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Spin-orbit interactions in thin magnetic films: from doping and interfaces to transport and skyrmions[1]

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The spin-orbit interaction is an inherent part of magnetism, which links up the independent world of spins to the atomic lattice, thus controlling many functional properties of magnetic materials. In the widely used $3d$ transition metal ferromagnetic films, the spin-orbit interaction is relatively weak, due to low atomic number, and to obtain strong spin-orbit effects it is necessary to include heavy metals. Here we show that large spin-orbit effects can be obtained by two separate routes. First, it is possible to enhance and tune the spin-orbit interaction by adding $5d$ platinum dopants into permalloy ($Ni_{81}Fe_{19}$) thin films by a cosputtering technique. This is achieved without significant changes of the magnetic properties, due to the vicinity of Pt to meeting the Stoner criterion for the ferromagnetic state. The spin-orbit interaction is investigated by means of transport measurements (the anisotropic magnetoresistance and anomalous Hall effect), ferromagnetic resonance measurements to determine the Gilbert damping, as well as by measuring the x-ray magnetic circular dichroism at the L_3 and L_2 x-ray absorption edges to reveal the ratio of orbital to spin magnetic moments. It is shown that the effective spin-orbit interaction increases with Pt concentration within the 0%–10% Pt concentration range in a way that is consistent with theoretical expectations for all four measurements. Second, we show how placing Pt in atomic contact with an ultrathin Co layer leads to strong spin-orbit-driven effects. As well as the well-known perpendicular magnetic anisotropy, a strong Dzyaloshinskii-Moriya interaction is induced, leading to homochiral Néel domain walls and chiral skyrmion bubbles.

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