東北大学 電気通信研究所

研究室外部評価資料

(2013 年度-2018 年度)

Activity Report of Research Laboratory for External Review

April 2013 - March 2019
(FY.2013-2018)

Research Institute of Electrical Communication
Tohoku University

情報ストレージシステム研究室

Information Storage Systems

A. 研究室名 / Research Laboratory

情報ストレージシステム研究室
Information Storage Systems

B. 構成員 / Faculty and Research Staff (as of May 1, 2019)

※ 欄を適宜追加削除等調整して下さい．期間内に異動等があった場合には，在籍期間を記載して下さい．

教授 / Professor	
氏名 Name	田中　陽一郎 Yoichiro Tanaka (April 2019 -)
分野名 Research Field	情報ストレージシステム Information Storage Systems
准教授 / Associate Professor	
氏名 Name	サイモン　グリーブス Simon Greaves (April 2003 -)
分野名 Research Field	情報ストレージデバイス Information Storage Devices
助教 / Assistant Professor	
氏名 / Name	

C. 研究目的 / Research Purpose

本研究室では大容量情報を保存出来る情報ストレージ技術に関する研究を行っている。近年、インターネットから無線通信に至る幅広い分野で映像や音声などの大容量マルチメディア情報が普及しており、情報ストレージシステムのさらなる高密度化が強く求められている。中心的な技術は、ハードディスクや磁気テープなどで使われている磁気記録技術であり、その特徴として挙げられるのは高速データ転送レートと低コスト、高密度大容量である。本研究室では、高密度磁気ストレージの実現のため、記録方式、デバイス、更にはシステムまでの広範な研究を行っている。1 ビットの面積が 10 ナノメータ四方以下という次世代の高速高密度情報ストレージ（テラビットストレージ）と、それを用いる高速省電力超大容量ストレージシステムの実現を目標にしている。

Our main interest lies in high-density information storage technology. In recent years, multi-media data, such as digital movies and ultra-high definition TV, that require very large storage capacities are being introduced in many internet and mobile communication applications, leading to a strong demand for high density information storage systems. The core technology is magnetic recording, as used in hard disk drives and magnetic tape storage, because it offers fast data transfer rates and low cost, high capacity storage. In this group we are studying recording methods, devices and systems for high density magnetic storage. Our aim is to realise fast, low power consumption, high capacity terabit storage (over 5 Tbits/inch^2 areal density), in which the size of each stored bit of information occupies an area of less than 10 nm by 10 nm.

D. 主な研究テーマ / Research Topics

1. 情報ストレージデバイスのマイクロ磁区シミュレーション
2. 次世代超高密度ハードディスクドライブに関する研究
3. 磁気ストレージに用いるヘッドとディスクの研究
4. その他磁気ストレージデバイス

1. Micromagnetic simulations of information storage devices
2. High areal density hard disk drives
3. Heads and disks for magnetic storage
4. Other magnetic storage devices

E. 学術論文等の編数 / The Number of Research Papers

		2013	2014	2015	2016	2017	2018	Total
	(1) 査読付学術論文 Refereed journal papers	10	9	12	7	9	7	54
	(2) 原著論文と同等に扱う 査読付国際会議発表論文 Full papers in refereed conference proceedings equivalent to journal papers							
	(3) 査読付国際会議 Papers in refereed conference proceedings							
	(4) 査読なし国際会議・シンポジウム等 Papers in conference proceedings							
	(5) 総説・解説 Review articles							
	(6) 査読付国内会議 Refereed proceedings in domestic conferences							
	(7) 査読なし国内研究会・講演会 Proceedings in domestic conferences		2		3	4	3	12
	(8) 著書 Books	1	1			1	1	4
	(9) 特許 Patents							
	(10) 招待講演 Invited Talks	1	1	3	3	2	1	11

F. 特筆すべき研究成果 / Significant Research Achievements (FY.2013-2018)

See Ref. 1. “#” mark indicates research carried out at a former organization.

2013-2018 年度の研究成果（論文・特許など）のうち，前半（2013-2015 年度）と後半（2016-2018 年度）それぞれで代表的な数件（2-3 件程度ずつ）について，参考資料を引用して，その特徴と学術的意義などを簡単に紹介する．英文のみ，もしくは和文と英文で記載.
要約は 300 字程度．論文誌の要約/Abstract のコピー可．学術面での国際的インパクトならびに社会的影響を 100 字程度で記載.
必ずしも当該期間内に発表・出版したものに限るのではなく，例えば過去に発表したものでもこの期間内に成果が得られたり，評価されるようになったりしたものも含むものとする．
インパクトファクターや被引用件数など，できる限り第三者が定量的に評価できる指標を用いてアピールすること．それらの指標にはそぐわない場合には，その事情とそれに変わる適当な評価指標・尺度を示すこと．

[2013-2015]

1. S. J. Greaves, Y. Kanai, and H. Muraoka, “Thermally assisted magnetic recording at 4 Tbit/in^2”, IEEE Transactions on Magnetics 49(6), pp.2665-2670, (2013).

Abstract: Simulations of heat assisted magnetic recording (HAMR) were carried out targeting an areal density of 4 Tbit/in^2. The effects of the heat spot radius, maximum temperature during recording, Curie temperature and thermal conductivity of the recording layer on the written tracks were investigated. Triple track squeeze simulations were used to determine the minimum track pitch. The paper concludes that the target of 4 Tbit/in^2 may be realized if stringent conditions on the heat spot and thermal conductivity are met.

International impact on both academic and social aspects： The background to this work is the growing need for high density, low cost data storage systems due to the explosive growth in the amount of data generated and transmitted. One possible future technology that might be adopted is heat assisted magnetic recording (HAMR). This work examined the prospects for realising an areal density of 4 Tbit/in^2 using HAMR and outlined the technical requirements for such a system. The areal density of 4 Tbit/in^2 was about ten times the density of hard disk storage at the time.

2. S. J. Greaves, “Domain wall pinning by antiferromagnets in magnetic nanowires”, IEEE Transactions on Magnetics 50(11), 2302304, (2015).

Abstract: The use of antiferromagnets to pin domain walls in ferromagnetic nanowires was investigated using simulations. Pinning was effective for both in-plane and perpendicularly magnetized nanowires with transverse, Néel and Bloch domain walls. Domain walls could be depinned using external applied fields or electric currents and a pulsed current mode could be used to shift domain walls from one pinning site to the next.

International impact on both academic and social aspects： The use of magnetic nanowires to store information has been under investigation for many years. Information can be stored in the form of magnetic domains and domain walls can be moved by passing an electric current through the wire. In theory, a three dimensional storage system can be realised if the nanowires are made in the form of loops standing on a substrate. One problem is maintaining a regular spacing between domain walls. This paper shows that exchange coupling between the magnetic nanowires and antiferromagnetic pinning sites is an effective way to pin domain walls. In contrast to alternative pinning methods such as patterning notches into the nanowires the proposed pinning method offers higher reliability and a narrower distribution of pinning strengths. An experimental demonstration of pinning of domain walls by antiferromagnets was also published by researchers at the University of York, UK, with whom we have collaborated.

[2016-2018]

1. S. Greaves, Y. Kanai, and H. Muraoka, "Multiple Layer Microwave Assisted Magnetic Recording", IEEE Transactions on Magnetics, 53(2), 3000510, (2017).

Abstract: Simulations of recording on media with two and three distinct recording layers are presented. A high frequency magnetic field is used to select the layer on which data are recorded. Layer-selective recording was confirmed for two layer granular media with narrow distributions. For three layer media magnetostatic interactions between the layers led to a loss of selectivity in the bottom recording layer. Readout of data is possible by staggering the transitions between bits in different layers or by using a spin-torque oscillator.

International impact on both academic and social aspects： This work considers another prospective future magnetic recording technology: microwave-assisted magnetic recording (MAMR). One advantage of MAMR is the ability to selectively record on different layers of a recording medium. This is accomplished by using recording layers with different ferromagnetic resonance frequencies. During recording a spin torque oscillator (STO) integrated into the write head generates a high frequency magnetic field at the resonance frequency of the target recording layer, thereby lowering the coercive field of that layer and allowing data to be recorded. This work showed that selective recording on up to three layers may be possible. If realised, the storage capacity of such a system would be much higher than conventional, single layer media. It was also shown that the STO used to assist magnetisation switching could also be used to detect the magnetisation of the recording medium via changes in its oscillation frequency.

2. S. J. Greaves, "Magnetic recording using a spin torque oscillator", IEEE Transactions on Magnetics 54(11), 3001705-1-5, (2018), doi 10.1109/TMAG.2018.2834933

Abstract: Simulations of the switching of magnetization using only the field from a spin torque oscillator (STO) were presented. Single phase and exchange coupled composite (ECC) grains were used and the switching probability calculated as a function of the STO position, frequency, and the magnetic properties of the grains. The results showed that ECC grains could be reliably switched by an STO for a wide range of STO positions and frequencies.

International impact on both academic and social aspects： The starting point for this work was to examine the possibility of switching the magnetisation of a magnetic grain or dot using only the magnetic field from a spin torque oscillator. It was shown that determinative switching of the magnetisation was possible for a range of magnetic structures. A magnetic dot with a STO above could form an element of a non-volatile memory. We are now investigating the potential to switch multiple magnetic layers using only the STO.

G. 特筆すべき活動 / Significant Activities (FY.2013-2018)

See Ref. 2-9. “#” mark indicates research carried out at a former organization.

研究室外部評価参考資料の 2 以降を参照しながら，2013-2018 年度のなどの活動の中から特筆すべきものを取り出し，前半（2013-2015 年度）と後半（2016-2018 年度）に分けて簡単に紹介する．英文のみ，もしくは和文と英文で記載．

[2013-2015]

ASTC project on microwave assisted magnetic recording

JST project on antiferromagnetically coupled media for microwave-assisted magnetic recording

For much of the period 2013-2018 we have been working on projects involving microwave-assisted magnetic recording (MAMR). The main funding from this has come from the ASTC academic-industry consortium, with additional funding from 2016-2018 coming from JST for a project involving Toshiba Corporation and a number of Japanese universities. The ASTC (advanced storage technology consortium) has members in Japan, the US and Europe and tasks academic members with work on projects of interest to the industry members. Our contribution has mostly focused on MAMR, specifically to develop an understanding of the physics behind the technology and to investigate the potential of selective, multiple layer recording systems. Our research has resulted in many publications, some of which are listed below. These cover aspects from the basic principles of MAMR (1, 2, 4, 9), multiple layer recording (3, 5) and optimisation of MAMR systems (6, 7, 8). Further papers have been written with collaborators on topics such as how to integrate the spin torque oscillator needed for MAMR into the write head.

1. S. Greaves, T. Katayama, Y. Kanai, H. Muraoka, “The Dynamics of Microwave-Assisted Magnetic Recording”, IEEE Trans. Magn., Vol. 51, No. 4, 3000107, April 2015.

2. S. J. Greaves, Y. Kanai, and H. Muraoka, “Microwave-Assisted Shingled Magnetic Recording”, IEEE Trans. Magn., Vol. 51, No. 11, 3001204, Nov 2015.

3. S. J. Greaves, Y. Kanai, H. Muraoka, “Microwave-Assisted Magnetic Recording on Dual-Layer and Dual-Thickness Bit Patterned Media”, IEEE Trans. Magn., Vol. 52, No. 7, 3000904, July 2016.

4. S. J. Greaves, Y. Kanai, H. Muraoka, “Microwave-Assisted Magnetic Recording on Exchange Coupled Composite Media”, IEEE Trans. Magn., Vol. 52, No. 7, 3001104, July 2016.

5. S. Greaves, Y. Kanai, and H. Muraoka, “Multiple Layer Microwave Assisted Magnetic Recording”, IEEE Trans. Magn., Vol. 53, No. 2, 3000510, Feb. 2017.

6. S. J. Greaves, H. Muraoka and Y. Kanai, “Optimisation of applied field pulses for microwave assisted magnetic recording”, AIP Advances 7, 056517-1-7, ‘(2017).

7. S. Greaves, Y. Kanai, and H. Muraoka, “Antiferromagnetically Coupled Media for Microwave-Assisted Magnetic Recording”, IEEE Trans. Magn., Vol. 54, No. 2, 3000111, Feb 2018.

8. S. J. Greaves, T. Kikuchi, Y. Kanai, and H. Muraoka, “Optimizing Dual-Layer Recording Using Antiferromagnetic Exchange Coupling”, IEEE Trans. Magn, Vol. 54, No. 11, DOI: 10.1109/TMAG.2018.2829509, Nov. 2018.

9. S. J. Greaves, H. Muraoka and Y. Kanai, "Magnetisation switching of ECC grains in microwave-assisted magnetic recording", AIP Advances 8, 056502-1-7, (2018), doi 10.1063/1.5006362.

[2016-2018]

MEXT project on research and development of highly-functional and highly-available information storage technology

This project was funded by the Ministry of Education, Culture, Sports, Science and Technology as part of its Research and Development on ICT for the Future Society programme. The project involved researchers at Tohoku University and staff from Hitachi Ltd and Hitachi Solutions East Japan, Ltd. The background to the project was the 2011 Great East Japan Earthquake and associated tsunami, which resulted in the loss of much important information, such as resident registry records and medical information etc., due to power failures and damage to servers and storage infrastructure. The vulnerabilities of existing storage systems exposed by the disaster prompted this project, which aimed to develop information storage technology that could safeguard and enable access to information promptly and accurately, even under circumstances of widespread devastation.

For improved disaster resilience it is necessary that storage systems be configured such that information is stored at multiple sites in a geographically distributed fashion, and that the system should recover quickly by reconstituting the surviving information. Geographical distribution algorithms were developed that take account of a site’s vulnerabilities, e.g. to earthquakes, tsunami, landslides etc. Successful demonstrations of mobile technologies were carried out during exercises intended to replicate the situation immediately following a disaster. By adjusting the number of data replicas according to the risk of data loss, the same amount of data could be protected with half the number of replicas, compared to conventional methods. This technology should enable disaster-resilient information platforms to be implemented at an affordable cost.

1. S. Matsumoto, T. Nakamura, and H. Muraoka, “Redundancy-based Iterative Method to Select Multiple Safe Replication Sites for Risk-aware Data Replication,” IEEJ Transactions on Electrical and Electronic Engineering, Vol. 11, No.1, pp. 96-102, 2016.

2. T. Nakamura, S. Matsumoto, M. Tezuka, S. Izumi, and H. Muraoka, “Comparison of Distance Limiting Methods for Risk-aware Data Replication in Urban and Suburban Area,” Journal of Information Processing, Vol. 24, No. 2, pp. 381-389, March 2016.

3. 松本慎也, 中村隆喜, 村岡裕明, 「リスクアウェア複製システムにおいて構成変更による再配置データ量を抑制する複製先部分再選択方式」, 情報処理学会論文誌, Vol. 58, No. 2, pp. 495-505, 2017.

4. L. Guillen, S. Izumi, T. Abe, H. Muraoka, and T. Suganuma, “SDN-based Network Control Method for Distributed Storage Systems,” Advances in Science, Technology and Engineering Systems Journal Vol. 3, No. 5, pp. 140-151, 2018.