Dynamical spin injection into solution-processed Carbon-nanotubes

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Molecular materials are enabling new, flexible, large-area and low-cost electronic devices, and in addition, have long spin lifetimes. Whereas the long spin lifetimes imply the weak spin-orbit interaction (SOI), Ando et al. have successfully shown conversion of a spin current to a charge current in a molecule, PEDOT:PSS[1], by using its non-negligible SOI and inverse spin Hall effect (ISHE), which was quite surprising in a field of spintronics. Their success is attributed to sufficient spin accumulation at the interface of PEDOT:PSS and YIG, a magnetic insulator, allowing to expect that the spin conversion can be observed in a wide variety of molecules. Since we have previously demonstrated the spin conversion in graphene[2], here in this study, we show the successful spin conversion in metallic single-walled carbon nanotubes (m-SWNTs).

A m-SWNTs layer was formed on a YIG substrate (Fig.1(a)) by dropping a m-SWNTs solution provided from Technology Research Association for Single Walled Carbon Nanotube (TASC) as a product of a NEDO project. The mean diameter of the SWNT is 1.2 nm and the purity is more than 95%. In the spin pumping measurement, the sample was placed in a nodal position of a TE_{011} cavity of an electron spin resonance system (the microwave frequency was set to be 9.12 GHz). An external static magnetic field was applied at an angle, θ, as illustrated in Fig. 1(a). Under the ferromagnetic resonance (FMR) condition of the YIG layer, a spin angular momentum is transferred from the YIG layer to the m-SWNTs layer, resulting in generation of a pure spin current propagated perpendicular to the film plane. Then, the spin current was converted into a charge current due to the ISHE of the m-SWNTs. The FMR spectra and the electromotive force (EMF) were observed at RT, where the MW power (P_{MW}) was set to be 1 mW, as shown in Fig 1(b). The polarity reversal of the EMF was observed when θ was changed from 0 to 180 degrees and no signal was observed at 90 degrees. In addition, the ISHE voltage (V_{ISHE}) linearly increased to P_{MW} and changed as a function of θ, (see Figs. 1(c) and (d)). These results strongly suggest that the EMF was generated by the ISHE in the m-SWNT layer.

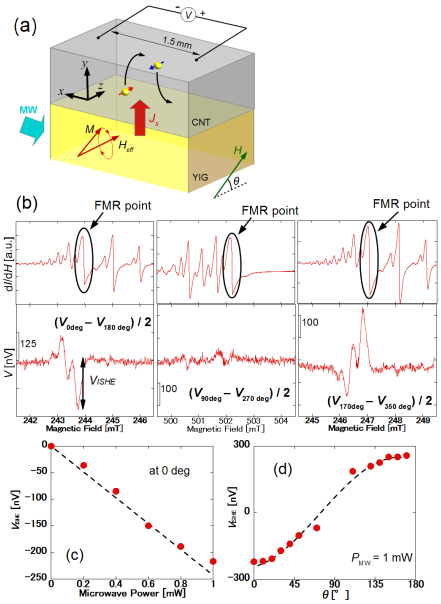

Fig.1 (a) A schematic illustration of the m-SWNT/YIG sample for dynamical spin injection. (b) Field dependence of FMR spectra and EMFs at θ = 0, 90, 180 degrees. (c) Power dependence of the V_{ISHE} at θ = 0 degree. (d) θ dependence of the V_{ISHE} at P_{MW} = 1 mW. Black dashed lines in (c) and (d) are fitting lines.

References [1] K. Ando et al., Nature Materials 12, 622 (2013). [2] R. Ohshima, M. Shiraishi et al., APL105, 162410 (2014).