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Magnetism and magnetization dynamics in thin film ferromagnets

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Bibliography

- [1] <http://www.mv.helsinki.fi/aphalo/photobio/lamps.html>.
- [2] N. Zheludev. The life and times of the led — a 100-year history. *Nat Photon* **1**, 189 (2007).
- [3] H. Round. A note on carborundum. *Electr. World* **49**, 309 (1907).
- [4] O. Lossev. Luminous carborundum detector and detection effect and oscillations with crystals. *Philosophical Magazine Series 7* **6**, 1024 (1928).
- [5] R. N. Hall, G. E. Fenner, J. D. Kingsley, T. J. Soltys and R. O. Carlson. Coherent light emission from GaAs junctions. *Phys. Rev. Lett.* **9**, 366 (1962).
- [6] M. I. Nathan, W. P. Dumke, G. Burns, J. F. H. Dill and G. Lasher. Stimulated emission of radiation from GaAs p-n junctions. *Applied Physics Letters* **1**, 62 (1962).
- [7] T. M. Quist, R. H. Rediker, R. J. Keyes, W. E. Krag, B. Lax, A. L. McWhorter and H. J. Zeigler. Semiconductor maser of GaAs. *Applied Physics Letters* **1**, 91 (1962).
- [8] J. N. Holonyak and S. F. Bevacqua. Coherent (visible) light emission from Ga(As_{1-x}P_x) junctions. *Applied Physics Letters* **1**, 82 (1962).
- [9] <http://en.wikipedia.org/wiki/File:PnJunction-LED-E.svg>.
- [10] http://upload.wikimedia.org/wikipedia/commons/0/09/Stimulated_-_Emission.svg.
- [11] M. Tonouchi. Cutting-edge terahertz technology. *Nat Photon* **1**, 97 (2007).
- [12] L. Berger. Emission of spin waves by a magnetic multilayer traversed by a current. *Phys. Rev. B* **54**, 9353 (1996).
- [13] J. Slonczewski. Current-driven excitation of magnetic multilayers. *Journal of Magnetism and Magnetic Materials* **159**, L1 (1996).
- [14] I. M. Miron, K. Garello, G. Gaudin, P.-J. Zermatten, M. V. Costache, S. Auffret, S. Bandiera, B. Rodmacq, A. Schuhl and P. Gambardella. Perpendicular switching of a single ferromagnetic layer induced by in-plane current injection. *Nature* **476**, 189 (2011).
- [15] J. E. Hirsch. Spin Hall effect. *Phys. Rev. Lett.* **83**, 1834 (1999).

- [16] K. Uchida, S. Takahashi, K. Harii, J. Ieda, W. Koshibae, K. Ando, S. Maekawa and E. Saitoh. Observation of the spin seebeck effect. *Nature* **455**, 778 (2008).
- [17] K. Uchida, H. Adachi, D. Kikuchi, S. Ito, Z. Qiu, S. Maekawa and E. Saitoh. Plasmonic generation of spin currents. *ArXiv e-prints* (2013). 1308.3532.
- [18] A. Kadigrobov, Z. Ivanov, T. Claeson, R. I. Shekhter and M. Jonson. Giant lasing effect in magnetic nanoconductors. *EPL (Europhysics Letters)* **67**, 948 (2004).
- [19] A. Kadigrobov, R. I. Shekhter and M. Jonson. Novel laser based on magnetic tunneling. *Low Temperature Physics* **31**, 352 (2005).
- [20] S. Blundell. *Magnetism in condensed matter*. Oxford University Press (2001).
- [21] R. O'Handley. *Modern magnetic materials*. John Wiley & Sons, Ltd (2000).
- [22] J. Kondo. Resistance minimum in dilute magnetic alloys. *Progress of Theoretical Physics* **32**, 37 (1964).
- [23] T. Jungwirth, J. Wunderlich and K. Olejnik. Spin Hall effect devices. *Nat Mater* **11**, 382 (2012).
- [24] W. Pauli. Zur quantenmechanik des magnetischen elektrons. *Zeitschrift fur Physik* **43**, 601 (1927).
- [25] S. Maekawa and S. Takahashi. *Spin Current*. Oxford University Press (2012).
- [26] S. Zhang. Spin Hall effect in the presence of spin diffusion. *Phys. Rev. Lett.* **85**, 393 (2000).
- [27] 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).
- [28] S. Murakami, N. Nagaosa and S.-C. Zhang. Dissipationless quantum spin current at room temperature. *Science* **301**, 1348 (2003).
- [29] M. N. Baibich, J. M. Broto, A. Fert, F. N. Van Dau, F. Petroff, P. Etienne, G. Creuzet, A. Friederich and J. Chazelas. Giant magnetoresistance of (001)Fe/(001)Cr magnetic superlattices. *Phys. Rev. Lett.* **61**, 2472 (1988).
- [30] G. Binasch, P. Grünberg, F. Saurenbach and W. Zinn. Enhanced magnetoresistance in layered magnetic structures with antiferromagnetic interlayer exchange. *Phys. Rev. B* **39**, 4828 (1989).
- [31] T. Valet and A. Fert. Theory of the perpendicular magnetoresistance in magnetic multilayers. *Phys. Rev. B* **48**, 7099 (1993).
- [32] A. Brataas, G. E. Bauer and P. J. Kelly. Non-collinear magnetoelectronics. *Physics Reports* **427**, 157 (2006).
- [33] A. Brataas, Y. V. Nazarov and G. E. W. Bauer. Finite-element theory of transport in ferromagnet-normal metal systems. *Phys. Rev. Lett.* **84**, 2481 (2000).

- [34] M. Zaffalon. *Spin Accumulation in Ferromagnetic/Normal and Ferromagnetic/Superconducting Systems*. Ph.D. thesis, Rijksuniversiteit Groningen (2006).
- [35] M. Tsoi, A. G. M. Jansen, J. Bass, W.-C. Chiang, M. Seck, V. Tsoi and P. Wyder. Excitation of a magnetic multilayer by an electric current. *Phys. Rev. Lett.* **80**, 4281 (1998).
- [36] E. Myers, D. Ralph, J. Katine, R. Louie and R. Buhrman. Current-induced switching of domains in magnetic multilayer devices. *Science* **285**, 867 (1999).
- [37] S. I. Kiselev, J. C. Sankey, I. N. Krivorotov, N. C. Emley, R. J. Schoelkopf, R. A. Buhrman and D. C. Ralph. Microwave oscillations of a nanomagnet driven by a spin-polarized current. *Nature* **425**, 380 (2003).
- [38] L. Landau and E. Lifshitz. On the theory of the dispersion of magnetic permeability in ferromagnetic bodies. *Physikalische Zeitschrift der Sowjetunion* **8**, 153 (1935).
- [39] T. L. Gilbert. A Lagrangian formulation of the gyromagnetic equation of the magnetization fields. *Phys. Rev.* **100**, 1243 (1955). The original reference in Physical Review is only an abstract for an APS Meeting. The full report was written published as "Armor Research Foundation Project No. A059, Supplementary Report, May 1, 1956".
- [40] T. Gilbert. A phenomenological theory of damping in ferromagnetic materials. *Magnetics, IEEE Transactions on* **40**, 3443 (2004).
- [41] B. Heinrich. Spin relaxation in magnetic metallic layers and multilayers. In J. Bland and B. Heinrich, editors, *Ultrathin Magnetic Structures III*, pages 143–210. Springer Berlin Heidelberg (2005).
- [42] S. M. Bhagat and P. Lubitz. Temperature variation of ferromagnetic relaxation in the 3d transition metals. *Phys. Rev. B* **10**, 179 (1974).
- [43] Y. Tserkovnyak, A. Brataas, G. E. W. Bauer and B. I. Halperin. Nonlocal magnetization dynamics in ferromagnetic heterostructures. *Rev. Mod. Phys.* **77**, 1375 (2005).
- [44] K. Xia, P. J. Kelly, G. E. W. Bauer, A. Brataas and I. Turek. Spin torques in ferromagnetic/normal-metal structures. *Phys. Rev. B* **65**, 220401 (2002).
- [45] D. Ralph and M. Stiles. Spin transfer torques. *Journal of Magnetism and Magnetic Materials* **320**, 1190 (2008).
- [46] V. Galitski and I. B. Spielman. Spin-orbit coupling in quantum gases. *Nature* **494**, 49 (2013).
- [47] H.-A. Engel, E. I. Rashba and B. I. Halperin. *Theory of Spin Hall Effects in Semiconductors*, chapter Theory of Spin Hall Effects in Semiconductors. John Wiley & Sons, Ltd (2007). ISBN 9780470022184.
- [48] E. van der Bijl and R. A. Duine. Current-induced torques in textured Rashba ferromagnets. *Phys. Rev. B* **86**, 094406 (2012).

- [49] A. Chernyshov, M. Overby, X. Liu, J. K. Furdyna, Y. Lyanda-Geller and L. P. Rokhinson. Evidence for reversible control of magnetization in a ferromagnetic material by means of spin-orbit magnetic field. *Nat Phys* **5**, 656 (2009).
- [50] M. Endo, F. Matsukura and H. Ohno. Current induced effective magnetic field and magnetization reversal in uniaxial anisotropy (Ga,Mn)As. *Applied Physics Letters* **97**, 222501 (2010).
- [51] H. Kurebayashi, J. Sinova, D. Fang, A. C. Irvine, J. Wunderlich, V. Novak, R. P. Campion, B. L. Gallagher, E. K. Vehstedt, L. P. Zarbo, K. Vyborny, A. J. Ferguson and T. Jungwirth. Observation of a Berry phase anti-damping spin-orbit torque. *ArXiv e-prints* (2013). 1306.1893.
- [52] X. Z. Yu, N. Kanazawa, Y. Onose, K. Kimoto, W. Z. Zhang, S. Ishiwata, Y. Matsui and Y. Tokura. Near room-temperature formation of a skyrmion crystal in thin-films of the helimagnet FeGe. *Nat Mater* **10**, 106 (2011).
- [53] F. Jonietz, S. Mühlbauer, C. Pfleiderer, A. Neubauer, W. Münzer, A. Bauer, T. Adams, R. Georgii, P. Böni, R. A. Duine, K. Everschor, M. Garst and A. Rosch. Spin transfer torques in MnSi at ultralow current densities. *Science* **330**, 1648 (2010).
- [54] I. M. Miron, T. Moore, H. Szambolics, L. D. Buda-Prejbeanu, S. Auffret, B. Rodmacq, S. Pizzini, J. Vogel, M. Bonfim, A. Schuhl and G. Gaudin. Fast current-induced domain-wall motion controlled by the Rashba effect. *Nat Mater* **10**, 419 (2011).
- [55] C. O. Avci, K. Garello, I. M. Miron, G. Gaudin, S. Auffret, O. Boulle and P. Gambardella. Magnetization switching of an MgO/Co/Pt layer by in-plane current injection. *Applied Physics Letters* **100**, 212404 (2012).
- [56] K.-W. Kim, S.-M. Seo, J. Ryu, K.-J. Lee and H.-W. Lee. Magnetization dynamics induced by in-plane currents in ultrathin magnetic nanostructures with Rashba spin-orbit coupling. *Phys. Rev. B* **85**, 180404 (2012).
- [57] L. Liu, C.-F. Pai, Y. Li, H. W. Tseng, D. C. Ralph and R. A. Buhrman. Spin-torque switching with the giant spin Hall effect of tantalum. *Science* **336**, 555 (2012).
- [58] K. Ando, S. Takahashi, K. Harii, K. Sasage, J. Ieda, S. Maekawa and E. Saitoh. Electric manipulation of spin relaxation using the spin Hall effect. *Phys. Rev. Lett.* **101**, 036601 (2008).
- [59] J. Kim, J. Sinha, M. Hayashi, M. Yamanouchi, S. Fukami, T. Suzuki, S. Mitani and H. Ohno. Layer thickness dependence of the current-induced effective field vector in Ta|CoFeB|MgO. *Nat Mater* **12**, 240 (2013).
- [60] C. Kittel. *Introduction to solid state physics, 7th edition*. John Wiley & Sons, Ltd (1996).
- [61] M. D'Yakonov and V. Perel'. Current-induced spin orientation of electrons in semiconductors. *Physics Letters A* **35**, 459 (1971).
- [62] M. I. D'Yakonov and V. I. Perel'. Possibility of orienting electron spins with current. *Soviet Journal of Experimental and Theoretical Physics Letters* **13**, 467 (1971).

- [63] Y. Niimi, M. Morota, D. H. Wei, C. Deranlot, M. Basletic, A. Hamzic, A. Fert and Y. Otani. Extrinsic spin Hall effect induced by iridium impurities in copper. *Phys. Rev. Lett.* **106**, 126601 (2011).
- [64] Y. Niimi, Y. Kawanishi, D. H. Wei, C. Deranlot, H. X. Yang, M. Chshiev, T. Valet, A. Fert and Y. Otani. Giant spin Hall effect induced by skew scattering from bismuth impurities inside thin film CuBi alloys. *Phys. Rev. Lett.* **109**, 156602 (2012).
- [65] C.-F. Pai, L. Liu, Y. Li, H. W. Tseng, D. C. Ralph and R. A. Buhrman. Spin transfer torque devices utilizing the giant spin Hall effect of tungsten. *Applied Physics Letters* **101**, 122404 (2012).
- [66] X. Wang, J. Xiao, A. Manchon and S. Maekawa. Spin-Hall conductivity and electric polarization in metallic thin films. *Phys. Rev. B* **87**, 081407 (2013).
- [67] Y. Tserkovnyak, A. Brataas and G. E. W. Bauer. Enhanced Gilbert damping in thin ferromagnetic films. *Phys. Rev. Lett.* **88**, 117601 (2002).
- [68] B. Heinrich, D. Fraitová and V. Kamberský. The influence of s-d exchange on relaxation of magnons in metals. *physica status solidi (b)* **23**, 501 (1967).
- [69] M. Fähnle and C. Illg. Electron theory of fast and ultrafast dissipative magnetization dynamics. *Journal of Physics: Condensed Matter* **23**, 493201 (2011).
- [70] F. D. Czeschka. *Spin Currents in Metallic Nanostructures*. Ph.D. thesis, Walther-Meißner-Institut für Tieftemperaturforschung der Bayerischen Akademie der Wissenschaften (2011).
- [71] N. Viglin, V. Ustinov and V. Osipov. Spin injection maser. *JETP Letters* **86**, 193 (2007).
- [72] M. Holub and P. Bhattacharya. Spin-polarized light-emitting diodes and lasers. *Journal of Physics D: Applied Physics* **40**, R179 (2007).
- [73] S. M. Watts and B. J. van Wees. A solid state paramagnetic maser device driven by electron spin injection. *Phys. Rev. Lett.* **97**, 116601 (2006).
- [74] Y. G. Naidyuk, O. P. Balkashin, V. V. Fisun, I. K. Yanson, A. Kadigrobov, R. I. Shekhter, M. Jonson, V. Neu, M. Seifert, S. Andersson and V. Korenivski. Stimulated emission and absorption of photons in magnetic point contacts. *New Journal of Physics* **14**, 093021 (2012).
- [75] L. Berger. Generation of dc voltages by a magnetic multilayer undergoing ferromagnetic resonance. *Phys. Rev. B* **59**, 11465 (1999).
- [76] Y. V. Sharvin. A possible method for studying Fermi surfaces. *Sov. Phys.-JETP* **21**, 655 (1965). [*Zh. Eksp. Teor. Fiz.* **48**, 984-985 (1965)].
- [77] G. Deutscher. Andreev-Saint-James reflections: A probe of cuprate superconductors. *Rev. Mod. Phys.* **77**, 109 (2005).
- [78] D. Daghero and R. S. Gonnelli. Probing multiband superconductivity by point-contact spectroscopy. *Superconductor Science and Technology* **23**, 043001 (2010).

- [79] R. J. Soulen, J. M. Byers, M. S. Osofsky, B. Nadgorny, T. Ambrose, S. F. Cheng, P. R. Broussard, C. T. Tanaka, J. Nowak, J. S. Moodera, A. Barry and J. M. D. Coey. Measuring the spin polarization of a metal with a superconducting point contact. *Science* **282**, 85 (1998).
- [80] M. A. Reed, C. Zhou, C. J. Muller, T. P. Burgin and J. M. Tour. Conductance of a molecular junction. *Science* **278**, 252 (1997).
- [81] I. K. Yanson, Y. G. Naidyuk, D. L. Bashlakov, V. V. Fisun, O. P. Balkashin, V. Korovin, A. Kononenko and R. I. Shekhter. Spectroscopy of phonons and spin torques in magnetic point contacts. *Phys. Rev. Lett.* **95**, 186602 (2005).
- [82] J. R. Tucker and M. J. Feldman. Quantum detection at millimeter wavelengths. *Rev. Mod. Phys.* **57**, 1055 (1985).
- [83] I. K. Yanson. Nonlinear effects in the electric conductivity of point junctions and electron-phonon interaction in normal metals. *Zh. Eksp. Teor. Fiz.* **66**, 1035 (1974). [*Sov. Phys.-JETP* 39 (1974) 506–513].
- [84] A. G. M. Jansen, F. M. Mueller and P. Wyder. *Superconductivity in d- and f-band metals*. Plenum, New York (1976).
- [85] Y. J. Song, A. F. Otte, V. Shvarts, Z. Zhao, Y. Kuk, S. R. Blankenship, A. Band, F. M. Hess and J. A. Stroscio. Invited review article: A 10 mK scanning probe microscopy facility. *Review of Scientific Instruments* **81**, 121101 (2010).
- [86] K. Besocke. An easily operable scanning tunneling microscope. *Surface Science* **181**, 145 (1987).
- [87] J. Frohn, J. F. Wolf, K. Besocke and M. Teske. Coarse tip distance adjustment and positioner for a scanning tunneling microscope. *Review of Scientific Instruments* **60**, 1200 (1989).
- [88] S. H. Pan, E. W. Hudson and J. C. Davis. ^3He refrigerator based very low temperature scanning tunneling microscope. *Review of Scientific Instruments* **70**, 1459 (1999).
- [89] attocube systems AG. www.attocube.com.
- [90] Y. Uehara, T. Fujita, M. Iwami and S. Ushioda. Superconducting niobium tip for scanning tunneling microscope light emission spectroscopy. *Review of Scientific Instruments* **72**, 2097 (2001).
- [91] A. F. Otte. *Magnetism of a single atom*. Ph.D. thesis, Leiden University (2008).
- [92] Y. G. Naidyuk and I. K. Yanson. *Point-Contact Spectroscopy*. Springer (2005).
- [93] F. J. Cadieu. Selectively thermalized sputtering for the deposition of magnetic films with special anisotropies. *Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films* **6**, 1668 (1988).
- [94] V. Neu and S. A. Shaheen. Sputtered Sm–Co films: Microstructure and magnetic properties. *Journal of Applied Physics* **86**, 7006 (1999).

- [95] R. Andreescu and M. J. O'Shea. Temperature dependence of coercivity and magnetic reversal in SmCo_x thin films. *Journal of Applied Physics* **97**, 10F302 (2005).
- [96] T. Speliotis and D. Niarchos. Microstructure and magnetic properties of SmCo films. *J. Magn. Magn. Mater.* **290-291**, Part 2, 1195 (2005). Proceedings of the Joint European Magnetic Symposia (JEMS' 04).
- [97] E. E. Fullerton, C. H. Sowers, J. P. Pearson, S. D. Bader, X. Z. Wu and D. Lederman. A general approach to the epitaxial growth of rare-earth-transition-metal films. *Appl. Phys. Lett.* **69**, 2438 (1996).
- [98] L. Zhang, J. Hu, J. Chen and J. Ding. Nanostructured SmCo_5 thin films with perpendicular anisotropy formed in a wide range of SmCo compositions. *Journal of Nanoscience and Nanotechnology* **11**, 2644 (2011).
- [99] L. N. Zhang, J. S. Chen, J. Ding and J. F. Hu. High-coercivity SmCo_5 thin films deposited on glass substrates. *J. Appl. Phys.* **103**, 113908 (2008).
- [100] Periodic report 3 : Fp7-fet-open : Stele : August 2012.
- [101] K. Buschow. Rare earth compounds. In E. Wohlfarth, editor, *Handbook of Ferromagnetic Materials*, volume Volume 1, pages 297–414. Elsevier (1980).
- [102] K. Strnat. Rare earth-cobalt permanent magnets. In E. Wohlfarth and K. Buschow, editors, *Handbook of Ferromagnetic Materials*, volume Volume 4, pages 131–209. Elsevier (1988).
- [103] K. Kumar. RETM_5 and $\text{RE}_2\text{TM}_{17}$ permanent magnets development. *Journal of Applied Physics* **63**, R13 (1988).
- [104] K. Buschow and A. Van Der Goot. Intermetallic compounds in the system samarium-cobalt. *Journal of the Less Common Metals* **14**, 323 (1968).
- [105] Y. Khan. A contribution to the Sm-Co phase diagram. *Acta Crystallographica Section B* **30**, 861 (1974).
- [106] H. Okamoto. Co-Sm (cobalt-samarium). *Journal of Phase Equilibria* **20**, 535 (1999).
- [107] U. Varetto. Molekel 5.4.0. Swiss National Supercomputing Centre, Lugano (Switzerland).
- [108] Y. Khan. Variation of period with valence electron concentration in RT_y one-dimensional long-period superstructures. *physica status solidi (a)* **23**, 425 (1974).
- [109] M. Q. Huang, W. E. Wallace, M. McHenry, Q. Chen and B. M. Ma. Structure and magnetic properties of $\text{SmCo}_{7-x}\text{Zr}_x$ alloys ($x = 0-0.8$). *Journal of Applied Physics* **83**, 6718 (1998).
- [110] K. Strnat. The hard-magnetic properties of rare earth-transition metal alloys. *Magnetics, IEEE Transactions on* **8**, 511 (1972).
- [111] A. Singh, R. Tamm, V. Neu, S. Fahler, C.-G. Oertel, W. Skrotzki, L. Schultz and B. Holzapfel. Epitaxial growth of highly coercive Sm-Co thin films using pulsed laser deposition. *Journal of Applied Physics* **97**, 093902 (2005).

- [112] A. Singh, V. Neu, R. Tamm, K. Rao, S. Faehler, W. Skrotzki, L. Schultz and B. Holzapfel. Pulsed laser deposited epitaxial Sm–Co thin films with uniaxial magnetic texture. *Journal of Applied Physics* **99**, 08E917 (2006).
- [113] Y. D. Yao, Y. Liou, J. C. A. Huang, S. Y. Liao, I. Klik, W. T. Yang, C. P. Chang and C. K. Lo. Enhancement of magnetoresistance in Co(1100)/Cr(211) bilayered films on MgO(110). *Journal of Applied Physics* **79**, 6533 (1996).
- [114] A. Singh, V. Neu, R. Tamm, K. S. Rao, S. Fähler, W. Skrotzki, L. Schultz and B. Holzapfel. Growth of epitaxial SmCo₅ films on Cr/MgO(100). *Appl. Phys. Lett.* **87**, 072505 (2005).
- [115] A. Singh, V. Neu, S. Fähler, L. Schultz and B. Holzapfel. Effect of composition on phase formation and magnetic properties of highly coercive Sm-Co films. *Journal of Magnetism and Magnetic Materials* **290-291**, Part 2, 1259 (2005). Proceedings of the Joint European Magnetic Symposia (JEMS' 04).
- [116] R. Tamm, K. S. Rao, S. Fähler, V. Neu, A. Singh, C.-G. Oertel, L. Schultz, B. Holzapfel and W. Skrotzki. Texture formation in epitaxial hard magnetic Sm₂Co₇ thin films. *Phys. Status Solidi A* **207**, 106 (2010).
- [117] F. J. Cadieu, R. Rani, T. Theodoropoulos and L. Chen. Fully in plane aligned SmCo based films prepared by pulsed laser deposition. *Journal of Applied Physics* **85**, 5895 (1999).
- [118] G. Zangari, B. Lu, D. E. Laughlin and D. N. Lambeth. Structure and magnetic properties of SmCo thin films on Cr/Ag/Si templates. *Journal of Applied Physics* **85**, 5759 (1999).
- [119] L. Peng, H. Zhang, Q. Yang, Y. Li, Y. Song and J. Shen. Correlation between sputtering parameters and composition of SmCo-based films for microelectromechanical system applications. *Journal of Applied Physics* **105**, 063915 (2009).
- [120] J. Wang, M. Ghantasala and R. McLean. Bias sputtering effect on ultra-thin SmCo₅ films exhibiting large perpendicular coercivity. *Thin Solid Films* **517**, 656 (2008).
- [121] G. Xue, L. Peng and H. Zhang. Effect of sputtering parameters on film composition, crystal structure, and coercivity of SmCo based films deposited on Si (100) substrates. *Chinese Physics Letters* **27**, 017501 (2010).
- [122] F. J. Cadieu, H. Hegde and K. Chen. High-energy product Sm-Co-based sputtered films, crystal texturing, and magnetic properties. *Journal of Applied Physics* **67**, 4969 (1990).
- [123] A. Singh, V. Neu, S. Fähler, K. Nenkov, L. Schultz and B. Holzapfel. Mechanisms of coercivity in epitaxial smco₅ thin films. *Phys. Rev. B* **77**, 104443 (2008).
- [124] E. E. Fullerton, J. S. Jiang, C. Rehm, C. H. Sowers, S. D. Bader, J. B. Patel and X. Z. Wu. A general approach to the epitaxial growth of rare-earth-transition-metal films. *Appl. Phys. Lett.* **69**, 2438 (1996).
- [125] B. L. Gordon and M. S. Seehra. Magnetic susceptibility of Mn²⁺ ions in MgO and evidence of clustering. *Phys. Rev. B* **40**, 2348 (1989).

- [126] J. van Wieringen and J. Rensen. Influence of lattice imperfections on the paramagnetic resonance of V^{2+} and Cr^{3+} in MgO. In W. Low, editor, *Paramagnetic resonance vol 1*, pages 105–112. Academic Press New York (1963).
- [127] M. Bartashevich, A. Andreev, E. Tarasov, T. Goto and M. Yamaguchi. Magnetic properties and spontaneous magnetostriction of a Sm_2Co_7 single crystal. *Physica B* **183**, 369 (1993).
- [128] C. H. Chen, S. J. Knutson, Y. Shen, R. A. Wheeler, J. C. Horwath and P. N. Barnes. The effect of particle size on coercivity and crystallinity of $SmCo_5$. *Applied Physics Letters* **99**, 012504 (2011).
- [129] L. Zhang, J. Hu, J. Chen and J. Ding. Microstructure and magnetic properties studies of $SmCo_5$ thin films grown on MgO and glass substrates. *Journal of Magnetism and Magnetic Materials* **321**, 2643 (2009).
- [130] S. Prucnal, A. Shalimov, M. Ozerov, K. Potzger and W. Skorupa. Magnetic and optical properties of virgin arc furnace grown MgO crystals. *J. Cryst. Growth* **339**, 70 (2012).
- [131] K. Baberschke. *Handbook of Magnetism and Advanced Magnetic Materials*, chapter Investigation of Ultrathin Ferromagnetic Films by Magnetic Resonance. John Wiley & Sons, Ltd (2007). ISBN 9780470022184.
- [132] M. Farle. Ferromagnetic resonance of ultrathin metallic layers. *Reports on Progress in Physics* **61**, 755 (1998).
- [133] J. Smit and H. G. Beljers. Ferromagnetic resonance absorption in $BaFe_{12}O_{10}$, a highly anisotropic crystal. *Philips Res. Rep.* **10**, 113 (1955).
- [134] H. Suhl. Ferromagnetic resonance in nickel ferrite between one and two kilomegacycles. *Phys. Rev.* **97**, 555 (1955).
- [135] J. Dubowik, K. Załęski, H. Głowiński and I. Gościańska. Angular dependence of ferromagnetic resonance linewidth in thin films. *Phys. Rev. B* **84**, 184438 (2011).
- [136] C. Chappert, K. L. Dang, P. Beauvillain, H. Hurdequint and D. Renard. Ferromagnetic resonance studies of very thin cobalt films on a gold substrate. *Phys. Rev. B* **34**, 3192 (1986).
- [137] W. Platow, A. N. Anisimov, G. L. Dunifer, M. Farle and K. Baberschke. Correlations between ferromagnetic-resonance linewidths and sample quality in the study of metallic ultrathin films. *Phys. Rev. B* **58**, 5611 (1998).
- [138] B. Heinrich, R. Urban and G. Woltersdorf. Magnetic relaxation in metallic films: Single and multilayer structures. *Journal of Applied Physics* **91**, 7523 (2002).
- [139] S. M. Bhagat and L. L. Hirst. Ferromagnetic resonance in nickel at low temperatures. *Phys. Rev.* **151**, 401 (1966).
- [140] S. M. Bhagat, J. R. Anderson and L. L. Hirst. Ferromagnetic resonance in pure iron at low temperatures. *Phys. Rev. Lett.* **16**, 1099 (1966).

- [141] J. N. Lloyd and S. Bhagat. Ferromagnetic resonance linewidths in Ni-Cu alloys. *Solid State Communications* **8**, 2029 (1970).
- [142] B. Heinrich, D. J. Meredith and J. F. Cochran. Wave number and temperature dependent landau-lifshitz damping in nickel. *Journal of Applied Physics* **50**, 7726 (1979).
- [143] S. Yakata, Y. Ando, T. Miyazaki and S. Mizukami. Temperature dependences of spin-diffusion lengths of Cu and Ru layers. *Japanese Journal of Applied Physics* **45**, 3892 (2006).
- [144] J. Kuneš and V. Kamberský. First-principles investigation of the damping of fast magnetization precession in ferromagnetic 3d metals. *Phys. Rev. B* **65**, 212411 (2002).
- [145] V. Kamberský. Spin-orbital Gilbert damping in common magnetic metals. *Phys. Rev. B* **76**, 134416 (2007).
- [146] K. Gilmore. *Precession damping in itinerant ferromagnets*. Ph.D. thesis, Montana state university (2007).
- [147] K. Gilmore, M. D. Stiles, J. Seib, D. Steiauf and M. Fähnle. Anisotropic damping of the magnetization dynamics in ni, co, and fe. *Phys. Rev. B* **81**, 174414 (2010).
- [148] K. Gilmore, Y. U. Idzerda and M. D. Stiles. Identification of the dominant precession-damping mechanism in Fe, Co, and Ni by first-principles calculations. *Phys. Rev. Lett.* **99**, 027204 (2007).
- [149] J. Lindner, I. Barsukov, C. Raeder, C. Hassel, O. Posth, R. Meckenstock, P. Landeros and D. L. Mills. Two-magnon damping in thin films in case of canted magnetization: Theory versus experiment. *Phys. Rev. B* **80**, 224421 (2009).
- [150] C. P. Poole and H. A. Farach. *The theory of magnetic resonance*. Wiley-Interscience (New York) (1972).
- [151] C. Kittel. On the gyromagnetic ratio and spectroscopic splitting factor of ferromagnetic substances. *Phys. Rev.* **76**, 743 (1949).
- [152] Z. Zhang, P. E. Wigen and S. S. P. Parkin. Pt layer thickness dependence of magnetic properties in Co/Pt multilayers. *Journal of Applied Physics* **69**, 5649 (1991).
- [153] S. Mizukami, Y. Ando and T. Miyazaki. The study on ferromagnetic resonance linewidth for NM/80NiFe/NM (NM = Cu, Ta, Pd and Pt) films. *Japanese Journal of Applied Physics* **40**, 580 (2001).
- [154] O. Mosendz, J. E. Pearson, F. Y. Fradin, G. E. W. Bauer, S. D. Bader and A. Hoffmann. Quantifying spin hall angles from spin pumping: Experiments and theory. *Phys. Rev. Lett.* **104**, 046601 (2010).
- [155] K. Ando, Y. Kajiwara, S. Takahashi, S. Maekawa, K. Takemoto, M. Takatsu and E. Saitoh. Angular dependence of inverse spin-Hall effect induced by spin pumping investigated in a Ni₈₁Fe₁₉/Pt thin film. *Phys. Rev. B* **78**, 014413 (2008).
- [156] H. Jiao and G. E. W. Bauer. Spin backflow and ac voltage generation by spin pumping and the inverse spin Hall effect. *Phys. Rev. Lett.* **110**, 217602 (2013).

- [157] L. Liu, R. A. Buhrman and D. C. Ralph. Review and analysis of measurements of the spin Hall effect in platinum. *ArXiv e-prints* (2011). 1111.3702.
- [158] M. T. Johnson, P. J. H. Bloemen, F. J. A. den Broeder and J. J. de Vries. Magnetic anisotropy in metallic multilayers. *Reports on Progress in Physics* **59**, 1409 (1996).
- [159] D. Bastian and E. Biller. Damping of ferromagnetic resonance in Ni-Fe alloys. *Physica status solidi (a)* **35**, 113 (1976).
- [160] C. Vittoria, S. D. Yoon and A. Widom. Relaxation mechanism for ordered magnetic materials. *Phys. Rev. B* **81**, 014412 (2010).
- [161] K. Fuchs and N. F. Mott. The conductivity of thin metallic films according to the electron theory of metals. *Proceedings of the Cambridge Philosophical Society* **34**, 100 (1938).
- [162] E. H. Sondheimer. The mean free path of electrons in metals. *Advances in Physics* **1**, 1 (1952).
- [163] J. Geissler, E. Goering, M. Justen, F. Weigand, G. Schütz, J. Langer, D. Schmitz, H. Maletta and R. Mattheis. Pt magnetization profile in a Pt/Co bilayer studied by resonant magnetic x-ray reflectometry. *Phys. Rev. B* **65**, 020405 (2001).
- [164] N. Nakajima, T. Koide, T. Shidara, H. Miyauchi, H. Fukutani, A. Fujimori, K. Iio, T. Katayama, M. Nývlt and Y. Suzuki. Perpendicular magnetic anisotropy caused by interfacial hybridization via enhanced orbital moment in Co/Pt multilayers: Magnetic circular X-ray dichroism study. *Phys. Rev. Lett.* **81**, 5229 (1998).
- [165] Z. S. Shan, J. X. Shen, R. D. Kirby, D. J. Sellmyer and Y. J. Wang. Temperature-dependent interface magnetism and magnetization reversal in Co/Pt multilayers. *Journal of Applied Physics* **75**, 6418 (1994).
- [166] A. A. Abrikosov and L. P. Gor'kov. *Zh. Eksp. Teor. Fiz.* **39**, 1781 (1960). [*Sov. Phys. JETP* **12** (1961) 1243].
- [167] C. H. Marrows and B. J. Hickey. Impurity scattering from δ -layers in giant magnetoresistance systems. *Phys. Rev. B* **63**, 220405 (2001).
- [168] J.-G. Zhu, V. Sokalski, Y. Wang and D. Laughlin. Noise mechanisms in small grain size perpendicular thin film media. *Magnetics, IEEE Transactions on* **47**, 74 (2011).
- [169] K. Garello, I. M. Miron, C. O. Avci, F. Freimuth, Y. Mokrousov, S. Blugel, S. Auffret, O. Boulle, G. Gaudin and P. Gambardella. Symmetry and magnitude of spin-orbit torques in ferromagnetic heterostructures. *Nat Nano* **8**, 587 (2013).
- [170] A. D. Caviglia, M. Gabay, S. Gariglio, N. Reyren, C. Cancellieri and J.-M. Triscone. Tunable Rashba spin-orbit interaction at oxide interfaces. *Phys. Rev. Lett.* **104**, 126803 (2010).
- [171] S. Monso, B. Rodmacq, S. Auffret, G. Casali, F. Fettar, B. Gilles, B. Dieny and P. Boyer. Crossover from in-plane to perpendicular anisotropy in Pt/CoFe/AlO_x sandwiches as a function of Al oxidation: A very accurate control of the oxidation of tunnel barriers. *Applied Physics Letters* **80**, 4157 (2002).

- [172] B. Rodmacq, S. Auffret, B. Dieny, S. Monso and P. Boyer. Crossovers from in-plane to perpendicular anisotropy in magnetic tunnel junctions as a function of the barrier degree of oxidation. *Journal of Applied Physics* **93**, 7513 (2003).
- [173] H. X. Yang, M. Chshiev, B. Dieny, J. H. Lee, A. Manchon and K. H. Shin. First-principles investigation of the very large perpendicular magnetic anisotropy at Fe|MgO and Co|MgO interfaces. *Phys. Rev. B* **84**, 054401 (2011).
- [174] M. Hayashi. Analytical expression for the harmonic Hall voltages in evaluating spin orbit torques. *ArXiv e-prints* (2013). 1307.5603.
- [175] K. Okamoto. A new method for analysis of magnetic anisotropy in films using the spontaneous Hall effect. *Journal of Magnetism and Magnetic Materials* **35**, 353 (1983).
- [176] U. H. Pi, K. W. Kim, J. Y. Bae, S. C. Lee, Y. J. Cho, K. S. Kim and S. Seo. Tilting of the spin orientation induced by Rashba effect in ferromagnetic metal layer. *Applied Physics Letters* **97**, 162507 (2010).
- [177] S. Emori, U. Bauer, S.-M. Ahn, E. Martinez and G. S. D. Beach. Current-driven dynamics of chiral ferromagnetic domain walls. *Nat Mater* **12**, 611 (2013).
- [178] K.-S. Ryu, L. Thomas, S.-H. Yang and S. Parkin. Chiral spin torque at magnetic domain walls. *Nat Nano* **8**, 527 (2013).
- [179] J.-H. Moon, S.-M. Seo, K.-J. Lee, K.-W. Kim, J. Ryu, H.-W. Lee, R. D. McMichael and M. D. Stiles. Spin-wave propagation in the presence of interfacial Dzyaloshinskii-Moriya interaction. *ArXiv e-prints* (2013). 1308.3341.
- [180] D. Cortés-Ortuño and P. Landeros. Influence of the Dzyaloshinskii-Moriya interaction on the spin-wave spectra of thin films. *Journal of Physics: Condensed Matter* **25**, 156001 (2013).
- [181] K. An, D. R. Birt, C.-F. Pai, K. Olsson, D. C. Ralph, R. A. Buhrman and X. Li. Control of propagating spin waves via spin transfer torque in a metallic bilayer waveguide. *ArXiv e-prints* (2013). 1308.6357.