Spin accumulation at the Fe/Si interface and two types of Hanle characteristics

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Electrical spin injection into semiconductor, especially silicon, has been intensely investigated. Evaluation of spin accumulation in three-terminal Hanle set-up has raised intense debate on the origin of too high spin accumulation voltage and too short spin lifetime [1 - 4]. Typical arguments were sequential tunneling through interface traps [2], stray field at the interface due to interface roughness [3] and magnetic-filed-dependent tunnel resistance [4]. These in various tunneling barrier materials such as Al_2O_3 or MgO so that the bias dependence characterization could not modify tunnel characteristics so much. Here we report the spin accumulation at the Fe/Si interface without dielectric tunnel barrier to understand the spin accumulation mechanism in three terminal Hanle effect.

Fabricated sample structure consists on n-type high phosphorus doped (∼10^{19} cm^3) SOI wafer with ion plantation method. Fe electrodes were grown by MBE on n^+-Si. Non-local spin valve characterization revealed spin relaxation time of 7.45ns and spin diffusion length of 1.66μm as shown in Fig.1. Three-terminal Hanle-type was composed of Fe electrode of 150×200 μm^2 and Ni silicide electrodes were used for non-ferromagnetic contacts. Bias current dependence of three terminals Hanle measurement results is shown in Fig.2. Two types of Hanle-like signals were observed to overlap. From Lorenzian fitting, spin lifetime were of the order of 400 ps and 3 ns for wider and narrower peaks, respectively. Compared the nonlocal spin lifetime (7.45 ns), the value of narrower peaks seems to be consistent, suggesting that the narrower peak to be Hanle signal whereas broader and tall peaks to be originated from other mechanism such as magnetic field dependent tunnel resistance [4]. Figure 3 shows the biased current dependence of Hanle-type signal on bias current. Disappearance of wider peak at high bias suggests tunneling resistance related origin which is consistent with Uemura case[4].

[1] S. P. Dash et al., Nature **462**, 491 (2009) [2] M. Tran et al., Phys. Rev. Lett. **102**, 036601 (2009).
[3] S. P. Dash et al., Phys. Rev. B **84**, 054411 (2011). [4] T. Uemura et al., App. Phys. Lett. **101**, 132411 (2012)

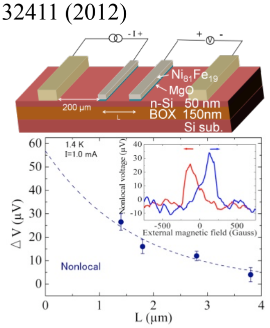
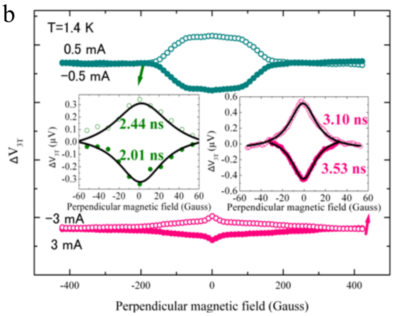


FIG .1. Nonlocal voltage as a function of length between ferromagnets including the schematics of nonlocal spin valve.



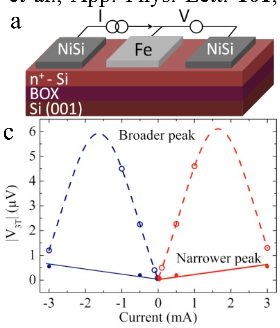


FIG. 2. (a) Schematics of three terminal Hanle geometry.
(b) Bias current dependence of three terminals Hanle effect at 1.3K.

(c) Comparison of broader and narrower peaks dependence on biasd current in three terminal Hanle type signals.