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Highly-efficient dynamic nuclear polarization in GaAs using a Heusler-alloy spin source

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1. Background

The injection and detection of spin polarized electrons using ferromagnet/semiconductor heterojunctions have attracted much interest. Recently, we demonstrated an efficient spin injection into GaAs using Heusler-alloy spin source[1]. Along with spin injection and detection, dynamic nuclear polarization (DNP) due to the hyperfine interaction between electron spins and nuclear spins is an important part of spintronics research. The purpose of this study is to demonstrate highly-efficient DNP using a Heusler-alloy spin source.

2. Experimental methods

Layer structures consisting of (from the substrate side) a 250-nm-thick i-GaAs layer, a 2.5-µm-thick n$^-$-GaAs layer (Si = 3×10^{16} cm^{-3}), and a 30-nm-thick n$^+$-GaAs layer (Si = 5×10^{18} cm^{-3}) were grown by molecular beam epitaxy on semi-insulating GaAs(001) substrates. A 1.1-nm-thick ultrathin CoFe layer and a 5-nm-thick Co_2MnSi layer were deposited by magnetron sputtering and successively annealed in situ at 350 °C. Using Ar ion milling technique and EB lithography, lateral spin transport devices were fabricated. As a reference, samples with a 5-nm-thick CoFe single layer were identically fabricated. Oblique Hanle effect measurements [2] were carried out in a non-local geometry at 4.2 K to investigate the strength of the nuclear field ($\mathbf{B}_n$) resulting from DNP. For this measurement, the oblique magnetic field of $\mathbf{B}_{ob} = B_{ob}\mathbf{u}$, where $\mathbf{u}$ = (sin15°, 0, cos15°) is a unit vector of the magnetic field, was applied, as shown in Fig. 1.

3. Results and Discussion

Figure 2(a) shows the typical B_{ob} dependence of the non-local voltage for a Co_2MnSi/CoFe/n-GaAs sample. The device was first initialized at B_{ob} = +30 mT for a hold time (t_{hold}) of 60 sec at an injection current of –40 µA. Then the magnetic field was swept from +30 mT to –30 mT with a sweep rate of 0.18 mT/s. This sweep rate was too fast for the nuclear field to reach the steady state, leading to the transient behavior of nuclear spins. When $\mathbf{B}_n$ and $\mathbf{B}_{ob}$ cancel each other, electron spins get polarized and the non-local voltage shows satellite peaks (indicated by arrows in Fig. 2(a)). Thus, one can estimate the strength of the nuclear field from satellite peak positions in the oblique Hanle signal. Figure 2(b) shows t_{hold} dependence of the observed satellite peak positions at $B_{ob} > 0$ for the Co_2MnSi/CoFe/n-GaAs sample and the CoFe/n-GaAs sample. For both samples the satellite peak position, or the nuclear field, shows almost exponential dependence on t_{hold}. This agrees with the time evolution of the DNP-induced nuclear field[2]. Importantly, the saturation value of the nuclear field of 37 mT for the Co_2MnSi/CoFe/n-GaAs sample is larger than that of 16 mT for the CoFe/n-GaAs sample. The spin polarization of electrons in the GaAs channel, estimated from the saturation value of $\mathbf{B}_n$, was 5.4% for the Co_2MnSi/CoFe/n-GaAs sample and 2.3% for the CoFe/n-GaAs sample, respectively. These values are almost consistent to those estimated from the magnitude of the spin signals (4.4% for the Co_2MnSi/CoFe/n-GaAs sample and 3.0% for the CoFe/n-GaAs sample [3]). Thus, the larger value of $\mathbf{B}_n$ observed in the Co_2MnSi/CoFe/n-GaAs sample is ascribed to the larger spin polarization of electrons injected into the GaAs channel.

4. Summary

We observed a larger nuclear field in the Co_2MnSi/CoFe/n-GaAs sample compared to the CoFe/n-GaAs sample due to the higher spin polarization of the Co_2MnSi spin source. This result indicates that the Heusler alloy is a promising spin source for nuclear spin polarization as well as for electron spin polarization in semiconductors.

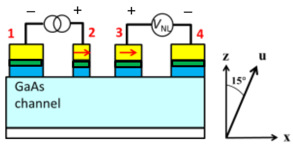

FIG. 1. Schematic configuration for oblique Hanle measurements.

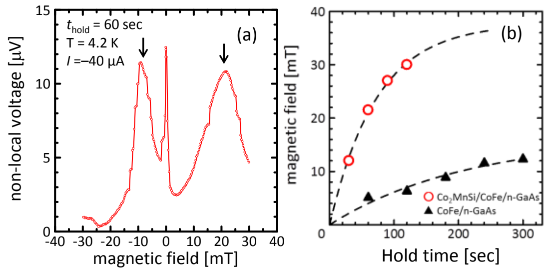

FIG. 2. (a) B_{ob} dependence of the non-local voltage for a Co_2MnSi/CoFe/n-GaAs sample, (b) t_{hold} dependence of the observed satellite peak position for $B_{ob} > 0$.

References

[1] T. Akiho et al., Phys. Rev. B (in press).
[2] P. Van Dorpe et al., Phys. Rev. B **72**, 035315 (2005).
[3] T. Uemura et al., APL **99**, 082108 (2011).