Spin injection into InAs heterostructures beyond fundamental limit

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Electrical spin injection into semiconductors is the key technology for practical spintronics devices. Spin injection through tunnel barrier has become popular to obtain high spin injection effect to avoid the so-called conductivity mismatch[1]. On the other hand, tunnel barrier greatly introduce contact resistance resulting in reduced injection current density. So, it is desirable to have less tunnel barrier for spin transistor applications as long as efficient spin tunneling is guaranteed. The InAs inverted heterostructure is ideal for that purpose because surface pinning position is in the conduction band together with high spin-orbit interaction[2][3]. We have fabricated spin valve devices with and without MgO tunnel barrier to compare spin injection efficiency in InAs/InGaAs/InAlAs inverted HEMT structure.

The 4.1 nm InAs channel layer of the HEMT is buried in the middle of InGaAs sub-channel layer to confirm mobility. The structure consist of 300/800 nm of InP/ $In_{0.52}Al_{0.48}As$ buffer layer, $1.2\times10^{12}cm^{-2}$ of Si δ-doping, 10 nm of $In_{0.52}Al_{0.48}As$ spacer layer, 5.6 nm of $In_{0.53}Ga_{0.47}As$ sub-channel, 4.1 nm of InAs main channel, 1.8 nm of $In_{0.53}Ga_{0.47}As$ sub-channel, 50 nm of $In_{0.52}Al_{0.48}As$ barrier layer and $In_{0.53}Ga_{0.47}As$ 10 nm cap-layer. The electrical transport parameters were characterized by Hall measurement, yielding 20,000 cm^2/Vs of mobility, 1.5×10^{12} cm^{-2} of carrier density and 300 Ohm/□ of sheet resistance at 1.4 K. MgO samples were subjected to post-anneal at 250°C for 40min to obtain better crystal quality.

The spin transport lengths were estimated at 1.4K to be 1.62 μm in nonlocal set-up as shown in Fig.1. The spin polarization were estimated to be 6.93 % (No annel) and 8.93% (annealed at 250°C) in the interface of $Ni_{81}Fe_{19}$/MgO/InAs. Local spin valve measurement on barrier-less sample (Fig.2.b) exhibited MR characteristics comparable to samples with MgO tunnel barrier (Fig.2a). The estimated spin injection efficiency of 5.3% was obtained without tunnel barrier, which is comparable to samples with tunnel barriers (Fig.3). The present high spin injection efficiency makes remarkable contrast with conductivity mismatch calculation ($\eta \approx 8\times10^{-7}$) [1]. This result is consistent with optical measurements [4], and first principle calculations [5]. The role of ballistic nature during spin injection will be discussed.

[1] G. Schmidt, et al, Phys. Rev. B **62**, R4790 (2000). [2] H. C. Koo, et al, Science **325,** 1515 (2009). [3] M. Ohno and K. Yoh, Phys. Rev. B **75,** 241308(R) (2007). [4] K.Yoh et al, Semi.Sci.Technol. 19,pp.1-4 (2004). [5] Wunnicke et al, J.Supercond./Novel Magn.16,171 (2003).

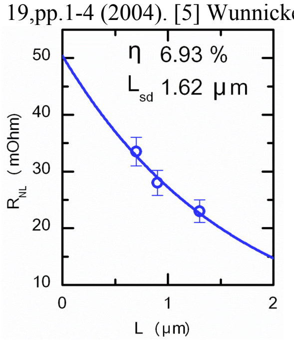

Fig.1 Non-local spin injection measurement result of NiFe/MgO/InAs I-HEMT structure

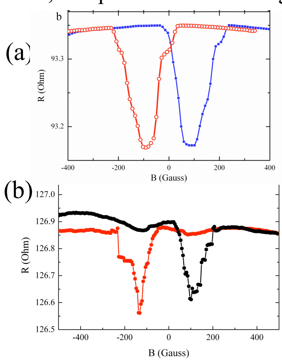

Fig.2 Local spin injection measurement results. (a)with MgO (b)Without MgO

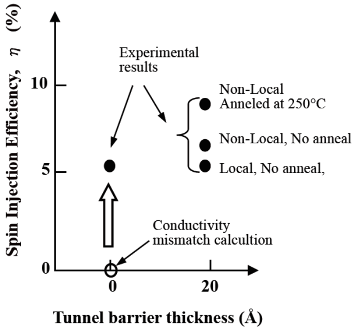

Fig.3 Spin injection efficiency comparison between samples with and without MgO tunnel barrier.