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A terahertz view on magnetization dynamics

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CHAPTER 1

Introduction

Magnetism has been known to mankind for centuries, but its fundamental understanding and the resultant technology started to take shape in the early 20th century. One of the major applications of magnetic materials can be found in modern data storage devices. Recent developments in information and communication (ICT) technology can be subdivided into three major aspects; data processing at high speeds, data storage using ensemble of spins in magnetic materials, and data transfer at fast speeds. The data storage density and the speed of data processing has been increasing at a tremendous rate, roughly 100% every 18 months, also known as Moore's law [1]; see Figure 1.1. The continuation of this trend in the future using conventional technologies is improbable since there are limitations to miniaturizing the physical size of the devices beyond a certain length regime. An alternative approach could involve spintronics, where spin degree of freedom is used for transport, that would meet the requirements of future ICT (such as low-power operation, nano-scale devices etc). In spintronics, spin polarized current can be achieved without having an electronic transport which minimizes the ohmic heating and enables green ICT applications. The effective manipulation, transport and control of spin degrees of freedom forms the basis of spintronics. Spintronics [2] emerged after the discovery of giant magneto-resistance (GMR) in 1988. GMR is defined as a change in resistance depending on the relative orientation of the two magnetic layers separated by a non-magnetic spacer. The implementation of GMR into hard disk drives (HDD) increased the areal density of the HDD drastically (See Figure 1.1a) and the impact of GMR on technology resulted in the Nobel prize for Physics in 2007 [3]. Besides GMR, recent works have also focused on developing spin based memories, such as spin-RAM, racetrack memory, spin transfer torque-MRAM [2–5]. These devices have already been incorporated into embedded systems.

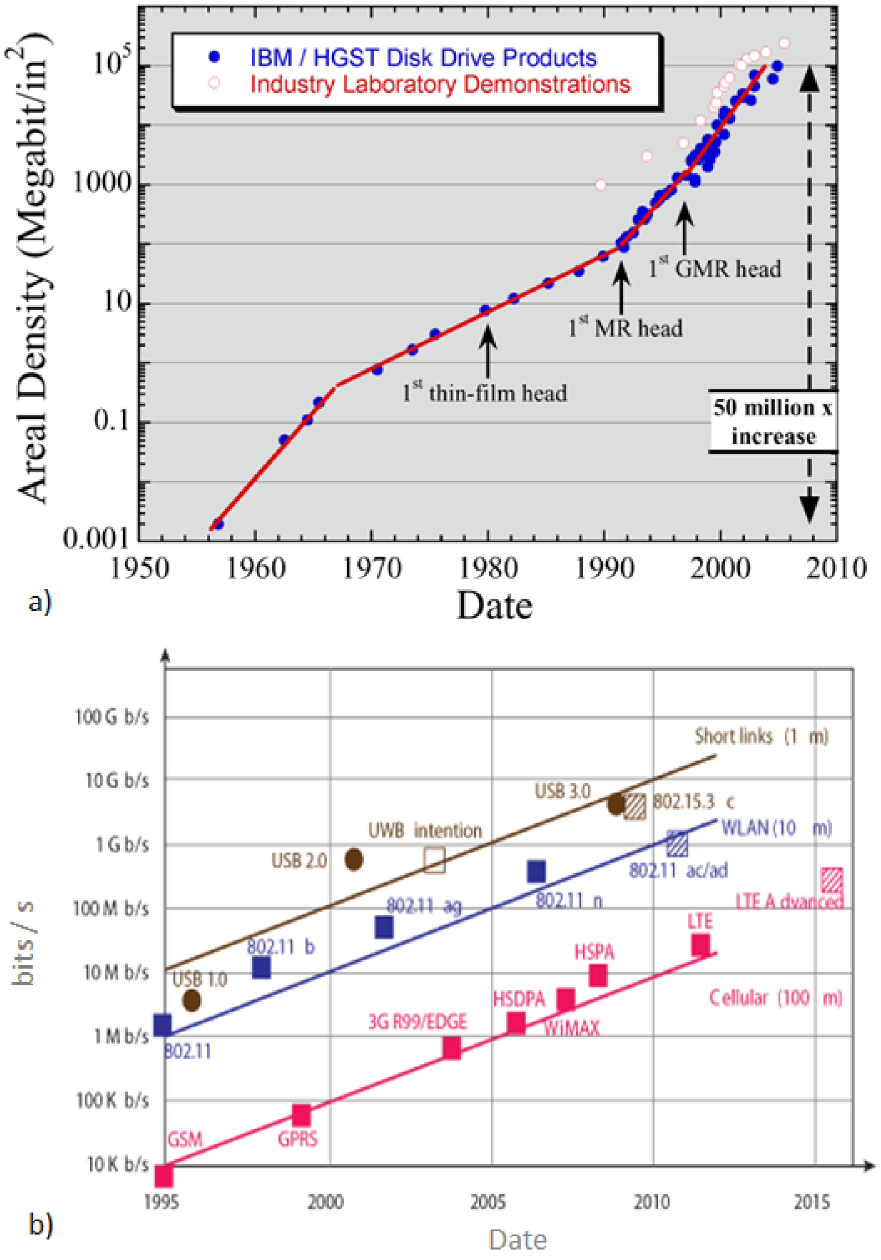

FIGURE 1.1: (a)Areal density growth of HDD devices as a function of time, taken from [6]. The slope of the curve has increased from the introduction of spintronics based GMR heads. (b) The rate of telecommunication as a function of time. The rate at which telecommunication takes places has doubled every 18 months [7].

The new field of antiferromagnetic spintronics is driven by the need for high-density storage devices operating at high frequencies. As shown in figure 1.1b, wireless data rates are also continuously increasing over the last few decades [8]. Following this trend, terabits per second (Tbps) rates can be realized very soon, provided that new spectral bandwidth to support such high data rates are made available. In this context, Terahertz (THz) bandwidth is envisioned as a key technology for wireless communication. THz band spanning 0.1 THz to 10 THz can support the Tbps links, which requires functional devices to operate at a THz frequency band [7].

An important question in the spintronics field is how to generate and detect spin current efficiently. While research in spintronics is focused on the generation and detection of spin current efficiently [9, 10], it is essential that developed devices can operate at THz frequencies. Recently, the spin dependent Seebeck effect has been established which converts heat in to spin current. This imposes a basic question - can spin generation and detection be achieved at THz frequencies? Recent research has shown that several spintronics concepts are valid in the THz frequency range. Linear THz spectroscopy has been used to study the GMR effect [11]. The anomalous Hall effect has been observed at THz frequencies [12]. Ultra-broad band THz generation has been achieved from the hetero-structure of ferromagnetic metal and non-magnetic metal [13], based on the principle of the inverse spin Hall effect. THz control of magnetic modes in the THz frequency range has been shown [14–16]. THz emission spectroscopy has been used to study the spin dynamics of magnetic modes [17, 18]. Advanced fields such as off resonant coupling of the spin to phonons/magnons [19] allows non-linear physical processes to be understood [20].

Despite significant progress in the science related to THz range spintronics, there are several interesting questions yet to be tackled. Can we use THz resonances in magnetic materials for advanced spintronics applications? How do fundamental scattering processes taking place at sub-picosecond timescales, affect the efficiency of spintronics processes? The work presented in this thesis aims to provide deeper understanding of THz control of magnetic resonances in magnetic materials. The thesis aims to exploit new materials systems for their characterization in the THz frequency range.

1.1 Outline of the thesis

In this thesis, different techniques are used to study and understand magnetization dynamics at THz frequency. In chapter 2, an overview of basic properties of magnetic materials and an outline of light-driven magnetization dynamics are provided. In chapter 3, the experimental techniques used in this thesis are discussed.

In chapter 4 of the thesis, the high frequency ferrimagnetic Mn-based Heusler alloys are studied for their future application as spin transfer torque oscillator in the sub-THz frequency range. These materials have high spin polarization and ferromagnetic modes from 0.15 to 0.35 THz. THz emission spectroscopy is employed to observe ferromagnetic modes and to characterize it further with temperature and external magnetic fields up to 10 T.

Then in chapter 5, the focus shifts to THz control of non-resonant magnetization dynamics in ferromagnetic CoFeB. Here, the THz pump Magneto-Optical Kerr effect is used to study the magnetic properties of CoFeB. The effect of THz excitation on ultra-fast demagnetization is studied and explained using the Eliot-Yafet scattering mechanism. Finally, the spin dependent scattering of conduction electrons is discussed to provide a microscopic understanding of the magnetization dynamics.

In the final chapter, THz radiation is used to excite the antiferromagnetic mode in NiO. The antiferromagnetic resonance mode is studied with the transient Faraday probe technique in the temperature range 3-290K, with an external magnetic field up to 10 T. Such THz control of antiferromagnetic mode helps in the understanding of the spin dynamics at sub-picosecond timescales for high frequency spintronics memory devices.

1.2 Bibliography

[1] R. R. Schaller, "Moore's law: past, present and future," *IEEE spectrum*, vol. 34, no. 6, pp. 52–59, 1997.

[2] S. Wolf, D. Awschalom, R. Buhrman, J. Daughton, S. Von Molnar, M. Roukes, A. Y. Chtchelkanova, and D. Treger, "Spintronics: a spin-based electronics vision for the future," *Science*, vol. 294, no. 5546, pp. 1488–1495, 2001.

[3] A. Fert, "Nobel lecture: Origin, development, and future of spintronics," *Reviews of Modern Physics*, vol. 80, no. 4, p. 1517, 2008.

[4] I. Žutić, J. Fabian, and S. D. Sarma, "Spintronics: Fundamentals and applications," *Reviews of modern physics*, vol. 76, no. 2, p. 323, 2004.

[5] A. D. Kent and D. C. Worledge, "A new spin on magnetic memories," *Nature nanotechnology*, vol. 10, no. 3, p. 187, 2015.

[6] J. R. Childress and R. E. Fontana Jr, "Magnetic recording read head sensor technology," *Comptes Rendus Physique*, vol. 6, no. 9, pp. 997–1012, 2005.

[7] I. F. Akyildiz, J. M. Jornet, and C. Han, "Terahertz band: Next frontier for wireless communications," *Physical Communication*, vol. 12, pp. 16–32, 2014.

[8] S. Cherry, "Edholm's law of bandwidth," *IEEE Spectrum*, vol. 41, no. 7, pp. 58–60, 2004.

[9] Y. Ohno, D. Young, B. a. Beschoten, F. Matsukura, H. Ohno, and D. Awschalom, "Electrical spin injection in a ferromagnetic semiconductor heterostructure," *Nature*, vol. 402, no. 6763, p. 790, 1999.

[10] A. Fert and H. Jaffres, "Conditions for efficient spin injection from a ferromagnetic metal into a semiconductor," *Physical Review B*, vol. 64, no. 18, p. 184420, 2001.

[11] Z. Jin, A. Tkach, F. Casper, V. Spetter, H. Grimm, A. Thomas, T. Kampfrath, M. Bonn, M. Kläui, and D. Turchinovich, "Accessing the fundamentals of magnetotransport in metals with terahertz probes," *Nature Physics*, vol. 11, no. 9, p. 761, 2015.

[12] R. Shimano, Y. Ikebe, K. Takahashi, M. Kawasaki, N. Nagaosa, and Y. Tokura, "Terahertz faraday rotation induced by an anomalous hall effect in the itinerant ferromagnet SrRuO3," *EPL (Europhysics Letters)*, vol. 95, no. 1, p. 17002, 2011.

[13] T. Kampfrath, M. Battiato, P. Maldonado, G. Eilers, J. Nötzold, S. Mährlein, V. Zbarsky, F. Freimuth, Y. Mokrousov, S. Blügel, *et al.*, "Terahertz spin current pulses controlled by magnetic heterostructures," *Nature nanotechnology*, vol. 8, no. 4, p. 256, 2013.

[14] T. Kampfrath, A. Sell, G. Klatt, A. Pashkin, S. Mährlein, T. Dekorsy, M. Wolf, M. Fiebig, A. Leitenstorfer, and R. Huber, "Coherent terahertz control of antiferromagnetic spin waves," *Nature Photonics*, vol. 5, no. 1, p. 31, 2011.

[15] T. Moriyama, K. Oda, and T. Ono, "Spin torque control of antiferromagnetic moments in NiO," *arXiv preprint arXiv:1708.07682*, 2017.

[16] Z. Jin, Z. Mics, G. Ma, Z. Cheng, M. Bonn, and D. Turchinovich, "Single-pulse terahertz coherent control of spin resonance in the canted antiferromagnet YFeO3, mediated by dielectric anisotropy," *Physical Review B*, vol. 87, no. 9, p. 094422, 2013.

[17] R. Mikhaylovskiy, E. Hendry, V. Kruglyak, R. Pisarev, T. Rasing, and A. Kimel, "Terahertz emission spectroscopy of laser-induced spin dynamics in TmFeO3 and ErFeO3 orthoferrites," *Physical Review B*, vol. 90, no. 18, p. 184405, 2014.

[18] J. Nishitani, K. Kozuki, T. Nagashima, and M. Hangyo, “Terahertz radiation from coherent antiferromagnetic magnons excited by femtosecond laser pulses,” *Applied Physics Letters*, vol. 96, no. 22, p. 221906, 2010.

[19] T. F. Nova, A. Cartella, A. Cantaluppi, M. Först, D. Bossini, R. Mikhaylovskiy, A. Kimel, R. Merlin, and A. Cavalleri, “An effective magnetic field from optically driven phonons,” *Nature Physics*, vol. 13, no. 2, p. 132, 2017.

[20] Z. Wang, S. Kovalev, N. Awari, M. Chen, S. Germanskiy, B. Green, J.-C. Deinert, T. Kampfrath, J. Milano, and M. Gensch, “Magnetic field dependence of antiferromagnetic resonance in NiO,” *Applied Physics Letters*, vol. 112, no. 25, p. 252404, 2018.