Spin transport and superconductivity in half-metallic nanowires and junctions
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Summary

The interest of this thesis lies in spin transport in normal metals and superconducting half-metallic junctions. Spin transport is strongly related to the spin polarization (P) of materials. Half-metallic ferromagnets, or half metals, with 100% spin polarization, are of interest as spin injector, promising a high efficiency; but also as a superconducting spin transport channel between two superconducting electrodes. There are, however, few half metals. Here, we study the oxide perovskite half metal $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) in combination with either normal metals (Pt and Ag) or superconductor NbTi.

In Chapter 3, we study the pinning and depinning of domain walls (DW) in halfmetallic LSMO nanostructures with a notch to stabilize a wall. Such walls can be stably pinned and depinned between 10 K and 300 K, which is observed by recording the magnetoresistance during a sweep of the magnetic field. We find a nearly linear decrease of the pinning fields with increasing temperature. Interestingly, both the resistance increase ΔR when pinning a DW, and $\Delta R/R_0$ (with R_0 the resistance at zero field) are proportional to temperature and reach maxima at 300 K. Our work indicates the feasibility of creating and manipulating DW in half-metallic LSMO across a wide range of temperatures. The question that is still open is whether the depinning and moving of the DWs can also occur by a transport current (of necessity spin-polarized), through the mechanism of spin transfer torque. Early research has revealed the threshold currents for such motion of the order of 10^8 A/m^2 in half-metallic wires, which would be a low value. A systematic study is still absent.

In Chapter 4, spin injection from LSMO into Ag is investigated. In a non-local measurement configuration, where a bar-shaped injector is connected to an also bar-shaped detector by a normal (N) metal bridge, a spin potential difference can be induced by simply flowing an electric current through the injector/N-metal interface. In the detector, the presence of a voltage unambiguously shows a pure spin current injected into the Ag bridge. The behavior of spin transport in Ag is thoroughly analyzed, *i.e.* spin polarization and spin lifetime, *etc.*, by varying the spacing between the injector and detector. The obtained results are consistent with the fitted values of Hanle precession measurements (using a perpendicular magnetic field). Theoretically, no conventional conductivity mismatch problem is expected in LSMO/Ag system, due to the difference in resistivity and spin diffusion length in Ag. This leads to the prediction of a high spin polarization of the injected spin current. The experimental results are not in agreement with this prediction, because of the existence of a spin-active interface.

We conclude that half-metallic LSMO can be efficient in injecting spin current if the interface is more carefully treated. By building an epitaxial interface, one would expect high spin polarization of the injected spin current.

An intriguing result is presented in Chapter 5, where we show that a spin-polarized supercurrent, carried by equal-spin triplets, is generated in lateral superconducting NbTi/LSMO junctions with different geometrical shapes. We see zero-resistance states in all the current-voltage curves taken at different temperatures, as a signature of the superconducting junctions. By examining the superconducting quantum interference (SQI) patterns, we find unambiguously the presence of Josephson coupling in the disk-shaped, bar-shaped, and square-shaped junctions, respectively. Moreover, the Fourier analyses on the obtained SQI patterns demonstrate rim supercurrents in the disk-shaped junction but a relatively homogeneous distribution of supercurrent in the square-shaped and bar-shaped junctions. Distinct from earlier work on Nb/Co disk junctions, here the triplet supercurrents are quite robust against in-plane magnetic field even up to 200 mT, where the spin texture has disappeared. We attribute this phenomenon to the half-metallic nature of LSMO, *i.e.* there is only one spin state. Moreover, the observation of triplets generation in NbTi/Ag(10 nm)/LSMO systems reveals the singlets to triplets conversion is possibly driven by the magnetic inhomogeneity in the LSMO top layer, rather than by interface coupling.

In addition to the analysis of the current distribution, the temperature-dependent critical supercurrent $I_c(T)$ is thoroughly measured and analyzed. Theorists predict a plateau, or even a peak in $I_c(T)$ should appear in superconducting half-metallic junctions as a consequence of exotic pairing symmetry, which is quite robust and regardless of the clean or diffusive regimes. In our case, the length of the disk-shaped junction is comparable to the dephasing length of triplet correlations. Therefore, we consider a 'short' junction case, and $I_c(T)$ is expected to show a $(1\text{-}T/T_c)^2$ dependence, which well fits our data. However, the maximum of $I_c(T)$ still remains to be found.

Finally, to gain more insight into the mystery of triplets in superconducting half-metallic junctions, in Chapter 6, we study long NbTi/LSMO junctions. The length of the junction is much larger than the dephasing length of triplet correlations in this case. We see superconductivity, or its onset in all junctions with varying dimensions, due to the long-range proximity effect. The Josephson coupling is also verified by inspecting the SQI patterns. Unlike the case of short junctions, long junctions all exhibit Gaussian-like SQI patterns. We assume triplet supercurrents transport in a diffusive regime. Moreover, $I_c(T)$ is measured down to 1.5 K. However, no maximum of $I_c(T)$ is seen. Quantitative analysis of the $I_c(T)$ obtained on the long superconducting half-metallic junctions will require a better theoretical framework.