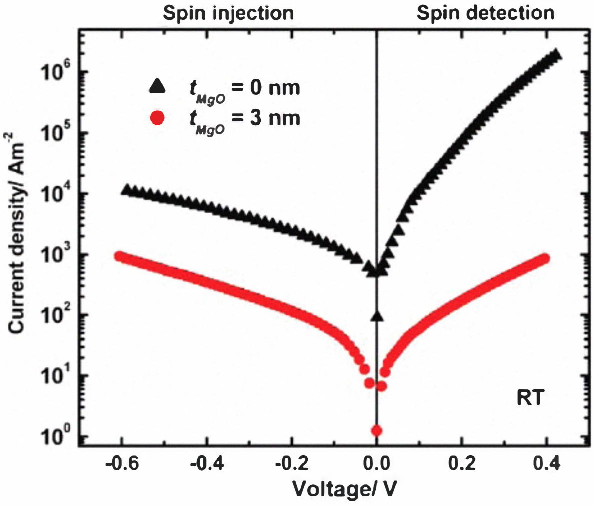

Fig.1 I–V characteristics of Fe_3O_4/GaAs(100) and Fe_3O_4/MgO/GaAs(100) at RT. A forward bias indicates the application of a negative voltage to the GaAs with respect to the top Au electrodes.

References

[1] P. K. J. Wong, W. Zhang, Y. B. Xu, S. Hassan and S. M. Thompson, IEEE Trans. Magn. **44**, 2640 (2008).

[2] Y. X. Lu, J. S. Claydon, Y. B. Xu, S. M. Thompson, K. Wilson and G. van der Laan, Phys. Rev. B **70**, 233304 (2004).

[3] J. C. Le Breton, S. Le Gall, G. Jézéquel, B. Lépine, P. Schieffer and P. Turban, Appl . Phys. Lett. **91**, 172112 (2007).

[4] T. Kiyomura, Y. Maruo and M. Gomi, J. Appl. Phys. **88**, 4768 (2000).

[5] S. Mitani, T. Moriyama and K. Takanashi, J. Appl. Phys. **93**, 8041 (2003).

[6] S. Guézo, P. Turban, C. Lallaizon, J. C. Le Breton, P. Schieffer, B. Lépine and G. Jézéquel, Appl. Phys. Lett. **93**, 172116 (2008).