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Dynamics of Domain Walls in the Antiferromagnetic Phase of Dysprosium: a Brief Review

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Abstract. This paper gives a brief review on the dynamics of domain walls in antiferromagnetic dysprosium. We present an analysis of experimental studies on the nature of thermal hysteresis during cooling to the ferromagnetic phase and subsequent heating from it, scaling laws of hysteresis loops, nonequilibrium state of domain walls and relaxation processes in antiferromagnetic phase of dysprosium.

REFERENCES

[1] E.K.H. Salje, *Multiferroic domain boundaries as active memory devices: Trajectories towards domain boundary engineering*, ChemPhysChem, 2010, vol. 11, no. 5, pp. 940–950.
[2] Y. Kim, M. Alexe and E.K.H. Salje, *Nanoscale properties of thin twin walls and surface layers in piezoelectric WO_{3-x}*, Appl. Phys. Lett., 2010, vol. 96, no. 3, 032904.
[3] T. Lottermoser and M. Fiebig, *Magnetoelectric behavior of domain walls in multiferroic $HoMnO_3$*, Phys. Rev. B, 2004, vol. 70, 220407(R).
[4] P. Chaudhary, H. Lu, A. Lipatov, Z. Ahmadi, J. Mcconville, A. Sokolov, J. Shield, A. Sinitskii, J.M. Gregg, and A. Gruverman, *Low-Voltage Domain-Wall $LiNbO_3$ Memristors*, Nanoletters, 2020, XXXX, XXX, XXX-XXX.
[5] E.K.H. Salje and K.A. Dahmen, *Crackling Noise in Disordered Materials*, Annu. Rev. Condens. Matter Phys., 2014, vol 5, pp. 233–254.
[6] A. Fukuda Y. Takanishi, T. Isozaki, K. Ishikawa and H. Takezoe, *Antiferroelectric chiral smectic liquid crystals*, J. Mater. Chem., 1994, vol. 4, pp. 997–1016.
[7] B.G. Park, J. Wunderlich, X. Martí, V. Holý, Y. Kurosaki, M. Yamada, H. Yamamoto, A. Nishide, J. Hayakawa, H. Takahashi, A.B. Shick and T. Jungwirth, *A spin-valve-like magnetoresistance of an antiferromagnet-based tunnel junction*, Natur. Mater., 2011, vol. 10, pp. 347–351.
[8] P. Wadley, B. Howells, J. Zelezny, C. Andrews, V. Hills, R.P. Campion, V. Novak, F. Freimuth, Y. Mokrousov, A.W. Rushforth, K.W. Edmonds, B.L. Gallagher and T. Jungwirth, *Electrical switching of an antiferromagnet*, Science, 2016, vol. 351, no. 6272, pp. 587–590.
[9] O. Gomonay, T. Jungwirth and J. Sinova, *High Antiferromagnetic Domain Wall Velocity Induced by Néel Spin-Orbit Torques*, Phys. Rev. Lett., 2016, vol. 117, 017202.

[10] T. Jungwirth, J. Sinova, A. Manchon, X. Marti, J. Wunderlich and C. Felser, *The multiple directions of antiferromagnetic spintronics*, Nature Phys., 2018, vol. 14, pp. 200–203.
[11] R. Duine, *Spintronics: an alternating alternative*, Nature Mater., 2011, vol. 10, pp. 344–345.
[12] D.D. Viehland and E.K.H. Salje, *Domain boundary-dominated systems: adaptive structures and functional twin boundaries, Adv. Phys.*, 2014, vol. 63, no. 4, pp. 267–326.
[13] E.G. Tveten, T. Müller, J. Linder and A. Brataas, *Intrinsic magnetization of antiferromagnetic textures*, Phys. Rev. B, 2016, vol. 93, 104408.
[14] A.V. Andrianov, A.N. Vasil'ev and Y.P. Gaidukov, *Low temperature magnetic phase diagrams of dysprosium and gadolinium*, Physica B, 1991, vol. 169, no. 1-4, pp. 469–470.
[15] A.V. Andrianov, Y.P. Gaidukov, A.N. Vasil'ev and E. Fawcett, *The magnetic phase diagrams of dysprosium*, J. Magn. Magn. Mater., 1991, vol. 97, no. 1-3, pp. 246–250.
[16] M.T. Alkhafaji and N. Ali, *Magnetic phase diagram of dysprosium, J. Alloys Compd.*, 1997, vol. 250, no. 1-2, pp. 659–661.
[17] A.S. Chernyshov, A.O. Tsokol, A.M. Tishin, K.A. Gschneidner and V.K. Pecharsky, *Magnetic and magnetocaloric properties and the magnetic phase diagram of single-crystal dysprosium*, Phys. Rev. B, 2005, vol. 71, 184410.
[18] E.B. Amitin, V.G. Bessergenev and Y.A. Kovalevskaya, *Features of the thermodynamic properties of dysprosium as a quasi-two- dimensional magnetic system*, Soviet Phys. JETP, 1983, vol. 57, no. 1, pp. 117–122.
[19] C. Isci and S.B. Palmer, *An ultrasonic study of the magnetic phases of dysprosium*, J. Phys. F: Met. Phys., 1978, vol. 8, no. 2, pp. 247–260.
[20] A.S. Chernyshov, Y. Mudryk, V.K. Pecharsky and K.A. Gschneidner, *Temperature and magnetic field-dependent x-ray powder diffraction study of dysprosium*, Phys. Rev. B, 2008, vol. 77, 094132.
[21] A.R. Jha, *Rare-earth materials: properties and applications* (Taylor and Francis Group, New York, 2014)
[22] J.F. Elliott, S. Legvold and F.H. Spedding, *Some magnetic properties of Dy metal*, Phys. Rev., 1954, vol. 94, no. 5, pp. 1143–1145.
[23] M.K. Wilkinson, W.C. Koehler, E.O. Wollan and J.W. Cable, *Neutron diffraction investigation of magnetic ordering in Dysprosium*, J. Appl. Phys., 1961, no. 32, p. S48.
[24] K.P. Belov, R.Z. Levitin and S.A. Nikitin, *Ferromagnetism and antiferromagnetism of rare-earth metals*, Sov. Phys. Usp., 1964, vol. 7, no. 2, pp. 179–208.
[25] M. Rosen, *Elastic Moduli and Ultrasonic Attenuation of Gadolinium, Terbium, Dysprosium, Holmium, and Erbium from 4.2 to 300° K*, Phys. Rev., 1968, vol. 174, no. 2, pp. 504–514.
[26] A. Del Moral and E.W. Lee, *The reversible susceptibilities of dysprosium and terbium*, J. Phys. F: Met. Phys., 1974, vol. 4, no. 2, pp. 280–290.
[27] S.B. Palmer and E.W. Lee, *The Elastic Constants of Dysprosium and Holmium, Proc. R. Soc. Lond. A*, 1972, vol. 327, pp. 519–543.
[28] S.B. Palmer, *Antiferromagnetic domains in rare earth metals and alloys*, J. Phys. F: Met. Phys., 1975, vol. 5, no. 12, pp. 2370–2378.
[29] S. Kobayashi, *Universal hysteresis scaling for incommensurate magnetic order in dysprosium*, Phys. Rev. Lett., 2011, vol. 106, 057207.
[30] T.J. Mckenna, S.J. Campbell, D.H. Chaplin and G.V.H. Wilson, *Domain effects near the order-disorder and order-order ferromagnetic transitions in Gd and Dy*, J. Magn. Magn. Mater., 1980, vol. 20, no. 2, pp. 207–211.
[31] T.J. Mckenna, S.J. Campbell, D.H. Chaplin and G.V.H. Wilson, *Temperature Modulation and Temperature Hysteresis Studies of Dysprosium*, *Phys. Status Solidi A*, 1983, vol. 75, no. 2, pp. 421–432.
[32] M.L. Corró, A.El Hichou, E. Cesari and S. Kustov, *Study of magnetic transitions in Dy by means of reversible Villari effect, J. Phys. D: Appl. Phys.*, 2016, vol. 49, 015001.
[33] S. Kustov, F. Masdeu and E. Cesari, *Mechanomagnetic spectroscopy of phase transitions in ferromagnetic shape memory alloys*, Appl. Phys. Lett., 2006, vol. 89, art. 061917.
[34] I. Liubimova, M. Corró Moyà, J. Torrens-Serra, V. Recarte, J. Pérez-Landazábal and S. Kustov, *Low Field Magnetic and Thermal Hysteresis in Antiferromagnetic Dysprosium*, Metals, 2017, vol. 7, no. 6, p. 215.
[35] G. Bertotti, *Hysteresis in magnetism* (Academic Press, San Diego, California, USA, 1998).

[36] J.P. Sethna, K.A. Dahmen and C.R. Myers, *Crackling noise*, Nature, 2001, vol. 410, no. , pp. 242–250.
[37] C.P. Steinmetz, *On the law of hysteresis*, Proc. IEEE, 1984, vol. 72, no. 2, pp. 197–221.
[38] S. Kobayashi, S. Takahashi, T. Shishido, Y. Kamada and H. Kikuchi, *Low-field magnetic characterization of ferromagnets using a minor-loop scaling law*, J. Appl. Phys., 2010, vol. 107, art. 023908.
[39] S.W. Chen, H. Guo, K.A. Seu, K. Dumesnil, S. Roy and S.K. Sinha, *Jamming behavior of domains in a spiral antiferromagnetic system*, Phys. Rev. Lett., 2013, vol. 110, 217201.
[40] M.C. Langner, S. Roy, A.F. Kemper, Y.D. Chuang, S.K. Mishra, R.B. Versteeg, Y. Zhu, M.P. Hertlein, T.E. Glover, K. Dumesnil and R.W. Schoenlein, *Scattering bottleneck for spin dynamics in metallic helical antiferromagnetic dysprosium*, Phys. Rev. B, 2015, vol. 92, 184423.
[41] I.M. Sharshakov, A.N. Korshunov and G.L. Polner, *Magnetic transformations and internal friction in polycrystalline dysprosium*, Fiz. Met. Metalloved., 1978, vol. 45, no. 1, pp. 204-205.
[42] A.M. Tishin and O.A. Shipilov, *Anomalous internal-friction in dysprosium at low-temperatures, Fiz. Tverd. Tela*, 1992, vol. 34, pp. 3554–3556.
[43] G.S. Burkhanov, S.A. Nikitin, A.M. Tishin, O.D. Chistyakov and O.A. Shipilov, *A study of elastic phenomena and relaxation processes in Dysprosium*, Mosc. Un. Phys. B**.,** 1993, vol. 48, no. 2, p. 43.
[44] R.A. Treder and M. Levy, *Ultrasonic study of dysprosium in a magnetic field*, J. Magn. Magn. Mater., 1977, vol. 5, no. 1, pp. 9–17.
[45] M. Rosen and H. Klimker, *Low-Temperature Elasticity and Magneto-Elasticity of Dysprosium Single Crystals*, Phys. Rev. B, 1970, no. 1, 3748.
[46] S. Kustov, M.-Ll. Corró, V. Kaminskii, A. Saren and K. Ullakko, *Elastic and anelastic phenomena related to eddy currents in cubic Ni_2MnGa*, Scr. Mater., 2018, vol. 147, pp. 69–73.
[47] Iu. Liubimova, K. Sapozhnikov, V. Nikolaev, M.-Ll. Corró and S. Kustov, *Ultrasonic study of thermal hysteresis in helical antiferromagnetic Dy*, Rev. Adv. Mater. Sci., 2018, vol. 57, pp. 241–245.
[48] S. Kustov, Iu. Liubimova, M. Corró, J. Torrens-Serra, X. Wang, C.R.S. Haines and E.K.H. Salje, *Temperature Chaos, Memory Effect, and Domain Fluctuations in the Spiral Antiferromagnet Dy*, Sci. Rep., 2019, vol. 9, 5076.