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Estimation of the spin diffusion length in p-type Si from the length dependence of lateral spin channel.

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Recently, Shikoh *et al.* have successfully achieved spin current in p-type Si by spin pumping and demonstrated spin transport via inverse spin Hall effect [1], which opened a new avenue in the field of spintronics. However, accurate estimation of the spin diffusion length and spin coherent time in p-type Si is still an open question, since they used the simplest model for the estimation.

In this study, we report the estimation of the spin diffusion length from the gap dependence between Py and Pd. Spins were injected in p-type Si from Py strip using ESR. The spins transport into the p-Si channel and then drained into the Pd strip. The Py and Pd strips are separated by a gap length (L). Two models were used for the approximation of experimental results. The first model takes into account spin damping in the p-Si channel only on the distance between Py and Pd:

$\frac{V_{ISHE}}{j_S^0} = \frac{A}{2} e^{-L/\lambda}$,

where V_{ISHE} is the voltage of the inverse spin Hall effect, j_S^0 is the density of spin current, A is the coefficient nondependent from L, λ is the spin diffusion length (when spins are directly injected from Py to Pd $V_{ISHE} = Aj_S^0$, see [2] for the details). In the second model, a size of the Py strip was taken into account, thus spin transport distance from Py to Pd was different for spins injected in different places of the Py strip, however, it was assumed that all spins travel directly in the direction of the Pd strip:

$\frac{V_{ISHE}}{j_S^0} = \frac{A}{2w_{NM}} \int_{-w_{FM}/2}^{0} e^{-\frac{L-x_{FM}}{\lambda}} dx_{FM} = \frac{A\lambda}{2w_{NM}} e^{-L/\lambda} \left(1 - e^{-\frac{w_{FM}}{2\lambda}}\right)$,

where w_{NM} is the width of Pd strip, w_{FM} is the width of Py strip, x_{FM} directed along the width of the Py strip. In both models, loss of half of the spin current was additionally assumed for trying to take into account losses due to the existence of perpendicular apart from lateral spin current damping in the p-Si layer. Fig. 1 shows the result of the model calculation. It can be seen that the 2nd model provides much more convenient fitting than the 1st model with spin diffusion length of 250 nm, comparing to 150 nm of the 1st model. This result shows that value of the spin diffusion length depends significantly on the used model. More detailed research is necessary to formulate a more precise model, which will be undertaken in near future.

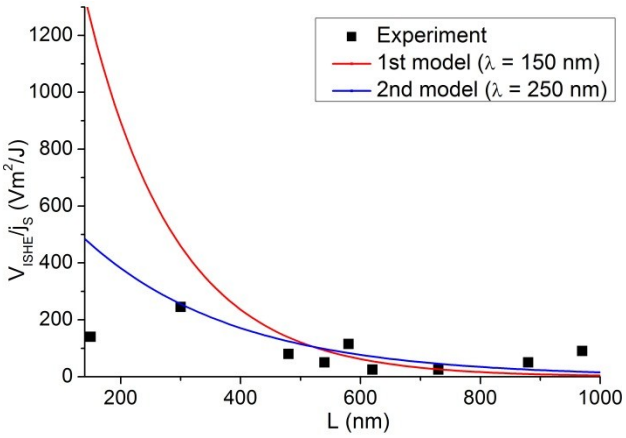

Fig.1 Gap length dependence of normalized ISHE voltage

[1] E. Shikoh *et al.*, PRL **110**, 127201 (2013).

[2] K. Ando and E. Saitoh, J. Appl. Phys. **108**, 113925 (2010)