Induced spin-orbit coupling in silicon thin films by bismuth doping

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Si possesses a low spin-orbit coupling, it allows a long spin lifetime but limits new device-designing possibilities in spintronics, particularly with the spin-charge conversion effects—the Spin Hall effect (SHE) and the Inverse Spin Hall effect (ISHE). However, if it can be engineered to possess a significant spin-orbit coupling, such additional functionality will pave the way to create all-Si spin devices consisting of injector, detector and transport medium made of Si. The purpose of this study is to create a sizable spin-orbit interaction in Si by implantation of a heavy element, bismuth (Bi).

To compare the spin-orbit coupling strength in the Si channel with and without Bi doping (samples SOI:P:B and SOI:P, respectively), we measured quantum corrections to the conductance in function of temperature. The elastic diffusion length (L_e), the spin-orbit coupling length (L_{so}) and the phase coherence length (L_ϕ) can be extracted from the magnetoconductance data by using the Hikami-Larkin-Nagaoka model (Fitting curve in black). L_e has the same order of magnitude (10 nm-25 nm) for both samples, however L_ϕ decreased after the Bi doping (with the strongest decrease from 177 nm to 35 nm at 2 K). In the case of SOI:P:Bi, the Bi doping is capable of inducing the spin-orbit coupling length of the same order of magnitude with the phase coherence length (L_{so}= 54 nm and L_ϕ= 35 nm at 2K).

The increased spin-orbit coupling strength led to the observed the crossover between the WL and the WAL. But since the spin-orbit coupling length is still higher than phase coherence length we did not observe a full polarity reversal of magnetoconductance correction. Increasing number of electrically activated Bi atoms can provide a way to further enhance the spin-orbit coupling without increase in Bi doping concentration. These results demonstrate a control over the strength of the spin-orbit coupling in Si channel using Bi doping.

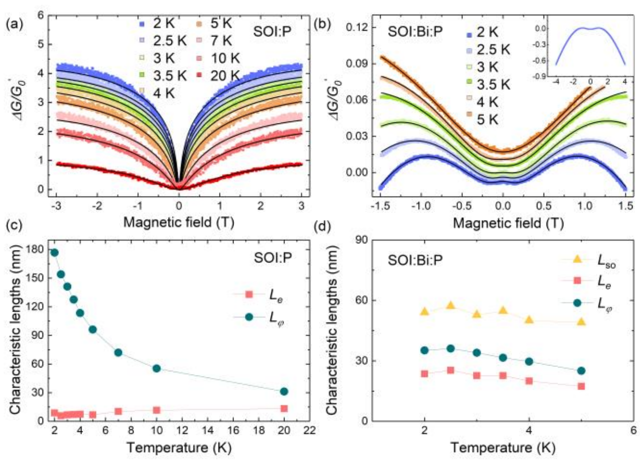

FIG. 3. (a) The normalized magnetoconductance $\Delta G/G_0`=(G(B)-G(B=0))/G_0`$ of (a) P-doped Si channel without Bi doping (SOI:P) and (b) P-doped Si channel with Bi doping (SOI:Bi) measured at different temperatures. Inset in panel (b) shows full magnetic field B scan range data measured at T=2 K. The curves are offset along the y-axis for clarity. Solid black lines show fitting by HLN model. Temperature dependence of the mean free path length L_e (squares), the phase coherence length L_ϕ (circles) and the spin-orbit coupling length L_{so} (triangles) of (c) P-doped Si channel without Bi doping (SOI:P) and (d) P-doped Si channel with Bi doping (SOI:P:Bi).