



Universiteit
Leiden
The Netherlands

Spin transport and superconductivity in half-metallic nanowires and junctions

Yao, J.

Citation

Yao, J. (2023, July 5). *Spin transport and superconductivity in half-metallic nanowires and junctions*. *Casimir PhD Series*. Retrieved from <https://hdl.handle.net/1887/3629768>

Version: Publisher's Version

License: [Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/3629768>

Note: To cite this publication please use the final published version (if applicable).

Bibliography

- [1] A. Hirohata, K. Yamada, Y. Nakatani, I.-L. Prejbeanu, B. Diény, P. Pirro, and B. Hillebrands. *Review on spintronics: principles and device applications*. Journal of Magnetism and Magnetic Materials **509**, 166711 (2020).
- [2] I. Žutić, J. Fabian, and S. D. Sarma. *Spintronics: fundamentals and applications*. Reviews of Modern Physics **76**, 323 (2004).
- [3] C. Chappert, A. Fert, and F. N. Van Dau. *The emergence of spin electronics in data storage*. Nature Materials **6**, 813–823 (2007).
- [4] H. Idzuchi, Y. Fukuma, and Y. Otani. *Spin transport in non-magnetic nanostructures induced by non-local spin injection*. Physica E: Low-dimensional Systems and Nanostructures **68**, 239–263 (2015).
- [5] J. Sinova, S. O. Valenzuela, J. Wunderlich, C. Back, and T. Jungwirth. *Spin Hall effects*. Reviews of Modern Physics **87**, 1213 (2015).
- [6] K. Ando, S. Takahashi, J. Ieda, Y. Kajiwara, H. Nakayama, T. Yoshino, K. Harii, Y. Fujikawa, M. Matsuo, S. Maekawa, et al. *Inverse spin-Hall effect induced by spin pumping in metallic system*. Journal of Applied physics **109**, 103913 (2011).
- [7] E. Saitoh, M. Ueda, H. Miyajima, and G. Tatara. *Conversion of spin current into charge current at room temperature: inverse spin-Hall effect*. Applied Physics Letters **88**, 182509 (2006).
- [8] L. Cornelissen, J. Liu, R. Duine, J. B. Youssef, and B. Van Wees. *Long-distance transport of magnon spin information in a magnetic insulator at room temperature*. Nature Physics **11**, 1022–1026 (2015).
- [9] A. Serga, A. Chumak, and B. Hillebrands. *YIG magnonics*. Journal of Physics D: Applied Physics **43**, 264002 (2010).
- [10] J. Linder and J. W. Robinson. *Superconducting spintronics*. Nature Physics **11**, 307–315 (2015).
- [11] M. Eschrig. *Spin-polarized supercurrents for spintronics: a review of current progress*. Reports on Progress in Physics **78**, 104501 (2015).
- [12] Q. Qin, S. He, W. Song, P. Yang, Q. Wu, Y. P. Feng, and J. Chen. *Ultra-low magnetic damping of perovskite $\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3$ thin films*. Applied Physics Letters **110**, 112401 (2017).

- [13] J Wang, L. Xie, C. Wang, H. Zhang, L. Shu, J. Bai, Y. Chai, X. Zhao, J. Nie, C. Cao, et al. *Magnetic domain-wall motion twisted by nanoscale probe-induced spin transfer*. Physical Review B **90**, 224407 (2014).
- [14] D Sanchez-Manzano, S Mesoraca, F Cuellar, M Cabero, V Rouco, G Orfila, X Palermo, A Balan, L Marcano, A Sander, et al. *Extremely long-range, high-temperature Josephson coupling across a half-metallic ferromagnet*. Nature Materials **21**, 188–194 (2022).
- [15] A. Manchon, H. C. Koo, J. Nitta, S. M. Frolov, and R. A. Duine. *New perspectives for Rashba spin–orbit coupling*. Nature Materials **14**, 871–882 (2015).
- [16] F. Vas'ko. *Spin splitting in the spectrum of two-dimensional electrons due to the surface potential*. Soviet Journal of Experimental and Theoretical Physics Letters **30**, 541 (1979).
- [17] F. Bergeret and I. Tokatly. *Spin-orbit coupling as a source of long-range triplet proximity effect in superconductor-ferromagnet hybrid structures*. Physical Review B **89**, 134517 (2014).
- [18] K.-R. Jeon, X. Montiel, S. Komori, C. Ciccarelli, J. Haigh, H. Kurebayashi, L. F. Cohen, A. K. Chan, K. D. Stenning, C.-M. Lee, et al. *Tunable pure spin supercurrents and the demonstration of their gateability in a spin-wave device*. Physical Review X **10**, 031020 (2020).
- [19] M. Baumgartner, K. Garelo, J. Mendil, C. O. Avci, E. Grimaldi, C. Murer, J. Feng, M. Gabureac, C. Stamm, Y. Acremann, et al. *Spatially and time-resolved magnetization dynamics driven by spin–orbit torques*. Nature Nanotechnology **12**, 980–986 (2017).
- [20] M. Smidman, M. Salamon, H. Yuan, and D. Agterberg. *Superconductivity and spin–orbit coupling in non-centrosymmetric materials: a review*. Reports on Progress in Physics **80**, 036501 (2017).
- [21] S. Komori, J. M. Devine-Stoneman, K. Ohnishi, G. Yang, Z. Devizorova, S. Mironov, X. Montiel, L. A. Olde Olthof, L. F. Cohen, H. Kurebayashi, et al. *Spin-orbit coupling suppression and singlet-state blocking of spin-triplet Cooper pairs*. Science Advances **7**, eabe0128 (2021).
- [22] E. Y. Tsymlal and I. Žutić. *Spin transport and magnetism*. (CRC press, 2012).
- [23] D. A. Allwood, G. Xiong, C. Faulkner, D. Atkinson, D. Petit, and R. Cowburn. *Magnetic domain-wall logic*. Science **309**, 1688–1692 (2005).
- [24] J. Franken, H. Swagten, and B. Koopmans. *Shift registers based on magnetic domain wall ratchets with perpendicular anisotropy*. Nature Nanotechnology **7**, 499–503 (2012).
- [25] S. S. Parkin, M. Hayashi, and L. Thomas. *Magnetic domain-wall racetrack memory*. Science **320**, 190–194 (2008).

- [26] S. Zhang and Z Li. *Roles of nonequilibrium conduction electrons on the magnetization dynamics of ferromagnets*. Physical Review Letters **93**, 127204 (2004).
- [27] K. Neeraj, N. Awari, S. Kovalev, D. Polley, N. Zhou Hagström, S. S. P. K. Arekapudi, A. Semisalova, K. Lenz, B. Green, J.-C. Deinert, et al. *Inertial spin dynamics in ferromagnets*. Nature Physics **17**, 245–250 (2021).
- [28] A. Vansteenkiste, J. Leliaert, M. Dvornik, M. Helsen, F. Garcia-Sanchez, and B. Van Waeyenberge. *The design and verification of mumax3*. AIP Advances **4**, 107133 (2014).
- [29] H. Yuan and X. Wang. *Domain wall pinning in notched nanowires*. Physical Review B **89**, 054423 (2014).
- [30] Y. Tokura and Y. Tomioka. *Colossal magnetoresistive manganites*. Journal of Magnetism and Magnetic Materials **200**, 1–23 (1999).
- [31] H. Hwang, S.-W. Cheong, N. P. Ong, and a. B. Batlogg. *Spin-polarized intergrain tunneling in $La_{2/3}Sr_{1/3}MnO_3$* . Physical Review Letters **77**, 2041 (1996).
- [32] A. Ramirez. *Colossal magnetoresistance*. Journal of Physics: Condensed Matter **9**, 8171 (1997).
- [33] E. Dagotto, T. Hotta, and A. Moreo. *Colossal magnetoresistant materials: the key role of phase separation*. Physics Reports **344**, 1–153 (2001).
- [34] G. G. Guzmán-Verri, R. T. Brierley, and P. B. Littlewood. *Cooperative elastic fluctuations provide tuning of the metal–insulator transition*. Nature **576**, 429–432 (2019).
- [35] S. Ramanathan. *Thin film metal-oxides*. Harvard University: Springer New York Dordrecht Heidelberg London, London (2010).
- [36] B. Nadgorny, I. Mazin, M. Osofsky, R. Soulen Jr, P. Broussard, R. Stroud, D. Singh, V. Harris, A. Arsenov, and Y. Mukovskii. *Origin of high transport spin polarization in $La_{0.7}Sr_{0.3}MnO_3$: direct evidence for minority spin states*. Physical Review B **63**, 184433 (2001).
- [37] N. Mottaghi, M. Seehra, R. Trappen, S. Kumari, C.-Y. Huang, S. Yousefi, G. Cabrera, A. Romero, and M. Holcomb. *Insights into the magnetic dead layer in $La_{0.7}Sr_{0.3}MnO_3$ thin films from temperature, magnetic field and thickness dependence of their magnetization*. AIP Advances **8**, 056319 (2018).
- [38] H. Boschker, M. Huijben, A. Vailionis, J. Verbeeck, S. v. van Aert, M. Luysberg, S. Bals, G. v. van Tendeloo, E. P. Houwman, G. Koster, et al. *Optimized fabrication of high-quality $La_{0.67}Sr_{0.33}MnO_3$ thin films considering all essential characteristics*. Journal of physics D: applied physics **44**, 205001 (2011).
- [39] H. Boschker, M. Mathews, P. Brinks, E. Houwman, A. Vailionis, G. Koster, D. H. Blank, and G. Rijnders. *Uniaxial contribution to the magnetic anisotropy of $La_{0.67}Sr_{0.33}MnO_3$ thin films induced by orthorhombic crystal structure*. Journal of Magnetism and Magnetic Materials **323**, 2632–2638 (2011).

- [40] L. E. Hueso, J. M. Pruneda, V. Ferrari, G. Burnell, J. P. Valdes-Herrera, B. D. Simons, P. B. Littlewood, E. Artacho, A. Fert, and N. D. Mathur. *Transformation of spin information into large electrical signals using carbon nanotubes*. Nature **445**, 410–413 (2007).
- [41] D. Van Delft and P. Kes. *The discovery of superconductivity*. Physics Today **63**, 38–43 (2010).
- [42] W. Meissner and R. Ochsenfeld. *Ein neuer effekt bei eintritt der supraleitfähigkeit*. Naturwissenschaften **21**, 787–788 (1933).
- [43] J. Bardeen, L. N. Cooper, and J. R. Schrieffer. *Theory of superconductivity*. Physical Review **108**, 1175 (1957).
- [44] L. P. Gor'kov. *Microscopic derivation of the Ginzburg-Landau equations in the theory of superconductivity*. Sov. Phys. JETP **9**, 1364–1367 (1959).
- [45] I. S. Aranson and L. Kramer. *The world of the complex Ginzburg-Landau equation*. Reviews of Modern Physics **74**, 99 (2002).
- [46] B. D. Josephson. *Possible new effects in superconductive tunnelling*. Physics Letters **1**, 251–253 (1962).
- [47] P. W. Anderson and J. M. Rowell. *Probable observation of the Josephson superconducting tunneling effect*. Physical Review Letters **10**, 230 (1963).
- [48] T. J. Blom, T. W. Mechielsen, R. Fermin, M. B. Hesselberth, J. Aarts, and K. Lahlabi. *Direct-write printing of Josephson junctions in a scanning electron microscope*. ACS Nano **15**, 322–329 (2020).
- [49] V. Ambegaokar and B. Halperin. *Voltage due to thermal noise in the dc Josephson effect*. Physical Review Letters **22**, 1364 (1969).
- [50] R. Dynes and T. Fulton. *Supercurrent density distribution in Josephson junctions*. Physical Review B **3**, 3015 (1971).
- [51] R. Fermin, D. Van Dinter, M. Hubert, B. Woltjes, M. Silaev, J. Aarts, and K. Lahlabi. *Superconducting triplet rim currents in a spin-textured ferromagnetic disk*. Nano Letters **22**, 2209–2216 (2022).
- [52] R. Fermin, B. de Wit, and J. Aarts. *Beyond the effective length: how to analyze magnetic interference patterns of thin-film planar josephson junctions with finite lateral dimensions*. Physical Review B **107**, 064502 (2023).
- [53] J. Ying, J. He, G. Yang, M. Liu, Z. Lyu, X. Zhang, H. Liu, K. Zhao, R. Jiang, Z. Ji, et al. *Magnitude and spatial distribution control of the supercurrent in Bi₂O₂Se-based Josephson junction*. Nano Letters **20**, 2569–2575 (2020).
- [54] J Pearl. *Current distribution in superconducting films carrying quantized fluxoids*. Applied Physics Letters **5**, 65–66 (1964).
- [55] Y. M. Ivanchenko and T. Soboleva. *Nonlocal interaction in Josephson junctions*. Physics Letters A **147**, 65–69 (1990).

- [56] A. Abdumalikov, G. Alfimov, and A. Malishevskii. *Nonlocal electrodynamics of Josephson vortices in superconducting circuits*. Superconductor Science and Technology **22**, 023001 (2009).
- [57] A. A. Boris, A. Rydh, T. Golod, H. Motzkau, A. Klushin, and V. M. Krasnov. *Evidence for nonlocal electrodynamics in planar Josephson junctions*. Physical Review Letters **111**, 117002 (2013).
- [58] S. Shapiro. *Josephson currents in superconducting tunneling: the effect of microwaves and other observations*. Physical Review Letters **11**, 80 (1963).
- [59] M. Eschrig et al. *Spin-polarized supercurrents for spintronics*. Physical Today **64**, 43 (2011).
- [60] J. Robinson, S Piano, G Burnell, C Bell, and M. Blamire. *Critical current oscillations in strong ferromagnetic π junctions*. Physical Review Letters **97**, 177003 (2006).
- [61] V. Ryazanov, V. Oboznov, A. Y. Rusanov, A. Veretennikov, A. A. Golubov, and J. Aarts. *Coupling of two superconductors through a ferromagnet: evidence for a π junction*. Physical Review Letters **86**, 2427 (2001).
- [62] K. Lahabi, M. Amundsen, J. A. Ouassou, E. Beukers, M. Pleijster, J. Linder, P. Alkemade, and J. Aarts. *Controlling supercurrents and their spatial distribution in ferromagnets*. Nature Communications **8**, 2056 (2017).
- [63] T. S. Khaire, M. A. Khasawneh, W. Pratt Jr, and N. O. Birge. *Observation of spin-triplet superconductivity in Co-based Josephson junctions*. Physical Review Letters **104**, 137002 (2010).
- [64] N. Banerjee, J. Robinson, and M. G. Blamire. *Reversible control of spin-polarized supercurrents in ferromagnetic Josephson junctions*. Nature Communications **5**, 4771 (2014).
- [65] H. Suominen, J Danon, M Kjaergaard, K Flensberg, J Shabani, C. Palmström, F Nichele, and C. Marcus. *Anomalous fraunhofer interference in epitaxial superconductor-semiconductor Josephson junctions*. Physical Review B **95**, 035307 (2017).
- [66] B. Börzsök, S. Komori, A. Buzdin, and J. Robinson. *Fraunhofer patterns in magnetic Josephson junctions with non-uniform magnetic susceptibility*. Scientific Reports **9**, 5616 (2019).
- [67] M. Alidoust, M. Willatzen, and A.-P. Jauho. *Fraunhofer response and supercurrent spin switching in black phosphorus with strain and disorder*. Physical Review B **98**, 184505 (2018).
- [68] F Chiodi, M Ferrier, S Guéron, J. Cuevas, G Montambaux, F Fortuna, A Kasumov, and H Bouchiat. *Geometry-related magnetic interference patterns in long SNS Josephson junctions*. Physical Review B **86**, 064510 (2012).

- [69] R. S. Keizer, S. T. Gönnenwein, T. M. Klapwijk, G. Miao, G. Xiao, and A. Gupta. *A spin triplet supercurrent through the half-metallic ferromagnet CrO₂*. Nature **439**, 825–827 (2006).
- [70] M. Anwar, F Czeschka, M Hesselberth, M Porcu, and J Aarts. *Long-range supercurrents through half-metallic ferromagnetic CrO₂*. Physical Review B **82**, 100501 (2010).
- [71] A. Singh, S. Voltan, K. Lahabi, and J. Aarts. *Colossal proximity effect in a superconducting triplet spin valve based on the half-metallic ferromagnet CrO₂*. Physical Review X **5**, 021019 (2015).
- [72] M. Eschrig and T. Löfwander. *Triplet supercurrents in clean and disordered half-metallic ferromagnets*. Nature Physics **4**, 138–143 (2008).
- [73] C Visani, Z Sefrioui, J Tornos, C Leon, J Briatico, M Bibes, A Barthélémy, J Santamaria, and J. E. Villegas. *Equal-spin Andreev reflection and long-range coherent transport in high-temperature superconductor/half-metallic ferromagnet junctions*. Nature Physics **8**, 539–543 (2012).
- [74] A. Singh, C. Jansen, K. Lahabi, and J. Aarts. *High-quality CrO₂ nanowires for dissipation-less spintronics*. Physical Review X **6**, 041012 (2016).
- [75] M Eschrig, J Kopu, J. Cuevas, and G. Schön. *Theory of half-metal/superconductor heterostructures*. Physical Review Letters **90**, 137003 (2003).
- [76] Y. Zhang, J. Liu, Y. Dong, S. Wu, J. Zhang, J. Wang, J. Lu, A. Rückriegel, H. Wang, R. Duine, et al. *Strain-driven Dzyaloshinskii-Moriya interaction for room-temperature magnetic skyrmions*. Physical Review Letters **127**, 117204 (2021).
- [77] A. Fernández-Pacheco, R. Streubel, O. Fruchart, R. Hertel, P. Fischer, and R. P. Cowburn. *Three-dimensional nanomagnetism*. Nature Communications **8**, 1–14 (2017).
- [78] J. Shibata, G. Tatara, and H. Kohno. *A brief review of field-and current-driven domain-wall motion*. Journal of Physics D: Applied Physics **44**, 384004 (2011).
- [79] M. Hayashi, L. Thomas, C. Rettner, R. Moriya, X. Jiang, and S. S. Parkin. *Dependence of current and field driven depinning of domain walls on their structure and chirality in permalloy nanowires*. Physical Review Letters **97**, 207205 (2006).
- [80] J.-S. Kim, M.-A. Mawass, A. Bisig, B. Krüger, R. M. Reeve, T. Schulz, F Büttner, J. Yoon, C.-Y. You, M. Weigand, et al. *Synchronous precessional motion of multiple domain walls in a ferromagnetic nanowire by perpendicular field pulses*. Nature Communications **5**, 3429 (2014).
- [81] S Fukami, M Yamanouchi, S Ikeda, and H Ohno. *Depinning probability of a magnetic domain wall in nanowires by spin-polarized currents*. Nature Communications **4**, 1–7 (2013).

- [82] R. Moriya, L. Thomas, M. Hayashi, Y. B. Bazaliy, C. Rettner, and S. S. Parkin. *Probing vortex-core dynamics using current-induced resonant excitation of a trapped domain wall*. *Nature Physics* **4**, 368–372 (2008).
- [83] M. Hayashi, L. Thomas, R. Moriya, C. Rettner, and S. S. Parkin. *Current-controlled magnetic domain-wall nanowire shift register*. *Science* **320**, 209–211 (2008).
- [84] A. Yamaguchi, T. Ono, S. Nasu, K. Miyake, K. Mibu, and T. Shinjo. *Real-space observation of current-driven domain wall motion in submicron magnetic wires*. *Physical Review Letters* **92**, 077205 (2004).
- [85] G. Tatara, H. Kohno, and J. Shibata. *Microscopic approach to current-driven domain wall dynamics*. *Physics Reports* **468**, 213–301 (2008).
- [86] W. Chen, L. Qian, and G. Xiao. *Resistance of domain-wall states in half-metallic CrO_2* . *Physical Review B* **98**, 174402 (2018).
- [87] A. Biehler, M. Kläui, M. Fonin, C. König, G. Güntherodt, and U. Rüdiger. *Domain structures and the influence of current on domains and domain walls in highly spin-polarized CrO_2 wire elements*. *Physical Review B* **75**, 184427 (2007).
- [88] A. Vailionis, H. Boschker, W. Siemons, E. P. Houwman, D. H. Blank, G. Rijnders, and G. Koster. *Misfit strain accommodation in epitaxial ABO_3 perovskites: lattice rotations and lattice modulations*. *Physical Review B* **83**, 064101 (2011).
- [89] A. Ruotolo, A. Oropallo, F. Miletto Granozio, G. Pepe, P. Perna, U. S. Di Uccio, and D. Pullini. *Current-induced domain wall depinning and magnetoresistance in $\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3$ planar spin valves*. *Applied Physics Letters* **91**, 132502 (2007).
- [90] J. Wang, S. Wu, J. Ma, L. Xie, C. Wang, I. A. Malik, Y. Zhang, K. Xia, C.-W. Nan, and J. Zhang. *Nanoscale control of stripe-ordered magnetic domain walls by vertical spin transfer torque in $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$ films*. *Applied Physics Letters* **112**, 072408 (2018).
- [91] T. Arnal, A. Khvalkovskii, M. Bibes, B. Mercey, P. Lecoeur, and A.-M. Haghiri-Gosnet. *Electronic properties of domain walls in $\text{La}_{2/3}\text{Sr}_{1/3}\text{MnO}_3$: magnetotransport measurements on a nanopatterned device*. *Physical Review B* **75**, 220409 (2007).
- [92] L. Marín, L. Morellón, P. A. Algarabel, L. A. Rodríguez, C. Magén, J. M. De Teresa, and M. R. Ibarra. *Enhanced magnetotransport in nanopatterned manganese nanowires*. *Nano Letters* **14**, 423–428 (2014).
- [93] M. Abuwasib, H. Lee, A. Gruverman, C.-B. Eom, and U. Singiseti. *Contact resistance to SrRuO_3 and $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$ epitaxial films*. *Applied Physics Letters* **107**, 242905 (2015).
- [94] Y. Wu, Y. Suzuki, U. Rüdiger, J. Yu, A. D. Kent, T. K. Nath, and C.-B. Eom. *Magnetotransport and magnetic domain structure in compressively strained colossal magnetoresistance films*. *Applied Physics Letters* **75**, 2295–2297 (1999).

- [95] N. Mathur, P. Littlewood, N. Todd, S. Isaac, B.-S. Teo, D.-J. Kang, E. Tarte, Z. Barber, J. Evetts, and M. Blamire. *Resistance of a domain wall in $\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3$* . Journal of Applied Physics **86**, 6287–6290 (1999).
- [96] M. Ziese. *Extrinsic magnetotransport phenomena in ferromagnetic oxides*. Reports on Progress in Physics **65**, 143 (2002).
- [97] S. R. Bakaul, W. Hu, T. Wu, and T. Kimura. *Intrinsic domain-wall resistivity in half-metallic manganite thin films*. Physical Review B **86**, 184404 (2012).
- [98] I. Žutić, J. Fabian, and S. Das Sarma. *Spintronics: fundamentals and applications*. Reviews of Modern Physics **76**, 323 (2004).
- [99] A. Hirohata, K. Yamada, Y. Nakatani, I.-L. Prejbeanu, B. Diény, P. Pirro, and B. Hillebrands. *Review on spintronics: principles and device applications*. Journal of Magnetism and Magnetic Materials **509**, 166711 (2020).
- [100] S. O. Valenzuela and M. Tinkham. *Direct electronic measurement of the spin Hall effect*. Nature **442**, 176–9 (2006).
- [101] G. E. W. Bauer, E. Saitoh, and B. J. van Wees. *Spin caloritronics*. Nature Materials **11**, 391 (2012).
- [102] D. Huertas-Hernando, Y. V. Nazarov, A. Brataas, and G. E. W. Bauer. *Conductance modulation by spin precession in noncollinear ferromagnet normal-metal ferromagnet systems*. Physical Review B **62**, 5700–5712 (2000).
- [103] F. J. Jedema, A. T. Filip, and B. J. van Wees. *Electrical spin injection and accumulation at room temperature in an all-metal mesoscopic spin valve*. Nature **410**, 345–348 (2001).
- [104] F. J. Jedema, H. B. Heersche, A. T. Filip, J. J. Baselmans, and B. J. van Wees. *Electrical detection of spin precession in a metallic mesoscopic spin valve*. Nature **416**, 713–6 (2002).
- [105] F. J. Jedema, M. V. Costache, H. B. Heersche, J. J. A. Baselmans, and B. J. van Wees. *Electrical detection of spin accumulation and spin precession at room temperature in metallic spin valves*. Applied Physics Letters **81**, 5162–5164 (2002).
- [106] M. Johnson and J. Byers. *Charge and spin diffusion in mesoscopic metal wires and at ferromagnet/nonmagnet interfaces*. Physical Review B **67**, 125112 (2003).
- [107] H. Idzuchi, Y. Fukuma, and Y. Otani. *Spin transport in non-magnetic nanostructures induced by non-local spin injection*. Physica E: Low-dimensional Systems and Nanostructures **68**, 239–263 (2015).
- [108] L. Berger. *Unified description of bulk and interface-enhanced spin pumping*. Physical Review Letters **96**, 077201 (2006).
- [109] Y. Tserkovnyak, A. Brataas, and G. E. W. Bauer. *Spin pumping and magnetization dynamics in metallic multilayers*. Physical Review B **66**, 224403 (2002).

- [110] S. M. Watts, J. Grollier, C. H. van der Wal, and B. J. van Wees. *Generation of dc voltages by a magnetic multilayer undergoing ferromagnetic resonance*. Physical Review B **59**, 11465 (1999).
- [111] M. V. Costache, M. Sladkov, S. M. Watts, C. H. van der Wal, and B. J. van Wees. *Electrical detection of spin pumping due to the precessing magnetization of a single ferromagnet*. Physical Review Letters **97**, 216603 (2006).
- [112] T. Kimura and Y. Otani. *Large spin accumulation in a permalloy-silver lateral spin valve*. Physical Review Letters **99**, 196604 (2007).
- [113] F. Rortais, C. Vergnaud, A. Marty, L. Vila, J. P. Attané, J. Widiez, C. Zucchetti, F. Bottegoni, H. Jaffrès, J. M. George, and M. Jamet. *Non-local electrical spin injection and detection in germanium at room temperature*. Applied Physics Letters **111**, 182401 (2017).
- [114] T. Kimura, J. Hamrle, and Y. Otani. *Estimation of spin-diffusion length from the magnitude of spin-current absorption: multiterminal ferromagnetic/nonferromagnetic hybrid structures*. Physical Review B **72**, 014461 (2005).
- [115] T. Maassen, I. J. Vera-Marun, M. H. D. Guimarães, and B. J. van Wees. *Contact-induced spin relaxation in Hanle spin precession measurements*. Physical Review B **86**, 235408 (2012).
- [116] Y. Fukuma, L. Wang, H. Idzuchi, S. Takahashi, S. Maekawa, and Y. Otani. *Giant enhancement of spin accumulation and long-distance spin precession in metallic lateral spin valves*. Nature materials **10**, 527–531 (2011).
- [117] O. M. van 't Erve, A. L. Friedman, C. H. Li, J. T. Robinson, J. Connell, L. J. Lauhon, and B. T. Jonker. *Spin transport and Hanle effect in silicon nanowires using graphene tunnel barriers*. Nature Communications **6**, 7541 (2015).
- [118] G. Schmidt, D. Ferrand, L. W. Molenkamp, A. T. Filip, and B. J. van Wees. *Fundamental obstacle for electrical spin injection from a ferromagnetic metal into a diffusive semiconductor*. Physical Review B **62**, R4790–R4793 (2000).
- [119] E. I. Rashba. *Theory of electrical spin injection: tunnel contacts as a solution of the conductivity mismatch problem*. Physical Review B **62**, R16267–R16270 (2000).
- [120] S. Takahashi and S. Maekawa. *Spin injection and detection in magnetic nanostructures*. Physical Review B **67**, 052409 (2003).
- [121] F. J. Jedema, M. S. Nijboer, A. T. Filip, and B. J. van Wees. *Spin injection and spin accumulation in all-metal mesoscopic spin valves*. Physical Review B **67**, 085319 (2003).
- [122] R. Godfrey and M. Johnson. *Spin injection in mesoscopic silver wires: experimental test of resistance mismatch*. Physical Review Letters **96**, 136601 (2006).
- [123] A. Fert and H. Jaffrès. *Conditions for efficient spin injection from a ferromagnetic metal into a semiconductor*. Physical Review B **64**, 184420 (2001).

- [124] Y. Lu, X. W. Li, G. Q. Gong, G. Xiao, A. Gupta, J. P. LeCoeur, J. Z. Sun, Y. Y. Wang, and V. P. Dravid. *Large magnetotunneling effect at low magnetic fields in micrometer-scale epitaxial $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$ tunnel junctions*. Physical Review B **54**, R8357 (1996).
- [125] V. Garcia, M. Bibes, Barthélémy, M. Bowen, E. Jacquet, J.-P. Contour, and A. Fert. *Temperature dependence of the interfacial spin polarization of $\text{La}_{2/3}\text{Sr}_{1/3}\text{MnO}_3$* . Physical Review B **69**, 052403 (2004).
- [126] G. Y. Luo, C. R. Chang, and J. G. Lin. *Influence of damping constant on inverse spin Hall voltage of $\text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_x/\text{platinum}$ bilayers*. Journal of Applied Physics **115**, 17C508 (2014).
- [127] G. Y. Luo, J. G. Lin, W.-C. Chiang, and C.-R. Chang. *Spin pump and probe in lanthanum strontium manganite/platinum bilayers*. Scientific Reports **7**, 6612 (2017).
- [128] W. Yan, L. C. Phillips, M. Barbone, S. J. Hamalainen, A. Lombardo, M. Ghidini, X. Moya, F. Maccherozzi, S. van Dijken, S. S. Dhesi, A. C. Ferrari, and N. D. Mathur. *Long spin diffusion length in few-layer graphene flakes*. Physical Review Letters **117**, 147201 (2016).
- [129] G. Mihajlovic, J. E. Pearson, S. D. Bader, and A. Hoffmann. *Surface spin flip probability of mesoscopic Ag wires*. Physical Review Letters **104**, 237202 (2010).
- [130] H. Idzuchi, Y. Fukuma, L. Wang, and Y. Otani. *Spin relaxation mechanism in silver nanowires covered with MgO protection layer*. Applied Physics Letters **101**, 022415 (2012).
- [131] Y. Cai, C. Qin, F. Kandaz, X. Shen, C. Zhou, M. Jia, Y. Luo, Y. Wu, and Y. Ji. *Quantifying spin relaxation in mesoscopic Cu channels via a multitude of nonlocal spin valves*. Physical Review B **100**, 144419 (2019).
- [132] M. Popinciuc, C. Józsa, P. J. Zomer, N. Tombros, A. Veligura, H. T. Jonkman, and B. J. van Wees. *Electronic spin transport in graphene field-effect transistors*. Physical Review B **80**, 214427 (2009).
- [133] X. Lou, C. Adelman, S. A. Crooker, E. S. Garlid, J. Zhang, K. S. M. Reddy, S. D. Flexner, C. J. Palmström, and P. A. Crowell. *Electrical detection of spin transport in lateral ferromagnet–semiconductor devices*. Nature Physics **3**, 197–202 (2007).
- [134] S. P. Dash, S. Sharma, R. S. Patel, M. P. de Jong, and R. Jansen. *Electrical creation of spin polarization in silicon at room temperature*. Nature **462**, 491–4 (2009).
- [135] C. Awo-Affouda, O. M. J. van 't Erve, G. Kioseoglou, A. T. Hanbicki, M. Holub, C. H. Li, and B. T. Jonker. *Contributions to Hanle lineshapes in Fe/GaAs nonlocal spin valve transport*. Applied Physics Letters **94**, 102511 (2009).
- [136] K.-R. Jeon, B.-C. Min, Y.-H. Park, S.-Y. Park, and S.-C. Shin. *Electrical investigation of the oblique Hanle effect in ferromagnet/oxide/semiconductor contacts*. Physical Review B **87**, 195311 (2013).

- [137] M. Abuwasib, H. Lee, A. Gruverman, C.-B. Eom, and U. Singisetti. *Contact resistance to SrRuO₃ and La_{0.67}Sr_{0.33}MnO₃ epitaxial films*. Applied Physics Letters **107**, 242905 (2015).
- [138] J. Bass and W. P. Pratt. *Spin-diffusion lengths in metals and alloys, and spin-flipping at metal/metal interfaces: an experimentalist's critical review*. Journal of Physics: Condensed Matter **19**, 183201 (2007).
- [139] T. Kimura, Y. Otani, T. Sato, S. Takahashi, and S. Maekawa. *Room-temperature reversible spin Hall effect*. Physical Review Letters **98**, 156601 (2007).
- [140] D. A. Abanin, A. V. Shytov, L. S. Levitov, and B. I. Halperin. *Nonlocal charge transport mediated by spin diffusion in the spin Hall effect regime*. Physical Review B **79**, 035304 (2009).
- [141] N. Mottaghi, M. S. Seehra, R. Trappen, S. Kumari, C.-Y. Huang, S. Yousefi, G. B. Cabrera, A. H. Romero, and M. B. Holcomb. *Insights into the magnetic dead layer in La_{0.7}Sr_{0.3}MnO₃ thin films from temperature, magnetic field and thickness dependence of their magnetization*. AIP Advances **8**, 056319 (2018).
- [142] H. Boschker, M. Huijben, A. Vailionis, J. Verbeeck, S. van Aert, M. Luysberg, S. Bals, G. van Tendeloo, E. P. Houwman, G. Koster, D. H. A. Blank, and G. Rijnders. *Optimized fabrication of high-quality La_{0.67}Sr_{0.33}MnO₃ thin films considering all essential characteristics*. Journal of Physics D: Applied Physics **44**, 205001 (2011).
- [143] X. Zou and G. Xiao. *Electronic transport and magnetoresistance in polycrystalline and epitaxial CrO₂ nanowires*. Physical Review B **77**, 054417 (2008).
- [144] S. Anwar and J. Aarts. *Anomalous transport in half-metallic ferromagnetic CrO₂*. Physical Review B **88**, 085123 (2013).
- [145] D. Fadil, S. Wu, P. Perna, B. Renault, M. Saïb, S. Lebargy, J. Gasnier, B. Guillet, J.-M. Routoure, S. Flament, et al. *Direct observation of magnetization reversal and low field magnetoresistance of epitaxial La_{0.7}Sr_{0.3}MnO₃/SrTiO₃(001) thin films at room temperature*. Journal of Applied Physics **112**, 013906 (2012).
- [146] I. A. Malik, H. Huang, Y. Wang, X. Wang, C. Xiao, Y. Sun, R. Ullah, Y. Zhang, J. Wang, M. A. Malik, et al. *Inhomogeneous-strain-induced magnetic vortex cluster in one-dimensional manganite wire*. Science bulletin **65**, 201–207 (2020).
- [147] G. Yang, C. Ciccirelli, and J. W. A. Robinson. *Boosting spintronics with superconductivity*. APL Mater. **9**, 050703 (2021).
- [148] C. Visani, Z. Sefrioui, J. Tornos, C. Leon, J. Briatico, M. Bibes, A. Barthélémy, J. Santamaría, and J. E. Villegas. *Equal-spin Andreev reflection and long-range coherent transport in high-temperature superconductor/half-metallic ferromagnet junctions*. Nature Physics **8**, 539–543 (2012).

- [149] R. S. Keizer, S. T. Gönnerwein, T. M. Klapwijk, G. Miao, G. Xiao, and A. Gupta. *A spin triplet supercurrent through the half-metallic ferromagnet CrO₂*. *Nature* **439**, 825–827 (2006).
- [150] M. Houzet and A. I. Buzdin. *Long range triplet Josephson effect through a ferromagnetic trilayer*. *Physical Review B* **76**, 060504 (2007).
- [151] T. S. Khaire, M. A. Khasawneh, J. Pratt W. P., and N. O. Birge. *Observation of spin-triplet superconductivity in Co-based Josephson junctions*. *Physical Review Letters* **104**, 137002 (2010).
- [152] J. W. Robinson, J. D. Witt, and M. G. Blamire. *Controlled injection of spin-triplet supercurrents into a strong ferromagnet*. *Science* **329**, 59–61 (2010).
- [153] M. S. Kalenkov, A. D. Zaikin, and V. T. Petrashov. *Triplet superconductivity in a ferromagnetic vortex*. *Physical Review Letters* **107**, 087003 (2011).
- [154] M. A. Silaev. *Possibility of a long-range proximity effect in a ferromagnetic nanoparticle*. *Physical Review B* **79**, 184505 (2009).
- [155] F. S. Bergeret, A. F. Volkov, and K. B. Efetov. *Long-range proximity effects in superconductor-ferromagnet structures*. *Physical Review Letters* **86**, 4096 (2001).
- [156] Y. V. Fominov, A. F. Volkov, and K. B. Efetov. *Josephson effect due to the long-range odd-frequency triplet superconductivity in SFS junctions with Néel domain walls*. *Physical Review B* **75**, 104509 (2007).
- [157] Y. Kalcheim, T. Kirzhner, G. Koren, and O. Millo. *Long-range proximity effect in La_{2/3}Ca_{1/3}MnO₃/(100)YBa₂Cu₃O_{7-δ} ferromagnet/superconductor bilayers: Evidence for induced triplet superconductivity in the ferromagnet*. *Physical Review B* **83**, 2–7 (2011).
- [158] E. Aikebaier, P. Virtanen, and T. Heikkilä. *Superconductivity near a magnetic domain wall*. *Physical Review B* **99**, 1–11 (2019).
- [159] Z. P. Niu. *A spin triplet supercurrent in half metal ferromagnet/superconductor junctions with the interfacial Rashba spin-orbit coupling*. *Applied Physics Letters* **101**, 062601 (2012).
- [160] F. S. Bergeret and I. V. Tokatly. *Singlet-triplet conversion and the long-range proximity effect in superconductor-ferromagnet structures with generic spin dependent fields*. *Physical Review Letters* **110**, 117003 (2013).
- [161] F. S. Bergeret and I. V. Tokatly. *Spin-orbit coupling as a source of long-range triplet proximity effect in superconductor-ferromagnet hybrid structures*. *Physical Review B* **89**, 134517 (2014).
- [162] M. Alidoust and K. Halterman. *Proximity induced vortices and long-range triplet supercurrents in ferromagnetic Josephson junctions and spin valves*. *Journal of Applied Physics* **117**, 123906 (2015).

- [163] S. H. Jacobsen, J. A. Ouassou, and J. Linder. *Critical temperature and tunneling spectroscopy of superconductor-ferromagnet hybrids with intrinsic Rashba-Dresselhaus spin-orbit coupling*. Physical Review B **92**, 024510 (2015).
- [164] B. Bujnowski, R. Biele, and F. S. Bergeret. *Switchable Josephson current in junctions with spin-orbit coupling*. Physical Review B **100**, 1–9 (2019).
- [165] J. R. Eskilt, M. Amundsen, N. Banerjee, and J. Linder. *Long-ranged triplet supercurrent in a single in-plane ferromagnet with spin-orbit coupled contacts to superconductors*. Physical Review B **100**, 224519 (2019).
- [166] M. A. Silaev, I. V. Bobkova, and A. M. Bobkov. *Odd triplet superconductivity induced by a moving condensate*. Physical Review B **102**, 100507 (2020).
- [167] M. Anwar and J. Aarts. *Inducing supercurrents in thin films of ferromagnetic CrO₂*. Superconductor Science and Technology **24**, 024016 (2011).
- [168] R. C. Dynes and T. A. Fulton. *Supercurrent density distribution in Josephson junctions*. Physical Review B **3**, 3015 (1971).
- [169] M. Eschrig and T. Löfwander. *Triplet supercurrents in clean and disordered half-metallic ferromagnets*. Nature Physics **4**, 138–143 (2008).
- [170] V. Ambegaokar and B. Halperin. *Voltage due to thermal noise in the dc Josephson effect*. Physical Review Letters **22**, 1364 (1969).
- [171] P. Dubos, H. Courtois, B. Pannetier, F. Wilhelm, A. Zaikin, and G. Schön. *Josephson critical current in a long mesoscopic S-N-S junction*. Physical Review B **63**, 064502 (2001).
- [172] B. Nadgorny, I. Mazin, M. Osofsky, R. Soulen Jr, P. Broussard, R. Stroud, D. Singh, V. Harris, A. Arsenov, and Y. Mukovskii. *Origin of high transport spin polarization in La_{0.7}Sr_{0.3}MnO₃: direct evidence for minority spin states*. Physical Review B **63**, 184433 (2001).
- [173] M. Eschrig, J. Kopu, J. C. Cuevas, and G. Schön. *Theory of half-metal/superconductor heterostructures*. Physical Review Letters **90**, 137003 (2003).
- [174] K. K. Likharev. *Superconducting weak links*. Review Modern Physics **51**, 101 (1979).
- [175] P. G. De Gennes. *Boundary effects in superconductors*. Review Modern Physics **36**, 225 (1964).
- [176] J. Chakhalian, J. W. Freeland, G. Srajer, J. Stremper, G. Khaliullin, J. C. Cezar, T. Charlton, R. Dalgliesh, C. Bernhard, G. Cristiani, H. U. Habermeier, and B. Keimer. *Magnetism at the interface between ferromagnetic and superconducting oxides*. Nature Physics **2**, 244–248 (2006).
- [177] L. Vasiliu-Doloc, J. W. Lynn, A. H. Moudden, A. M. d. Leon-Guevara, and A. Revcolevschi. *Structure and spin dynamics of La_{0.85}Sr_{0.15}MnO₃*. Physical Review B **58**, 14913 (1998).

- [178] A. Vansteenkiste, J. Leliaert, M. Dvornik, M. Helsen, F. Garcia-Sanchez, and B. Van Waeyenberge. *The design and verification of mumax3*. AIP advances **4**, 107133 (2014).
- [179] H. Boschker, M. Mathews, P. Brinks, E. Houwman, A. Vailionis, G. Koster, D. H. A. Blank, and G. Rijnders. *Uniaxial contribution to the magnetic anisotropy of $\text{La}_{0.67}\text{Sr}_{0.33}\text{MnO}_3$ thin films induced by orthorhombic crystal structure*. Journal of Magnetism and Magnetic Materials **323**, 2632–2638 (2011).
- [180] B. Börcsök, S. Komori, A. Buzdin, and J. Robinson. *Fraunhofer patterns in magnetic Josephson junctions with non-uniform magnetic susceptibility*. Scientific Reports **9**, 5616 (2019).
- [181] M. Anwar, F. Czeschka, M. Hesselberth, M. Porcu, and J. Aarts. *Long-range supercurrents through half-metallic ferromagnetic CrO_2* . Physical Review B **82**, 100501 (2010).
- [182] J. Bardeen, L. N. Cooper, and J. R. Schrieffer. *Theory of superconductivity*. Physical Review **108**, 1175 (1957).
- [183] S. Voltan, A. Singh, and J. Aarts. *Triplet generation and upper critical field in superconducting spin valves based on CrO_2* . Physical Review B **94**, 054503 (2016).
- [184] J. Chakhalian, J. Freeland, G. Srajer, J. Stremper, G. Khaliullin, J. Cezar, T. Charlton, R. Dalgliesh, C. Bernhard, G. Cristiani, et al. *Magnetism at the interface between ferromagnetic and superconducting oxides*. Nature Physics **2**, 244–248 (2006).
- [185] J. C. Cuevas and F. S. Bergeret. *Magnetic interference patterns and vortices in diffusive SNS junctions*. Physical Review Letters **99**, 217002 (2007).
- [186] A. Barone and G. Paterno. Physics and applications of the Josephson effect. Vol. 1 (Wiley Online Library, 1982).