Giant Spin-Orbit Torque in a Two-Dimensional Hole Gas at the Surface of Hydrogen-Terminated Diamond

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Two-dimensional hole gas (2DHG) is created at the surface of hydrogen-terminated (H-) diamond, which has been intensively studied as a field effect transistor [1]. In addition, the inner electric field perpendicular to the carrier plane induces the strong Rashba-type spin-orbit coupling [2], which leads to possible charge-to-spin conversion through the Rashba-Edelstein effect. In this study, the charge-to-spin conversion in H-diamond was observed by performing the second harmonic Hall measurement, which is a potential technique to estimate spin-orbit torque (SOT) efficiency [3].

A Hall-bar shaped H-diamond (001) / $Ni_{80}Fe_{20}$ (Py) device was prepared by using e-beam lithography and e-beam deposition, and the transverse second harmonic voltage was measured at room temperature (RT) under the application of an alternative current and an in-plane magnetic field H_{ext} with angle φ (see Fig. 1). The SOT efficiency ξ_{DL} was investigated from φ and H_{ext} dependence of transverse second harmonic voltage. The ξ_{DL} is negative at the samples with thin Py (≦ 5 nm) due to SOT from the 2DHG, and it is positive at the samples with thicker Py (≧ 7 nm) because self-induced SOT in Py becomes dominant in thick Py layer (see Fig. 2). The Rashba-Edelstein length in the 2DHG λ_{REE}^{2DHG}, which is equivalent to the inverse Rashba-Edelstein length λ_{IREE} or the product of spin Hall angle θ and spin diffusion length λ_s, was estimated as an index of the charge to spin conversion efficiency in 2DHG. The estimation of λ_{REE}^{2DHG} was implemented by solving the spin diffusion equation, in which the 2DHG is considered as the boundary condition for the Py, i.e., the spin-dependent chemical potential at the bottom of the Py layer is set to be $E\lambda_{REE}^{2DHG}$, where E is the electric field generated by the applied AC current. The theoretical fitting curve as well is shown in Fig.2, and λ_{REE}^{2DHG} is estimated to be -0.19 ± 0.07 nm, which is comparable to $\theta\lambda_s$ of Pt (0.05 nm [4] at RT) and λ_{IREE} in $LaAlO_3$ / $SrTiO_3$ (0.2 nm at RT [5]). The sign reversal of ξ_{DL} for the t_{Py} was not observed in the sample of oxygen-terminated (O-) diamond / Py, because O-diamond does not host 2DHG on its surface, which is the supporting evidence of the successful observation of the efficient spin conversion in the 2DHG.

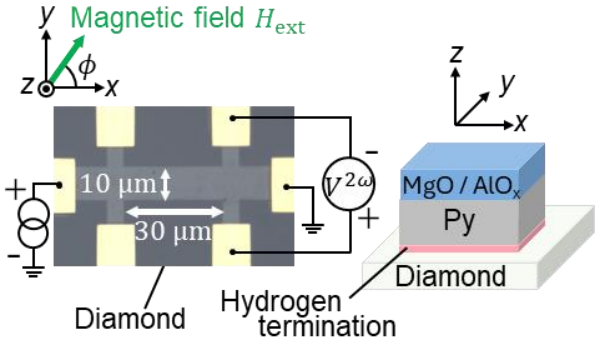

Figure 1: Device structure and measurement setup.

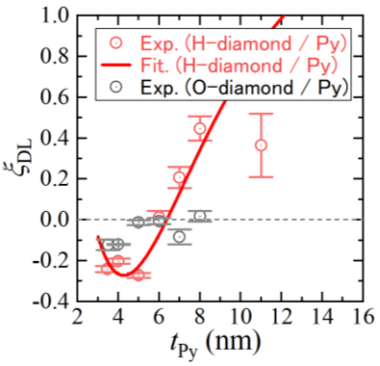

Figure 2: Py thickness dependence of SOT efficiency in H- (O-) diamond / Py samples.

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