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JODIE CHRISTNER, EDITOR

TECHNICAL COMMITTEE UPDATE: MAGNETIC SEPARATION UPDATE

By David Ross Kelland

The development of magnetic separation fundamentals has occurred in parallel with new commercial applications. In the early 1970's, high gradient magnetic separations (HGMS) was a subject for research in the U.S. and, starting shortly thereafter, in several other countries. At the same time, large matrix-type HGMS machines were introduced into the kaolin clay industry where they continue to brighten large amounts of clay. Recently, research has extended the range of HGMS to materials with the very smallest magnetic properties and to particles in the nanometer size range. The commercial applications have steadily increased with the introduction of superconducting magnets and have found their way into the water treatment and immunotherapy industries.

Research Progress

The most recent fundamental work at MIT has been the separation of nanometer size protein coated magnetite particles used for enhancement of MRI imaging of tumors. These particles ranged from 20 to 200 nm falling in the size range where diffusion is important and may dominate magnetic forces. Kelland (1) derived a lower limit of between 3 and 30 nanometers for particle capture by magnetic force opposed by a diffusion-caused particle concentration gradient. More recently, Fletcher (2) wrote a comprehensive paper on diffusion-controlled particle separation including interparticle effects, magnetic dipole interactions and the effect of fluid flow. His calculation of the critical particle size for capture is about 10 nm.

The recent experiments at MIT showed successful separations of particles down to 20 nm. This work was encouraged by experimental evidence of concentration profiles of manganese carbonite particles less than 400 nm by Kramer, Jansen and Perenboom (3). Their profiles appeared after 30 seconds or 1 minute but calculations based on the Gerber model (4) failed to explain such short times. Such calculations match better the earlier work of Takayasu (5) with Ferrofluids where these were repelled from a wire in 1-2 hours. Our results corroborate short times, as little as 5 seconds but better at 25 sec. both under fluid flow and in continuous axial repulsive mode separators. This latter type of separator combines high gradients with the continuous flow characteristic of open gradient designs.

Further fundamental efforts continue in open gradient separation techniques in which the field gradient is provided

by the magnet itself across thin sheets of materials to be separated. Gerber and Boehm (6) have looked at the effect of particle size and ambient air pressure, the increase of the pressure yielding better particle curtain stability and hence better separation results. This advance appears to extend this technique toward smaller particles in the micron size range. The effect of collision processes was also modelled and matched by experiment. This kind of modelling is important for the eventual transfer of such new techniques to industrial processes.

Because magnet design is so important to efficient magnetic separation, considerable interest and effort has gone into superconducting magnets for this use. While some of these efforts have used superconducting magnetic separators for high fields such as the 10T applied to mineral separations by Cheremnykh (7), SC magnets are now used in clay separators to provide fields up to 5T for increased brightness but higher power costs now tip the balance of economics in favor of SC magnets even at lower fields. Another advantage seems to be the ability to wind special coils to control the force density and profile. This approach frees the designer from the saturation limitations of iron (8).

Another route to improving magnetic separation performance is through the enhancement of the magnetic properties of the particulates to be separated. Some recent work on cryogenic cooling to increase susceptibility has been reported (9) and it should be noted that the interest in biological cell separation by tagging with magnetic particles remains high particularly now that successful protein coating for specificity has been achieved.

Two other applications are still the subjects of ongoing research. One is the fractionation of lunar soils (10) and the other is the extraction of heavy metals by the use of microorganisms (11) where their level can be reduced to 1 ppb. Finally, the different approaches to influencing magnetic particles by alternating and pulsed fields or non-magnetic particles in eddy current separators (12) are still the subject of investigation.

Commercial Applications

The main commercial and industrial applications of magnetic separation occur in three industries: mineral beneficiation (mainly clay), water treatment and biological imaging and cell separation. Clay brightening increasingly uses superconducting magnetic separators. These are large machines offered by more than one company.

A very steadily growing field of application for HGMS is that of industrial water treatment. Magnetic separation improves

the performance and economics of polishing boiler condensates, sewage treatment secondary effluents, high pressure boiler feedwater and ultrapure nuclear reactor feedwater where the requirement is less than 1 ppb of heavy metals. Over the last 15 years there have been 60 installations mostly in the U.S. but also in Sweden, Brazil, Thailand, Spain and Japan.

In the pharmaceuticals area, several companies now offer magnetic separators (not necessarily HGMS) for cell separations based on the technology of tagging magnetic particles with protein antibodies which specifically attach to antigens such as cancer cells. The technique is often used in leukemia when the stem cells in bone marrow which become blood cells must be killed off by radiation and replaced. A blood sample is taken before radiation of the patient and cleaned magnetically of all cancerous and pre-cancerous cells before reintroduction. The technique is highly successful.

Some of the applications noted here require treatment of particles in the nanometer range. With new techniques being developed in current research in this size range, the future for HGMS new technology transfer seems to be bright. The parallel progress in research and commercial applications continues today and will into the foreseeable future.

References

- (1) D.R. Kelland, Submicron Magnetic Particle Separation, presented Fine Particle Society Meeting, Chicago, April 1982. Subsequently published, *Particulate Science and Technology* 3:101-113, 1985.
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- (7) P.A. Cherepnykh, *IEEE Trans. Magn.*, MAG-28, 1, January, 1992.
- (8) J. Gerhold, *IEEE Trans. Magn.*, MAG-28, 1, January 1992.
- (9) P. Krist, J. Boehm, R. Gerber and D.R. Kelland, *IEEE Trans. Magn.*, MAG-28, 5, September 1992.
- (10) R.R. Oder, *IEEE Trans. Magn.*, MAG-27, 6, November 1991 (See also D.R. Kelland, *Space Solar Power Review*, 3,121 (1982)).
- (11) A.S. Bahaj, D.C. Ellwood and J.H.P. Watson, *IEEE Trans. Magn.*, MAG-27, 6, November 1991.
- (12) D. Fletcher, R. Gerber, L. Tarrant, and T. Reid, *IEEE Trans. Magn.*, MAG-28, 5, September 1992.

TECHNICAL COMMITTEE UPDATE: MICROMAGNETICS-IMPACTING SCIENTIFIC AND TECHNOLOGICAL ADVANCES

By Professor Jian-Gang Zhu

Recently there have been significant advances in the field of micromagnetics. This research has contributed much needed knowledge and understanding for the development of magnetic storage technology. Significant advances in magnetic imaging techniques have further stimulated the development of micromagnetic theory because direct experimental observations of micromagnetic properties have been obtained.

In the area of modeling thin film recording media, micromagnetic theory has been combined with the Landau-Lifshitz-Gilbert dynamic equations to describe fundamental magnetization processes. These modeling studies have been

very successful in yielding calculated results that show remarkable agreement with experimental evidence. Over the past few years, studies have focused on recording and noise properties and their correlations with film microstructures. These microstructures produce local magnetization fluctuations which cause recording noise in the model. The model prediction that intergranular ferromagnetic exchange coupling can significantly enhance medium noise, especially at high recording densities, has been widely accepted and verified by many experimental investigations. This understanding has made significant impact to the development of high density and low noise thin film longitudinal media.

Recently, ARPA and the National Storage Industry Consortium has co-sponsored a nation-wide research program to develop thin film media to support 10 Gbits per square inch areal densities. To achieve such high recording density not only requires the medium to have high coercivity, but also extremely low medium noise and high coercive squareness. Orienting crystalline easy axes of the magnetic grains along the recording direction can result in a highly square hysteresis loop, however, modeling studies show that orientation could also yield high medium noise at high recording densities in an environment of magnetostatic interaction. A new film microstructure is needed to accomplish the goal. The micromagnetic modeling study has taken the initiative to analyze magnetic hysteresis properties and noise characteristics for various microstructures. The new direction in this area is to study films with novel microstructures by utilizing the micromagnetic model. This approach will provide guidance for the development of more advanced thin film media for higher recording densities.

Progress has been made to include thermally activated magnetization processes in the micromagnetic modeling of the thin film recording media. The work is considered to be difficult due to the intensive computation required. The study has shown that significant thermal decay of a longitudinally recorded signal starts to occur for grains having a volume twice as large as the superparamagnetic limit for isolated magnetic grains. This result raises concerns about developing the 10 Gbit per square inch thin film media since small grains are required to achieve a high signal to noise ratio.

Micromagnetic modeling of magnetoresistive heads has provided substantial understanding of the performance characteristics and domain stability of various bias designs. Using modeling to evaluate designs for future giant magnetoresistive heads has been an important and successful approach in the on-going NIST/NSIC program in developing recording heads for 10 Gbit per square inch density disk drives.

Micromagnetic studies of small magnetic particles continue to make significant progress. Many of the advances were stimulated by micromagnetic experimental results made possible only recently through advances in magnetic microscopy imaging technology. One new technique has been demonstrated for detecting the magnetic switching of individual particles using a transmission electron microscope (TEM) to detect the polarity of the field produced by the particle. Using this technique, the switching field of a single isolated particle of γ -Fe₂O₃ has been measured, as well as the angular dependence of the switching field.

Another new technique has been developed for measuring the switching fields of artificially-fabricated individual sub-micron magnetic particles. It uses a magnetic force microscope (MFM), in which an in situ magnetic field can be applied. This allows the study of remnant hysteresis states of the particles as a function of external field. By fabricating an array of these particles with designed interparticle separations and particle sizes, cooperative switching of the particles in the array due to interparticle magnetostatic interactions has been studied and characterized. A model combining the finite element method (FEM) and micromagnetic theory has been developed to study small magnetic particles and has been utilized to study the micromagnetic structures of these fabricated particles. Excellent agreement between the experimental measurements and micromagnetic calculations has been achieved. Since FEM is used for a numerical discretization of a particle, the model enables studies of the effect on the magnetic switching modes and characteristics of irregular particle geometry and imperfections inside particles.

MFM has been also used as an ultra-sensitive magnetometer to study the magnetic hysteresis of single isolated natural magnetic particles, such as barium-ferrite and metallic Fe recording particles. It has been demonstrated that the MFM technique is capable of measuring particles with dimensions as small as 40 nm and magnetic moments as weak as 10^{-14} emu. Such investigations can provide direct information about micromagnetic magnetization reversal modes. A study of cobalt-titanium doped barium-ferrite particles was able to provide a relationship between the switching field of an isolated particle and particle diameter. A combined micromagnetic modeling study has suggested that an excessively doped region on an edge or in a corner of a particle can act as a nucleating center where reversal initiates at a significantly reduced switching field value. The MFM study also demonstrated that magnetizing a particle 80 nm in diameter parallel to the particle platelet surface can force the particle into a multidomain state. The MFM imaging was able to clearly resolve the two opposite-polarity domains in the particle. This multidomain formation process was also accurately predicted by the micromagnetic modeling.

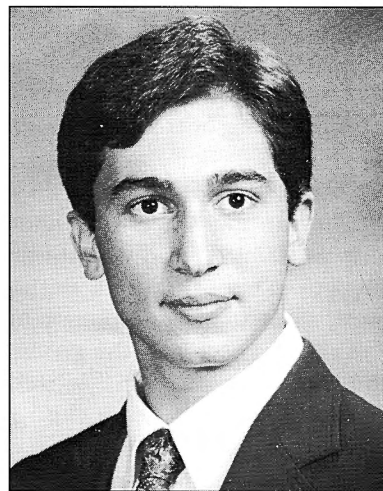
The scanning electron microscopy with spin polarization analysis (SEMPA) technique has also facilitated many micromagnetic studies. An excellent example is the study on the 180 degree surface domain wall in ferromagnetic material. The SEMPA technique enables direct measurement of the magnetization configurations on the material surface. Combined micromagnetic calculations showed excellent agreement with experimental observations and provided further understanding of surface spin orientations due to internal two-dimensional vortex wall structures.

Micromagnetic investigations of thermally activated magnetization reversals in elongated magnetic particles, such as CrO_2 , have shown that magnetic switching can be initiated from a section of the particle which could be much smaller than the particle volume. This result explains the experimental observations of this phenomenon for CrO_2 particles.

Due to the limited length of this article, many important advances in the field of micromagnetics, which should have been discussed here, may have not been included. Nevertheless, micromagnetic modeling studies not only have

enriched our fundamental understanding about magnetic materials, but also have been providing guidance for many advances of magnetic recording technology. With the availability of more and more powerful workstations, supercomputers, and massively parallel computers, this field will be more fruitful and will make greater impact in a broad range of technological applications.

MAGNETICS SOCIETY NATIONAL MERIT SCHOLARSHIP WINNER



Olgun Guvench

We are happy to announce that the winner of the 1993 National Merit Scholarship, sponsored by the IEEE Magnetics Society, is Olgun Guvench, son of Mustafa and Serpil Guvench of Falmouth, Maine.

Olgun will attend Harvard University where he will major in biochemistry in preparation for a career in medicine. Olgun hopes that earning a medical degree will enable him to make a positive difference in people's lives. Olgun, as a junior, was one of 103 top students from the United States and various places around the world including France, Singapore and Yugoslavia who participated in the 1991 Research Science Institute sponsored by the Center for Excellence in Education. His oral presentation of his research was judged to be among the top fifteen in the program. His other academic achievements include the Maine Scholars Award, National Honor Society membership, USA Mathematics Talent Search qualifying scores, the Princeton Book Award, Women's Literary Union delegate, and the Presidential Academic Fitness Award.

Olgun's exceptional academic record is complemented by his involvement in a wide variety of extra-curricular activities. As a freshman he founded the school newspaper and has been the editor in chief all 4 years. In addition, he is co-editor of the yearbook, a member of the National Honor Society, the Math team, the Foreign Language Club and various committees. In his freshman year he received the Jeffrey Robertson Memorial Award for his outstanding scholarship, citizenship and service, and as a junior received the Daughters of the American Revolution Good Citizenship Award as voted by his classmates. Some of Olgun's other activities include the Portland Youth Symphony, the Jazz Ensemble and a principal player in several drama productions.

NATIONAL ENGINEERS WEEK GOES SHOPPING

IEEE NEWS, WASHINGTON, Sept. 29 — The American Shopping Mall. For better or for worse, it has become the suburban village square, a gathering place where folks of all ages go not just to shop, but to eat, play, exercise, flirt and just hang out. And for National Engineers Week 1994, to be celebrated February 20-26, they'll also flock to see solar-powered cars, try their hand at building popsicle-stick bridges, and listen to engineers explain technological wonders.

That's because engineers all over the country will be organizing interactive exhibits and technology fairs for "Engineering Goes Public," National Engineers Week's newest program. The goal is to give everyone from children to senior citizens a greater understanding and appreciation of technology and the role of engineers in shaping the world we live in.

Local E-Week councils have pioneered these mall events, and report that the programs are well-attended, effective and even fun for participants and volunteers alike. There are many advantages to sponsoring an engineering day at the mall: **low cost**, since many shopping centers will offer the space free of charge; **access to the general public** — a large captive audience is already there, especially on a busy Saturday; and **excitement**, because of the wide variety of interactive displays, contests and technology exhibits possible in such a large, informal environment.

The possibilities for the "Engineering Goes Public" program are limited only by your imagination and creativity. With space-age vehicle demonstrations, interactive computer displays and toothpick-and-marshmallow building contests, every engineering discipline can get in the act. Engineering students contribute their infectious youthful enthusiasm. And the mall's public relations staff and commercial tenants can help out with free publicity, prizes and refreshments. Like the mall itself, your "Engineering Goes Public" can become a true community project.

To get started, contact your local section. For a detailed handbook on every aspect of planning a mall event, write to National Engineers Week, 1420 King Street, Alexandria, Va. 22314. As always, Pender McCarter or Chris Currie of IEEE in Washington are happy to answer your questions about "Engineering Goes Public" or any National Engineers Week program. Call them at 202-785-0017.

See you at the mall.

MAGNETICS SOCIETY SCHOLARSHIP PROGRAM

We are pleased to announce the 1995 competition of the Magnetics Society Scholarship Program. This program has been established for the children of Magnetics Society members through the annual nationwide scholarship competition conducted by the National Merit Scholarship Corporation. The National Merit Scholarship Corporation (NMSC) is an independent, nonprofit organization whose major purposes are: (1) to identify and honor exceptionally talented high

school students and to aid as many as possible in obtaining a college education, and (2) to enable business enterprises and other organizations to contribute more readily and effectively to the support of higher education through scholarship grants.

One Magnetics Society Scholarship will be awarded in the Spring of 1995 to a student who will complete high school requirements and who will enter a regionally accredited U.S. college in 1995 to pursue courses of study leading to one of the traditional baccalaureate degrees.

The Magnetics Society winner will be chosen through the facilities of NMSC from among children of Magnetics Society members who meet the competition requirements established by NMSC. The winner will be chosen on the basis of test scores, academic record, leadership, and significant extracurricular accomplishments.

The Magnetics Society Scholarship will be a renewable award covering up to four years of full-time study or until baccalaureate degree requirements are completed, whichever occurs first. The amount of the stipend accompanying the scholarship will be related to the individual winner's financial situation and the costs of attending the college of the winner's choice. The maximum amount that may be awarded to a winner is \$4,000.00 per year; the minimum will be \$1,000.00 per year.

Descriptive material and entry blanks for the Magnetics Society Scholarship may be obtained by writing to the Magnetics Society Scholarship Program Director listed below. Interested children of members should arrange to take the PSAT exam in October of this year if they are high school juniors.

Completed entry blanks must be returned to the Program Director by January 31, 1994.

Dr. Ernst Schloemann
Magnetics Society Scholarship Program Director
%Raytheon Company
Research Division
131 Spring Street
Lexington, MA 02173

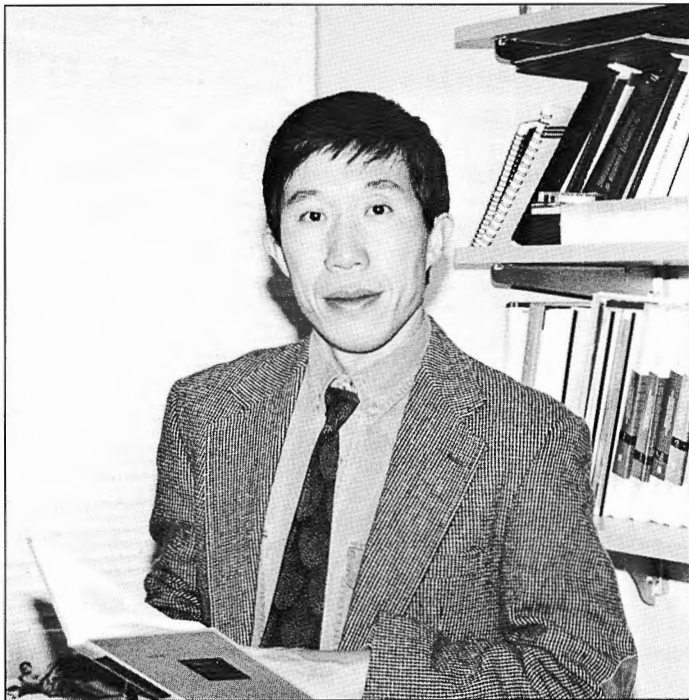
IEEE Magnetics Society Newsletter is published quarterly by the Magnetics Society of The Institute of Electrical and Electronics Engineers, Inc. Headquarters of the IEEE is 345 East 47th Street, New York, NY 10017-2394. \$1.00 per member per year (included in Society fee) for each member of the Magnetic Society. Printed in USA. Second-class postage paid at New York, NY and at additional mailing offices. **Postmaster:** Send address changes to IEEE Magnetics Society Newsletter, IEEE, 445 Hoes Lane, Piscataway, NJ 08854-4150.

The objective of the **IEEE Magnetics Society Newsletter** is to publicize activities, conferences, workshops and other information of interest to the Society membership and technical people in the general area of applied magnetics. Copy is solicited from the Magnetics Society membership, organizers of conferences, officers of the Society and local chapters and other individuals with relevant material. The Newsletter is published in January, April, July and October. Submission deadlines are December 1, March 1, June 1, and September 1, respectively.

Please send contributions to:

Dr. Jodie A. Christner
Dept. 2H2
IBM Corporation
3605 Hwy 52 North
Rochester, MN 55901-7829
TEL: 507/253-5513
FAX: 507/253-4146
E-Mail: J.CHRISTNER@IEEE.ORG.

PROFESSOR ZHU NAMED NSF YOUNG INVESTIGATOR



Professor Zhu

In May of this year, Professor Jian-Gang (Jimmy) Zhu received the National Science Foundation Young Investigator Award. This NSF award provides five years' support for Professor Zhu's research and educational activities. An excerpt from the award letter explains:

"This award represents recognition of your (Professor Zhu's) significant achievements as a teacher, researcher, and educational innovator; your potential for future contributions to the nation's engineering and scientific enterprise."

Background of the Award

The National Science Foundation Young Investigator Award, formerly the Presidential Young Investigator Award, provides cooperative support for the research and educational activities of some of the Nation's most outstanding and promising young science and engineering faculty. The awards are also designed to enhance the academic career of recent Ph.D. recipients by providing flexible support for research and educational activities. Additionally, it seeks to promote public awareness of the work of academic scientists and engineers and to foster contact and cooperation between industry and institutions that support research and education.

About Professor Zhu

Dr. Jian-Gang Zhu is currently an Assistant Professor in the Department of Electrical Engineering at the University of Minnesota. He is also associated with the Center for Micromagnetics and Information Technologies. He received his

B.S. degree in physics from the Huazhong University of Science and Technology, Wuhan, China, in 1982. His Ph.D. degree in physics was received from the University of California at San Diego in 1989. In 1985, he joined the Center for Magnetic Recording Research at UCSD under the supervision of Professor H. Neal Bertram. As a recipient of an IBM research fellowship, he continued his research work as a postdoctoral fellow at CMRR from 1989 to 1990. During his years at CMRR, he, together with Professor Neal Bertram, developed a micromagnetic simulation model to study magnetization processes in thin film recording media and performed extensive analysis of media noise and correlations with film microstructures. A summary of this work was published as a chapter in the Solid State Physics book series edited by Ehrenreich and Turnbull¹.

In September, 1990, he joined the faculty of the University of Minnesota where he is continuing research in the field of magnetic recording. Currently, his research focuses on important magnetic aspects of high density magnetic recording via both modeling and experimental approaches. Over the past three years, he has established a sizable research group as well as a computer workstation laboratory and a high performance recording measurement laboratory. Two of his Ph.D. students have graduated recently and both of them are presently working in the recording industry. He is also developing a magnetic recording laboratory course designed to introduce recording to undergraduate students through hands-on experience.

In addition to his NYI award, he currently holds the McKnight Land Grant Professorship at the University of Minnesota. He is also a recipient of the 1993-94 IBM Faculty Development Award, and the 1993-94 3M Company Non-tenured Faculty Award.

1. "Fundamental Magnetization Processes in Thin Film Recording Media" by H. Neal Bertram and J.-G. Zhu, Solid State Physics, Edited by H. Ehrenreich and D. Turnbull, vol. 46, pp. 271-371, 1992.

IEEE FELLOW NOMINATIONS

The Fellow Nominating Subcommittee of the Magnetics Society has established a "clearing house" for nominations for the IEEE Fellow Awards.

If you intend to nominate a Magnetics Society member for this award, please let me know about it. Hopefully, this information will avoid duplication of effort and will prevent worthy candidates from being overlooked.

Fellow Nominating Subcommittee
% Richy Josephs
Innovative Instrumentation Inc.
220 Limestone Lane
Willow Grove, PA 19090

215-659-6719 (office)
215-646-3272 (factory voice/fax)

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Terms Expire 31 December 1995

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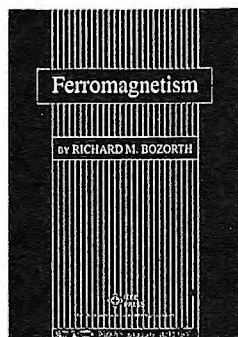
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IEEE REYNOLD B. JOHNSON INFORMATION STORAGE AWARD



The IEEE Reynold B. Johnson Information Storage Award was established by the Board of Directors in 1991 and may be presented annually "for outstanding contributions to the field of information storage, with emphasis in the area of computer storage." Recipient selection is administered by the Awards Board through its Technical Field Awards Council.

The Award consists of a bronze medal, certificate and five thousand dollars, and is sponsored by IBM Corporation. It is named in honor of Reynold B. Johnson, who is renowned as a pioneer of magnetic disk technology and was founding manager of the IBM San Jose Research and Engineering Laboratory, San Jose, California in 1952, where IBM research and development in the field was centered.

The Award was presented for the first time in 1993 to: JOHN M. HARKER.

CALL FOR NOMINATIONS:

REYNOLD B. JOHNSON INFORMATION STORAGE AWARD

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IEEE Awards and Recognition
345 East 47th Street
New York, NY 10017
Phone: 212-705-7882
FAX: 212-223-2911

IMMINK AWARDED THOMSON MEDAL

Kees A. Schouhamer Immink, Magnetics Society member, has been awarded the 1993 J.J. Thomson Medal by the Institution of Electrical Engineers. This award is "For many major contributions to the development of digital audio recording systems, in particular for his theoretical and practical contributions to system theory for optical and magnetic recording."

Biography

Kees A. Schouhamer Immink received the B.S. degree from the Rotterdam Polytechnic in 1967, and the M.S. and Ph.D. degrees from the Eindhoven University of Technology in 1974 and 1985, respectively, all in electrical engineering.

Dr. Immink joined the Philips' Research Laboratories in Eindhoven in 1968, where his work primarily concerned the signal processing side of optical recording systems, later becoming responsible for the design and development of coding techniques for the Compact Disc, Compact Disc Video, experimental erasable optical audio discs, R-DAT, and DCC recorders.

He holds more than thirty patents, mainly in the area of digital recording, and has written numerous papers in the field of coding techniques for optical and magnetic recorders. He is author of the monograph "Coding Techniques for Digital Recorders" and co-author of Principles of Optical Disc Systems, and "Reed-Solomon Codes and Their Applications."

He was elected a Fellow of the Audio Engineering Society in 1985, a Fellow of the IEE in 1987, and a Fellow of the IEEE in 1990; he received the AES Silver Medal Award in 1992.

NOMINATIONS REQUESTED FOR ACHIEVEMENT AWARD

The Magnetics Society of the IEEE honors one of its outstanding members each year for his or her lifelong professional achievement. This is the highest award of the Magnetics Society and is given for scientific, technical and service contributions to the society. The award is presented at Intermag each year and consists of a diploma with citation and a cash prize.

The past award winners were Fred Luborsky 1981, Herb Storm 1982, Harold Lord 1984, Joe Suozzi 1985, Fritz Friedlaender 1986, Andrew Bobeck 1987, Floyd Humphrey 1988, Paul Biringier 1989, Daniel Gordon 1990, Emerson Pugh 1991, Yoshifumi Sakurai 1992 and William Doyle 1993.

Nominations are requested. For your convenience, please use the standard form for a Fellows nomination without references and endorsements (section #10-12). Any member of the Magnetics Society may nominate a candidate at any time. To be considered for the 1994 award, nominations should be received before April 1, 1994. Please send nominations to:

Floyd B. Humphrey
Chairman, Achievement Awards Committee
P.O. Box 722
Meredith, NH 03253-0722

CONFERENCE CALENDAR

Last Update 11/19/93

MAY 24-26, 1994

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Giuseppe Pelosi

Department of Electrical Engineering

University of Florence

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E-Mail: SIENA94@INGFII.CINECA.IT.

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Edward Della Torre

George Washington University

Dept. of Electrical Engineering & Computer Science

Washington, DC 20052

TEL: 202-944-5517, FAX: 202-944-5296

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I. R. Harris

School of Metallurgy and Materials

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