REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing date sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services. Directorate for information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the office of Management and Budget. Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY
(Leave blank)

2. REPORT DATE

30 AUGUST 2005

3. REPORT TYPE AND DATES COVERED

FINAL REPORT 01-June-02 - 31-May-05

4. TITLE AND SUBTITLE

Microwave solitons and precessional dynamics in magnetic thin films - physics and devices

5. FUNDING NUMBERS

Research Agreement: DAAD19-02-1-0197
(ARO Proposal Number P-42866-PH)

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8. PERFORMING ORGANIZATION REPORT NUMBER

None

9. SPONSORING/MONITORINGAGENCYNAME(S) AND ADDRESS(ES)

U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
42866.1-PH

11. SUPPLEMENTARY NOTES

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12a. DISTRIBUTION/AVAILABILITY STATEMENT

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13. ABSTRACT (Maximum 200 words)

There were two focus areas in the original proposal, (I) soliton and short pulse phenomena in ferrite films and (II) linear and nonlinear wave propagation in metallic ferromagnetic films and structures. Under I, considerable effort was devoted to the problem of loss and decay that limits soliton and short pulse phenomena for signal processing and communications and other devices important for Army applications. New results on nonlinear damping, high power foldover, and higher order soliton formation and production were also obtained. New results on soliton trains through modulational instability and recurrence processes were also realized. Under II, progress was made in the characterization of high power microwave and spin wave instability processes in Permalloy films. The one year overlap between this program and the new ARO MURI program on GHz Electromagnetic Wave Science and Devices for Advanced Battlefield Communications, in which Colorado State University is a major participant, allowed for new work as well. This includes the development of active feedback rings for broadband chaotic signal generation in YIG, work on the use of parametric pumping to trap and clone short spin wave pulses, and the production of soliton fractal signals. This work is ongoing under the new MURI program. (200 words)

14. SUBJECT TERMS

Microwave magnetic solitons, ferrite films, metallic magnetic films, spin wave instability, microwave losses, nonlinear dynamics, nonlinear microwave processes in ferrite films, chaos, fractals, magnetic loss and decay, nonlinear damping, foldover, modulational instability, recurrence

15. NUMBER OF PAGES

14

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT **Unclassified**	**18. SECURITY CLASSIFICATION OF THIS PAGE** **Unclassified**	**19. SECURITY CLASSIFICATION OF ABSTRACT** **Unclassified**	**20. LIMITATION OF ABSTRACT** **UL**

Standard Form 298 (Rev. 2/89)
Prescribed by ANSI Std 239-18
298-102

(1) Institution Cover Page

FINAL REPORT
to the
UNITED STATES ARMY RESEARCH OFFICE
Condensed Matter Physics Program
Technical Manager: Dr. Marc Ulrich

Microwave Solitons and Precessional Dynamics in Magnetic Thin Films - Physics and Devices

Research Agreement DAAD19-02-1-0197
ARO Proposal No. P-42866-PH
01 June 2002 - 31 May 2005

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August 30, 2005

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(2) TABLE OF CONTENTS

Section numbers (#) follow ARO Form 18 page 3 specifications.

(4) STATEMENT OF PROBLEM STUDIED

ARO Grant DAAD19-02-1-0197 has supported a three year research program to study the nonlinear magnetization dynamics and the related device physics that are needed for the development of the next generation of microwave and millimeter wave devices for radar and defense related signal processing applications. There were two focus areas enumerated in the original proposal, (I) soliton and short pulse phenomena in ferrite films and (II) linear and nonlinear wave propagation in metallic ferromagnetic films and structures. Both focus areas have the potential for real devices for use in current and future Army systems. Both focus areas also pose important fundamental problems in microwave and millimeter wave magnetics. The proposed Focus Area I work included (1) standing MME solitons in YIG films and YIG film resonators, (2) envelope soliton collisions, (3) soliton trains in active resonant rings for pulse oscillators and frequency comb generators, (4) soliton train generation by mode beating, (5) nonlinear soliton to magnetostatic wave convolvers, (6) active rings based on wide yttrium iron garnet (YIG) films, (7) short microwave pulse generation due to nonlinear compression, and (8) envelope soliton "tunneling." The proposed Focus Area II work included (1) diagnostic Brillouin light scattering (BLS) and inductive magnetodynamic probe (IMP) analyses of linear band stop, band pass, and phase shift metallic ferromagnetic film devices developed by Celinsky and Camley at the University of Colorado at Colorado Springs under a separate Army Research Office program, and (2) additional microwave and probe work on these devices operated at high power. At high power levels, parametric spin wave generation and ferromagnetic resonance foldover and bistability effects, are expected to produce new filtering, phase shifting, and possibly limiting functions for radar applications.

There were significant accomplishments in both focus areas listed above. Under Focus Area I, considerable effort was devoted to the problem of loss and decay that limits the achievement of soliton and short pulse phenomena for signal processing and communications as well as other devices important for Army applications. New results on nonlinear damping, high power foldover, and higher order soliton formation and production were also obtained. New results on soliton trains through modulational instability and recurrence processes were also realized. In Focus Area II, progress was made in the characterization of high power microwave and spin wave instability processes in Permalloy films. The approximately one year overlap between this program and the new ARO MURI program on GHz Electromagnetic Wave Science and Devices for Advanced Battlefield Communications, in which Colorado State University is a major participant, allowed for new work as well. This includes the development of active feedback rings for broadband chaotic signal generation in YIG, work on the use of parametric pumping to trap and clone short spin wave pulses, and the production of soliton fractal signals. This work is ongoing under the new MURI program.

(5) SUMMARY OF THE MOST IMPORTANT RESULTS

a. Overview

The ended soliton and precessional dynamics program under Research Agreement DAAD19-02-1-0197 (P-42866-PH) had two focus areas: (1) soliton and short pulse phenomena in ferrite film; (2) linear and nonlinear wave propagation in metallic films and structures.

This section summarizes the main work on the program. The Focus Area I results relate to polycrystalline as well as single crystal and thin films yttrium iron garnet (YIG) materials. The soliton work was done on narrow single crystal YIG thin film wave guides excited by microwave pulses applied to a microstrip antenna across the strip. The Focus Area II work relates to new results on the high power spin wave instability properties of Permalloy films.

The summary below is broken down into five subsections on (1) losses in ferrite materials and films, (2) nonlinear processes in ferrite films, (3) soliton trains, (4) active rings, and (5) nonlinear processes in metal films. In order to keep the overview compact and direct, citations to published papers and other references are omitted here, and the discussion is limited to brief bullet summaries of motivations and results. Archival papers and presentations are listed in Section (6a). The listed papers are being provided to the ARO separately as per the reporting procedures outlined in ARO Form 18.

Reference 13 in Section (6a) is not included in the subsections below. This paper summarizes some of the material presented by the Principal Investigator at the recent U. S. Army Workshop on Advanced Active Thin Film Materials for the Next Generation of Meso-Scale Army Applications, Destin, Florida, May 10 - 12, 2005. The presentation and Ref. 13 included results on the broad band chaos feedback experiments summarized briefly in subsection 4 below and results on the cloning and trapping of spin wave pulses for versatile long delay line applications.

Selected results of the program were also included in the internal ARO publication, Army Research Office Physics Division Highlights, 2001-2003, page 13-14, "Nonlinear spin waves in magnetic thin films - new possibilities for signal processing."

1. Losses in ferrite materials and films

Propagation loss is the key limiting factor in many microwave magnetic devices. This applies to single crystal film devices that involve soliton propagation and magnetostatic wave pulse delay as well as polycrystalline material based devices such as circulators and isolators. In the course of the research on soliton propagation, it proved necessary to revisit several loss issues.

In the area of low single crystal loss, this led to work in two directions. One concerned three magnon splitting and confluence processes for parametrically pumped magnons in narrow single crystal YIG waveguides. At relatively low frequencies, one can drive the splitting process and parametrically excite half frequency magnetostatic backward volume waves from the directly excited surface waves. In the time domain, this results in the production of extremely narrow pulses that can be useful for microwave signal processing, secure communications, and digital radar applications. In this work [Ref. 3 in Section (6a)], Brillouin light scattering techniques were used to map the spatio-temporal response of both the excited surface waves in the film waveguide and the parametrically excited backward volume waves at one half the pump frequency. The results include fascinating stroboscopic pictures of the film with the power in these modes as the signals build, propagate, and decay into the film. Quantitative connections with the expected magnon modes were also made through the special technique of wave vector selective Brillouin light scattering.

In a slightly different approach, spin wave signals and their decay in YIG films has also been studied by a pulse technique. Here, magnetic field pulses of short duration, rather than microwave signals, were used to excite magnetostatic wave pulse propagation in the film with one microstrip transducer and the response was measured at an output transducer some distance down stream on the YIG waveguide strip [Ref. 11 in Section (6a)]. It was found that the pulse rise time, the pulse field amplitude, and static field could be used to tune the spectra for these "rise time generated" spin waves. The work shows that pulses, in addition to microwave signals, can be used to tune the response of the propagated spin wave pulse in the YIG film waveguide. This work overlaps between this ending ARO grant and the currently active ARO MURI grant on "GHz Electromagnetic Wave Science and Devices for Advanced Battlefield Communications."

Losses in bulk YIG were also investigated. One motivation here is concerned with obtaining the lowest possible losses in easier-to-make and lower cost polycrystalline materials. One important breakthrough was in the production of near theoretical density polycrystalline YIG and the first-time realization in actual practice of the lowest ferromagnetic linewidth ever realized in polycrystalline ferrites [Ref. 2 in Section (6a)]. This was done through the use of hot isostatic pressing (HIPPING) to press a nominally dense material to remove closed pores and achieve theoretical density. The grain sizes in the YIG system used for this initial work were in the 8 micron range. Future plans include work on materials sintered at lower temperatures to maintain a smaller grain size, hipping to theoretical density, and the realization of a very high power capability.

These hipped YIG materials were also used to study, and solve for the first time in 40 years, the problem of off resonance loss in polycrystalline ferrites. Many devices, such as circulators and some isolators, are operated well below or well above the FMR field point in order to use the high dispersion and avoid the large loss found at FMR. These off resonance losses are generally lower than those encountered at the FMP peak position and make for lower insertion loss and other useful properties. The problem has been that these off resonance losses have always been found to be greater than single crystal losses and to depend on microstructure. In this work [Ref. 9 in Section (6a)], it was found that previously neglected low wave number electromagnetic branch spin waves, close to the usual nonmagnetic electromagnetic branch dispersion line, contribute significantly to the two magnon scattering losses at high field and cause the previously baffling response. The practical impact of these results is that it may be possible to tailor the microstructure to minimize this low wave number two magnon effect, and thereby reduce the device losses to near single crystal values.

2. Nonlinear processes in ferrite films

Just as the linear damping is the starting point for the control of loss in ferrite devices, the increase in the damping when the power is increased is of prime importance in the nonlinear regime. Reference 6 in Section (6a) describes measurements on the decay rate as a function of power for propagating spin wave pulses in narrow YIG waveguides through the inductive magnetodynamic probe (IMP) technique. The data show that there is a threshold, as one would expect, for the onset of nonlinear damping. Additionally, there is evidence for both a first order term that scales with the power and a second order term that scales with the square of the power.

Reference 4 in Section (6a) presents a "tour de force:" (as one reviewer called it) on the foldover that occurs in the ferromagnetic resonance profile at high power levels due to heating. There are two foldover effects, one due to the generation of spin waves and one due to heating. The heating effects were isolated through the use of rather thick films of single crystal YIG. For these experiments, the thickness was 100 µm. The foldover occurs because the heating effect increases as one moves up the tail of the FMR absorption curve from low or high field at fixed frequency, or from low or high frequency at fixed field. Since the heating changes the magnetization, the mono-directional change in the FMR position with magnetization will result in an asymmetry in the change in the profile for up sweeps and down sweeps. It was possible do an empirical calibration of the temperature and magnetization change with power and model the response extremely well. There are practical ramifications, in the realization of a thermally induced bistability. Extremely simple thermally driven YIG film bistable power switches could easily be developed, based on these results.

Finally, Ref. 7 in Section (6a) presents comprehensive results on the formation of so-called higher order solitons in YIG film waveguides. The criterion for the formation of a soliton was taken to be a flat phase profile across the pulse. This is the prime indicator of the presence of a non-dispersive nonlinear pulse. The results showed that one can realize actual solitons peaks with flat phase profiles only over a very narrow range of propagation times. Moreover, as the number of peaks in the multiple peaked soliton is increased, this time span can become smaller and smaller. This means that the propagation of actual solitons is fairly restrictive, much more so than previously thought. Careful measurements of the peak velocities as a function of the peak power were also made. It was possible to demonstrate that the localized soliton peak velocity is a linear function of the actual power at the peak. A nice match with simple soliton theory, based on the method of envelopes and the nonlinear spin wave dispersion, was found.

3. Soliton trains

As noted in the original proposal, the use of soliton pulse trains offers an attractive way to produce phase locked phase shift keyed (PSK) pulse signals for use in microwave signal processing and communications. The current technology to produce such signals is much more complicated. Three important papers were published in this area. The first [Ref. 1 in Section (6a)] concerns the important phenomena of recurrence, first discovered by Fermi, Pasta, and Ulam in 1955 and considered to be one of the breakthroughs in the area of nonlinear wave phenomena. In our work, it was possible to produce spatial recurrence through the nonlinear mixing of two closely spaced cw magnetostatic wave signals. The resulting modulational instability produced period doubling, cnoidal wave trains, and solitons, all with a clear and simple spatial recurrence.

It was also found that a extremely simple model, in which all frequency component of the signal were superimposed with an appropriate nonlinear phase shift, could be used to match the data almost perfectly. This gives a direct connection between the well understood induced modulational instability process for the mixing of two nonlinear waves and recurrence. After protracted discussions and several rebuttals, the battle to publish this (in our opinion) critical and fundamental result in recurrence was rejected by Physical Review Letters and published in J. Appl. Phys.

The second and third sets of results in this area concerned the production of soliton trains by modulational instability processes. Ref. 8 in Section (6a) considers self modulational instability processes, based on a single cw input signal. This work utilized YIG films with pinned surface spins and the corresponding presence of so-called dipole gaps in the spin wave dispersion response of frequency w_k versus vs. wave number k. The change in sign for the dispersion coefficient $D = \partial^2 w_k / \partial k^2$, defined as the curvature of the $w_k(k)$ dispersion curve, as one moves from one side of the dipole gap to the other in frequency, made it possible to use the spontaneous modulational instability process to produce both bright and dark soliton trains.

This was the first reported production of dark solitons through an SMI process. There is, as of yet, no theoretical explanation of this empirical result. The ability to produce both bright and dark soliton trains in one and the same YIG film or YIG film device holds significant advantages for digital signal processing applications. While bright soliton trains consist of phase locked pulses with phase jumps of 360° between pulses, dark soliton trains show a phase change of 180° just at the center of each pulse. This property, and the mix of the bright and dark pulse train phase properties could, in concept, lead to a new generation of PSK digital pulse signal processing techniques and devices. This paper did appear in Physical Review Letters.

Reference 10 in Section (6a) considers induced modulational instability processes in which two cw input signals, closely spaced in frequency, are used to produce soliton trains. Even though the YIG waveguide configuration corresponds to an attractive nonlinearity and bright solitons, it was found that one can change the input power and produce dark solitons as well. It appears that one can explain these responses if higher order nonlinear terms are included on the nonlinear Schrödinger equation analysis, namely, through use of the more general Landau-Ginzburg equation.

4. Active rings

Nearly from the beginning of the ARO supported microwave magnetic thin film soliton program at Colorado State University, work on the production of soliton trains through the use of active feedback rings has been an important aspect of the work. Early on, Dr. Ming Chen suggested feedback as a way to produce a "soliton oscillator." Over the course of previous grants, it was possible to use feedback to produce trains through an "interrupted" feedback scheme to prevent oscillation, then through a combination of timed pulse inputs and feedback to control the train without switching, and finally the use of feedback rings with no microwave signal input whatsoever to produce trains of soliton eigenmodes in the film. All of this work is documented in previous final reports and archival papers.

In this most recent work, it has been possible to use feedback to produce broad band chaotic spin wave signals in the frequency domain and solitary chaotic pulses in the time domain. These kinds of signals were realized through the simple step of a reduction in the value of the static biasing field for the YIG film device. Previously, this field was kept rather high in order to avoid the action of so-called "three wave processes" that involve half frequency spin waves in addition to the usual propagating soliton pulse at some selected carrier frequency. It is this avoidance that allows one to produce solitons through other "four wave processes" in the first place. If the field is reduced to lower values, however, one drops the position in frequency of the entire spin wave band so that both four wave and three wave processes are allowed. It is this combination that produces the broad band chaos. Reference 12 in Sec. (6a) describes this work. The paper is currently in the first rebuttal stage with Physical Review Letters.

5. Nonlinear processes in metal films

While YIG films provide unique properties for thin film microwave devices because of their low loss, they also have a major drawback because of the relatively low magnetization, with a saturation induction ($4p M_s$) of about 1800 G. Ferrites in general can have $4p M_s$ values approaching 5000 G, but no more. Metallic thin films, such as iron and Permalloy, for example, have much saturation inductions, typically in the 20,000 G range for iron based alloys and in excess of 10,000 G for Permalloy. Professors Zbigniew Celinski and Robert Camley at the University of Colorado at Colorado Springs (UCCS) have been working on low power band pass filters based on metal films for several years, and are working on related new materials and extended device concepts for band stop filters and phase shifters as part of the new MURI program noted above.

While low power operation is the first line of study for many microwave devices, the next level of concern generally concerns the ability to handle high power. This aspect of metallic films for microwave magnetic device applications is addressed in the initial study reported in Ref. 5 of Sec. (6a). This work reports on spin wave instability processes for in-plane magnetized Permalloy films at low field, in the so-called "subsidiary absorption" regime, well below the FMR field, where the dominant processes responsible for the spin wave related nonlinear loss concerns half frequency spin waves. Measurements and theoretical analyses for the full butterfly curve microwave threshold versus static field response were done. The results generally show that these processes are consistent with the standard instability theory used for ferrites for many years, but with suitable modifications to account for the thin film geometry and the presence of metallic relaxation processes. Ongoing work is extending these measurements and analyses to the resonance regime that directly connects to the FMR band stop, band pass, and phase shifter device work at UCCS.

b. Education and Human Resources

Personnel supported and degrees granted during the current grant period are indicated below:

High school summer apprenticeships:	8
Undergraduate research students:	4
Graduate students:	8
Master of Science degrees:	5
Ph.D. degrees granted:	3
Postdoctoral fellows:	11
Visiting scientists:	4

c. Publications and Presentation Statistics

Publications and presentations produced under the current grant are listed in Section (6a). Statistics for the program are indicated below.

Archival journal publications (including accepted, in press publications but not conference proceedings):	11
Conference proceedings articles (in press)	0
Journal articles submitted:	2
Journal articles in preparation:	1
Presentations (# of titles)	48

The above publications include:

Physical Review Letters:	1
Physical Review B:	3
Journal of Applied Physics:	6
IEEE Trans. Magnetics Lab	1

d. Collaborations and Connections

The CSU group has an ongoing interaction with the group of Professor Mark Ablowitz in the Department of Applied Mathematics at the University of Colorado at Boulder. Professor Ablowitz' group is interested in, among other things, the electromagnetic basis of the

NLS equation in magnetics, two dimensional soliton processes in nonlinear optics, and the slow approach collision problem. Other theoretical collaborations include Professor Andrei Slavin at Oakland University, Rochester Michigan and Professor Craig Zaspel, Montana State University, Bozeman.

There have also been extensive international collaborations. We maintain an intensive cooperation with the group of Professor Boris Kalinikos at the St. Petersburg Electrotechnical University, St. Petersburg, Russia and Professor Yuri Fetisov at the Moscow Institute of Radioelectronics and Automation. Professors Kalinikos and Fetisov have contributed greatly to the ARO program.

We also maintain a strong collaboration with the group of Professor Burkard Hillebrands, University of Kaiserslautern, Germany. This collaboration led to, among other things, the development of the time and space resolved Brillouin light scattering measurement capability used for the work in Ref. 3 of Section (6a).

Active Industrial collaborations include Dr. J. Douglas Adam at Northrop Grumman Corporation, Baltimore, Maryland, Mr. Gil Argentina and Munson Chan at Pacific Ceramics, Santa Clara, California, and Drs. H. Gerald Van Hook and Jerome J. Green, both microwave ferrite consultants from Lexington, Massachusetts (previously affiliated with Raytheon Company).

(6) PUBLICATIONS AND PRESENTATIONS

a. Publications:

1. "Spatial recurrence for nonlinear magnetostatic wave excitations," M. M. Scott, B. A. Kalinikos, and C. E. Patton, J. Appl. Phys. **95**, 5877-5880 (2003).

2. "Near theoretical microwave loss in hot isostatic pressed (hipped) polycrystalline yttrium iron garnet," A. V. Nazarov, D. Ménard, J. J. Green, C. E. Patton, G. M. Argentina, and H. J. Van Hook, J. Appl. Phys. **94**, 7227-7234 (2003).

3. "Brillouin light scattering analysis of three magnon splitting processes in yttrium iron garnet films," C. Mathieu, V. T. Synogatch, and C. E. Patton, Phys. Rev. B **67**, 104402-1 - 104402-8 (2003).

4. "Thermal microwave foldover and bistability in ferromagnetic resonance," Y. K. Fetisov and C. E. Patton, IEEE Trans. Magn. **40**, 473-482 (2004).

5. "High power ferromagnetic resonance and spin wave instability processes in Permalloy films," S. Y. An, P. Krivosik, M. A. Kraemer, H. M. Olson, A.V. Nazarov, and C. E. Patton, J. Appl. Phys. **96**, 1572 - 1580 (2004).

6. "Nonlinear damping of high power magnetostatic waves in yttrium iron garnet films," M. M. Scott, C. E. Patton, M. P. Kostylev, and B. A. Kalinikos, J. Appl. Phys. **95**, 6294 - 6301 (2004).

7. "Spatial evolution of higher order microwave magnetic envelope solitons in yttrium iron garnet thin films," M. Wu, M. A. Kraemer, M. M. Scott, C. E. Patton, and B. A. Kalinikos, Phys. Rev. B **70**, 54402-1 - 54402-9 (2004).

8. "Generation of dark and bright spin wave envelope soliton trains through self-modulational instability in magnetic films," M. Wu, B. A. Kalinikos, and C. E. Patton, Phys. Rev. Lett. **93**, 157207-1 - 157207-4 (2004).

9. "High field microwave effective linewidth in polycrystalline ferrites," N. Mo, Y. Y. Song, and C. E. Patton, J. Appl. Phys. **97**, 093901 (2005).

10. "Excitation of bright and dark envelope solitons for magnetostatic waves with attractive nonlinearity," Phys. Rev. B 71, 174440-1 to 4 (2005).

11. “Fast pulse excited spin waves in yttrium iron garnet thin films,” Mingzhong Wu, Boris A. Kalinikos, Pavol Krivosik, and Carl E. Patton, Journal of Applied Physics, in press (2005).

12. “Self-generation of chaotic solitary spin wave pulses in magnetic film active feedback rings,” Mingzhong Wu, Boris A. Kalinikos, and Carl E. Patton, Physical Review Letters, under review (2005).

13. “Nonlinear ferrite film microwave signal processing for advanced battlefield communications – physics and devices,” Carl E. Patton, Mingzhong Wu, Kevin R. Smith, Vitaliy I. Vasyuchka, and Boris A. Kalinikos, Integrated Ferroelectrics, under review (2005).

b. Presentations

Presentations by Principal Investigator:

1. "Low frequency losses in ferrite microwave devices," 47th Annual Conference on Magnetism and Magnetic Materials, Tampa, Florida, November 15, 2002. (Paper presented on behalf of Dr. Ernst Schloemann).

2. "Microwave magnetic envelope soliton formation from long input pulses in yttrium iron garnet thin films," 47th Annual Conference on Magnetism and Magnetic Materials, Tampa, Florida, November 15, 2002.

3. "Brillouin light scattering on spin wave excitations in magnetic thin films," Colloquium, City University of Hong Kong, January 28, 2003.

4. "Some quirks in precession dynamics - the anti-Larmor response," the 2003 IEEE International Magnetics Conference, Boston, Massachusetts, April 3, 2003.

5. "Parametric pumping, nonlinear spin waves, and spin wave instability in Permalloy films," Lecture: National Institute of Standards and Technology Nanomagnetodynamics Workshop at the Summer Meeting of the National Storage

Industry Consortium, Monterey, California, June 26, 2003.

Special Colloquium, Department of Materials Science, University of Maryland, College Park, September 23, 2003.

Special Colloquium, Department of Physics, Queens College CCNY, New York, New York, September 25, 2003.

Special Colloquium, Free University of Berlin, Germany, January 19, 2004.

Special Colloquium, University of Regensburg, Germany, January 20, 2004.

Special Colloquium, Ruhr University, Bochum, Germany, January 26, 2004.

6. "Microwave envelope solitons in magnetic thin films,"

   Colloquium, Department of Applied Physics and Mathematics, Columbia University, New York, New York, September 24, 2003.

   Colloquium, Department of Physics, University of Nebraska, Lincoln, January 20, 2005.

7. "Microwave Ferrite Science and Technology," Colorado State University Materials Science Colloquium, Fort Collins, Colorado, September 29, 2003.

8. "Some informal and unofficial comments on phenomenological damping," The 9th Joint MMM-Intermag Conference, Anaheim, California, January 7, 2004.

9. "Spin wave instability, damping, and critical modes in Permalloy films," Electromagnetics Division Seminar, National Institute of Standards and Technology, Boulder, Colorado, February 17, 2004.

10. "Precession dynamics in magnetic thin films - extension to heads and media," Information Storage Industry Consortium (INSIC) Winter Meeting, San Diego, California, February 24, 2004.

11. "A romp through low and high power magnetic loss parameters and measurement techniques for microwave ferrites," Workshop on Modern Measurements of Ferrite Materials for Microwave and Millimeter Wave Devices, IEEE International Microwave Symposium 2004, Fort Worth, Texas, June 7, 2004.

12. "New materials and configurations for 10-100 GHz microwave devices," Invited lecture:

    Workshop on New Technologies for Frequency Agile Microwave Circuits and Systems, IEEE International Microwave Symposium 2004, Fort Worth, Texas, June 7, 2004.

    Rockwell Scientific, Thousand Oaks, California, July 27, 2004.

13. "Low and high power magnetic loss parameters and measurement techniques for microwave ferrites":

    Featured presentation, Advanced Microwave Ferrite Program Review Board Meeting, University of Idaho, Moscow, Idaho, August 31, 2004.

    Invited lecture, University of Versailles, France, September 20, 2004.

14. "Losses in precessional dynamics - overview of physical relaxation processes," Lecture, Nexbias ultraswitch Summer School, Biarritz, France, September 12, 2004.

15. "Losses in precessional dynamics - phenomenological damping," Nexbias ultraswitch Summer School Lecture, Biarritz, France, September 13, 2004.

16. "Precessional dynamics in magnetic systems - I. Basic precession concepts. II. Phenomenological damping.

    Seminar, Seagate Technology, Inc., Bloomington, Minnesota, January 13, 2005.

    Seminar, Center for Materials Research and Analysis, University of Nebraska, Lincoln, January 21, 2005.

17. "Precessional dynamics in magnetic systems - basic concepts, physical relaxation processes, and phenomenological damping, Department of Electrical Engineering, University of Minnesota, Minneapolis, Special Workshop, January 14, 2005.

18. "Nonlinear ferromagnetic resonance, pulsed field precession dynamics, and spin wave loss in Ni-Fe films," Information Storage Industry Consortium (INSIC) Winter Meeting, Palo Alto, California, March 1, 2005.

19. "Self generation of solitary, chaotic, spin wave pulses," International Magnetics Conference, Nagoya, Japan, April 6, 2005.

20. "Phenomenological damping models as drive to equilibrium," International Magnetics Conference, Nagoya, Japan, April 7, 2005.

21. "Spin wave modulational instability and spin wave envelope soliton generation in magnetic films," Joint Colloquium, Departments of Physics and Mathematics, University of Colorado at Colorado Springs, April 28, 2005.

22. "Nonlinear ferrite film microwave signal processing for advanced battlefield communications – physics and devices," U. S. Army Workshop on Advanced Active Thin Film Materials for the Next Generation of Meso-Scale Army Applications, Destin, Florida, May 11, 2005.

23. "Spin wave envelope solitons in magnetic film feedback rings," International Conference on Nonlinear Waves, Integrable Systems, and Applications, University of Colorado at Colorado Springs and at Boulder, June 6, 2005.

24. "Envelope solitons in magnetic films," Condensed Matter Colloquium, Department of Physics, New York University, June 23, 2005.

Presentations by other group members:

1. "Microwave magnetic envelope soliton formation from long input pulses in yttrium iron garnet thin films," Y. K. Fetisov, 47th Annual Conference on Magnetism and Magnetic Materials, Tampa, Florida, November 15, 2002.

2. "Generation of bright and dark envelope solitons from magnetostatic spin waves with attractive nonlinearity," M. M. Scott, the 2003 IEEE International Magnetic Conference, Boston, Massachusetts, March 28, 2003.

3. "Microwave magnetic envelope solitons in yttrium iron garnet thin films," M. Wu, the 2003 CSU Materials Science Colloquium, Fort Collins, Colorado, September 29, 2003.

4. "Subsidiary absorption and resonance saturation spin wave instability processes in Permalloy thin films – thickness effects and critical modes," P. Krivosik, 9th Joint MMM-Intermag Conference, Anaheim, California, January 6, 2004.

5. "High field microwave effective linewidth in polycrystalline ferrites – physical origins and intrinsic limits," N. Mo, 9th Joint MMM-Intermag Conference, Anaheim, California, January 6, 2004.

6. "Pulsed laser deposited single crystal LiZn ferrite films with narrow ferromagnetic resonance linewidths," Y. Song, 9th Joint MMM-Intermag Conference, Anaheim, California, January 6, 2004.

7. "Spatial evolution of higher order microwave magnetic envelope solitons in yttrium iron garnet thin films," M. Wu, 9th Joint MMM-Intermag Conference, Anaheim, California, January 6, 2004.

8. "Two-magnon scattering processes in thin magnetic films," P. Krivosik, seminar at NIST, Boulder, Colorado, May 21, 2004.

9. "Nonlinear spin wave excitation in thin metal films," H. M. Olson, the 2004 INSIC Meeting, Monterey, California, July 21, 2004.

10. "Ferromagnetic relaxation in Permalloy thin films – a consistency check for ferromagnetic resonance technique and pulsed inductive magnetometry, " S. A. Kalarickal, 49th MMM Conference, Jacksonville, Florida, November 8, 2004.

11. "Two-magnon scattering processes in magnetic thin films – a simple and mathematically tractable model," P. Krivosik, 49th MMM Conference, Jacksonville, Florida, November 8, 2004.

12. "Origin of the low field microwave effective linewidth in ferrites," N. Mo, 49th MMM Conference, Jacksonville, Florida, November 8, 2004.

13. "Generation of bright and dark dipole exchange spin wave soliton trains through induced modulational instability," M. Wu, 49th MMM Conference, Jacksonville, Florida, November 8, 2004.

14. "Rise time generated spin waves for strip line driven small angle switching processes in yttrium iron garnet thin films," M. Wu, 49th MMM Conference, Jacksonville, Florida, November 8, 2004.

15. "Spin wave modulational instability and spin wave envelope soliton generation in magnetic films," M. Wu, Nonlinear Waves Seminar, University of Colorado at Boulder, Boulder, Colorado, April 12, 2005.

16. "Generation of spin wave envelope solitons through modulational instability," M. Wu, International Conference on Nonlinear Waves, Integrable Systems, and Applications, University of Colorado at Colorado Springs and Boulder, Colorado, June 4, 2005.

17. "The cloning of magnetostatic wave pulses by parametric pumping," K. R. Smith, 50th MMM Conference, San Jose, California, October 30, 2005. (Abstract accepted)

18. "Generation of period tunable spin wave envelope soliton trains through induced modulational instability," M. Wu, 50th MMM Conference, San Jose, California, October 30, 2005. (Abstract accepted)

19. "Spin wave envelope soliton fractals in magnetic film based active feedback rings," M. Wu, 50th MMM Conference, San Jose, California, October 30, 2005. (Abstract accepted)

20. "Nonlinear precessional dynamics in thin magnetic metal films for high-speed switching," K. Srinivasan, the 2005 INSIC EDHR Program Meeting, Monterey, California, July 20, 2005.

(7) LIST OF PARTICIPATING PERSONNEL

Personnel supported and degrees granted during the current grant period are indicated below:

High school summer apprenticeships: 8
(REAP - Research Engineering Apprenticeship Program, managed by the Academy of Applied Science and funded by the ARO)

Sarah Matthews, Poudre High School (2002)
Paul Baker, Poudre High School (2002)
Naomi Ott, Poudre High School (2002)
Adam Collet, Poudre High School (2003)
Dana Flook, Poudre School (2003)
Mike Grinolds, Poudre High School (2003)
Bailer Beitscher, Poudre High School (2004)
Robin Dempsey, Poudre High School (2004)

Undergraduate research students: 4

Karl Achieu
Kostadin Algarov
Byron Griffin
Michael Kabatek

Graduate students: 8

Michael Kraemer (Ph. D. July 2005)
Alexey Nazarov (Ph.D. August 2002)
Mark Scott (Ph.D. May 2002)

Richard Cox (Ph.D. Candidate)
Anthony Gorges (Graduate student)
Sangita Kalarickal (Ph.D. Candidate)
Nan Mo (Ph.D. Candidate)
Heidi Olson (Ph.D. Candidate)
Kevin Smith (Ph.D. Candidate)

Master of Science degrees: 6
Ph.D. degrees granted: 3

Postdoctoral fellows: 11

Dr.Aung-Yong An
(now at Kookmin University, Korea)
Dr. Igor Kalinichenko
Dr. Pavol Krivosik
Dr. Christoph Mathieu
(presently at Seagate, Inc., Rochester, MN)
Dr. Alexi Nazarov
(presently at Seagate, Inc., Rochester, MN)
Dr. Mark Scott
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Dr. Young-Yeal Song
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Dr. Kumar Srinivasan
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Visiting scientists: 4

Dr. Jerome J. Green
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Dr. H. Jerrold Van Hook
(Microwave Consultant, retired from Raytheon)