University of California, San Diego ISSN: 0888-7381

CMRR Report

Center for Magnetic Recording Research

Number 28 Summer 2007

Research Highlight

Writing and Reading On Patterned Media

by Jack Wolf

Contents:

New CMRR Endowed Chair

On August 21, 2007, a reception was held at CMRR in honor of CMRR Director **Paul H. Siegel** who was awarded an Endowed Professorship at UCSD. Among the many guests were Paul's wife Darcy, son Oren and daughter Micah.

Left to Right , Paul H. Siegel and James Lemke

Frieder Sieble, Dean of the Jacobs School of Engineering, began the proceedings by explaining what a great honor it is to be awarded an endowed chair at UCSD. He also spoke of Paul's many achievements in research, teaching and service. The program continued with remarks by Larry Larson (ECE Chairman), Eric Fullerton, Larry Milstein, Jack Wolf, Gordon Hughes, Ami Berkowitz, James Lemke (founder of CMRR), and former students Joseph Soriaga and Jilei Hou. Professor Wolf also read a congratulatory letter from CMRR Professor Emeritus Neal Bertram who could not attend. Paul ended the formal proceedings with a heart warming "thank you."

Wolf Receives an IEEE Award

Jack Keil Wolf, the Stephen O. Rice Professor of Electrical and Computer Engineering at UCSD and CMRR has been awarded the 2007 Aaron Wyner Distinguished Service Award by the IEEE Information Theory Society.

This award recognizes his many years of inspiring leadership and service to the Information Theory Society.

Sheldon Schultz Prize for Excellence

On May 9, 2007 the **Schultz Prize** was awarded to co-recipients **Maik Duwensee** and **Bart Raeymaekers**. The prize is presented in recognition of CMRR graduate students who have distinguished themselves through the creativity of their research and the impact of their publications.

Left to Right, Maik Duwensee, Professor Emeritus Sheldon Schultz, Professor Frank Talke, and Bart Raeymaekers

Maik first came to CMRR as a visiting student in Professor Talke's group during the academic year 1999/2000. He returned to the University of Rostock and completed his Diploma Degree. He rejoined the Talke group in November 2002 as a Ph.D. student. In June 2006, he was awarded the **Best University-Industry Paper Award** from the Information Storage and Processing Systems (ISPS), a division of the ASME. This past June Maik was awarded a Ph.D. His dissertation was entitled "Numerical and Experimental Investigations of the Head/Disk Interface." Maik is currently employed at **Hitachi Global Storage Technologies**, a CMRR sponsor, in San Jose, California.

Bart joined Professor Talke's group in 2005. He received his undergraduate degree from KaHo St. Lieven in Ghent, Belgium. In 2004, Bart received his master's degree in mechanical engineering at Vrue Universiteit Brussels. In 2006 he was awarded the **Barbara J. and Paul D. Saltman Distinguished Teaching Award** as a graduate teaching assistant in the Department of Mechanical and Aerospace Engineering. This past June, Bart was awarded a Ph.D. His dissertation was entitled "Sliding Contacts and the Dynamics of Magnetic Tape Transport." In September 2007, Bart began a MBA program at MIT, Sloan School of Management, in Cambridge, MA.

If you are interested in making a donation of any amount to the **Schultz Prize**, you will help move us closer to the endowment target of $50,000. Checks should be made payable to "UC San Diego Foundation" with a notation on the check or a brief cover letter designating the contribution for the "Schultz Prize." You can also submit an online donation at http://www.jacobsschool.ucsd.edu/external/external_giving/ Click on "Give Now" and under fund select "Schultz Prize."

Your donation is 100% tax-deductible, and an official acknowledgement of your contribution will be provided to you. All correspondence pertaining to the Schultz Prize can be directed to:

Prof. Paul H. Siegel, Director
University of California-San Diego
Center for Magnetic Recording Research, #0401
9500 Gilman Drive
La Jolla, CA 92093-0401

From the Director

As we begin the 2007-2008 academic year, there are many good things to report.

First, two of our graduate students have recently returned from very rewarding experiences as summer interns at **Marvell Semiconductor** and **Seagate Technology**. Both of these companies have been strong supporters of CMRR programs over the years, and the resulting close ties facilitate such mutually beneficial interactions.

Next, in late September, I visited two or our most actively involved sponsors, **Toshiba Corporation** and **Fujitsu Limited**, at their Ome and Kawasaki facilities. After providing an overview of the latest CMRR research in perpendicular and patterned-media recording, I had the opportunity to discuss strategic directions in storage technology with my hosts, who included Akihiko Takeo and Dr. Akira Kikitsu of Toshiba, and Atsuo Iida and Dr. Takashi Uchiyama of Fujitsu. You may recall that Takeo-san spent 18 months as a Visiting Scholar at CMRR a few years ago. Dr. Akihiro Inomata of Fujitsu Laboratories has been with us the past year, and Dr. Toshio Ito will be following in his footsteps. At CMRR, we value very highly such genuine partnerships with industry.

Most recently, all of us at CMRR, like all of you I'm sure, were thrilled to see advanced storage technology receive world-wide attention in the aftermath of the awarding of the Nobel Prize in Physics to Albert Fert and Peter Grünberg for their 1988 discovery of Giant Magnetoresistance (GMR) in magnetic multilayers. We congratulate our colleagues at Université Paris-Sud and Forschungszentrum Jülich on this ultimate recognition of their brilliant achievement.

Finally, I'd like to express my sincere gratitude to UCSD, especially Prof. Frieder Seible, Dean of the Jacobs School of Engineering, for the great honor recently bestowed upon me – an appointment to a CMRR endowed chair. My affiliation with the Center, dating back to my first visit in 1985, has been a continuous source of personal and professional satisfaction. I feel truly fortunate to be a part of this remarkable organization and the data storage technology community to which it belongs.

I hope you enjoy the rest of this issue of CMRR Report, and I look forward, with you, to another year of collaboration and progress in magnetic recording research.

CMRR Student Receives an ASME Award

Ralf Brunner a graduate student in Professor Frank Talke's group has been awarded a Graduate Student Fellowship Award from the ASME Information Storage and Processing Systems Division. This honor consists of a monetary award and free registration for the annual ISPS Conference. The award was presented at the Conference Dinner on June 18th , 2007 at Santa Clara University. Congratulations Ralf.

Research Highlight

WRITING AND READING ON PATTERNED MEDIA

Jack K. Wolf, CMRR Professor

Introduction

Patterned media offers the potential of ultra high density recording but is resplendent with new and challenging technical problems that give smiles to the researcher and tears to the engineer. Not the least of these problems is the reliable writing and the reading on this media.

A rapidly growing body of literature exists on various problems related to signal processing for patterned media [1-15]. In this report we give a very brief introduction to some of the problems that our group at CMRR has been pursuing on this subject.

Problems Associated With Reliable Writing of Digital Data

In current HDD's with disks covered with a continuous magnetic coating, a bit can be written anywhere on the disk. Of course, there is some sanity in the placement of these bits. This sanity is enforced by servo markers and sector headers which define the positions of tracks and sectors. In writing, once the position of a sector and a track are found, the placement of the bits on this track is governed by the write clock. This same clock is used in reading. In reading, variations in the angular velocity of the spinning disk are compensated for by timing recovery and tracking circuitry.

For patterned media, bits can only be written on magnetic islands which are embossed into the disk. Thus the placement of the written bits is governed not by a clock but by the locations of the magnetic islands on the disk. This phenomenon introduces a number of new difficulties not present in continuous media. For example, even if the islands were laid out in a perfect geometric pattern, in order to write a bit on a given island, the write head would have to identify the exact position of the island in question. This problem is exacerbated by the fact that there will be irregularities in the placement of the islands. Thus, even if one knew the exact placement of a given island, one may not know the position of other neighboring islands.

As a result, errors may occur in the write process. These errors can take the form of inverted bits (i.e., errors), extra bits (i.e., insertions) or missing bits (i.e., deletions). Relatively little is known about the design and performance of efficient error correcting codes that can correct errors, insertions and deletions. One avenue of research we are pursuing is the search for good codes that correct such imperfections.

Problems Associated With Reliable Reading of Digital Data

Even if ways are found for reliably writing digital data on patterned media, many problems exist for reliably reading this data.

Consider, for example, the effect of an island being shifted from its nominal position by a shift of δx and δz in the down-track and cross-track direction respectively. (See Figure 1.)

Assume that these shifts are statistically independent Gaussian random variables of zero mean and variance σ^2. Let the read-back voltage induced in a read-head centered at (x,z) by an island centered at $(x+\delta x, z+\delta z)$ be expressed in the Taylor series expansion:

$$V(x+\delta x, z+\delta z) = V(x,z) + \delta x V_x(x,z) + \delta z V_z(x,z) + \tfrac{1}{2}[(\delta x)^2 V_{xx}(x,z) +$$

$$2\delta x \delta z V_{xz}(x,z) + (\delta z)^2 V_{zz}(x,z)] + \zeta(x,z)$$

Here, the subscripts indicate partial derivatives, and $\zeta(x,z)$ is the modeling error due to representing the read-back voltage with the first and second derivative. Define e(x,z) as:

$$e(x,z) = \delta x V_x(x,z) + \delta z V_z(x,z) + \tfrac{1}{2}[(\delta x)^2 V_{xx}(x,z) + 2\delta x \delta z V_{xz}(x,z) + (\delta z)^2 V_{zz}(x,z)].$$

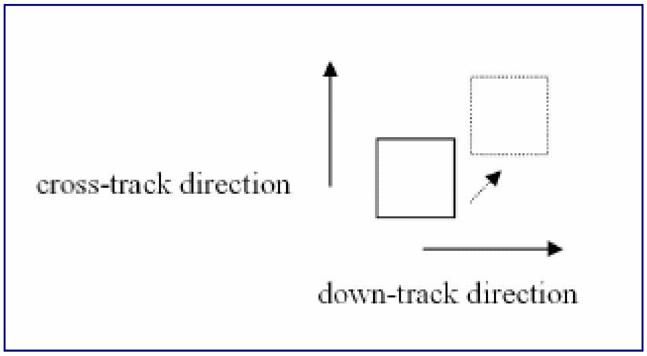
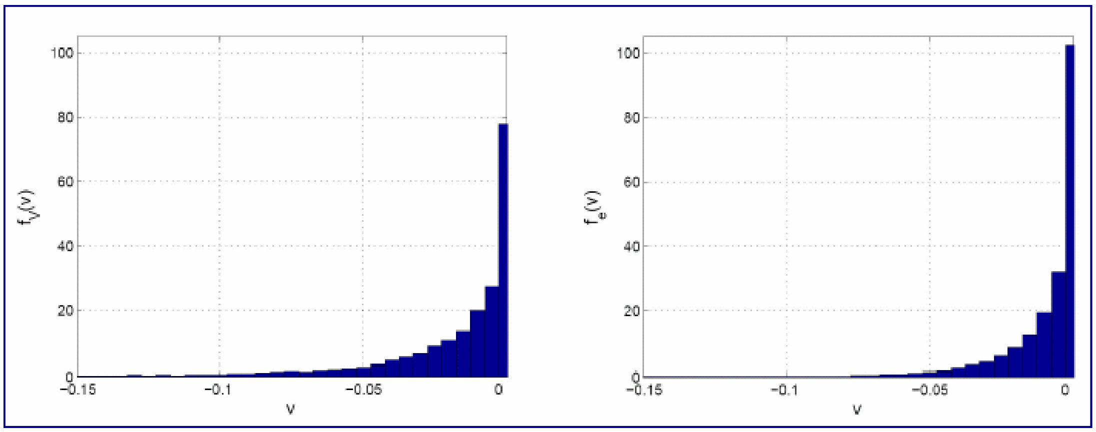


Figure 1.



6000 samples, 6 hours

76582 samples, 1 minute

Figure 2.

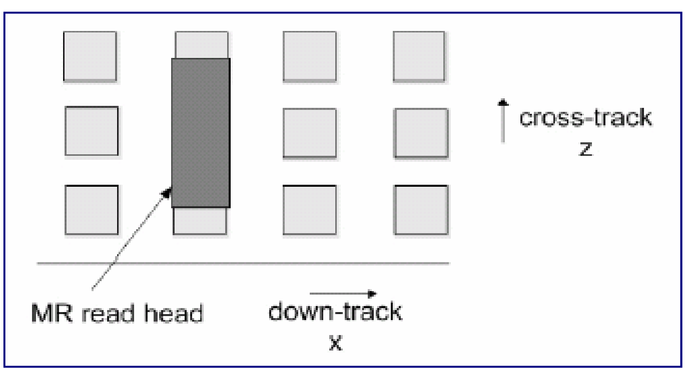


Figure 3.

Then e(x,z) is the second order approximation to the island jitter noise, while the true jitter noise is given as:

$$[V(x+\delta x, z+\delta z) - V(x,z)].$$

One might wonder why a second order approximation was used. The answer is that a second order approximation gives a very good approximation to the true jitter noise and is much easier to compute than the true value. A comparison of the probability density function of the second order approximation and probability density function of the true jitter noise is shown in Figure 2 for a particular choice of the function V(x,z). On the other hand, a first order approximation (using only the terms $\delta x V_x(x,z)$ and $\delta z V_z(x,z)$) would not suffice since the derivatives $V_x(x,z)$ and $V_z(x,z)$ are zero. Furthermore, even if these derivatives were not zero, the terms δx and δz would predict that the jitter noise is Gaussian which most certainly it is not!

Another problem which we have considered concerns the situation where the read-head cannot be made as small as a single island so that islands on more than a single track induce voltages in the read-head. In Figure 3, we show the case where the read-head is centered over a middle track but where the islands on a total of 3 tracks induce voltages on the read-head. In what follows we will assume this special case.

Again we assume there is no error in writing any desired pattern on the islands. The usual approach in reading is to attempt to read the data on the middle track while considering the voltages induced by the data on the two neighboring tracks as noise. Such a situation is called detection with inter-track interference. If the inter-track interference is comparable to the desired signal from the middle track, even the best detector will have poor performance.

Here we consider a case where the read signal induced by the two interfering tracks is of the same order of magnitude as the signal induced by the middle track. Instead of thinking of the signal from the neighboring interfering tracks as noise, the entire output signal from the read-head (due to all three tracks) is considered as information. The good news is that we are reading the data from all three tracks simultaneously so that we have a big boost to the throughput from the read-head. The bad news is that certain patterns of recorded channel bits on the three tracks give identical outputs from the read-head so that only a subset of these patterns can be used, thus reducing the information storing capacity of the disk.

It is best to understand our approach by a simple example. In this simple example we will ignore intersymbol interference (ISI) along the tracks but the reader should be assured that this assumption is not a limitation to the technique but rather is made to simplify the explanation. Let us denote the three channel bits recorded in position i on the three tracks as U_i, M_i, L_i, where U_i, M_i, L_i each take on the values -1 and +1. The letters U, M and L were chosen to stand for <u>U</u>pper, <u>M</u>iddle, and <u>L</u>ower (track). We assume that the read-head linearly combines the signal from the three tracks so that the noiseless output of this head, Y_i, corresponding to these recorded bits is given as:

$$Y_i = G_U U_i + G_M M_i + G_L L_i.$$

The quantities G_U, G_M, and G_L are constants which can be computed from a micromagnetic model of the head.

In what follows we normalize the noiseless output by setting $G_M = 1$. Further, we assume that the head is symmetric so that $G_U = G_L = \gamma$. Thus the noiseless output is given as:

$$Y_i = \gamma(Ui + L_i) + M_i.$$

Table I shows the 8 possible recorded channel bit patterns for (U_i, M_i, L_i) and the corresponding values for the noiseless output Y_i.

Note that if $\gamma = 0$, there are only two distinct noiseless outputs, -1 and +1, corresponding to whether the middle recorded channel bit is a -1 or a +1. This is the case of no inter-track interference where the read-head sees only one track.

If γ is less than 1/2, the noiseless output will be negative whenever the middle bit is negative and will be positive whenever the middle bit is positive. Thus, in the absence of noise one could detect the middle bit with perfect reliability by observing the sign of the output, but in the presence of noise the reliability of this decision rapidly decreases as γ increases.

Table I : Recorded Channel Bits and Noiseless Outputs

U_i	M_i	L_i	Y_i
-1	-1	-1	$-1 - 2\gamma$
-1	-1	+1	-1
+1	-1	-1	-1
+1	-1	+1	$-1 + 2\gamma$
-1	+1	-1	$+1 - 2\gamma$
-1	+1	+1	+1
+1	+1	-1	+1
+1	+1	+1	$+1 + 2\gamma$

If γ is greater than 1/2, note that the polarity of the noiseless output is not always the same as the polarity of the channel bit on the middle track. For example, if a +1 is recorded on the middle track and if two -1's are recorded on the upper track and the lower track, the noiseless output from the read-head would be:

$$Y_i = +1 - 2\gamma$$

which is negative for γ greater than 1/2. Thus a simple threshold detector which assumes that the polarity of Y_i is equal to the polarity of the bit to be detected sometimes would fail in detecting the polarity middle bit <u>even in the absence of any noise</u>.

The number of distinct noiseless outputs depends on the value of γ. This dependence is summarized in Table II.

Table II: Number of Distinct Noiseless Outputs for Different Values of γ.

Value of γ	Number of Distinct Noiseless Outputs
0	2
$0 < \gamma < 1/2$	6
1/2	5
$1/2 < \gamma < 1$	6
1	4

To understand the consequences of this table, let us consider in more detail the case where $\gamma = 1$. This case corresponds to a read-head that spans all 3 tracks and has essentially the same response for all three tracks. The noiseless response to all possible values of (U_i, M_i, L_i) is given in Table III.

Table III: Noiseless Outputs for $\gamma = 1$

(U_i,	M_i,	L_i)	Noiseless Read-Head Output, Y_i
-1	-1	-1	-3
-1	+1	-1	-1
+1	-1	-1	-1
-1	-1	+1	-1
+1	-1	+1	+1
-1	+1	+1	+1
+1	+1	-1	+1
+1	+1	+1	+3

Note that all three patterns containing a single +1 have the same noiseless output so that a detector could not differentiate between them even in the absence of any noise. The same is true for the three patterns containing two +1's. This suggests using only one of the three patterns containing one +1, say (-1, +1, -1), and one of the three patterns containing two +1s, say (+1, -1, +1), in recording. We could then write using one of the four patterns,

$$\{(-1, -1, -1), \quad (-1, +1, -1), \quad (+1, -1, +1), \quad (+1, +1, +1)\}$$

on the three tracks to store two bits of information. Thus in the absence of noise, a detector observing the output from the read-head could correctly detect these two information bits. If noise is present, errors will occur but the probability of error will depend upon the signal-to-noise ratio. If the noise is additive and Gaussian with mean 0 and variance σ^2, it is easy to compute the probability of error in detecting a symbol consisting of the two information bits:

$$\text{Pr[symbol error]} = 3/2Q(1/\sigma^2).$$

Here, $Q(\alpha)$ is the area under a normalized (zero mean, unit variance) Gaussian from α to infinity. The probability of bit error is bounded as:

$$1/2 \text{ Pr[symbol error]} < \text{P[bit error]} < \text{Pr[symbol error]}$$

where if one uses a Gray code to map the two information bits to the four channel patterns, the lower bound is tight at high signal-to-noise ratio.

We next consider the case of a read-head that does not extend fully over the upper and lower island. This is the situation shown in Figure 1. In such a case, $\gamma < 1$. As shown in Table I, for all value of γ in the range $0 < \gamma < 1$, except for $\gamma = 1/2$, there are six distinct noiseless outputs. One can easily choose six of the input patterns to yield these six distinct noiseless outputs. Mapping information to these six patterns, one can see that the information storage capacity in this case is $(1/3)\log_2(6) = 0.8617$ bits per island. The case of $\gamma = 1/2$ is special in that the two noiseless outputs $(-1+2\gamma)$, and $(+1-2\gamma)$ coincide in which case there are only five distinct noiseless outputs and the capacity is $(1/3)\log_2(5) = 0.7740$ bits per island. The performance in additive white Gaussian noise depends heavily on the value of γ. An interesting choice for γ is $\gamma = 1/3$ in which case the six noiseless output values are: {-5/3, -3/3, -1/3, +1/3, +3/3, +5/3} which are uniformly spaced on the real line. The probability of symbol error in this case is:

$$\text{Pr[symbol error]} = 5/3Q(1/3\sigma^2).$$

It is easy to obtain an exact expression for the probability of symbol error for an arbitrary value of γ but the result is not as pretty. Care should be taken in comparing the formulas obtained for the probability of symbol errors for different values of γ since the peak value of the noiseless output signal, the variance of the Gaussian noise and the symbol size may all, like γ itself, be a function of the read-head characteristics.

The previous description summarizes some of the research performed by Hao Wang, Seyhan Karakulak, H. Neal Bertram, Paul H. Siegel and myself on signal processing for patterned media. Interested readers should attend our CMRR review where more up-to-date information is described in much greater detail.

References

1. R. White, R. New, and R. Pease, “Patterned media: A viable rout to 50 Gbit/in2 and up for magnetic recording?,” *IEEE Trans. Magn.*, Vol. 33, pp. 990-995, Jan. 1997.

2. S. Nair, and R. New, “Patterned media recording: Noise and channel equalization,” *IEEE Trans. Magn.*, Vol. 34, pp. 1916-1918, Jul. 1998.

3. G. Hughes, “Read channels for patterned media,” *IEEE Trans. Magn.*, Vol. 35, pp. 2310-2312, Sept. 1999.

4. G. Hughes, “Patterned media write designs,” *IEEE Trans. Magn.*, Vol. 36, pp. 521-527, Mar. 2000.

5. G. Hughes, *Patterned Media, the Physics of Ultra-High-Density Magnetic Recording*, M. Plumer, J. van Ek, and D. Weller, Eds., Berlin, Germany, Springer-Verlag, 2001, ch. 7.

6. M. Albrecht, C. Rettner, A. Moser, M. Best, and B. Terris, “Recording performance of high-density patterned perpendicular magnetic media,” *Appl. Phys. Ltrs*., Vol. 81, pp. 2875-2877, Oct. 2002.

7. G. Hughes, “Read channels for patterned media with trench playback,” *IEEE Trans. Magn.*, Vol. 39, pp. 2564-2566, Sept. 2003.

8. P. Nutter, D. McKirdy, B. Middleton, D. Wilton, and H. Shute, “Effect of island geometry on the replay signal in patterned media storage,” *IEEE Trans. Magn.*, Vol. 40, pp. 3551-3558, Nov. 2004.

9. A. Takeo and N. Bertram, “Pulse shape, resolution, and signal-to-noise ratio in patterned media recording,” *J. Appl. Phys*., Vol. 97, pp. 104-1 to 104-3, 2005.

10. Y. Suzuki, H. Saito, H. Aoi, H. Muraoka, and Y. Nakamuri, “Reproduced waveform and bit error rate analysis of a patterned perpendicular medium R/W channel,” *J. Appl. Phys*., Vol. 97, pp. 108-1/3, 2005.

11. H. Richter, A. Dobin, R. Lynch, R. Brockie, O. Heinonen, K. Gao, J. Xue, R. van der Veerdonk, P. Asselin, and M. Erden, “Recording potential of bit-patterned media,” *Appl. Phys. Ltrs*., Vol. 88, pp. 222512-1/3, May 2006.

12. N. Yasuaki, N. Mitsuhiro, O. Yoshihiro, O. Hisashi, A. Hajime, M. Muraoki, and N. Yoshihisa, “A study of LDPC coding and iterative decoding system using patterned media,” *IEIC Technical Report*, Vol. 106, pp. 43-48, 2006.

13. J. Hu, T. Duman, E. Kurtas, and F. Eden, “Coding and iterative decoding for patterned media storage systems,” *Electronics Letters*, Vol. 42, pp. 934-935, Aug. 2006.

Graduate Degrees Awarded

Maik Duwensee, a mechanical engineering student in Professor Frank Talke's lab, received his Ph.D. in Spring 2007. Maik's dissertation was entitled "Numerical and Experimental Investigation of the Head/Disk Interface." His main research was focused on air bearing and particle based simulations of the head/disk interface of discrete track recording and patterned media. After graduation, Maik joined **Hitachi Global Storage Technologies**, a CMRR sponsor, in San Jose, California. He is currently working on the development of Hitachi's enterprise class hard disk drives.

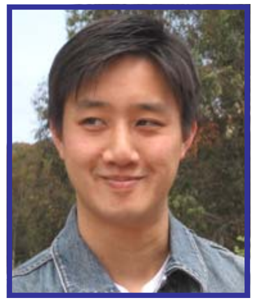
Aravind Murthy, a member of Professor Frank Talke's lab received his Ph.D. in September 2007. Aravind's dissertation was entitled "Investigation of the Effect of Shock, Vibration, Surface Texture and Surface Pattern on the Dynamics of the Head Disk Interface." His research mainly focused on: 1) shock investigation in different form factor hard disk drives, and 2) effect of surface texture and surface pattern on the dynamics of the head disk interface. Aravind has accepted a position as a HDI Engineer in the Advanced Technology group at **Hitachi Global Storage Technologies**, San Jose, CA, a CMRR sponsor.

Bart Raeymaekers, a graduate student in Professor Talke's group received his Ph.D. in June 2007. His dissertation was entitled "Sliding Contacts and the Dynamics of Magnetic Tape Transport." In September 2007, Bart began a MBA program at MIT, Sloan School of Management, in Cambridge, MA.

Graduate Students & Researchers Near Completion

Student	Level	Advisor	Dept	Research	Completion
Junsheng Han	Ph.D.	Siegel	ECE	Error-correcting codes, iterative decoding, network coding	2007
Mohammad Hosssein Taghavi	Ph.D.	Siegel	ECE	Finite-length study of capacity-approaching codes	2008
Jianfeng (John) Xu	Ph.D.	Talke	MAE	Head/disk interface, near-contact recording, simulation tribology	2007

New Graduate Students

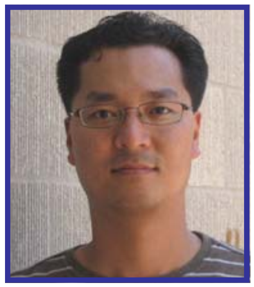


Keith Chan has joined Professor Eric Fullerton's group after completing a M.S. degree in Physics at the University of California-San Diego. With a background in the synthesis of various nanowire materials, Keith will focus his attention on the design and applications of functional magnetic nanostructures.

Kenneth Domond is a new BS/MS student in Professor Frank Talke's group. He received his BS degree at the University of California-San Diego and is continuing his education in mechanical engineering. His focus is on mechanical design, analysis, and modeling of hard disk suspension. He is a member of the National Society of Black Engineers. Outside of class, he enjoys mountian biking, exploring foods, and dabbling in hip hop culture.

Bhupendra Kumar is a new material science and engineering Ph.D. student in Professor Sungho Jin's group. He received his B. Tech degree from IT-BHU, India, in ceramic engineering and a M. Sc. Degree from NUS, Singapore in materials science. He worked for two years at NUS and NTU as a research associate before joining UCSD. His research interest includes transparent conducting oxides, optoelectronic properties of nanostructured materials, and ink jet and transfer printing of nanostructured materials. He enjoys outdoor sports, such as, soccer, cricket etc. He also enjoys reading, and cooking.

Stephanie Moyerman is a new graduate student from Philadelphia, Pa. She graduated from Harvey Mudd College in the spring of 2006 with B.S. Degrees in mathematics and physics. She is now pursuing her Ph.D. in physics with CMRR Professor Eric Fullerton, specializing in magnetic materials. Since 2006, she has been traveling the world studying judo under the Thomas J. Watson Fellowship. Aside from judo, she enjoys rugby and extreme sports.



Young (Michael) Oh is a new Ph.D. graduate student from Seoul, Korea Professor Sungho Jin's research group. His research interest is patterned media using AFM lithography. He received his B.S. and M. Sc. degrees in chemistry from Hanyang University in Seoul, Korea. Since 2000, he has been working at the research institute of Samsung Cheil Industries, Inc. and is currently supported by the company while he earns his Ph.D. Outside of classes, Michael enjoys swimming and traveling.

New Graduate Students

Erik Shipton is a graduate student in the physics department. He is currently working with Professor Eric Fullerton in the field of nanomagnetism.

Eitan Yaakobi is a new graduate student from Israel working with Professors Jack Wolf and Paul Siegel. He received his B.A. degrees in computer science and mathematics from the Technion, Haifa, Israel. His M.Sc. degree in computer science also from the Technion was based upon a thesis entitled "Error-Correction of Multidimensional Bursts." Eitan spent last summer working at **Marvell Semiconductor, Inc**., a CMRR sponsor, on the problem of asymmetry correction in optical recording channels.

Postdoctoral Scholars

Ioan Tudosa joined Professor Eric Fullerton's group in August 2007 as a postdoctoral scholar. He received his B.Sc. in engineering physics in 1999 from Al. I. Cuza University in Romania and his Ph.D. in applied physics from Stanford University in 2005. Following graduation Ioan spent two years at Max Planck Institut for Microstructure Physics in Halle, Germany. His research interests are fast magnetization switching and applications of spin injection. Ioan also spent a year of his graduate studies at Ohio State University and became a football fan watching the Buckeyes. In his free time Ioan enjoys swimming, hiking, going to the beach, and improv theater.

New Undergraduate Student

Bryan Lettner is a new undergraduate student working in Fred Spada's lab. His work involves degaussing and measuring fields of degaussers. He is a physics major and will graduate in June 2009.

Visitors

Uwe Boettcher is a visiting student from Germany doing an internship in Professor Frank Talke's group. He has been studying electrical engineering at Dresden University of Technology since 2003. In 2005, he received his pre-degree and specialized in precision mechanics. Besides his work, Uwe enjoys jogging, swimming and playing the guitar.

Niels Herter is a visiting student in Professor Frank Talke’s group for the academic year 2007-2008. Niels is here on a scholarship from the German Academic Exchange Service (DAAD). In 2004, he entered the mechanical engineering program at the University of Rostock . In 2007, he passed his intermediate diploma with a specialty in structural engineering. Outside of the lab, Niels enjoys playing soccer and golf.

Jan Krueger is a visiting student in Professor Frank Talke’s group for the academic year 2007-2008. Jan is here on a scholarship from the German Academic Exchange Service (DAAD). In 2003, he joined the mechanical engineering program at the University of Rostock. In 2005, he passed his pre-diploma successfully, specializing in drive technology and automobile technology. Outside of the lab, Jan enjoys sailing and windsurfing.

Maja Maria Stoevhase is a visiting student in Professor Frank Talke's group for the academic year 2007-2008. Maja is here on a scholarship from the German Academic Exchange Service (DAAD). In 2003, she joined the mechanical engineering program at the University of Rostock .In 2005, she passed her pre-diploma successfully, specializing in structural and fluid mechanics. Outside of the lab, Maja enjoys tennis, soccer and traveling.

Industrial Visitor

Toshio Ito is a new industrial visitor from **Fujitsu Laboratories LTD.**, Japan. His appointment at CMRR is from October 2007 through September 2008. He will work with Professors Paul Siegel and Jack Wolf. His research focus will be on signal processing for bit patterned media recording. Welcome Toshio!

Gifts, Grants and Awards

CMRR Professor Eric Fullerton has been elevated to the grade of Senior Member in the IEEE.

Assistant Professor Deli Wang, a CMRR Research Affiliate, has been selected by the Academic Senate to be one of the 2007-08 Hellman Faculty Fellows.

Professors Paul Siegel and Raymond de Callafon have received funding from the Information Storage Industry Consortium (INSIC) for their proposal, "Advanced patterned servo analysis via micro-track modeling, vibration analysis and signal processing." This project is in close collaboration with the Data Storage Institute (DSI), Singapore.

Summer Internships

Seyhan Karakulak a CMRR Ph.D. student working with Professors Siegel & Wolf had an internship this summer at Qualcomm, San Diego. Her work involved communication design and analysis.

Aravind Murthy a CMRR Ph.D. student in Professor Talke's group had a summer internship at Delta Design, Inc. in Poway CA. His internship explored ways to control integrated circuit temperatures.

Mohammad Hossein Taghavi a CMRR Ph.D. student in Professor Siegel's group had a summer internship in the ALGO/LMA lab, at Ecole Polytechnique Federale de Lausanne, Switzerland. He worked on decoding algorithms.

Jianfeng Xu a CMRR Ph.D. student in Professor Talke's group had an internship at **Seagate Technology** in Pittsburgh, PA. His work involved the experimental study of tribology on the head/disk interface.

Eitan Yaakobi a CMRR Ph.D. student working with Professors Siegel & Wolf spent the summer at **Marvell Semiconductor, Inc**. a CMRR sponsor.

CMRR Research Review Highlights

The Fall 2007 Research Review and Advisory Council Meeting will be held on October 31st-November 1, 2007. For further information on the Fall Review, please contact Betty Manoulian at 858-534-6707 or bmanoulian@ucsd.edu .

The Spring Research Review held in May 2007 was a well attended success. Over forty five people from CMRR Industrial Sponsor companies and other invited guests participated in the meeting, including several who participated via teleconference.

In addition to the sessions devoted to technical presentations of CMRR research results, the Review featured a special presentation by **Brad Engel,** Ph.D. of Freescale Semiconductor Inc. entitled, "Development and Commercialization of Manetoresistive Random Access Memory (MRAM) Technology."

CMRR Sponsor company employees may access the abstracts and viewgraphs of all Research Review presentations on the CMRR website in the Sponsor Resources section at http://cmrr.ucsd.edu/sponsors/
Contact Jan Neumann with any questions regarding Sponsor Resources at jneumann@ucsd.edu .

Recent Papers and Invited Talks

Professor Emeritus Ami E. Berkowitz
S. Bruck, E. Goering, Y.J. Tang, G. Schultz, and A.E. Berkowitz, **"**Unusual Co moment reduction in the NiCoO/Co exchange bias system,**"** *Journal of Magnetism and Magnetic Materials,* Vol. 310, No. 2, Pt. 3, (March 2007), pp. 2316-2318.

S. Roy, C. Sanchez-Hanke, S. Park, M. R. Fitzsimmons, Y.J. Tang, J.I. Hong, D.J. Smith, B.J. Taylor, X. Liu, M.B. Maple, A.E. Berkowitz, C.-C. Kao and S.K. Sinha, "Evidence of modified magnetism at a buried permalloy/Co interface at room temperature," *Phys. Rev. B*, Vol. 75, No. 1, (2007), pp. 014442.

Professor Emeritus H. Neal Bertram
H.N. Bertram, and B. Lengsfield, "Energy barriers in composite media grains," *IEEE Transactions on Magnetics,* Vol. 43, No. 6, (June 2007), pp. 2145-2147.

V. Lomakin, B. Livshitz, and H.N. Bertram, "Magnetization reversal in patterned media," *IEEE Transactions on Magnetics,* Vol. 43, No. 6, (June 2007), pp. 2154-2156.

Professor Eric E. Fullerton
A. Barman, S. Wang, O. Hellwig, A. Berger, E.E. Fullerton, and H. Schmidt, "Ultrafast magnetization dynamics in high perpendicular anisotropy [Co/Pt]n multilayers," *J. Appl. Phys*., Vol. 101, (2007), pp. 09D102-1-3.

A. Barman, S. Wang, O. Hellwig, E. Dobisz, D. Kercher, E.E. Fullerton and H. Schmidt, "Size dependent precessional dynamics in [Co/Pd]8 patterned nanomagnet arrays," Presented at *10th Joint Intermag/MMM Conference,* Baltimore, MD, Jan 7-11, 2007.

Professor Sungho Jin
A.I. Gapin, X-R. Ye, L-H. Chen, D. Hong, and S. Jin, "Patterned media based on soft/hard composite nanowire array of Ni/CoPt," *IEEE Transactions on Magnetics,* Vol. 43, No. 6, (June 2007), pp. 2151-2153.

C. Choi, D. Hong, A.I. Gapin, and S. Jin, "Control of m-h loop shape in perpendicular recording media by ion implantation," *IEEE Transactions on Magnetics,* Vol. 43, No. 6, (June 2007), pp. 2121-2123.

Professor Paul H. Siegel
B. Moision, A. Orlitsky, and P.H. Siegel, "On codes with local joint constraints," *Linear Algebra and its Applications,* Vol. 422, No. 2-3, (April 2007), pp. 442-454.

M.H. Taghavi and P.H. Siegel, "Equalization on graphs: linear programming and message passing," Proc. 2007 *IEEE International Symposium Information Theory*, Nice, France, (June 24-29, 2007).

J. Han, and L. Lastras, "Reliable memories with subline accesses," Proc. 2007 *IEEE International Symposium Information Theory,* Nice, France, (June 24-29, 2007).

J. Han, P.H. Siegel, and R. Roth, "Bounds on single-exclusion numbers and stopping redundancy of MDS codes," Proc. 2007 *IEEE International Symposium Information Theory*, Nice, France, (June 24-29, 2007).

M.H. Taghavi, "Graph-based decoding in the presence of ISI," *Algorithms, Inference, & Statistical Physics Workshop*, Santa Fe, New Mexico, (May 2007).

Professor Frank E. Talke
J. H. Wang, and F.E. Talke, "Simulation of tape edge wear of magnetic tapes," *Wear*, Vol. 262, No. 5-6, (February 2007), pp.499-504.

B. Raeymaekers, I. Etsion, and F.E. Talke, "Enhancing tribological performance of the magnetic tape/guide interface by laser surface texturing," *Tribology Letters*, Vol. 27, No. 1, (July 2007), pp. 89-95.

B. Raeymaekers and F.E. Talke, "Characterization of taped edge contact with acoustic emission," ASME *Journal of Vibration and Acoustics*, Vol. 129, No. 4, (August 2007), pp. 525-529.

M. Duwensee, S. Suzuki, J. Lin, D. Wachenschwanz, and F.E. Talke, "Simulation of the head disk interface for discrete track media**,"** *Microsystem Technologies*, Vol. 13, No. 8-10, (May 2007), pp. 1023-1030.

Professor Jack K. Wolf
J.K. Wolf, "An introduction to tensor product codes and applications to digital storage systems," *Information Theory Workshop 2006. ITW'06* Chengdu China. (October 2006), pp. 6-10.

S. Karakulak, P.H. Siegel, J.K. Wolf, and H.N. Bertram, "A new read head model for patterned media storage," *The Magnetic Recording Conference (TMRC 2007).* Minneapolis, MN, (May 21-23, 2007), Paper E3 (invited).

J.K. Wolf, "The amazing growth of digital storage," 10th Canadian Workshop on Information Theory, Edmonton, Alberta, (June 2007),. Keynote speaker.

CMRR
Center for Magnetic Recording Research

New CMRR Website

The CMRR website has a new look. We have updated many pages and improved the navigation. Please visit us at:

http://cmrr.ucsd.edu/

CMRR Research Cited

In a recent issue of *Economist Magazine* **CMRR**'s research on disk erasure is cited, "Scientists at the Centre for Magnetic Recording Research at the University of California, San Diego, have put shards of ground-up platters under a scanning magneto-resistive microscope and reconstructed traces of the original data."

To read the complete article go to:

http://www.economist.com/science/displaystory.cfm?story_id=9276300

Director:
Paul H. Siegel

Newsletter Editor:
Jan Neumann James

Photography:
Ray Descoteaux
Betty Manoulian

Contributors:
Betty Manoulian
Jan Neumann
Paul Siegel
Iris Villanueva
Jack Wolf

http://cmrr.ucsd.edu

CMRR
University of California, San Diego
Center for Magnetic Recording Research, 0401
9500 Gilman Drive
La Jolla, CA 92093-0401