SYMPOSIUM J

Magneto-Optical Materials for Photonics and Recording

November 29 - December 2, 2004

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* Invited paper

TUTORIAL

FT J: Heat-Assisted/Hybrid Recording–The Next Generation in Magnetic Recording
Monday November 29, 2004
1:30 PM - 5:00 PM
Berkeley (Sheraton)

The continued increase in information-storage densities in magnetic hard disk drives is facing a fundamental challenge. This superparamagnetic limit is a consequence of the instability in the magnetization of grains in magnetic media as bit dimensions; therefore, grain volumes are scaled down. Heat-assisted or hybrid recording is one of the solutions being put forward to overcome this limit. This tutorial will explain the challenge facing hard-disk-drive technology. The key features required of a heat-assisted magnetic recording system, and how such a system may overcome the limits faced by hard disk drives, will be explained. Topics to be discussed will include the formation of small optical spots, head integration, and media requirements. Many materials challenges feed into each of these elements and will be described in this tutorial, as will current work in the field.

Instructor:
T.E. Schlesinger
Carnegie Mellon University

SESSION J1: Magnetic-Photonic Crystals I
Chairs: Koji Ando and Miguel Levy
Tuesday Morning, November 30, 2004
Berkeley (Sheraton)

8:30 AM *J1.1
Magnetophotonic Crystals. Mitsuteru Inoue, Dept. of Electrical & Electronic Eng., Toyohashi University of Technology, Toyohashi, Aichi, Japan.

Magnetophotonic crystals, which are one-, two-, or three-dimensional periodic composites of macroscopic magnetic media of different refractive indices. Because of their periodic structures, the magnetophotonic crystals affect the propagation of light providing the photonic bandgap, localized modes in the gap and large enhancement of magneto-optical properties associated with the localization of light. For higher modes of light, the propagation properties of light can be changed by controlling the direction of magnetization with a magnetic filed. In this paper, based mainly on our recent studies, preparation of magnetic ferrite base one-, two-, and three-dimensional magnetophotonic crystals is presented and their fundamental linear and nonlinear optical and magneto-optical properties are described. Some applications of the media for optical communication and light modulation will also be introduced.

9:00 AM *J1.2
Magnetic Photonic Crystals as Artificial Magnetoelectric Media. Alex Figotin and Ilya Vitebskiy; Mathematics, University of California at Irvine, Irvine, California.

Usually, plane electromagnetic waves in homogeneous or periodic heterogeneous media display the fundamental property of spectral symmetry w(k) = w(-k). This relation is a direct consequence of the time reversal and/or space inversion symmetry. If neither of the symmetries applies, the medium can support spectral asymmetry, which implies that plane waves propagate in one direction faster or slower than in the opposite direction. In media with linear magnetoelectric effect such a phenomenon has been known for decades. The problem with magnetoelectric crystals though is that the degree of electromagnetic spectral asymmetry is negligible (0.001 or less). This situation is further aggravated by complicated and often uncontrolled domain structure of natural magnetoelectric materials. All the above problems can be avoided in magnetic photonic crystals, which are periodic arrays of ferromagnetic and other dielectric components. Indeed, the presence of a ferromagnetic constituent can eliminate the time reversal from the macroscopic symmetry group of the periodic array. The space inversion can always be removed by proper choice of the periodic structure geometry, even if each individual constituent is a centrosymmetric material. In this way, the macroscopic symmetry of magnetic photonic crystal can always be made compatible with that of a magnetoelectric crystal. Such a composite will not display any static magnetoelectric effect, but dynamically it can behave like an artificial magnetoelectric medium with huge magnetoelectric response and strong electromagnetic spectral asymmetry, unachievable in any natural material. At least at frequencies below 200 GHz, an appreciable spectral asymmetry can be achieved in periodic stacks composed of common ferrimagnetic and other dielectric components (A. Figotin and I. Vitebsky, Phys. Rev. E63, 066609, 2001). Strong spectral asymmetry can result in the phenomenon of electromagnetic unidirectionality (A. Figotin and I. Vitebskiy, Phys. Rev. B67, 2003). A unidirectional periodic medium, being perfectly transparent for plane electromagnetic waves propagating in a certain direction, "freezes" the radiation of the same frequency propagating in the opposite direction. At the frequency of the frozen mode, the electromagnetic radiation incident on the surface of a unidirectional photonic slab can pass inside the slab with little or even no reflectance, where it gets trapped in the form of a coherent frozen mode with gigantic amplitude and zero group velocity.

9:30 AM *J1.3
Magneto-Optical Response of a One-Dimensional All-Garnet Photonic Crystal in Transmission and Reflection. Soren Kahl and Alexander M. Grishin; Condensed Matter Physics, Royal Institute of Technology, Kista, Stockholm, Sweden.

We present spectra of transmittance, reflectance, Faraday and Kerr rotation for a periodic garnet multilayer structure (magneto-photonic crystal, MPC). The structure consists of eight quarter-wave layers of each bismuth and yttrium iron garnet and a four times thicker central bismuth iron garnet layer. The total thickness is around 1.5 μm and resonance wavelength is around 750 nm. The measurements in reflection were performed with a silver mirror deposited on top of the MPC. The rotation of the plane of polarization is enhanced strongly in reflection. The peak value obtained close to 750 nm, 18 deg, is about 4.5 times higher than if the light passes once through 1.5 μm of pure bismuth iron garnet. This also corresponds to more than threefold enhancement of the rotation as compared to the case of light transmitted through the MPC. Due to the absorption in bismuth iron garnet and the silver mirror, reflectance of only 13% was measured at resonance for the silver-coated MPC. The surface roughness with rms value of 11 nm is sufficient to produce some depolarization at the resonance wavelength, about 5% for the silver-coated MPC. MPCs that work in reflection could be attractive for two-dimensional magneto-optical imaging. This depends on how quickly the magnetic field falls off with increasing distance from the magnetic sample under investigation as well as on the reflectance from the MPC and the sample.

10:30 AM J1.4
New Garnet Films for Magneto-Optical Photonic Crystals. Sergey I. Khartsev and Alexander M. Grishin; Condensed Matter Physics, Royal Institute of Technology, Stockholm-Kista, Sweden.

Engineering of garnet materials which are structuraly compatible and possess high optical contrast with bismuth iron garnet Bi3Fe5O12 (BIG) was the main objective of this study. New La3Ga5O12 garnet (LGG) has been synthesized in the form of epitaxial films pulsed laser deposited on Gd3Ga5O12(111) single crystal. X-ray diffraction reveals epitaxial quality of LGG films: they are single phase, exclusively (hhh) oriented and have a strong in-plane texture. Several TE and TM propagating modes have been detected from "dark" spectra in 2.5 um thick LGG film by prism coupling technique. The refractive index was calculated to n = 1.98 at 655 nm (compared to 1.97 and 2.65 in Gd3Ga5O12 and Bi3Fe5O12 garnets correspondingly). Multiple light scattering in LGG film creates sharp interference pattern in the spectrum recorded in the normal incidence geometry. These data were used to determine the wavelength dispersion of the refraction index. It follows Sellmeier's relation n2̂ = 1 + 2.75/[1-(144nm/λ)2̂] and appears to be as small as 3.8% in the range from 400 to 1000 nm. Epitaxial BIG/LGG/GGG heterostructure was fabricated by pulsed laser deposition of LGG layer and the following deposition of Bi3Fe5O12 film by rf magnetron sputtering. In both processes we used stoichiometric ceramic targets. Giant Faraday rotation above 6 deg/um, which is characteristic for BIG/GGG(111) films, has been preserved in BIG/LGG/GGG(111) structures.

10:45 AM J1.5
Observation of Enhanced Faraday Effect in Garnet-Based Magnetophotonic Crystals. Andrey A. Fedyanin[1], Oleg A. Aktsipetrov[1], Daisuke Kobayashi[2], Kazuhiro Nishimura[2], Hironaga Uchida[2] and Mitsuteru Inoue[2]; [1]Quantum Electronics Division, Department of Physics, Moscow State University, Moscow, Russian Federation; [2]Department of Electrical and Electronic Engineering, Toyohashi University of Technology, Toyohashi, Japan.

Photonic crystals (PC) are dielectric microstructures with periodic modulation of refractive index in one or several spatial directions with period comparable with optical wavelength. The key feature of PC is the photonic band gap (PBG), which represents the prohibition of the propagation of light with the certain wave vector inside PC. PBG manifests itself in reflection and transmission spectra as the spectral region with full reflection and strongly suppressed transmission. One of the important issues regarding the application of PBG materials is the development of the magnetophotonic crystals (MPC), i.e. PC formed from magnetic materials. MPC open up prospects for new spintronic devices utilizing magneto-optical effects. For example, the enhancement of Faraday effect is observed in one-dimensional MPC with the half-wavelength-thick defect layer formed from magnetic material and the Bragg reflectors composed from nonmagnetic materials [1]. The practical difficulty of fabrication of magnetic Bragg reflectors is the magnetic film thickness control critical for the Bragg reflector quality. Another problem is the requirement of the transparent magnetic materials. Bi-substituted yttrium-iron-garnet (Bi:YIG) films are very convenient materials for the MPC fabrication due to low absorption in red and infrared regions, large magneto-optical response and small saturation magnetic fields. In this paper, the fabrication of magnetophotonic crystals formed from Bi-substituted yttrium-iron-garnet layers is reported. Enhancement of the Faraday effect at the PBG edges associated with the multiple reflection interference and light nonreciprocity in MPC is experimentally observed. MPC are fabricated from several repeats (from 4 to 6) of quarter-wavelength-thick layers of Bi-substituted yttrium-iron-garnet and silicon oxide. The PBG is centred at about 950 nm. Coercitivity of MPC is approximately 30 Oe for both configurations. For the tangential field application, saturating magnetic field is slightly above 100 Oe. For the normal configuration of the field application, saturating magnetic field is close to 2 kOe. Transmission spectra of MPC have a low transmission region from 850 nm to 1100 nm corresponding to the PBG and the interference fringes outside it. At shorter wavelengths the transmission becomes smaller and tends to zero at approximately 550 nm correlating with absorption band of Bi:YIG. The spectrum of the Faraday rotation angle demonstrate the strong suppression inside the PBG and a peak at the long-wavelength edge of PBG at 1100 nm, where it enhances up to -0.7 degrees. It corresponds to an effective value of about -1.5 degrees per micron at 1100-nm wavelength. [1]. M. Inoue, K. Arai, T. Fujii, and M. Abe, J. Appl. Phys. 83, (1998) 6768.

11:00 AM J1.6
Nonlinear magneto-optics in garnet magnetophotonic crystals. Oleg A. Aktsipetrov[1], Tatyana V. Murzina[1], Tatyana V. Dolgova[1], Andrey A. Fedyanin[1], Mitsuteru Inoue[2], Kazuhiro Nishimura[2] and Hironaga Uchida[2]; [1]Department of Physics, Moscow State University, Moscow, Russian Federation; [2]Toyohashi University of Technology, Toyohashi, Japan.

Objectives of the studies presented in this paper are two-fold: the first being the design and fabrication of the 1-D magnetophotonic crystals and magnetophotonic microcavities composed from Bi-substituted iron-yttrium garnet (Bi:YIG) films and the second being observations studies of the magnetization-induced nonlinear optical effects in magnetophotonic crystals and microcavities. The motivation of development of new magnetic materials with photonic band gap (PBG) is straightforward: magnetophotonic crystals (MPC) and magnetophotonic microcavities (MMC) yield a mechanism for molding the flow of light flexible under external control impacts. The motivation of nonlinear optical studies is observation giant enhancement of nonlinear optical analogs of Faraday and Kerr effects in MPC and MMC: nonlinear magneto-optical Kerr effect (NOMOKE) in magnetization-induced second- (SHG) and third-harmonic generation (THG) exceeds linear magneto-optical effects by two orders of magnitude. This paper is devoted to the observation of magnetization-induced variations in intensity, polarization rotation and relative phase for the SH and TH waves generated in magnetic materials with PBG. NOMOKE is studied in MPC and MMC both for magnetization-induced SHG and THG. Magnetization-induced SHG is observed in MMC with the single spacer formed from Bi:YIG layer. Localization of the fundamental radiation, resonant with the microcavity mode, in the garnet spacer enhances manyfold the absolute values of and the magnetization-induced SHG intensity in the Bi:YIG microcavity. The transversal NOMOKE in SHG reveals itself in the magnetization-induced variation of the SH intensity with the magnetic contrast up to 0.65, and in the large, close to 180 deg. shift of the relative SH phase. The large, up to 85 deg. magnetization-induced rotation of the SH wave polarization plane is observed for the longitudinal NOMOKE configuration. Noticeable NOMOKE is observed in magnetization-induced third-harmonic generation from magnetophotonic microcavities. The magnetization-induced variations of the THG intensity with the magnetic contrast up to 0.10 are observed in transversal NOMOKE configuration. This is worth noting the first realization of phase-matched magnetization-induced SHG is reported in this paper. Magnetization-induced SHG reveals the intensity enhancement by a factor of more than 100 if the fundamental radiation is tuned across the PBG edge of MPC consisted of stack of magnetic garnet layers. The enhancement is a manifestation of the phase-matching conditions fulfilled at the PBG edge of the MPC. The giant magnetic effects in intensity and polarization rotation of the magnetization-induced SH and TH waves observed in garnet MPC and MMC open up new applications of MPC as magneto-photonic nonlinear-optical devices.

11:15 AM J1.7
One-Dimensional Magnetic Photonic Crystal Waveguides by Electron-Beam Writing. Xiaoyue Huang[1], Rong Li[2], Haichun Yang[2], Hassaram Bakhru[3] and Miguel Levy[1,2]; [1]Physics, Michigan Technological University, Houghton, Michigan; [2]Materials Science, Michigan Technological University, Houghton, Michigan; [3]Physics, State University of New York at Albany, Albany, New York.

This talk will discuss the fabrication and testing of on-chip photonic crystals in ferrite waveguides. Magnetic photonic crystals have been demonstrated in the form of stacked layers, where the beam is transmitted across the film, normal to the surface.[1,2] An alternative to stacked magnetic photonic crystals is that of planar periodic structures patterned on magnetic film waveguides. A stacked configuration has the advantage that it avoids the shape induced birefringence inherent in an optical guide. Birefringence will generally degrade the performance of Faraday rotator devices, one of the key applications of magneto-optical materials. On the other hand, the fabrication of multiple defects in the optical bandgap and of high finesse grating segments is more promising in planar waveguide devices. These features are advantageous to the fabrication of flat top spectral response magnetic photonic crystals [3] and to the simultaneous optimization of Faraday rotation and transmission intensity in such crystals.[4] This talk will describe the fabrication and performance of one-dimensional photonic crystal structures produced by electron-beam lithography on Bi-substituted yttrium iron garnet (Bi:YIG) ridge waveguides. Standard photolithography is used to form the waveguide ridges. The electron-beam pattern transfer relies on ion implantation and wet etching. The Bi:YIG films are fabricated on $Gd_3Ga_5O_{12}$ (GGG) (111) single crystal substrates by rf magnetron sputtering from sintered ceramic targets. Thickness tuning is used to prepare waveguides of different TE and TM mode index characteristics, with birefringence $\Delta n = n_{TE} - n_{TM}$ below 0.003. Optical transmission and mode coupling results at 1.5μm-wavelength in the photonic crystals will be presented and their dependence on waveguide birefringence will be addressed. Support by the National Science Foundation under grant ECS-0115315 is gratefully acknowledged. [1] M. Inoue, K. Arai, T. Fujii and M. Abe, "One-dimensional magnetophotonic crystals," J. Appl. Phys. vol. 85, pp. 5768-70, (1999). [2] S. Kahl and A. M. Grishin, "Enhanced Faraday rotation in all-garnet magneto-optical photonic crystal," Appl. Phys. Lett. vol. 84, pp. 1438-40, (2004). [3] M. Levy, H. C. Yang, M. J. Steel and J. Fujita, "Flat top response in one-dimensional magnetic photonic bandgap structures with faraday rotation enhancement," IEEE J. Lightwave Technol. vol. 19, pp. 1964-69 (2001). [4] M. J. Steel, M. Levy, and R. M. Osgood, Jr., "Photonic bandgaps with defects and the enhancement of Faraday rotation," IEEE J. Lightwave Technol. vol. 18, pp. 1297-1308 (2000).

11:30 AM J1.8
Artificially Induced Perturbations in Chirped Magneto-Optical Bragg Gratings. Fredrik Jonsson[1] and Christos Flytzanis[2]; [1]Photonic Nanostructures Group, National Microelectronics Research Centre, Cork, Ireland; [2]Laboratoire Pierre Aigrain, Ecole Normale Superieure, Paris, France.

Magneto-optical Bragg gratings are dielectric media possessing a periodic or semi-periodic spatial modulation of its optical or magneto-optical properties. In this context, chirped magneto-optical Bragg gratings possess a spatial grating period that is strictly increasing or decreasing with the spatial coordinate along the grating, providing a flat plateau of high reflectance in the spectrum. The purpose of the work here presented is to show on the possibilities opened by the application of magneto-optically induced perturbations in chirped Bragg gratings. We predict that by introducing such perturbations, the band blocking reflectance of the grating is opened up, allowing for tuneable narrow band transmission windows in the spectrum. For Bragg gratings in waveguides, the necessary magneto-optical perturbation can be induced in a selective manner by means of a local change in magnetization along the grating. In particular, by changing the position of the induced perturbation, e.g. by translating a pickup coil, tuneability of the transmitted wavelength of the device is obtained. An optimization analysis of the predicted effect was performed using perturbation width and peak value as independent parameters for various grating strengths and chirp. In the analysis of optical resonance, we also show on the analogy between the introduced Lorentzian perturbation and an effective Fabry-Perot cavity, concatenated in serial to the index grating. Due to the nonreciprocal nature of optical resonance in magneto-optical media, the wavelengths at peak transmission are undergo a lifting of degeneracy between left and right circular polarization states. This effect is shown to be applicable for the introduction of polarization state diversity for closely spaced wavelength channels, providing a higher resolution and signal-to-noise ratio in dense wavelength multiplexed systems. The numerical simulation of the proposed device is based on a modified transfer matrix algorithm, taking into account the gyration of the polarization ellipse in the discretized elements of the structure, as well as the ellipticity changes occurring at the interfaces of the elements. We also discuss the inverse problem associated with magneto-optical gratings possessing a nonlinear optical response of the medium, and the impacts of nonlinearities on the optical transmission. This project was supported by the EU IST-510162 project PHAT.

11:45 AM J1.9
Electro-Optic and Magneto-Optic Photonic Bandgap Materials. Kevin Y. Zou[1], Yanyun Wang[1], Kewen Li[1], Hua Jiang[1] and Bethanie Hills Stadler[2]; [1]Boston Applied Technologies, Woburn, Massachusetts; [2]University of Minnesota, Minneapolis, Minnesota.

As communications and signal processing extend to higher data rates and faster speeds, conventional electronic signal processing methods are being stretched to their physical limits. Photonics appears to meet the requirements posed by the advanced data processing. Innovative photonic materials that enable high performance photonic devices are the foundation of the photonic technology. Photonic Bandgap Materials (PBG) is an exciting new class of materials and electro-optic and magneto-optic materials are critical for active and passive photonic ICs. Very small photonic ICs can be assembled using PBG devices. This work presents a study of electro-optic and magneto-optic films made by a Metal-Organic Chemical Liquid Deposition (MOCLD) method. Electro-optic thin film, La-modified Pb(Mg1/3Nb2/3)O3-PbTiO3 (PMN-PT) and magneto-optic thin film, rare earth doped yttrium iron garnet (YIG) have been grown at different conditions. Low temperature growth on buffered semiconductor substrates has been studied for semiconductor device integration. High quality PLMNT film with EO coefficient of 1x10-16 (m/V)2 was obtained with MOCLD. Doped and undoped YIG onto MgO and glass substrates and also onto buffered semiconductors were successfully deposited using MOCLD method. Several of these films had successful rotations that were of device quality. Based on these high quality functional films, photonic bandgap structures such as waveguide isolator and electro-optic modulator were designed and fabricated.

SESSION J2: Magnetic-Photonic Crystals II
Chairs: Koji Ando and Miguel Levy
Tuesday Afternoon, November 30, 2004
Berkeley (Sheraton)

1:30 PM *J2.1
Room temperature photo-induced gyrotropy in CdMgTe-CdMnTe semimagnetic semiconductor magneto-photonic micro-cavity. Sylvain BahBah[2], Robert Frey[2], Gerald Roosen[2], Regis Andre[3] and Christos Flytzanis[1]; [1]Laboratoire Pierre Aigrain, Ecole Normale Superieure, Paris, France; [2]Laboratoire Charles Fabry. Insitut d'Optique, Universite Paris Sud, Orsay, France; [3]Laboratoire deSpectrometrie Physique, Universite Joseph Fourier Grenoble, St Martin d'Heres, France.

Magneto-photonic micro-cavities with semimagnetic semiconductor nanostructures show characteristic polarization state sensitive features when excited close to the exciton-polariton modes in the presence of a static magnetic field[1,2]. These gyrotropic features can also be photo-induced with a circularly polarized light beam and large photo-induced magneto-optic Kerr polarization rotations were obtained with moderate beam intensities in such micro-cavities when operated at the intermediate to weak coupling regime at low temperatures[3]. Here we report photo-induced polarization state modifications brought in by pump pulses of various polarization states for a probe beam incident onto a reflecting CdMgTe-CdMnTe magneto-photonic micro-cavity operating in the strong coupling regime at room temperature and compare the magnetic field induced and photo-induced contributions there. Photo-induced magneto-optic Kerr polarization rotations of several degrees are obtained at room temperature for pump beams of 1 micro-Joule/cm2 in the absence of any magnetic field. The cavity and quantum confinement along with the spin exchange interaction play a key role here and a theoretical model is presented; the results are of interest as well for optical signal processing. The micro-cavity used in our experiment was grown by molecular beam epitaxy with the back and front cavity mirrors formed by stacking 21 and 1.5 lamda/4-thick CdMgTe/CdMnTe pairs and between them inserting three 8 nm thick quantum wells separated from each other by 7.1 nm thick CdMgTe layers located at each of the six intensity maxima of the 3 lamda-thick CdMgTe intracavity material. Each quantum well was composed of three 7-monolayer thick CdTe parts separated by two 2-monolayer thick intervals; such asymmetric micro-cavity configuration was chosen to maximize the polarization state rotations. In our experiment the photo-induced modifications of the exciton-cavity polariton modes and the resulting reflectivity, polarization and ellipticity change spectra brought in by a pump pulse having a definite polarization state and frequency were sensed with a linearly polarized probe pulse as a function of different parameters; the probe and pump beams were provided from two identical optical parametric generators pumped by a picosecond duration frequency tripled Nd-YAG laser [3]. The pump source generates large exciton polariton densities of the same polarization state as the pump pulse that set up an effective magnetization in the microcavity. 1.M.S. Skolnick, T.A. Fisher, D.M. Whittaker, Semicond. Sci. Techn. 13. 645 (1998) 2.M haddad, R.Andre, R.Frey, C. Flytzanis, Solid State Commun. 111,61 (1999) 3.D.Pereda Cubian, M.Hadda, R.Andre, R.Frey, G. Roosen, J.L. Arce Diego, C. Flytzanis, Phys. Rev. B67, 045308 (2203) 2

2:00 PM *J2.2
YIG Thin Film-Based Two-Dimensional Magnonic and Magneto-Photonic Crystals. Sergei A. Nikitov[1], Yu A. Filimonov[1], Yu V. Gulyaev[1], Ph. Tailhades[2] and Chen S. Tsai[3]; [1]Institute of Radioengineering and Electronics, Russian Academy of Sciences, Moscow, Russian Federation; [2]CIRIMAT-UMR CNRS 5085, Universite Paul Sabatier, Toulouse, France; [3]Electrical Engineering and Computer Science, University of California, Irvine, Irvine, California.

Propagation properties of photonic crystals (PCs), stop-bands in particular, depend on the wavelength of the waves involved. Conventional PCs made of opals, colloid particles, nanostructured films, etc., are normally studied in the visible light frequency range. Such PCs when operating in a microwave frequency range must carry large dimensions. In contrast, magnonic crystals (MCs) operating in the same microwave frequency range involve micron size dimensions. The properties of microwave propagation in MCs are closely related to spin waves. In this paper, we report the first experimental realization of such MCs and present the theoretical and experimental results on spin waves propagation. From the practical point of view two-dimensional (2-D) MCs that utilize ferromagnetic waveguide with 2-D inhomogeneities of magnetization is preferred. We have fabricated yttrium-iron-garnet (YIG) film-based MCs in which 2-D arrays of holes are incorporated. The holes diameter and periodicity were chosen close to the half-wavelength of the magnetostatic spin wave (MSW) in order to fulfill Bragg reflection condition. The YIG film dimensions are 1.5 cm x 0.5 cm in area and 5 um in thickness. The periodic structures of holes were prepared by the photolithography method. Depth of holes was varied from 1.0 to 4.5 um in order to ensure sufficient changes in the magnetic parameters of the YIG film. The holes period was varied from 20 to 40 um. The spin wave spectrum in 2-D periodic structures has been calculated using Landau-Lifshitz equation for magnetization motion, Maxwell equations with respective boundary conditions at the film surfaces and periodic boundary conditions. It was found that stop bands exist in the spin wave spectrum. The location of stop-band depends on the external magnetic field and the film parameters. Delay-line configurations were fabricated in the YIG film-based 2-D MCs for experimental study of the MSW spectrum. The stop bands for spin waves were found to be tunable by an external magnetic field. In addition, the MSW excitation band in the MC was found to decrease by an order of magnitude. Specifically, the measured bandwidth was reduced from 400 to 50 MHz when the 2-D holes structure was incorporated in the YIG film. Furthermore, the propagation of optical waves in a magnetic waveguide with periodic domain structures, called magneto-photonic crystals (MPC), has been investigated. It is shown that conversion between propagating modes in 2-D periodic domain structures depends strongly on the parameters of the domain structure. Dispersion and anisotropic properties of the interacting modes and the dependence of the intensity of the converted mode on the parameters of the domain structures will be reported.

3:00 PM J2.3
Imaging by a Flat Lens and Slow Microwaves in Left-Handed Metamaterials. Plarenta Vodo[1,2], Emiliano DiGennaro[1,2], Patanjali V. Parimi[1,2], Wentao T. Lu[1,2] and Srinivas Sridhar[1,2]; [1]Physics, Northeastern University, Boston, Massachusetts; [2]Electonic Materials Research Institute(EMRI), Boston, Massachusetts.

We have demonstrated negative refraction of microwaves in a photonic crystal (PC) prism and imaging by a flat lens made of a dielectric photonic crystal using negative refraction. The features of the image formation, including sub-wavelength resolution, are discussed. For a flat slab (Veselago) lens made of negative index media with refractive index -1, the formation of an image inside and outside the flat slab can be obtained using ray tracing. Experimental results show that this is not the case in our flat lens, due to Bloch modulation of the waves inside the PC. An imaging theory explaining the image formation for these new lenses is described and is in good agreement with our experimental results and numerical simulations. Pulse measurements on PC using a Microwave Transition Analyzer in order to measure the group velocity are carried out. By sending a 30ns width pulse with a carrier frequency ranging between 9 and 11 GHz, we analyze the signal delay due to the sample. The microwave group velocity is observed to be as low as 1/50 the speed of light, and is consistent with the large dispersion observed in these metamaterials. Collaborators: John Derov and Bev Turchenetz, AFRL, Hanscom. Work supported by AFOSR and NSF-PHY-0098801.

3:15 PM J2.4
Solvable Model of Two-Dimensional Magnetophotonic Crystal. Alexander Khanikaev[1], Mitsuteru Inoue[1,2], Alexander Granovsky[3] and Alexey Vinogradov[3]; [1]Toyohashi University of Technology, Toyohashi, Aichi, Japan; [2]CREST, Japan Science and Technology Corporation, Tokyo, Japan; [3]Moscow State University, Moscow, Russian Federation.

In the past decade, there has been great deal of interest in photonic crystals (PCs) in which the dielectric constituents are periodically arranged [1]. These crystals have many interesting properties as far as basic physics is concerned but also in relation to technological applications. Apparently, possibility to tune such properties of PCs like band structure or dispersion by some external influences may enhance significance of PCs for applications considerably [2]. It was recently reported [3] that PCs formed from active magneto-optical components (MPC), create new possibilities for applications. It was theoretically and experimentally shown that a huge enhanced Faraday rotation appears in one-dimensional MPC. The experimental results for three-dimensional MPCs were reported in Ref. [4, 5]. We present the two dimensional exactly soluble model of the magnetophotonic crystal that is generalization of model developed in Ref. [6] for PC formed from magnetoactive dielectric sheets. Band structure of 2D MPC was analyzed in presence of external magnetic field for both, Faraday (external magnetic field lies in the plane of 2D MPC) and Voigt (external magnetic field is orthogonal to the plane of 2D MPC) geometries. Shown, that for Faraday geometry, external magnetic field, due to optical activity of sheets reduces symmetry of crystal. As result, it removes degeneracy in the photonic band structure. It allows us to conclude that possibility to create full band gaps in PCs composed from magnetoactive material by applying external magnetic field exists. However, because of small intensity of magnetooptic activity, width of new opened full band gaps will be vanishing. Found, that for Faraday geometry despite week character of magnetooptic activity, strong sensitivity of dispersion for electromagnetic modes near band edges appears. This effect, obviously, can essentially increase importance of MPCs for applications owing to possibility to tune dispersion of PCs by external magnetic field. It is very important especially for such promising and challenging structures like super-lenses and super-prisms that have in their basis PC's structure. Finally, it was found, that for Voigt geometry optical activity doesn't affect band structure for p-polarization, whereas changes in band structure for s-polarization are negligible. [1] E. Yablonovitch, T.J. Gmitter, and K.M. Leung, Phys. Rev. Lett. 67, 2295 (1991) [2] A. Figotin, Y. Godin, and I. Vitebsky, Phys. Rev. B 57, 2841 (1998) [3] H. Kato, T. Matsushita, A. Takayama, M. Egawa, K. Nishimura, M. Inoue, J. Appl. Phys. 93, 3906 (2003) [4] C. Koerdt, G. L. J. A. Rikken, E. P. Petrov, Appl. Phys. Lett. 82, 1538 (2003) [5] A.V. Baryshev, T. Kodama, K. Nishimura, H. Uchida, and M. Inoue, J. Appl. Phys. 95, 7336 (2004) [6] T.J. Shepherd, P.J. Roberts, and R. Loudon, Phys. Rev. E 55, 6024 (1997)

3:30 PM J2.5
Superprism effect in magnetophotonic crystals,. Alexey Petrovich Vinogradov[1], Alexander Mikhailovich Merzlikin[1], Alexander Borisovich Granovsky[2], Mitsuteru Inoue[3,4] and Alexander Khanikaev[3]; [1]ITAE OIVT Russian Academy of Sciences, Moscow, Russian Federation; [2]Faculty of Physics, Lomonosov Moscow State University, Moscow, Russian Federation; [3]Department of Electrical and Electronic Engineering, Toyohashi University of Technology, Toyohashi, Japan; [4]CREST, Japan Science and Technology Agency, Saitama, Japan.

Photonic crystals have attracted wide and sustained interest in the past few years, in particular due to an opportunity to control of light propagation on the wavelength scale. The one-dimensional photonic crystals have long been used in practice as periodic multiplayer dielectric mirrors, but two-dimensional and three-dimensional photonic crystals have only recently been widely adopted. Their unique dispersion properties allow one to fabricate light collimated devices of super-small scales [1]. A superprism is a representative example of such devices [2]. The superprism effect consists in considerable deviation of a light beam caused by small changes of system parameters, such as angle of incidence or frequency. Additional attractive features of PC appear at usage of magneto-optical materials. These new advantages consist not only in increase of magneto-optical effects [3, 4] (the Faraday and Kerr effects for example) but also in opportunity to control the PC properties by external magnetic field. In this communication we present model calculations of photonic band structure for 2D PC built up of magneto-optical matrix with square holes to study for the first time the magnetic superprism effect. We employ a simple square lattice model and restrict ourselves to lossless case. It is shown that an external magnetic field applied perpendicularly to the holes changes significantly 2D PC band structure and thus propagation of light through PC. The effect exists even for a weak magneto-optical activity of the matrix but only for the definite set of model parameters. Thus, it makes possible to deflect a light beam by applying magnetic field without variation of frequency or initial angle of incidence. Besides, it is possible to control super-resolution and super-dispersion of conventional superprism [2] by magnetic field. 1. J. D. Joannopoulos, P. R. Villeneuve and S. Fan // Nature 386, 143, (1997) 2. T. Baba, M. Nakamura // IEEE J. of Quant. Electr., 38, 909, (2002) 3. M. Inoue, K. Arai, T. Fujii, V. Abe // J. Appl. Phys., 85, 5768, (1999) 4. A. P. Vinogradov, A. M. Merzlikin, A. B. Granovsky, M. Inoue // Journal of Communication Technology and Electronics 49, 88, (2004)

3:45 PM J2.6
Three-Dimensional Magnetophotonic Crystals Based on Synthetic Opals: Fabrication and Properties.
Baryshev Alexander[1,2], Kazuhiro Nishimura[1], Tsuyoshi Kodama[1], Hirogana Uchida[1] and Mitsuteru Inoue[1,3]; [1]Toyohashi University of Technology, Toyohashi, Aichi , Japan; [2]Ioffe Physico-Technical Institute, St. Petersburg, Russian Federation; [3]CREST, Japan Science and Technology Corporation, Tokyo, Japan.

Magnetophotonic crystals (MPCs) [1], composite materials in which magnetic materials are implanted into the dielectric lattice, have attracted major interest, because the control of the electromagnetic wave by MPC structure is expected to be a key technology for future applications in optoelectronics. Three-dimensional MPCs are of interest because they give a possibility for three-dimensional light control. Due to their magnetic properties the Faraday and magneto-optical Kerr effects in photonic band gap are expected to be much stronger, therefore three-dimensional MPCs could be much effective than existing devices. Today, there are a few kinds of three-dimensional photonic crystals which can be used for preparation of MPCs: synthetic opals, inverted opals and colloidal crystals. In present work we utilized high-quality opal photonic crystals [2] for the visible as a matrix for impregnating with magnetic material. Crystalline structure of opal sample has continuous net of voids those were filled by magnetic material. Opal-ferrite spinel and opal-garnet three-dimensional MPCs for the visible spectral region were prepared using a fabrication procedure developed. We studied an influence of concentration of reactants and temperature conditions (in the case of garnets) on magnetic properties of MPCs. Investigation of these samples by SEM, X-ray diffraction analyses and vibrating sample magnetometer shows that magnetic materials are synthesized in voids of opal matrices and obtained composites have typical magnetic properties. Since the photonic band structure is of fundamental interest, we investigated an influence of quantity of magnetic materials inside of opal samples on optical properties of MPCs synthesized. It was shown that the Faraday rotation outside the stop gaps has the behavior of magnetic component. We found the considerable changes of the Faraday rotation angle in photonic band gap of MPCs in comparison to bulk magnetic material implanted. [1] M. Inoue and T. Fujii, J. Appl. Phys. 81, 8 (1997). M. Inoue, K. I. Arai, T. Fujii, and M. Abe, J. Appl. Phys. 85, 8 (1999). [2] A. V. Baryshev, A. V. Ankudinov, A. A. Kaplyanskii, V. A. Kosobukin, M. F. Limonov, K. B. Samusev, and D. E. Usvyat, Physics of the Solid State 44, p. 1648 (2002).

SESSION J3: MO-Disk and Heat-Assisted Magnetic Recording
Chairs: William Challener and Richard Gambino
Wednesday Morning, December 1, 2004
Berkeley (Sheraton)

8:15 AM *J3.1
Three-Dimensional Magneto-Optical Recording. Akiyoshi Itoh, Electronics and Computer Science, Nihon University College of Sci. & Tech., Funabashi, Chiba, Japan.

Three-dimensional magneto-optical (MO) recording is one of the prosperous candidates of next generation ultra high density recording. Magnetic amplifying MO system (MAMMOS) is an excellent method for achieving high areal recording density with an enhanced read out signal from recorded marks much smaller than the optical resolution limit by utilizing the magnetic characteristics of a magnetic multi layer structure. In this paper, it is reported that the newly developed Double-MAMMOS (three-dimensional MAMMOS) scheme and the experimental results. A part of this work has been done as the national project of 3D-MO (3-dimensional MO) project. It started at September 1998 and ended March 2002 as a part of the national project Nanometer-Scale Optical High Density Disk Storage System and aimed at achieving 100 Gb/in2 in storage density. First, the simply stacked MAMMOS structure consists of recording layers and reading layers was discussed. However, the read out signal from the reading layer located at the far side of the incoming optical beam becomes smaller due to the penetration of the light through the other layers, so another configuration is necessary. Double-MAMMOS scheme consists of 2-recording layers of differing compensation temperature (Tcomp) and one readout layer was proposed and discussed. For low reading power, the films are at T1 which corresponds to the Tcomp of the 2nd recording layer, where the 2nd layer will not yield any stray field in principle. However, at T1 the magnetization in the 1st recording layer is not equal to zero, so the information in the 1st layer is copied and expanded in the read out layer by the yielded stray field. Conversely, for high reading power, at temperature T2 the 1st recording layer does not yield any stray field, so the information is copied from the 2nd layer to the read out layer. We can then choose the recording layer where information is read by changing the read optical power. Through painstaking trial and error, changing layer configuration, magnetic characteristics such as magnetization, its temperature dependence and Tcomp, we finally found the optimal conditions. With write/read test it is succeeded to show the results corresponding to a 100 Gb/in$\hat{2}$ (50 Gb/in$\hat{2}$ x 2) recording density. The test used a high NA (0.85) lens and a 413 nm blue laser through a 0.35 mm glass substrate. However, it is necessary to record twice for separately recording information into two layers which are different in Curie temperature. Then, we also propose a new type of Double-MAMMOS in which the recording layers can hold quadri-valued information by single writing process.

8:45 AM *J3.2
High-Density Magneto-Optical Recording with DWDD and DTE. Toshimori Miyakoshi, Tsutomu Shiratori, Yasuyuki Miyaoka and Yasushi Hozumi; Canon Inc., Tokyo, Japan.

A technique which can attain a recording density of 15 Gbit/inch2 (80 nm/bit, 540 nm/track) with the existing optical parameters of DVD has already been developed, in which the signals are recorded by magnetic field modulation (MFM) and reproduced by domain wall displacement detection (DWDD). If this technique could be employed in a DVD, a capacity of more than 20 GB per layer would be achieved. However, in order to perform such high-density recording, it has so far been necessary to place a magnetic field modulation head close to the recording film. This has made it difficult to apply the reproduction technology to a DVD type optical disk, which has a sandwiched-film structure, or to a Blu-ray type disk system, which has an optical head placed on the film side of the disk. In order to overcome this difficulty, we proposed a new recording method named Domain Tail Erasing (DTE), with which minute marks much smaller than a spot size can be written by light intensity modulation, as can be done with MFM. This new recording method enables high-density recording far beyond the optical resolution limit with a medium combining the layer structure of DWDD with that of light intensity modulation direct overwrite (LIMDOW). A recording performance nearly identical to that using MFM was confirmed with this method, using conventional optics with a wavelength of 660 nm and NA of 0.60. However, the DTE method still requires a bias magnet, which remains a disadvantage in cases in which a thinner drive apparatus is required. We have therefore also made the bias magnets unnecessary by introducing a device to generate a magnetic field as a magnetic film included inside the medium. In order to obtain a sufficiently strong bias field to perform recording with a bias layer introduced into the DTE medium, the stray field distribution during the recording process was studied by simulation. A stray field most effectively worked on the recording layer when the Curie temperature of the bias layer was designed at a certain level below the recording temperature. Furthermore, by replacing part of the bias layer with a bias assist layer, which had a higher Curie temperature and lower coercive force, an even stronger stray field was generated. According to the simulation, a non-bias DTE medium was designed, and a sufficiently low jitter value and dropout rate were obtained without bias magnets at a bit length of 80 nm and a track pitch of 740 nm, using the same optical parameters as those of existing DVDs.

9:15 AM *J3.3
Ultra High Density Recording MO Recording by a Magnetic Domain Expansion Readout Technique of ZF MAMMOS.
Hiroyuki Awano, H. Ido, M. Tani and N. Ohta; Development & Technology Division, Hiatchi Maxell Ltd., Tsukubagun, Ibaraki, Japan.

Generally speaking, an areal recording density of optical disk strongly depends on a focused laser spot size. Linear recording density of an ordinary optical disk such as recordable DVD can be expressed by optical resolution limit. It can be expressed by half size of focused laser spot. However, in the case of Magneto-Optical (MO) disk, special magnetic properties named as magnetic domain expansion readout technique breaks the optical resolution limit. By using it, the linear recoding density can be improved at least 5 times larger than that of ordinary optical disk. In order to improve more high linear recording density, more minimum domain size of MO recording layer should be improved like a HDD recording material. We have proposed it named as Zero Field MAMMOS (Magnetic Amplifying MO System). For ZF MAMMOS, an expansion readout layer, an expansion trigger layer, a magnetic coupling force control layer, a recording layer and a recording magnetic field assist layer are stacked with a magnetron sputtering apparatus on a polycarbonate substrate. The groove depth is about 40nm and track width is 0.18um. On the surface, 15um over coat is covered. Read/Write testing was performed from the covered layer side. Therefore, both side recording can be accepted. The Write/Read tester has a blue laser diode of 405 nm wavelength and objective lens with numerical aperture of 0.85. R/W linear velocity was 4 m/sec. The laser spot size is about 400nmand the optical resolution limit size becomes about 200nm. Recording mark length dependence of CNR for the ZF MAMMOS and a MO conventional disk are measured using spectrum analyzer. Resolution band width is 30kHz. In the case of conventional disk, CNR value of longer mark of 400nm as same as laser spot size shows large enough for practical use. However, the CNR of 200nm is small value for actual signal processing because it is beyond the optical resolution limit. On the other hands, in the case of ZF MAMMOS, even if recording mark length is 60nm. It is much shorter than the optical resolution limit of 200nm, the large CNR value can be kept. The areal density (Track width : 0.18um, Bit length : 60nm) becomes 60Gb/in2. Thus, it is found that write/read characteristic of ZF MAMMOS is very attractive for high density recording. Also, using improved recording material with minimizing domain reversal unit, rather shorter mark less than 60nm would be reproduced with large CNR value. This indicates that MO has a potential as a removable hard disk.

9:45 AM J3.4
Estimation of Damping Factor by Time-Resolved Measurement of Magnetization Dynamics. Arata Tsukamoto[1,2], Katsuji Nakagawa[2], Akiyoshi Itoh[2], Aleksei Kimel[1], Andrei Kirilyuk[1] and Theo Rasing[1]; [1]NSRIM Institute, University of Nijmegen, Nijmegen, Netherlands; [2]College of science and technology, Nihon University, Chiba, Japan.

The speed limits for thermomagnetic writing are of vital importance for magneto-optical recording, which has become one of the most important technologies for removable storage media. In particular, the speed of the thermally assisted copying within magnetically amplified magneto-optical systems (MAMMOS) is of high technological interest [1]. Conventional pure magnetic recording schemes have a serious and unavoidable problem known as the ferromagnetic resonance (FMR) limit. Nevertheless, laser pulse writing was shown to lead to a potentially much faster process of magnetization reversal, of the order of a few picoseconds [2,3]. These experiments demonstrated the intrinsic capability of ultrafast high-speed rewritable storage under the thermomagnetic scheme. Here we present results of time-resolved study of ultrafast magnetic response of Gd23.1Fe71.9Co5.0 MAMMOS structures under near actual read temperature condition (423 K). By an all-optical pump and probe method we demonstrated that the photo-excitation could effectively excite coherent spin waves in the magnetic material. An intense (pump) optical beam excites the medium due to an ultrafast laser-induced heating and a less intense (probe) beam monitores this photo-excited state through the magneto-optical Kerr effect. Time-domain measurements on the consequently excited precession give information on the magnetic anisotropy, switching and damping phenomena. Precession frequencies of several GHz and relaxation times in the nanosecond range were observed under various external magnetic fields. The Gilbert damping parameter α could be derived by directly fitting the time dependencies of time domain MOKE measurement. The experimental curve is very well fitted by the Landau-Lifshitz-Gilbert equation with $\alpha = 0.15$. From the comparison of the experimental and theoretical data, the α parameter for different samples was deduced and analyzed. Acknowledgment This work is partially supported by Grant-in-Aid for Scientific Research of the Ministry of Education and economy in Japan No. 16360182 and No. 15760226, the EU project SPINOSA, the EU-Network DYNAMICS. [1] H. Awano, S. Imai, M. Sekine, M. Tani, N. Ohta, K. Mitani, N. Takagi, H. Noguchi, and M. Kume: IEEE Trans. Magn. 36 2261 (2000). [2] J. Hohlfeld, T. Gerrits, M. Bilderbeek, H. Awano, N. Ohta, and T. Rasing, Trans. Magn. Soc. Jpn, 25 202 (2001). [3] J. Hohlfeld, Th. Gerrits, M. Bilderbeek, Th. Rasing, H. Awano, and N. Ohta, Phys. Rev. B 65 012413 (2002).

10:15 AM *J3.5
Hybrid Recording Features and Material Prospects.
Nobuyuki Inaba and Norio Ota; Hitachi Maxell Ltd., Tsukuba-gun, Ibaraki, Japan.

Conventional magnetic recording drives with areal density beyond 1 Tb/in2 will be faced with the contradictory problems, superparamagnetic limit and head field limit. Although extremely high magnetic anisotropy (Ku) media are needed to maintain the thermal stability of the recorded tiny bits, the media can not be recorded by available heads. Thermally assisted magnetic recording, or hybrid recording, is expected to solve the problems by employing a thermo-magnetic writing scheme, i.e. by using local heating to temporally reduce the medium coercivity below the writing head field. First feature of the hybrid recording is high resolution recording capability by sharp thermal gradient as well as applying head field gradient. When the focused laser was irradiated locally to the perpendicular magnetic recording media during the writing process, the clear bit patterns could be recorded by applying the head fields, which were much smaller than the coercivitiy at room temperature. The second feature is pico-second order high-speed magnetization reversal. A pico-second order magnetization reversal is observed in the Gd-Fe-Co perpendicular thin film, when a 100 femto-second laser is irradiated on the film. This switching speed is much faster than the ferromagnetic resonance frequency. This result suggests that the hybrid recording system will overcome the ferromagnetic resonance limit as well as the paramagnetic limit. Since the hybrid recording solve the head field limit problem, the hybrid recording media will be able to use extremely high Ku materials, such as FePt and CoPt L10 ordered alloy permanent magnet materials, Co/Pt and Co/Pd multilayer thin films, and Tb-Fe-Co magneto optical recording media, whose Ku values are more than 107 erg/cc. The bit transitions are determined by the heating profile of the media as well as the head field gradient. Therefore, tiny bit patterns will be probably recorded in the strong exchange coupling media. The hybrid recording media have huge alternative of not only high Ku materials but also the film structure.

10:45 AM *J3.6
Pseudo-binary alloys and exchange springs - adjusting the properties of high-anisotropy FePt films for media applications in thermally assissted magnetic recording.
Jan-Ulrich Thiele, San Jose Research Center, Hitachi Global Storage Technologies, San Jose, California.

Magnetic media using materials with high magneto-crystalline anisotropy, K_U, combined with a thermal assist to overcome write field limitations have been proposed as a potential technology to extend the areal density of magnetic recording beyond current limitations. Here we present an overview of recent work on adapting the properties of materials based on the high- K_U $L1_0$ phase of FePt for the requirements of thermally assisted magnetic recording (TAR). In addition to the micro-structural and magnetic properties in TAR the temperature dependence of the magnetic properties of the media plays a crucial role. Specifically, the temperature coefficient of the switching field, dH_K/dT, determines the shape and sharpness of the written transition as well as the stability of the recorded information. One example for controlling the relevant magnetic properties of FePt are the pseudo-binary $L1_0$ alloys such as, e.g., $Fe_{55-x}Ni_xPt_{45}$ ($0 \leq x \leq 55$ at.%) [1]. However, for applications in TAR single layer media fabricated from such alloys face the dilemma that to sufficiently reduce H_K to enable writing requires heating to temperatures close to the Curie temperature, which is prohibitively high for most high-K_U $L1_0$ materials. Therefore we recently proposed a novel bi-layer structure consisting of a ferromagnetic high anisotropy layer of, e.g., FePt, exchange coupled to a FeRh layer [2]. At close to equiatomic compositions FeRh is antiferromagnetic at low temperatures. Interestingly, upon heating beyond a critical temperature, T_{AF-FM}, FeRh becomes ferromagnetic for temperatures $T_{AF-FM} < T < T_C$. T_{AF-FM} can be adjusted between room temperature and 200 °C by small changes in composition or by doping with Ir or Pt. This unique feature opens intriguing possibilities for media applications for thermally assisted recording: At a storage temperature, $T_S < T_{AF-FM}$, where FeRh is in its anti-ferromagnetic state, the magnetic information is stored in the high anisotropy (=high stability) FePt layer. For writing at increased temperature, $T_{AF-FM} < T_W < T_{C,FeRh}$, FeRh becomes ferromagnetic, effectively lowering the anisotropy and increasing the total magnetic moment of the bilayer, thus lowering its coercivity, via an exchange spring mechanism. The additional moment of the ferromagnetic FeRh thus helps magnetization reversal of the high anisotropy FePt layer at temperatures well below its Curie temperature. In addition to the concept and properties of the bilayer system relevant for TAR, recent studies on the magnetic and structural properties of FeRh will be presented. [1] J.-U. Thiele, K. R. Coffey, M. F. Toney, J. A. Hedstrom, and A. J. Kellock, "Temperature dependent magnetic properties of highly chemically ordered $Fe_{55-x}Ni_xPt_{45}$ $L1_0$ films", J. Appl. Phys., Vol. 91, pp. 6595-6600, 2002. [2] J.-U. Thiele, S. Maat and E. E. Fullerton, "FeRh/FePt exchange spring films for thermally assisted magnetic recording media", Appl. Phys. Lett., Vol. 82, pp. 2859-2861, 2003.

11:15 AM *J3.7
Femtosecond Laser Pulse Induced Magnetization Dynamics.
Julius Hohlfeld, Seagate Research, Pittsburgh, Pennsylvania.

The development of laser systems that emit ultra-short laser pulses with pulse energies up to several mJ/pulse opened the way to induce and study magnetization dynamics on a femtosecond time scale. In this talk I will focus on four different topics in this new area of femto-magnetism that are of key importance for future high-density heat assisted magnetic recording: 1) the ultra-fast breakdown (erasure) of the magnetization magnitude within a few 100fs after the optical excitation, 2) the precession of the magnetization vector that is induced by fs laser pulses when the direction of the external field and the magnetization in thermal equilibrium enclose an angle different from $n*\pi$, 3) the speed limit of thermo-magnetic writing when the static external field points in the opposite direction as the initial magnetization direction, and 4) the new technique of ultra-fast laser pulse induced ferromagnetic order in materials that undergo an anti-ferromagnetic - to - ferromagnetic transition at elevated temperature. Acknowledgments This work was performed as part of the Information Storage Industry Consortium (INSIC) program in Heat Assisted Magnetic Recording (HAMR), with the support of the U. S. Department of Commerce, National Institute of Standards and Technology, Advanced Technology Program, Cooperative Agreement Number 70NANB1H3056.

11:45 AM J3.8
Near-Field Radiation from a Ridge Waveguide in the Vicinity of a Solid Immersion Lens.
Kursat Sendur, Chubing Peng and William Challener; Seagate Technology Research Center, Pittsburgh, Pennsylvania.

There has been an increasing interest for generating intense optical spots smaller than the diffraction limit of an objective lens. In addition to near-field imaging, intense sub-wavelength optical spots have potential applications in lithography and bio-chemical sensing. Near-field techniques that enhance localized surface plasmons can obtain intense optical spots beyond the diffraction limit for optical data storage. The magnetic storage industry is also interested in sub-wavelength optical spots for heat assisted magnetic recording (HAMR) to overcome the superparamagnetic limit. HAMR is a potential technique to extend the physical limits of conventional magnetic recording. An optical spot is used to heat the recording medium to reduce its coercivity and enable recording by an external field. To achieve a density of 1 Tb per square inch, an optical spot diameter of 25 nm is required. A total dissipated power of 1-4 mW is required in the medium to enable recording data rates of 1 Gb/s. The ridge waveguide transducer (RWT) has been suggested as a near-field aperture for data storage. Various RWT designs have been investigated using electromagnetic modeling techniques, including finite difference time domain (FDTD) and finite element method (FEM). Models for a focused beam of light were integrated with the FEM and FDTD for more realistic scenarios. The focused spot size that can be obtained from a lens is proportional to the wavelength, and inversely proportional to the numerical aperture (NA) of the lens. Solid immersion lenses (SIL), in which the light is focused in a high refractive index solid, achieve smaller optical spots than the conventional diffraction limit of air-spaced objective lenses. Increasing the NA using a SIL increases the electric field at the focal region. Placing a near-field transducer in the proximity of such enhanced electric fields increases the near-field radiation from the transducer as well. Surface plasmon modes can be optically excited in a metal film using the Otto excitation technique in which light is incident from a high refractive index material onto the metal film via a thin low index dielectric spacer. Due to the total internal reflection at the high-low index boundary, evanescent waves are created which couple efficiently into the surface plasmon modes over the metal film. By placing a low-index material between the SIL and RWT a similar effect is obtained. We investigated the near-field optical system which is composed of a SIL, a RWT, and a thin low-dielectric index spacer in between. The RWT is optimized to yield a high transmission efficiency. This optical system provides a spot size of 31 nm and a maximum absorbed optical power density of 7.5×10^{-4} mW/nm^3. For a bit-aspect ratio of 1, these numbers are close to the range required by HAMR to achieve 1 Tb per square inch. With a higher bit-aspect ratio and a better recording medium design, this design yields a much higher areal density.

SESSION J4: Optical Isolators
Chairs: Koji Ando and Miguel Levy
Wednesday Afternoon, December 1, 2004
Berkeley (Sheraton)

1:30 PM J4.1
Temperature Dependence Free Magneto-Optical (Tb,Bi)Fe Garnet Films Grown By LPE Method.
Nobuo Imaizumi[1], Takashi Fukuhara[1], Yasuhiko Kuwano[2] and Kenichi Shiroki[1]; [1]Opto Laboratory, Namiki Precision Jewel Co., Ltd., Tokyo, Japan; [2]Research & Development, Dai-Ichi Kiden Co., Ltd, Chiofu-city, Tokyo, Japan.

Bi-substituted Tb-Fe Garnet Films grown by Liquid-Phase

Epitaxial(LPE) method are demonstrated as candidate temperature dependence free Faraday Rotators in the telecom devices or optical sensors applications. It has been well known that Tb3Fe5O12 and Bi3Fe5O12 show opposite sign in temperature characteristics of the Faraday Rotation;θFR and the combined solid solution of (Tb,Bi)3Fe5O12 is theoritically expected to become the temperature dependence free magneto-optical garnet crystal by controlling the composition x in the chemical formula Tb(3-x)BixFe5O12. In experimental, the bulk garnet crystal, Tb2.54Bi0.46Fe5O12 grown by a flux method, with almost zero temperature dependence at 1310nm, was reported by T.TAMAKI[1]. From the cost oriented industrial point of view, the LPE grown method should be desirable to make the temperature dependence free garnet material in the actual applications such as optical isolators or sensors. For the LPE grown method, lattice constant of the substrate crystal plays a dominant part on the final grown composition and the magneto-optical characteristics. Several types of substituted GdGaGarnet(SGGG) substrates are applied in the tests. The lattice constants of the SGGG substrates are among 12.46 and 12.50A. Thickness of the tested grown films are 131 to 586μm, and the θFR and temperature dependences are measured with a stabilized laser source at 1310nm. Temperature coefficients (TC) of the θFR are estimated using follwoing relation; $\Delta\theta$FR/90, where $\Delta\theta$FR shows difference of the FR angles in the temperature range betwee -10 and +80°C. As reported by TAMAKI, at x=0.48~0.56 in the Tb(3-x)BixFe5O12, a couple of very low temperature dependence garnet films are fabricated on the lattice constant of 12.465A SGGG substrates through the LPE-Grown processing with optimized flux compositions. Thicknesses of the films are 232 to 322μm, and the θFR are 13 to 15degs. From -0.0024 to +0.0012deg/°C of the TCs are measured. By using the 45deg ofθFR normalization, above data are equivalent to -0.0081 to +0.0034deg/°C. The minimum data of +0.0034deg/°C is observed with the Tb2.54Bi0.48Fe5O12 composition. The data indicates that the tested LPE garnet films are well suppressed their temperature dependences less than one tenth compared to the conventional Faraday rotators in the telecom devices. [1] T.TAMAKI: Doctoral thesis, Tokyo Institute of Technology 1993

1:45 PM J4.2
Fabrication of Integrated Magneto-Optic Isolator.
Sang-Yeob Sung, Xiaoyaun Qi, John Reinke, Samir K. Mondal, Sun Sook Lee and Bethanie J. H. Stadler; ECE, Univ. of Minnesota, Minneapolis, Minnesota.

In optical applications, especially in optical communication, protecting light sources from harmful reflected energy is very important. With magneto-optic isolators, these light sources can be protected to extend their lifetime and performance by blocking back-reflected light. The active element in these optical isolators is a magneto-optical garnet. However, garnet is difficult to integrate with semiconductors due to the high thermal budget usually required to obtain the garnet crystal structure. For example, current isolator garnets cannot be integrated monolithically into a photonic integrated circuit due to the growth process, liquid phase epitaxy, which requires growth temperatures of >900 °C and also garnet substrates. In this work, magneto-optical garnets were grown monolithically by low-temperature reactive RF sputtering, followed by an ultra-short (<15 sec) annealing. The refractive indices of the resulting garnets were measured using Fourier transform infrared (FTIR) spectroscopy. These garnets were grown onto several single and multilayered buffer layers, including yttrium oxide, which gave the best results. This buffer had an index of 1.9 and was more similar in thermal expansion to YIG than the other buffer layers. Various rib waveguides were fabricated by both wet etching and reactive ion etching (RIE). The width of the waveguides varies from 2 to 12 μm and the heights were varied from 0.5 to 1.0 μm. Sm-Co thin films were used for the biasing magnets. They were deposited on top of claddings of Si3N4 and yttrium oxide, all using the same sputtering system that was used to deposit the garnet films. These magnetic films had high enough remanent fields to saturate the garnet waveguides, and they had coercivities of 700 Oe. The Faraday rotations and waveguide losses of the subsequent isolators were measured using laser wavelengths of 0.632, 1.33 and 1.55μm.

2:00 PM *J4.3
Waveguide Optical Isolators Fabricated by Wafer Bonding.
Tetsuya Mizumoto[1] and Hideki Yokoi[2]; [1]Dept. of Electrical and Electronic Engineering, Tokyo Institute of Technology, Tokyo, Japan; [2]Dept. of Electronic Engineering, Shibaura Institute of Technology, Tokyo, Japan.

Optical isolators are indispensable to protect optical active devices from unwanted reflections. The waveguide version of isolator is desired for an application to photonic integrated circuits. Also, the waveguide isolator is expected to contribute to the cost reduction of devices. To integrate an isolator with a semiconductor device, it is a critical issue to integrate a magnetooptic garnet with a compound semiconductor. We developed a wafer bonding technique to accomplish this and demonstrated an isolator operation in the interferometric isolator that is composed of a GaInAsP guiding layer and employs a nonreciprocal phase shift. Also, we achieved a bonding between a magnetooptic garnet and $LiNbO_3$ to construct a semileaky waveguide isolator, which has the great advantages of relaxed fabrication tolerance and wide operating wavelength range. In this presentation, the wafer bonding of garnet with III-V compound semiconductor and $LiNbO_3$ is discussed including the surface treatment for hydrophilic bonding as well as the surface activation bonding in a vacuum chamber. For the hydrophilic bonding, it is essential to make the wafer surfaces hydrophilic prior to bonding. We examined the effectiveness of surface treatment for making hydrophilic surfaces. For all wafers we examined, it was effective to expose wafers to weak oxygen plasma for making hydrophilic surfaces. Also, the design and performance of the interferometric and the semileaky isolator are discussed for the application to optical fiber communication. In a preliminary experiment, an isolation of 5dB was obtained in the interferometric isolator composed of a GaInAsP guiding layer, on which Ce:YIG was directly bonded as an upper cladding layer. In the semileaky isolator, $LiNbO_3$ is bonded on a Ce:YIG guiding layer. In this waveguide, the electromagnetic field of TE modes are confined in the guiding layer, while TM modes are radiated into a $LiNbO_3$ cladding layer. A unidirectional mode conversion is provided by the anisotropy of $LiNbO_3$ and the Faraday rotation of Ce:YIG. We obtained an isolation of 7.2dB/cm at 1550nm wavelength in a fabricated semileaky isolator. Further studies toward the improvement of isolation characteristics will be addressed for both types of waveguide isolators.

2:30 PM J4.4
Experiments Towards the Realisation of a Monolithically-Integrated Optical Isolator Incorporating Quasi-Phase Matched Magneto-Optical Effects.
Barry Holmes, David C. Hutchings and Joseph J. Bregenzer; E&EE (Optoelectronics), The University of Glasgow, Glasgow, United Kingdom.

When coupling laser diodes to optical waveguides, fibres or components, the inevitable back reflections that arise from the connection interface propagate into the laser cavity, resulting in what is known as /reflection/ or /injection/ noise [1]. This creates instabilities, restrictions on the operational speed of the devices and also reduced lifetime. Currently, in order to prevent these back reflections, bulk optical isolators have to be inserted into the laser-waveguide/fibre assembly. This not only introduces complexity in the alignment of the components, but also leads to a reduction in production throughput and, therefore, an inevitable increase in costs. Consequently, the development of a monolithically-integrated laser-optical isolator is probably one of the most important goals in the ever-increasing integration of optical components and will result not only in a reduction of dimensions and costs, but also an increase in the functionality, lifetime, and speed of photonic devices. Recently, we reviewed various architectures and designs and proposed a planar device [2] consisting of a passive reciprocal mode converter (RMC), coupled to a nonreciprocal magneto-optic mode converter (NRMC). We report here upon the progress that we have made to date in realising each of these critical components. The most efficient RMCs utilise an angled waveguide geometry and whilst several groups have reported upon the theoretical properties of such structures [3], to our knowledge, only one has actually fabricated them through the use of a two-stage dry/wet etch process [4]. Results from prototype GaAs-AlGaAs RMCs that have been fabricated by our group, using three separate but novel approaches, will be presented. Each method results in a one-stage dry etch process, thereby eliminating the requirement of realignment and remasking of the sample for each subsequent etch, as well as reducing fabrication errors that are inevitably introduced through the wet etch stage. This significantly reduces the complexity and time taken to produce such samples and facilitates a far greater degree of control over design tolerances and run-to-run repeatability. Also reported are the initial results from experiments toward the realisation of the NRMC stage, in which we are investigating the integration a Ce-YIG cladding layer with a GaAs-AlGaAs waveguide through the use of different buffer layers. In order to overcome the inherent problem of shape birefringence, which normally leads to phase mismatched loss of polarisation coherence, we are utilising a quasi-phase matched Faraday effect approach, through the periodic reversal of the applied magnetic field. 1 K. E. Stubaker and M. B. Small 1984 IEEE J. Quantum Electron. 20 472 2 D. C. Hutchings 2003 J. Appl. Phys. D. 36 2222 3 H. El-Rafaei and D. Yevic 2003 J. Lightwave Technol. 21 1544 4 J. Z. Huang, R. Scarmozzino, G. Nagy, M. J. Steel, and R. M. Osgood, Jr. 2000 IEEE Photon. Technol. Lett. 12 317

3:15 PM *J4.5
$Cd_{1-x}Mn_xTe$ Magneto-Optical Waveguide for Monolithical Integration of Optical Isolator into Optoelectronics Circuits.
Vadym Zayets, Nanoelectronics Research Institute, AIST, Tsukuba, Ibaraki, Japan.

Optical isolator and circulator are essential components of optical information systems. Non-reciprocal effect of magneto-optical materials is used to achieve these functions. Monolithic integration of these magneto-optical devices with semiconductor optoelectronic devices has been impossible because conventional magneto-optical devices use oxide garnets. Diluted magnetic semiconductor $Cd_{1-x}Mn_xTe$ has merits for the integration. It can be grown epitaxially on GaAs substrates and it exhibits a huge Faraday effect near its absorption edge. We fabricated $Cd_{1-x}Mn_xTe$ on GaAs (001) substrate using molecular beam epitaxy (MBE). The waveguide consists of $Cd_{1-x}Mn_xTe$ (x=0.2) core and $Cd_{1-x}Mn_xTe$ (x=0.24) cladding. The measured optical loss is below 1 dB/cm for wide wavelength range and it increase when wavelength approaches to the $Cd_{1-x}Mn_xTe$ band gap closer than 40 nm. However, maximum TM-TE mode conversion ratio was only 34 % [1]. To fabricate an integrated optical isolator the magneto-optic mode conversion in waveguide should exceed 95 %. We proposed to use graded-refractive-index layers to increase magneto-optical mode conversion in $Cd_{1-x}Mn_xTe$ waveguide [2]. The waveguide core was sandwiched between two a 500-nm-thick $Cd_{1-x}Mn_xTe$ (x=0.24-0.2) graded-refractive-index (GRIN) layers, for which the Mn concentration was changed linearly with thickness. The graded-refractive-index layer effectively reduces phase mismatch between TE and TM modes. It results a high magneto-optical mode conversion in the waveguide. For λ=730 nm the mode conversion is almost complete under magnetic field 5 kGauss. However, wavelength range of the complete mode conversion was relatively narrow about 5 nm. To increase wavelength range of complete mode conversion we proposed to use an annealing. During annealing of $Cd_{1-x}Mn_xTe$ waveguide the Mn atoms diffuses. It results a very smooth refractive index gradient in GRIN layer and smaller refractive index step between waveguide core and cladding. The $Cd_{1-x}Mn_xTe$ was annealed under Cd flux at 400 deg C. The wavelength range of complete mode conversion was increased to 60 nm. Due to high Faraday effect (100 deg/cm/kGauss at λ=740 nm) and low optical loss, the magneto-optical figure-of-merit was high about 200 deg/dB/kG. The prism coupling was used for isolation measurement. The isolation ratio was achieved above 20 dB under magnetic field 5 kGauss. The high isolation ratio, low optical loss, high figure-of-merit and complete mode conversion obtained in a magneto-optical waveguide grown on a semiconductor substrate shows the feasibility of monolithical integration of an optical isolator with semiconductor optoelectronic devices. I would like to thank K.Ando, M.C.Debnath and H. Saito for their contribution. This work is supported by Industrial Research Grand Program in '02 from NEDO. [1] W.Zaets and K. Ando, Appl. Phys. Lett. 77 , 1593-1595 (2000) [2] V.Zayets, M. C. Debnath, and K. Ando, Appl. Phys. Lett. 84, 565-567 (2004).

3:45 PM J4.6
Hybrid Semiconductor-Ferromagnetic-Metal Active Optical Isolator. Vadym Zayets and Koji Ando; Nanoelectronics Research Institute,AIST, Tsukuba, Ibaraki, Japan.

Progress in optical communication systems requires an ever higher level of integration of different optical elements. The optical isolator is an essential component of such integration. It protects laser diodes and optical amplifiers from unwanted reflections and is necessary to ensure source stability, especially when the fast switching and a large bandwidth are required. The integration of the isolator is a difficult task. It is necessary to use a magneto-optical material to fabricate an optical isolator. At present magnetic garnets are used as the magneto-optical material for bulk optical isolator. The garnet-made isolators have not been monolithically integrated with semiconductor optoelectronic devices, because these oxide crystals can not be grown on semiconductor substrates. We propose to use ferromagnetic metals for the optical isolator. We show that an optical semiconductor amplifier covered by a ferromagnetic layer has a large difference in values of loss/gain for modes propagating in the opposite directions when the magnetization is perpendicular to the light propagation direction and lies in the film plane [1]. Thus, the amplifier covered by ferromagnetic can itself act as an optical isolator. This design of the isolator can be beneficial for a monolithic integration of the optical isolator with semiconductor optoelectronic devices and one can make a part of optical waveguide amplifier as an optical isolator simply by depositing a ferromagnetic metal on it. We study theoretically the waveguide isolator operating at a wavelength of 790 nm, which consists of a $GaAs_{0.9}P_{0.1}/Al_{0.3}Ga_{0.7}As$ quantum-well (QW) optical amplifier covered by Co layer. To reduce the absorption by the Co layer, a buffer layer of p-$Al_{0.7}Ga_{0.3}As$ is inserted between the absorbing Co layer and $GaAs_{0.9}P_{0.1}/Al_{0.3}Ga_{0.7}As$ QW amplifying core layer. Optical field of a waveguide mode exponentially penetrates through the buffer layer into the Co layer. The propagation constants of the waveguide modes were calculated by solving Maxwell equations for the multilayer structure. The high isolation ratio of 180 dB/cm was calculated for realistic optical gain of quantum well of 1500 cm-1. The isolation ratio of the optical amplifier covered by Fe and Ni layers was calculated to be 150 dB/cm and 60 dB/cm, respectively. The result shows the feasibility of usage ferromagnetic-metal-semiconductor hybrid for monolithical integration of optical isolator into semiconductor optoelectronic circuits. This work is supported by Support of Young Researchers with a Term from MEXT. [1]. W. Zaets and K.Ando, IEEE Photon. Technol. Lett. 11, 1012 (1999).

4:00 PM J4.7
Fabrication of a TE Mode Semiconductor-Waveguide-Type Optical Isolator Based on the Nonreciprocal Loss Shift. Hiromasa Shimizu[1] and Yoshiaki Nakano[1,2]; [1]Research Center for Advanced Science and Technology, University of Tokyo, Meguro-ku, Tokyo, Japan; [2]JST, Saitama, Japan.

Optical isolators are indispensable for stable operation of telecommunication semiconductor lasers. Commercially available optical isolators are composed of Faraday rotators and linear polarizers. However, they are not compatible with semiconductor lasers. Semiconductor-waveguide-type optical isolators, which can be integrated with edge-emitting semiconductor lasers, are desired for reducing overall system sizes. We have proposed and fabricated a TE mode semiconductor-waveguide-type optical isolator based on the nonreciprocal loss shift. Although TM mode semiconductor-waveguide-type optical isolators have been proposed[1,2], experimental demonstrations have been limited[3]. Furthermore, TE mode waveguide-type optical isolators are desired for integration with edge-emitting semiconductor lasers which generally operate in the TE mode. Here we report a TE mode waveguide-type optical isolator using Fe on an InP substrate. The operation wavelength is 1.55μm. For realizing the TE mode nonreciprocal loss shift, the magnetization vector of the magneto-optical material is aligned parallel to the magnetic field vector of the TE mode light. To make this alignment possible, the magneto-optical layer is placed on one side of the waveguide sidewalls, and the magnetic field is applied perpendicular to the waveguide. The device consisted of a semiconductor optical amplifier (SOA) and Fe thin film on one sidewall. The operation principle is as follows: in the TE mode, a nonreciprocal loss shift is brought about by the transverse Kerr effect near the interface between the Fe and the core (SOA) layers. The propagation loss for the forward traveling light is compensated by the optical gain of the current injected InGaAsP multiple quantum well active layer, whereas the propagation loss for the backward traveling light still remains. Thus, the optical isolator operation is realized. In our simulation using the perturbation theory, nonreciprocal loss shifts as high as 17.5dB/mm are predicted. We have fabricated the prototype devices mentioned above. The SOA layer stack was grown by metal-organic vapor phase epitaxy and the Fe thin films were deposited by electron-beam evaporator. We measured the amplified spontaneous emission (ASE) intensity under the magnetic field B=2kG. The device was 0.5mm long and kept at 17°C and the emitted light was resolved to TE and TM mode components. Here we define the nonreciprocal ASE ratio R as (ASE(+B)-ASE(-B))/ASE(0kG.). R=2.3% was obtained for the TE mode at a current density of 14.5kA/cm^2. On the other hand, nonreciprocal ASE was not observed for the TM mode. These results indicate that the Fe layer brought about the nonreciprocal loss shift for the TE mode in the fabricated device, which is promising for the semiconductor-waveguide-type optical isolator proposed above. [1] M. Takenaka et al., IPRM, 289, (1999). [2] W. Zaets et al., IEEE., Photon. Tech. Lett., 11, 1012, (1999). [3] M. Vanwolleghem et al., OFC, TuE6, (2004).

SESSION J5: Poster Session: Magneto-Optical Materials I
Chair: Richard Gambino
Wednesday Evening, December 1, 2004
8:00 PM
Exhibition Hall D (Hynes)

J5.1
Magneto-Optical Properties of Multilayered FePt for High Density Recording. Hojun Ryu, Dongwoo Suh, Yongwoo Park, Eunkyung Kim, Yonggoo Yoo, Woosug Jung and Muncheol Paek; ETRI, Daejeon, South Korea.

FePt thin film has been the one of the good candidates for high density magneto-optical recording media due to the large polar kerr rotation angle at the short wavelength. To investigate the potential for high density recording by using magneto-optical effect, we introduce the Si3N4/FePt/Si3N4/Al/Si multilayer structure. We have fabricated the multilayer thim film by sputtering method keeping the working pressure of 5x10-3 torr. To obtain the various composition of FePt thin film, we used co-sputtering of Fe and Pt target indivisually controlling the applied power. The Al layer thickness is fixed as 500 nm for reflection layer, and the thickness of dielectric layer which is sandwiched with FePt layer is also fixed for 405 nm wavelength measurement. And the refractive index of Si3N4 is 1.78 measured by ellipsometry, and the composition of FePt is analyzed by AES(Auger Electron Spectroscopy) and RBS(Rutherford Backscattering Spectroscopy) for the confirmation of AES analysis, the magnetic properties is obtained by AGM(Alternating Gradient Magnetometer) and Spectral Polar Kerr Measurement system. X-ray diffractometry is employed for the structure identification. Kerr rotation angle and the ellipticity of FePt layer with thickness change also have been obtained by computer simulation. The thickness of FePt thin films are varied form 5 nm to 30 nm for the thickness effect investigation. According to the XRD patterns, the structure of the FePt thin films have (111) textured tetragonal(L10). The maximum Kerr rotation angle is 0.82 degree at 10 nm thickness of Fe35Pt65. But the thickness of FePt increased upto 30 nm, the Kerr angle is slightly decreased to 0.62 degree. The Fe 3d-bands and Pt 5d-bands of larger spin-orbit coupling effect cause the Kerr rotation angle increments in the thinner film. This tendency is very similar and the calculated results relatively well supported the experimental data.

J5.2

Bi:YIG Waveguides on Glass Substrates : Etching Conditions and Seed Layers Effects. Jean-Luc Deschanvres[1], Aude Bouchard[2], Pierre Benech[2] and Dominique Persegol[3]; [1]LMGP, ENSPG - CNRS, St Martin D Heres, France; [2]IMEP, INPG, Grenoble, France; [3]GEEO, Meylan, France.

The development of the telecommunication network especially at the access level requires the production at low cost of the different optical components, which are involved in the propagation, the modulation, the amplification of the light. One of these optical components is the optical isolator, which protect the light sources from backreflected light. Currently isolators are only available as discrete components and are based on the use of the high magneto-optic effect of the bismuth substituted yttrium iron garnets. Garnets are traditionally grown by liquid phase epitaxy (LPE) at high temperatures on monocrystal GGG wafers. In order to produce cheaper components we proposed to elaborate the garnet films on glass substrates with an atmospheric aerosol MOCVD process. The deposition process is based on the pyrolysis of an ultrasonic generated aerosol, which contained dissolved organometallic precursors. As source solution yttrium and iron acetylacetonates and bismuth triphenyl were dissolved in butanol at a concentration of 0,03Mol/l. Well adherent 0.5 μm thick films have been deposited in the temperature range 470°C - 530°C with deposition rates between 0.1 and 0.5μm/h. The composition of the deposited layers depended on the deposition conditions (substrate temperature, aerosol flow, composition of the source solution). The as deposited films were amorphous and very smooth. Polycrystalline films were obtained by post annealing treatments during few hours at temperatures between 600°C and 650°C. The films with a composition closed to the stoechiometric value exhibited a pure non-textured polycrystalline garnet structure. By using a classical photolithography process combined with a wet chemical etch process with diluted solution of orthophosporic or chlorydric acid, ridges with width ranging from 3 to 40 μm have been obtained. For the as deposited films the etching rate was more than one order of magnitude higher than for annealed films and it depended also on the Bi content. The annealing step was crucial because cracks appeared due to the thermal expansion mismatch between the garnet film and the glass substrate. We have tested two types of glass substrates. One with a high annealing point but a low thermal expansion and the other with a lower annealing point but with a thermal expansion well matched to the garnet film. More over In order to reduce the stress induced by the annealing, we performed the etching before the annealing. Despite of this fact, cracks appeared in the ridges during annealing for the first type of glass. For the second one because of the lower annealing temperature (600°C), the crystallization was not homogenous. In order to improve the crystallization process we have used as seed layer a thin film of Y_2O_3 . With this structure we have obtained uniform crystallized ridges which exhibited enhanced propagation properties of the light at 1.55 μm.

J5.3

Magnetorefractive Effect in Magnetophotonic Crystals. Sergey Gennad'evich Erokhin[1], Yulia Viktorovna Boriskina[1], Alexander Borisovich Granovsky[1], Alexei Petrovich Vinogradov[2] and Mitsuteru Inoue[3]; [1]Faculty of Physics, Magnetism Department, M.V.Lomonosov Moscow State University, Moscow, Russian Federation; [2]Institute for Theoretical and Applied Electrodynamics, Moscow, Russian Federation; [3]Department of Electrical and Electronic Engineering, Toyohashi University of Technology, Toyohashi, Japan.

Photonic crystals made from magnetic materials, known also as magnetophotonic crystals (MPCs), exhibit remarkable magneto-optical properties accompanied by two orders of magnitude enhancement in their Faraday and Kerr rotation [1,2]. The unique properties arise from the localization of light as a result of multiple interference of light within MPC. Besides traditional magneto-optical effects connected with spin-orbit interaction, a new magneto-optical effect in magnetic materials with large magnetoresistance, so-called magnetorefractive effect (MRE), was discovered and studied thoroughly (see [3] and references therein). The effect consists of considerable changes in the dielectric function, and therefore in optical properties, of systems with large magnetoresistance when they are magnetized. The usage of magnetic materials with large MRE as constituent materials of MPCs makes possible to enhance MRE and to fabricate tunable by magnetic field optical devices. Magnetic nanogranular alloys "ferromagnetic metal-insulator" with tunnel-type magnetoresistance, for example Co-(Al-O) with metallic volume fraction close to the percolation threshold, are promising as prospective components of MPCs because they exhibit large MRE, more than 1%, and are partly transparent in a wide spectral range [3]. We present results on theoretical investigation of optical properties of one-dimensional MPCs composed from magnetic nanogranular thin film Co-(Al-O) layer sandwiched by a couple of dielectric multilayer reflectors. Optical and MRE parameters for Co-(Al-O) layer were taken from experimental data [3]. Since the MRE in Co-(Al-O) is well pronounced at infrared wavelengths [3] calculations were carried out for three wavelengths: 1, 3 and 5 mm. We adjusted the thickness of both dielectric and magnetic layers to obtain optimal conditions for light localization within magnetic layer for each wavelength. It is shown that when the Co-(Al-O) layer thickness is between 5 and 10 nm the MRE in reflection mode for MPC reaches more than 10% that is at least one order of magnitude larger than that for all studied magnetic granular alloys. This example shows that MRE may be significantly enhanced in MPCs. We also discuss promising magnetic composites materials with large MRE for development tunable by magnetic field MPCs operating at microwaves. This work was supported by the Russian Foundation for Basic Research, International Center for Fundamental Physics in Moscow, and the Dynasty Foundation. 1. I. L. Lyubchansky at al., J.Phys. D: Appl. Phys. 36 (2003) R277 2. M. Inoue at al., J.Appl.Phys. 85 (1999) 5988 3. A. B. Granovsky at al., JETP, 96 (2003) 1104

J5.4

Fabrication of One-Dimensional Photonic Crystal Structures on Bi-Yttrium Iron Garnet (Bi:YIG) Films by Focused Ion Beam Processing. Xiaoyue Huang[1], Rong Li[2], Haichun C. Yang[2], Peter D. Moran[2] and Miguel Levy[1,2]; [1]Physics, Michigan Technological University, Houghton, Michigan; [2]Materials Science, Michigan Technological University, Houghton, Michigan.

The fabrication of multiple defects in the optical bandgap and of high finesse grating segments are advantageous to the production of flat top spectral response magnetic photonic crystals [1] and to the simultaneous optimization of Faraday rotation and transmission intensity in such crystals.[2] In this presentation we explore the formation of single and multi-defect one-dimensional photonic crystals by focused ion beam (FIB) patterning on Bi-substituted yttrium iron garnet (Bi:YIG) film waveguides. The FIB fabrication is done using a Ga-ion beam at a current of about 60 pA. Milling on the garnet films lasts for several minutes. Of particular interest to this investigation is the fabrication of high aspect ratio grating grooves in the garnet film as advantageous to the production of high finesse compact planar photonic crystals.[1] A comparison with electron-beam patterning techniques will be presented. The Bi:YIG films are fabricated on $Gd_3Ga_5O_{12}$ (GGG) (111) single crystal substrates by rf magnetron sputtering from sintered ceramic targets. Atomic force analysis on these samples shows 100nm to 300nm-depth for 175nm-wide grating grooves. The feasibility of producing even higher depth to width aspect ratios by focused ion beam techniques on magnetic garnet films will also be addressed. Support by the National Science Foundation under grant ECS-0115315 and the Department of Defense under grant DAAD 17-03-C-0115 is gratefully acknowledged. [1] M. Levy, H. C. Yang, M. J. Steel and J. Fujita, "Flat Top Response in One-Dimensional Magnetic Photonic Band Gap Structures with Faraday Rotation Enhancement," IEEE J. Lightwave Technol. vol. 19, pp. 1964-69 (2001). [2] M. J. Steel, M. Levy, and R. M. Osgood, Jr., "Photonic Bandgaps with Defects and the Enhancement of Faraday Rotation," J. Lightwave Technol. vol. 18, pp. 1297-1308 (2000).

J5.5

Influence of Temperature on Photonic Band Gap Effects in Magnetic Photonic Crystals. N. N. Dadoenkova[1], Igor L. Lyubchanskii[1], M. I. Lyubchanskii[1], E. A. Shapovalov[1], Meidong Huang[2], Y.P. Lee[2], Kiwon Kim[3] and Th. Rasing[4]; [1]Theory of Electronic and Kinetic properties of Disordered Systems, Donetsk Physical & Technical Institute of the National Academy of Sciences of Ukraine, Donetsk, Ukraine; [2]Quantum Photonic Science Research Center and Department of Physics, Hanyang University, Seoul, South Korea; [3]Department of Physics, Sunmoon University, Asan, South Korea; [4]NSRIM Institute, University of Nijmegen, Nijmegen, Netherlands.

Magnetic photonic crystals are an object of intensive experimental and theoretical researches because of the promising applications in photonics [1]. These magnetic photonic crystals are constructed using magnetic and non-magnetic materials. This fact allows to control the optical properties of magnetic photonic crystals by employing an external magnetic field, since the magnetization of magnetic components in these crystals follows the direction of applied field. Another possibility to control the optical (magneto-optical) properties of magnetic photonic crystals is the change of temperature. Influence for temperature on the magnetic photonic crystal properties is two-fold. Firstly, the temperature variation, near the temperature for spin-reorintation transitions, leads possibly to a change of the magnetization direction in the magnetic layers of magnetic photonic crystal. Secondly, above the temperature for order-disorder phase transition, the magnetic components in magnetic photonic crystals are transformed to the paramagnetic state and loose their magneto-optical properties. In the present communication, we report the results of theoretical investigation on how temperature affects the photonic band gap effects in magnetic photonic crystals. [1] I. L. Lyubchanskii, N. N. Dadoenkova, M .I. Lyubchanskii, E. A. Shapovalov, and Th. Rasing. J. Phys.D: Appl. Phys. 36, R277 (2003).

J5.6

Optical Properties of Magneto-Photonic Crystals.

Vladimir Igorevich Belotelov[1] and Anatolii Konstantinovich Zvezdin[2]; [1]M.V. Lomonosov Moscow State University, Moscow, Russian Federation; [2]Institute of General Physics, RAS, Moscow, Russian Federation.

Periodic dielectric media, or photonic crystals (PhC), are promising structures for controlling the propagation of electromagnetic radiation. With respect to PhC applications to optical devices, it is advantageous to apply external magnetic fields or use magnetic materials as the constituents of PhC. This can lead to some new interesting phenomena of magnetooptics. We have studied magnetooptical (MO) properties of PhCs composed of dielectric materials with varying magnetic properties that implies an investigation of the magnetic field influence on the electromagnetic waves propagation in PhCs. For the calculation of transmittance, reflectance and MO effects in 1D case transfer matrix method was utilized [1]. Theoretical investigations of 2D- and 3D- PhCs have been performed on the basis of solving eigenvalues problem obtained from Maxwell equations. Magnetic part of the medium polarization has been considered as a perturbation and corresponding MO effects were calculated in the first order of perturbation theory [2]. Enhancement of the Faraday effect in 1D PhC's has been revealed for the first time by M. Inoue et al. [1]. Later it was shown theoretically [3] that for the optimal sets of magnetic and nonmagnetic layers in 1D PhC, almost 100% transmission and high Faraday rotation of order 55 deg. are possible. In our work we consider similar 1D PhC made of alternating Bi:YIG and GGG layers with structure defect (missing layers). For some optimal configurations of 1D PhC structure we found that its transmittance strongly depends on the magnetization direction of two symmetrically located layers, i.e. magnetization reversal in these two layers leads to the change in transmittance on the operating wavelength by several orders. This phenomenon is of great importance for the creation of optical switches. By the method of plane waves expansion transmission and reflectance coefficients dependences on the magnetization were calculated for 2D case. For 2D PhCs two main geometries have been examined: the Faraday and Voigt configurations. It was found that similarly to 1D case the enhancement of the Faraday and Voigt effects takes place when wave frequency approaches extremum frequencies of wave bands. However, these effects take their maximum value not exactly at , but at its close proximity where transmission coefficient is not too small. For the magnetic material with magnetooptical parameter the Faraday rotation angle can be as large as for near infrared radiation. We also analyze photonic diagrams for 2D- and 3D- PhCs which enabled us to investigate a super-prism effect (high dispersion) in the presence of the gyrotropic properties of the PhC. This work is supported by RFBR (02-02-17389, 03-02-16980) and "Dynasty" fund. [1] M. Inoue, T. Fujii, J. Appl. Phys. 81, 5659 (1997). [2] A.K. Zvezdin, V.I. Belotelov, Euro. Phys. J. B 37, 479 (2004). [3] M. Levy, H.C. Yang, M.J. Steel et al. J. Lightwave Technol. 19, 1964 (2001).

J5.7

Optical, Magnetic and Transport Effects in $LaGa_{1-x}Mn_xO_3$: Experiment and Modeling. Natalia Noginova, Geoffrey Chelule, Feng Chen and Vladimir Gavrilenko; NSU, Norfolk, Virginia.

Manganese doped perovskites are materials promising for data storage, demonstrating optically and field induced memory effects. Optical absorption, electric conductivity, and magnetic resonance of $LaGa_{1-x}Mn_xO_3$ crystals have been studied for different temperatures and compositions. Electron energy structure and optical functions of $LaGa_{1-x}Mn_xO_3$ are calculated by ab initio pseudopotential method within density functional theory using generalized gradient approximation. Theoretical results are discussed in comparison with the experimental optical absorption spectra for different alloy compositions. We determine the dependence of the Jahn-Teller (JT) distortion on the manganese concentration from the equilibrium total energy analisys, and discuss effects of Jahn-Teller distortion on magnetic and transport properties of materials with different concentration x.

J5.8

Theory for the Magneto-Optic Spectra of Nanocomposite Materials Using Coupled Dipole Methods.

Damon Allen Smith[1,2], B. L. Scott[1,2], Yuri Barnakov[2], Shantia White[3] and Kevin L. Stokes[1,2]; [1]Physics, University of New Orleans, New Orleans, Louisiana; [2]Advanced Materials Research Institute (AMRI), University of New Orleans, New Orleans, Louisiana; [3]Physics, Dillard University, New Orleans, Louisiana.

We present calculations of the magneto-optical (MO) response of composites which contain closely-spaced nanoparticles. The materials are modeled as collections of coupled dipoles using a new approach based on a discrete dipole approximation (DDA). This approximation allows for dipole-dipole interactions between the partices and is justified when the individual particle size is much smaller than the wavelength of incident radiation. Due to the presence of off-diagonal components in the dielectric tensor of magneto-optically active materials, a matrix transformation into a right-left circular coordinate system is performed. This allows for diagonalization of the dielectric tensor and subsequent calculations of the polarizations of individual nanoparticles within the composite system. An effective dielectric constant is determined from the average polarizations, which is then used to calculate the MO spectra. Shifts in the peaks of the optical cross-sections and MO spectrums are seen with variations in both the geometrical configuration and interparticle distance of the nanoparticles. The optical cross-sections of nonmagnetic materials were calculated and verified against calculations made using the standard DDA algorithm, DDSCAT. Qualitative agreement is found between our model and a polymer/nanoparticle composite containing various volume fractions of included magnetite particles. It is surmised that our new model will allow for guidance in the fabrication of nanocomposite materials with tunable MO characteristics.

J5.9

Effects of 1 MeV C^+ Irradiation on the Magnetic Properties of Ni(60Å)/Cu/Si(100). Sang-Won Shin[1,3], Chungnam Whang[1], Jong-Han Lee[2,3], In-Hoon Choi[2], Jonghan Song[3], Teagon Kim[3], Junsik Lee[4] and Kibong Lee[4]; [1]Institute of Physics and Applied Physics, Yonsei Univ., Seoul, South Korea; [2]Material Science and Engineering, Korea Univ., Seoul, South Korea; [3]Advaced Analysis Center, Korea Institute of Science and Technology, Seoul, South Korea; [4]Physics, Pohang Univ. of Science and Technology, Pohang, South Korea.

The effects of 1 MeV C ion irradiation with various ion dose and flux on epitaxial Ni(60Å)/Cu/Si(100) which possessing perpendicular magnetic anisotropy (PMA). After ion irradiation, the magnetic and structural properties were analyzed by the magneto-optical Kerr effect (MOKE) and grazing incident diffraction (GID). 1 MeV C ion irradiation was performed into Ni/Cu thin films with various ion doses ranged from 1 to 7.5x10^{15} ions/cm^2. As increasing ion dose, the coercivity of Ni/Cu thin film decreased from 16.2 %(1x10^{15} ions/cm^2) to 72.1 %(7.5x10^{15} ions/cm^2). It means that the spin reorientation toward in-plane magnetization induced by ion irradiation depends on the ion dose. It is known that the magnetic anisotropy of Ni/Cu is closely related to the magnetoelastic anisotropy of strained Ni film due to the lattice mismatch with the Cu(001) layer. From the GID measurement, as increasing ion dose, the peak position of Ni moves gradually toward the bulk Ni(200) peak position and the half width of the Cu(200) peak is getting narrow. It implies the fact that the relaxation of the strain and grain growth induced by ion irradiation is a function of ion dose. In order to investigate ion flux effect, 1 MeV C^+ irradiation with a dose of 1x10^{16}/cm^2 was carried out by varying ion flux (100, 380 nA/cm^2). As increase of ion flux, the coercivity of Ni/Cu thin film decreased and spin orientation more rapidly changed from PMA to in-plane. It is concluded that ion dose and flux plays an important role of modification of the magnetic properties of Ni/Cu thin film.

J5.10

Magneto-Optics of Coupled Magnetite Gold Nanoparticle Materials. Yuri Anatolievich Barnakov[1,2], Lee B. Scott[1], Damon Smith[1] and Kevin L. Stokes[1]; [1]AMRI, UNO, New Orleans, Louisiana; [2]Chemistry, BIP SB RAS, Ulan-Ude, Russian Federation.

We present a study of the magneto optical properties of a binary nanoparticle system in which one component is a magneto-optically active material and the other is a noble metal. Excitation of the surface plasmon in a noble metal nanoparticle leads to a significant concentration of the electromagnetic field on and near the surface of particle. The magneto-optical response of nearby magnetic nanoparticles should be affected due to this locally-enhanced electromagnetic field. For this reason, we have investigated the synthesis and magneto-optical properties of coupled magnetite (Fe_3O_4) - gold nanoparticles. The chemically synthesized 8-10 nm magnetite and 2-4 nm gold nanoparticles were linked with the organic molecule, mercaptodecanoic acid (MUA). Due to bifunctionality of this organic ligand, a chemical bridge is formed from the surface of the particles with carboxyl groups (COOH, in the case of magnetite) and with thiol groups (SH, in the case of gold) In order to investigate an influence of origin of bonds in binary nanocomposities on magneto-optical properties, test samples of magnetite single phase and physically-mixed magnetite-gold colloids were studied as well. All samples were characterized by UV-visible optical absorption spectroscopy, X-ray Diffraction (XRD), Dynamic Light Scattering (DLS), Fourier Transform Infrared Spectroscopy (FTIR) and Transmission Electron Microscopy (TEM). Faraday rotation spectra were taken from samples placed on single TEM grid. This allows correlating features in the Faraday spectra with the morphology of the nanoparticles in a straightforward manner. It was observed that the physically-mixed particles have a tendency to segregate forming two sets of randomly distributed clusters. However, chemically linked particles are uniformly dispersed over the TEM grid. Faraday rotation spectra show that chemically linked particles exhibit a red-shift and broading of Intervalence Charge Transfer (IVCT) band of superparamagnetic magnetite nanoparticles. In contrast, unlinked particles show only a slight change in the intensity of IVCT without any change of peak position. We suggest that the observed changes in Faraday rotation spectrum of chemically-linked binary nanoparticles are due to the modification of optical properties near the surface plasmon resonance frequency of the gold nanoparticles.

SESSION J6: Magneto-Optical Sensors and Characterization

Chairs: William Challener and Richard Gambino
Thursday Morning, December 2, 2004
Berkeley (Sheraton)

9:00 AM *J6.1

Application of Magnetic Garnet Films for Magnetooptical Imaging of Magnetic Field Distributions. Horst Doetsch, Carsten Holthaus and Alexei Yourievich Trifonov; Dpt. of Physics, University of Osnabrueck, Osnabrueck, Germany.

Rare–earth iron garnet films of high quality can be grown by liquid phase epitaxy on paramagnetic substrates of gadolinium galliumgarnet. Such films are currently used for imaging of the spatial distribution of magnetic fields. This application is based on the Faraday rotation which can strongly be enhanced by bismuth incorporation. If gray scale imaging is desired, one is bound to use in–plane magnetized films. The physical properties of the films can be controlled by the chemical composition, the growth conditions and the crystallographic orientation. The sensor properties like sensitivity, dynamic range, signal linearity and unambiguity must be optimized according to the application desired. These properties, however, are not independent of each other. In addition, they strongly depend on the optical wavelength. Thus, it is necessary to find compromises. The influence of Faraday rotation, Faraday ellipticity, optical absorption, magnetic anisotropies and film thickness on the performance of a magnetooptical indicator film is investigated. Based on the swing of the photoresponse, a new optimization process is introduced. The process is experimentally verified and application examples are demonstrated. Furthermore, two methods are presented to enhance the sensitivity of magnetooptical sensors. Using specific crystallographic orientations, an easy plane of magnetization can be induced which is inclined with respect to the film plane. If the magnetization lies in this plane a very high sensitivity is achieved. The dependence of the geometrical orientation of the easy plane on the growth direction is calculated and the sensitivity and dynamic range are derived. Experimental results of a [112] oriented garnet film are in good agreement with calculations. Garnet films which are magnetized along the film normal due to a strong induced uniaxial anisotropy support magnetic domains. If the collapse field perpendicular to the film plane is small, such films can be used as very sensitive indicator films. Such films are easier to prepare than sensitive in–plane films. However, the spatial resolution is limited by the size of the domains. This disadvantage can be avoided by applying a bias field in the film plane. Directly at the in–plane collapse field the sensor film is in–plane magnetized yielding high spatial resolution at still high sensitivity. The variation of magnetooptical images with in–plane induction is demonstrated. Experimental results are in agreement with calculations. Magneto–optical imaging becomes complicated, if the cubic anisotropy of the garnet films must be taken into account. This is the case for very sensitive films. The influence of this anisotropy on the sensor performance depends on the crystallographic orientation. It is shown how this influence can be minimized.

9:30 AM *J6.2

Growth and Characterization of Magnetooptic Garnet Films with Planar Uniaxial Anisotropy. Vincent J. Fratello, Irina Mnushkina and Steven J. Licht; Integrated Photonics, Hillsborough, New Jersey.

Bismuth-doped rare earth iron garnets (Bi:RIG) are well known magnetooptic materials with large Faraday rotations in the visible and infrared. The Faraday rotation in bismuth doped garnets is essentially proportional to the bismuth concentration and so growth conditions must be optimized to maximize this doping. Bi:RIG have achieved high volumes in telecommunications applications such as isolators, circulators, interleavers, switches and variable optical attenuators. Materials for these devices have positive uniaxial anisotropy such that the domains are constrained to be magnetized perpendicular to the film. However interesting new devices can be enabled by negative uniaxial anisotropy. A better understanding of the requirements to achieve magnetooptic devices with negative uniaxial anisotropy is sought in this study. Growth-induced uniaxial anisotropy arises from ionic ordering on sites made non-equivalent by the growth direction. It can result from rare earth-rare earth pairs, bismuth-rare earth combinations and/or transition metal doping. Almost all growth-induced anisotropy studies have occurred on the easy growth, non-facet (111) direction and result in positive uniaxial anisotropy, Ku. In the demagnetized state, this results in serpentine stripe domains of alternating up and down orientation. When a bias field greater than the saturation magnetization is applied, the domains anti-parallel to the field collapse and the material becomes a saturated single domain such as is required for magnetooptic isolators. Negative growth-induced anisotropy has been seen in films containing praseodymium and neodymium, since these large light rare earths have unique magnetic ordering opposite to the rest of the rare earths. But these ions also come with a host of complex magnetic properties including high damping to slow down device speeds and very high first and second order cubic magneto-crystalline anisotropies that create additional non-uniform effects. Best planar device success has been achieved with (100) $Bi_xLu_{3-x}Fe_{5-y}Ga_yO_{12}$ films on (100) gadolinium gallium garnet substrates. These have been used in magnetooptic indicator applications in contact with magnetic domains and magnetic fluxes in materials including high temperature superconductors and magnetic tape. However, the growth conditions needed to produce negative uniaxial anisotropies involve high undercoolings resulting in poor process control. Therefore there has been a need to develop a more complete understanding of growth-induced anisotropy, particularly in orientations other than (111). The present study covers different combinations of rare earths and transition metals to yield negative anisotropy films with high Faraday rotations, tunable anisotropy, strong, uniform, reversible response to magnetic fields, high speed and reproducible properties. These films are expected to find new applications in magnetic field and current sensors and new telecommunications devices.

10:30 AM J6.3

Novel Magneto-Optic Layers Based on Semiconductor Nanostructures for Kerr Microscopy. Catherine Gourdon[1], V. Jeudy[1], G. Karczewski[2], E. L. Ivchenko[3], T. Okada[4,1] and R. Andre[5]; [1]Groupe de Physique des Solides, Universities Paris 6 and 7 - CNRS UMR 7588, Paris, France; [2]Institute of Physics, Polish Academy of Sciences, Warsaw, Poland; [3]A. F. Ioffe Physico-technical Institute, Russian Academy of Sciences, St Petersburg, Russian Federation; [4]Itoh Laboratory, Osaka University, Osaka, Japan; [5]Laboratoire de Spectrometrie Physique, Universite J. Fourier - CNRS 5588, Grenoble, France.

Novel magneto-optic layers based on diluted magnetic semiconductor (DMS) heterostructures have been have designed, characterized and used for the first time for imaging the magnetic flux pattern at the surface of superconducting thin films [1-2]. The great advantage of DMS structures over conventional magneto-optic layers based on Eu-compounds or iron garnets is that they have no magnetic influence on the studied film since they are paramagnetic and not ferro- or ferrimagnetic materials. Faraday (or Kerr) rotation in DMS quantum wells (QW) is known to be quite large owing to the giant Zeeman splitting of the exciton level. In order to enhance Kerr rotation CdMnTe QWs in CdMgTe barriers are arranged in a Bragg structure placed in an asymetrical optical cavity. An evaporated Al layer or the superconducting film itself serves as back mirror of the cavity. The QWs are located at anti-nodes of the electric field in the cavity. The sample is prepared as a wedged structure in order to allow the tuning of the QWs excitonic resonance through a minimum of the reflectivity spectrum. In these conditions we measure a Faraday rotation angle of 54 deg/T at the QWs (e1-hh1) exciton transition. Using the transfer matrix method the reflection coefficient and the Kerr rotation angle are calculated and found in good agreement with experimental results. The spatial resolution is 1 micrometer. It is limited by the optical aperture of the microscope objective. The magnetic resolution is 8 mT, comparable to that of conventional magneto-optical layers for

high-resolution Kerr microscopy. Using these samples as a magneto-optic layers, we obtained images of the intermediate state of type-I superconducting indium layers at 1.8 K. The intermediate state consists of an intricate pattern of superconducting and normal (flux bearing) domains. A disordered array of magnetic flux tubes is observed at low magnetic field. A typical labyrinth pattern of flux lamellae builds up with increasing applied field. The size and quasi-period of these structures are compared with the predictions of the intermediate state models. Different growth mechanisms are found for flux tubes and lamellae. In order to improve the magnetic sensitivity on the one hand and to avoid the chemical etching of the light absorbing substrate on the other hand, we designed and prepared a semiconductor microcavity magneto-optic layer. A CdMgTe/CdMnTe Bragg mirror is grown on top of a transparent substrate, followed by a CdMnTe/CdMgTe cavity. An aluminum mirror is then evaporated. Advantages and drawbacks of this new kind of magneto-optic layer will be shown. Our final goal is to study the dynamics of flux penetration in superconductors by time-resolved imaging. The advantages of DMS-based magneto-optic layers for time-resolved Kerr imaging will also be discussed. [1] C. Gourdon et al. Appl. Phys. Lett. 82, 230 (2003) [2] V. Jeudy, C. Gourdon, T. Okada, Phys. Rev. Lett. 92, 147001 (2004)

10:45 AM J6.4
Clamped Ferroelectric and Magnetic Domain Walls and Their Application to Memory Engineering. Eiichi Hanamura, Chitose Institute of Science and Technology, Chitose, Japan.

The theoretical and experimental studies of crystals with magnetic and ferroelectric (FEL) orderings were reviewed by Smolenskii and Chupis. There are very few natural muliferroic crystals that are both ferroelectric and ferromagnetic in the same phase. On the other hand, a number of antiferromagnetic (AFM) ferroelectrics have been found. Some of those show weak-ferromagnetism and its domain structures. We will discuss a family of rare-earth metal manganites. These crystals have Curie temperatures for FEL as high as 1000K and Neel temperature of an order of 100K. We will show first how to observe the FEL and AFM domain structures by the interference effects of second harmonic generation[1]. Here we can determine the both signs of FEL and sublattice magnetization of AFM order parameters independently. Then we have found the clamping of these order parameters at these domain boundaries[1,2].The FEL domain bounadary(DB) is always accompanied with the AFM DB but the AFM DB can exist independently. The microscopic model is presented to understand the origin of these clampings of the order-parameters at the DB's[3]. We have found that the antisymmetric exchange-interaction and the spin anisotropy energy which depends on the sign of FEL stabilize the AFM DB clamped at The FEL DB and that the AFM DB can exist alone. We will also discuss the case of FEL and weak-ferromagnetic ordering. These are candidates of memory system in which the magnetic memory can be switched by application of the electric field or the electric polarization by the magnetic field. We will discuss these phenomena in YMnO_3, ErMnO_3, TrMnO_3 and GaFeO_3. [1] T. Iizuka-Sakano, E. Hanamura and Y. Tanabe: J. Phys.:Condens. Matter, 13(2001)3031. [2] M. Fiebig, Th. Lottermoser, D. Froehlich, A.V .Golsev, and R.V. Pisarev, Nature, 419(2002)818. [3] E. Hanamura and Y. Tanabe:J. Phys. Soc. Jpn. 72(2003)2959. .

11:00 AM J6.5
Temperature Dependent Magnetic Linear Dichroism by Momentum-Resolved Electron Energy-Loss Spectroscopy. Yasuo Ito[1,2], Yoshie Murooka[1,2], Russell E. Cook[2], Michel van Veenendaal[1,2], Nanda Menon[3] and Dean J. Miller[2]; [1]Physics, Northern Illinois University, DeKalb, Illinois; [2]Materials Science Division, Argonne National Laboratory, Argonne, Illinois; [3]Gatan Inc., Pleasanton, California.

Since the advent of the spin-based electronics, tremendous efforts have been focused on fabrication and characterization of nanomagnetic structures. Since the spin transport occurs through the bulk of multi-layered nanostructures, probes directly sensitive to the magnetic anisotropy of the bulk and its interfaces are of great interest. So far, intense research activities to probe the magnetic anisotropy have been centered on polarized synchrotron X-ray spectroscopy techniques. However, the spatial resolution of these techniques is currently limited to 50 nm. Therefore, there is an urgent need for a technique capable of probing the magnetic anisotropy on length scale less than a few nanometers. Previously, we confirmed the possibility of detecting nanometer scale magnetic anisotropy (magnetic linear dichroism (MLD)) at room temperature [1], using Momentum-Resolved Electron Energy-Loss Spectroscopy (MREELS) performed in the Scanning Transmission Electron Microscope (STEM) with a less than 1 nm diameter electron probe [2]. The Fe L_{23} difference spectrum was successfully extracted from a pair of spectra acquired from an oriented antiferromagnetic α-Fe_2O_3 (hematite) microcrystalline as a model sample with different convergence angles, i.e., collecting different ratios of parallel to perpendicular components of the scattering vector. However, these experiments left a question of the origin of the anisotropy, structural or pure magnetic. Hematite exhibits magnetic phase transition at 263K (Morin temperature) without structural change. Below this transition temperature its magnetic moment flips 90 degree and orients along the c-axis. Here, we present the temperature dependent MLD due to the magnetic phase transition probed by STEM MREELS in hematite microcrystalline particles. The Fe L_{23} EEL spectra were acquired from an oriented microcrystalline above (300K) and below (98K) the Morin temperature. The difference spectrum agrees with the calculated MLD spectrum based on the atomic multiplet theory for the octahedrally coordinated Fe^3 ion. The present result is also consistent with those obtained from a single crystal natural [3] and synthetic [4] hematite sample. The STEM MREELS technique has been evolved toward a practical level to probe nanometer-scale element-specific magnetic anisotropy. [1] Y. Ito et al., Microscopy and Microanalysis 9 Suppl. 2, (2003) 314CD. [2] J. Yuan, N.K. Menon, J. Appl. Phys. 81, (1997) 5087; N.K. Menon, J. Yuan, Ultramicroscopy 78, (1999) 185. [3] P.A. van Aken, S. Lauterbach, Phys. Chem. Minerals 30 (2003) 469. [4] P. Kupier et al., Phys. Rev. Lett. 70 (1993), 1549. [5] This work is supported by the US Department of Education, State of Illinois under HECA, and work at Argonne, carried out in the Electron Microscopy Center, is supported by the U.S. Department of Energy, Basic Energy Sciences-Materials Sciences, under Contract #W-31-109-ENG-38.

11:15 AM J6.6
Nonlinear magneto-optical diagnostic of giant magneto-resistance nanogranular films. Evgenia Mikhailovna Kim[1], Tatyana V. Murzina[1], Oleg A. Aktsipetrov[1] and Anatolii F. Kravets[2]; [1]Physics Department, Moscow State University, Moscow, Russian Federation; [2]Institute of Magnetism, National Academy of Sciences of Ukraine, Institute of Magnetism, National Academy of Sciences of Ukraine, Kiev, Ukraine.

Magnetic nanomaterials such as multilayered structures and granular films have received considerable attention because of a number of new magnetic phenomena observed in these systems: the oscillatory coupling through the nonmagnetic spacers, spin-dependent electron scattering and tunneling, giant magnetoresistance (GMR), etc. Apart from these phenomena magnetic structures reveal significant magnetization induced nonlinear-optical effects as nonlinear magneto-optical Kerr effect (NOMOKE) in second- [1] and third- [2] harmonics generation. Magnetization induced optical second harmonic generation (SHG) can serve as a powerful tool for studying the magnetic properties of surfaces and interfaces where the inversion symmetry is broken. The nonlinear-optical studies were performed using the unfocussed output of a Q-switched YAG:Nd+3 laser at the wavelength of 1064nm with a pulse width of about 15ns, repetition rate of 24Hz. The samples studied are magnetic granular films of the composition CoxAg1-x and Cox(Al2O3)1-x exhibiting giant magnetoresistance effect at room temperature. Nanogranular films were prepared by co-evaporation of Co and Ag (Al2O3)1-x from two independent electron-beam sources on ceramic substrates, the base pressure during the deposition was lower than 10-4 Pa. The thickness of the films was about 400nm. The crystalline structure was studied by X-ray diffraction and transmission electron microscopy which allowed us to estimate the mean size of Co granules in the annealed films. All types of magnetic granular films exhibit the GMR effect. Nonlinear optics allows to study the crystallographic symmetry of the samples, the azimuthal anisotropy of the SHG and THG intensity can measured, which show the existence of a mirror plane in the film structure. Azimuthal dependencies measured for CoxAg1-x and Cox(Al2O3)1-x films reveal that the structure of the first films is isotropic and the second one is anisotropic and possesses of m - symmetry. Nonlinear magneto-optical Kerr effect (NOMOKE) allows to characterize the magnetic properties of the materials, namely the magnetic contrast. The THG magnetic contrast is about 15 percent Cox(Al2O3)1-x films, which exceeds for at least an order of magnitude the values typical for magneto-optical Kerr effect (MOKE). Also we can evaluate the power of magnetization of the materials, for that the phase difference between of magnetic and nonmagnetic components of the nonlinear susceptibility is necessary to know. The magnetoinduced phase shift in THG and SHG was measured for all of the studied materials in the opposite directions of the magnetization Mup/down. The largest phase shift in THG was observed for Cox(Al2O3)1-x films, 2270, and the power of magnetization is about 2.3, respectively. For CoxAg1-x films we observed the correlation of NOMOKE with GMR.

11:30 AM J6.7
Giant Third-Order Nonlinear Magneto-Optical Kerr Effect in Thin Magnetic Films. Tatyana V. Murzina[1], Jane M. Kim[1], Oleg A. Aktsipetrov[1], Viktor G. Lifshits[2] and Mitsuteru Inoue[3]; [1]Physics Departmnet, Moscow State University, Moscow, Russian Federation; [2]Institute of Automatics and Control Processes Far Eastern Branch RAS, Vladivostok, Russian Federation; [3]Toyohashi University of Technology, Toyohashi, Japan.

Nonlinear magneto-optical Kerr effect in magnetization-induced second-harmonic generation (SHG)is a well recognized and an effective probe of magnetism of surfaces, interfaces and nanostructures. This sensitivity arises from a simultaneous breakdown of the structural and time-reversal symmetry, which occurs at surfaces and interfaces in the case of centrosymmetric materials. Second-order nonlinear magneto-optical Kerr effect (NOMOKE) in SHG, which appears in magnetization-induced changes in the polarization, phase or the intensity of the SHG radiation can exceed the linear magneto-optical Kerr effect (MOKE) by several orders of magnitude. Till the very last time, the nonlinear magneto-optics was restricted to the second-order NOMOKE, while third-order NOMOKE was not studied. Nevertheless, magnetization induced third-harmonic generation (THG) appears to be a sensitive probe of magnetizm in nanomaterials. In this paper, the results of the experimental observation of third-order NOMOKE in magnetic thin films are presented. It is demonstrated that the third-order NOMOKE parameters in thin films are comparable with that of the second-order and exceed the linear MOKE by an order of magnitude. The samples studied are thin films of Co and epitaxially grown Fe(110) of the thickness of 100-200 nm, Bi-doped yttrium iron-garnet films of 200 nm thick. The THG measurements were performed using YAG:Nd laser operating at 1064 nm wavelength and pulse duration of 15 ns. A saturating magnetic field of 2 kOe was applied by permanent magnets in the geometry of the transversal, longitudinal or polar Kerr effect. The magnetization induced phase shift of the third harmonic (TH) wave is observed, which stays in agreement with the phenomenological wave was studied by the THG interferometry for the opposite directions of the magnetic field applied. For polar and longitudinal configurations of the third-order NOMOKE, a rotation of the polarization plane of TH wave is observed, which stays in agreement with the phenomenological treatment of the magnetization-induced cubic susceptibility tensor. The rotation angles of the TH wave polarization up to 20 deg. were observed for Co films, which is the same order effect as the second-order NOMOKE. For the transversal magnetic field application, odd in magnetization variations in the intensity and phase of the frequency-tripled light are observed. The THG magnetic contrast in thin metal films is about 0.15 and for Bi-YIG is about 0.8. The largest magnetization-induced phase shit of 70 deg. is observed for Co films. Thus, the observed third-order NOMOKE reveals giant enhancement. Large values of the third-order NOMOKE should be attributed to the role of the surfaces and interfaces in magnetization-induced THG.

SESSION J7: Magneto-Optical Materials II
Chair: Richard Gambino
Thursday Afternoon, December 2, 2004
Berkeley (Sheraton)

1:30 PM J7.1
Suitability of Fe-doped BaTiO3 for waveguide magnetooptic isolators. Ashok Rajamani[1], David Bono[1], G. F. Dionne[1,2] and Caroline A. Ross[1]; [1]Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts; [2]Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Massachusetts.

This study investigates the suitability of Fe-doped BaTiO3 and other perovskites as an optical isolator material that can be integrated as a waveguide onto a silicon based optoelectronic circuit. BaTiO3 perovskite is chosen for this study because it is a transparent material that grows epitaxially on MgO. Three different compositions of Fe-doped BaTiO3 films, with 20, 30 and 50% Fe substituted for Ti, were grown by pulsed laser deposition (PLD), using an excimer laser of 248 nm (KrF) wavelength, at temperatures of 700 C and laser fluences on the order of 1-2 J/m$\hat{2}$ in vacuum. Films were characterized by wavelength dispersive spectroscopy, x-ray diffraction, and magnetic and optical measurements. The films grow tetragonally with (001) texture on MgO(100) substrates. Fe4+ replaces Ti4+ in BaTiO3 to produce ferromagnetic behavior, but such a dopant can also increase optical absorption. Ferromagnetism with a Curie temperature of 625 C was observed in these films, which have saturation moments ranging from 11 - 15 emu/cm$\hat{2}$ and an in-plane remanent magnetization. The low saturation moment indicates that most of the Fe ions are coupled antiferromagnetically, but ferromagnetic superexchange interactions are expected to occur between Fe4+ ions and any Fe3+ ions present in the structure. The Fe3+ ions are found in association with oxygen vacancies which occur because the films are grown in vacuum and are therefore off-stoichiometry. This exchange coupling leads to clusters of Fe ions associated with oxygen vacancies forming ferromagnetic regions within an otherwise paramagnetic or antiferromagnetic spin arrangement, and accounts for the weak ferromagnetism. Faraday rotation at the telecommunications wavelength of 1.55 um was measured to an accuracy of 1 millidegree in the hard-axis direction, perpendicular to the film plane. Saturation Faraday rotation decreases from 0.109 deg/um for Fe = 50 at% to 0.033 deg/um for Fe = 20 at%, while optical absorption decreases much faster. There is therefore an improvement in the magnetooptic figure of merit (ratio of Faraday rotation to optical absorption) as the Fe content decreases from 50% to 20%. Other iron-based perovskite structures have also been investigated, including orthoferrites of the formula AFeO3. CeFeO3, for example, shows a Faraday rotation of 0.8 deg/um, but its absorption is higher than that of the Fe-doped BaTiO3. We will discuss how materials for waveguide isolators with low levels of absorption can be synthesized using the iron content of these perovskite films as the controlling parameter.

1:45 PM J7.2
Dependence of Ferromagnetic Properties of GaN:Mn on Codoping by Mg and Si. Mason J. Reed[1], Erdem F. Arkun[1], Acar E. Berkman[1], Nadia El-Masry[1], Meredith L. Reed[3], John Zavada[2] and Salah M. Bedair[3]; [1]Materials Science and Engineering, North Carolina State University, Raleigh, North Carolina; [2]Army Research Office, Durham, North Carolina; [3]Electrical And Computer Engineering, North Carolina State University, Raleigh, North Carolina.

The effects of codoping of GaN:Mn films by silicon and magnesium is investigated. Three sets of samples; GaN:Mn, GaN:Mn:Si and GaN:Mn:Mg, are grown by metal organic chemical vapor deposition on sapphire under identical conditions, while dopants are injected into the gas phase during growth. The Mn concentration in all films is kept constant, and the dopant (silicon and magnesium) concentration is varied. Secondary ion mass spectroscopy (SIMS) confirmed that Mn concentration in the films does not change as dopants are added. Ferromagnetic properties is measured by a superconducting quantum interference device (SQUID). The highest saturation magnetization of 1.02 emu/cc is measured for GaN:Mn, whereas the saturation magnetization of co-doped films i.e. GaN:Mn:Si and GaN:Mn:Mg decreases as the concentration of dopants (silicon or magnesium) increases. These results are explained based on the change of the Fermi level position within the bandgap of GaN:Mn with respect to the 3d-Mn impurity band. The addition of magnesium and silicon is responsible for the change in the Fermi level position and also the occupancy of the Mn impurity band. Therefore, the ferromagnetic properties in this material system is dependent on the Fermi level position in the bandgap, and the availability of carriers in the Mn impurity band. This suggests that ferromagnetism observed in this material system is carrier mediated. The results exclude the possibility of secondary phases and spin glass behavior as the origin of ferromagnetism in the samples investigated in this study.

2:00 PM J7.3
The Effect of Mn Concentration on Curie Temperature and Magnetic Behavior of MOCVD Grown GaMnN Films. Acar Erkan Berkman[1], Erdem F. Arkun[1], Mason J. Reed[1], Meredith L. Reed[3], John Zavada[2], Nadia El-Masry[1] and Salah M. Bedair[3]; [1]Materials Science and Engineering, North Carolina State University, Raleigh, North Carolina; [2]Army Research Office, Durham, North Carolina; [3]Electrical and Computer Engineering, North Carolina State University, Raleigh, North Carolina.

Growth of dilute magnetic semiconductor GaMnN showing ferromagnetic behavior above room temperature was achieved. GaMnN films were grown by MOCVD using $(EtCp_2)Mn$ as the precursor for in-situ Mn doping. Structural characterization of the GaMnN films was achieved by XRD, SIMS and TEM measurements. XRD and TEM confirmed that the films were single crystal solid solutions without the presence of secondary phases. SIMS analysis verified that Mn was incorporated homogeneously throughout the GaMnN layer which was 0.7 μm thick. Ferromagnetic behavior for these films was observed along c-direction (out of plane orientation) in a Mn concentration range of 0.025-2 %. The saturation magnetization ranged between 0.18 and 1.3 emu/cc for different growth conditions. Curie temperatures of the GaMnN films ranged from 270 to above 400K depending on the Mn concentration. This dependence of Curie temperature on concentration of Mn in GaMnN indicates that the grown films are random solid solutions. SQUID measurements ruled out the possibility of spin-glass and superparamagnetism in these MOCVD grown GaMnN films. The grown films were electrically semi-insulating; however PL measurements showed that the films were still optically active after Mn doping. This study showed that the growth of III-Nitride films doped with Mn require special growth conditions to achieve ferromagnetism above room temperature, and the magnetic response of the film depends on the Fermi level position.

2:15 PM J7.4
Structural Analysis of Mn-doped ZnO Thin Films Deposited by RF Magnetron Sputtering. C. Liu[1], F. Yun[1], Pierre Ruterana[2], Sang-Jun Cho[1], B. Xiao[1] and Hadis Morkoc[1]; [1]Dept. of Electrical Engineering, Virginia Commonwealth University, Richmond, Virginia; [2]SIFCOM UMR 6176 CNRS-ENSICAEN, 6,

Boulevard du Marechal Juin, 14050 Caen Cedex, France.

There is not dearth of reports in the literature arguing in favor and also against Mn-doped ZnO being ferromagnetic with Curie temperatures exceeding room temperature. In this vein, we have deposited Mn-doped ZnO thin films by RF magnetron sputtering on c-plane sapphire substrates, and analyzed them. The magnetic properties of the Mn-doped ZnO films have been measured by a superconducting quantum interference device (SQUID) magnetometer. Clear hysteresis in magnetization vs. magnetic field was observed at room temperature. The magnetization measurements as function of temperature under zero-field-cooled and field-cooled conditions showed significant difference up to 300 K. High-resolution x-ray diffraction measurements revealed that the Mn-doped ZnO films possessed a single phase wurtzite structure without shift of ZnO (0002) peak position. Transmission electron microscopy analysis shows a columnar growth with small rotations around the [0001] axis of the wurtzite structure, with an average domain size of 50 nm. This columnar growth is disrupted during Mn-doping which leads to a ZnO film containing a high density of Mn related cubic and hexagonal precipitates. The origin of the ferromagnetic properties of the Mn-doped ZnO film will be discussed.

2:30 PM J7.5
Magnetic Properties of Epitaxially Grown Zn1-xCoxO Thin Films. Feng Yun[1], Varatharajan Rengarajan[2], Jeff Nause[2] and Hadis Morkoc[1]; [1]Virginia Commonwealth University, Richmond, Virginia; [2]Cermet, Inc., Atlanta, Georgia.

Incorporation of magnetic impurities into a host semiconductor has been used for decades to obtain diluted magnetic semiconductor (DMS), driven by an interest in magnetoelectronics, and in particular the recent prospects of spintronics. This new class of materials finds potential applications in devices such as transistors, LEDs, memory elements, sensors and optical switches. Theoretical prediction of ferromagnetism above room temperature in transition metal doped ZnO has spurred the experimental efforts in this field. However, there are quite conflicting reports as to the presence of ferromagnetic behavior as well as the origin of such behavior. We have conducted a systematic approach of magnetic characterization using a series of Zn1-xCoxO samples with different cobalt composition. The Zn1-xCoxO thin films were epitaxially grown by metalorganic chemical vapor deposition (MOCVD) on quartz and ZnO substrates. The Co composition was adjusted by controlling the bubbler temperature and flow of carrier gas. Various magnetic measurements were performed using a Quantum Design MPMS system, which utilizes a superconducting quantum interference device (SQUID) magnetometer. Magnetic hysteresis curves were observed at 5K which persisted at 300K, characteristic of ferromagnetic behavior. Temperature dependent magnetization was recorded at both zero-field cooled (ZFC) and field cooled (FC) conditions. Changes of magnetization were observed under ZFC and FC conditions in some samples from 5K up to 300K. Composition-dependent changes in magnetization were also observed among samples with different cobalt doping, indicative of ferromagnetism related directly to cobalt incorporation. Discussion of the magnetic characteristics and their possible origin in our epitaxial Zn1-xCoxO layers will be presented as well as analysis using Curie-Weiss law and material parameters.