International Symposium on

Coherent Optical Science

Conference Hall, The University of Electro-Communications, Tokyo, Japan

16 July 2005

Program

9:15~9:30 **Opening Session** (Chair: Prof. K. Ueda)

Opening Remarks: Prof. Takashi Masuda (President of UEC)

Introduction: Prof. Kohzo Hakuta (Leader of UEC-COE program)

9:30~11:30 **Session1: Coherent Manipulation and Atom Optics** (Chair; Prof. K. Hakuta)

Michael Fleischhauer (University of Kaiserslautern, Germany) ***Linear and nonlinear matter-wave optics with ultra-slow light*** **(invited)**

Ken-ichi Nakagawa(UEC) ***Coherent atom optics and their applications***

Matthew Eisaman (Harvard University, U.S.A.)***Progress toward Generating, Storing, and Communicating Single-Photon States using Coherent Atomic Memory*** **(invited)**

Fam Le Kien(UEC) ***Trapping of cesium atoms in the vicinity of a subwavelength-diameter fiber***

12:00~14:00 **Poster presentation**

14:00~16:00 **Session 2: Near Field Optics and Ultrafast Phenomena** (Chair; Prof. M. Takeda)

Lambertus Hesselink (Stanford University, U.S.A.) *Plasmonic nano-structures for application in ultra-high performance optical storage and bio-sensors* **(invited)**

Hajime Nishioka (UEC) ***Frequency-domain phase conjugator for a few cycle optical pulses***

Min Gu (Swinburne University of Technology, Australia) ***Near-field laser tweezers*** **(invited)**

Hitoki Yoneda (UEC) ***Optical properties of warm dense matter created with ultra-short-pulse laser***

16:30~18:30 **Session 3: Laser and Photonic Devices** (Chair; Prof. S. Ohtani)

Markus Pollnau (University of Twente, Netherlands) ***Optic waveguides in crystalline oxide materials: Growth, structuring, characterization, and applications*** **(invited)**

Nobuyuki Nakamura (UEC) ***Physics and Application of Highly Charged Ions***

Lei Xu (Fudan University, China) ***Directional lasing from micro-cavities*** **(invited)**

Ken-ichi Ueda (UEC) ***Big impact of fiber lasers onto the solid state technology***

18:30 **Closing Remarks: Prof. Kohzo Hakuta**

19:00~20:30 **Reception**

Session1: Coherent Manipulation and Atom Optics

S1

Linear and Nonlinear Matter-Wave Optics with Ultra-Slow Light

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The propagation of light in cold atomic vapors with electromagnetically induced transparency [1] can be associated with a substantial reduction of the group velocity controllable by an external field. The physical origin of the group velocity reduction is the formation of quasi-particles, dark-state polaritons, which are superpositions of electromagnetic and matter excitations (spin-waves). The possibility to control the propagation of dark-state polaritons allows for a new regime of matter-wave optics, which will be discussed in this talk. As examples for potential applications I will propose a laser--matter-wave hybrid Sagnac interferometer, which combines the advantages of laser gyroscopes (large area) with that of matter-wave devices (high sensitivity) [2], discuss the possibility of efficient photon-photon interactions mediated by atom-atom scattering [3] and discuss the possibility to study quantum-Hall physics with neutral atoms[4,5].

[1] M. F., A. Imamoglu, J.P,Marangos, Rev. Mod. Phys.**77** (2005)

[2] F. Zimmer and M. F., Phys. Rev. Lett. **92,** 253201 (2004)

[3] M. Masalas and M.F., Phys. Rev. A **69**, 061801 (2004)

[4] G. Juzeliunas, P.Öhberg, Phys.Rev.Lett. **93**, 033602 (2004)

[5] J.Ruseckas, G. Juzeliunas, P.Öhberg, M.F., Phys.Rev.Lett. **95**, 010404 (2005)

S2

Coherent atom optics and their applications

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Recently coherent manipulations of ultra cold atoms and Bose-Einstein condensate atoms have been of considerable interest and they have been applied to the precision measurements and they will be also applied to the quantum information processing. In this symposium, I will present our recent investigations about the coherent atom optics and their applications including the production and manipulation of Bose-Einstein condensate atoms, an atomic interferometer for the precision gravity measurements, and an atom chip.

S3

Progress toward Generating, Storing, and Communicating Single-Photon States using Coherent Atomic Memory

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We report on our progress toward generation, storage and communication of single-photon states using atomic memory. Specifically, we describe experiments demonstrating conditional generation of single-photon pulses of light with controllable propagation direction, timing, and pulse shapes. The approach is based on preparation of an atomic ensemble in a state with a desired number of atomic spin excitations, which is later converted into a photon pulse by exploiting long-lived coherent memory for photon states and electromagnetically induced transparency (EIT). In addition, we describe investigations of EIT at the single-photon level. We transmit conditionally generated single-photon states through a second atomic ensemble, and observe that the nonclassical nature of the transmitted field is only preserved when its frequency is within the EIT transparency window of the ensemble. Finally, we discuss the prospects for long-distance quantum communication using these techniques.

S4

Trapping of cesium atoms in the vicinity of a subwavelength-diameter fiber

Fam Le Kien[1], J. Q. Liang[1], V. I. Balykin[2], and K. Hakuta[1]

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Due to recent developments in taper fiber technology, thin fibers can be produced with diameters down to 50 nm. Thin fiber structures can be used as building blocks in future atom and photonic micro- and nanodevices. We show that a tapered fiber with an intense evanescent field can be used for *microscopic* trapping and guiding of individual atoms. Our method is based on the use of a subwavelength-diameter silica fiber with a single (red-detuned) or two (red- and blue-detuned) light beams launched into it. The great advantages of our scheme are (a) localization of atoms to a subwavelength region, (b) high efficiency to detect individual atoms, (c) high accessibility to the trapped atoms, and (d) achievement of strong coupling between light and matter.

Session 2: Near Field Optics and Ultrafast Phenomena

S5

Plasmonic nano-structures for application in ultra-high performance optical storage and bio-sensors

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Surface plasmon waves provide a powerful means for coupling optical waves to sub-wavelength structures in metals. In this presentation we describe two applications where surface plasmons are key to achieving significantly improved results over previous approaches. The first is a C-shaped sub-wavelength aperture that has a million-fold increase in power throughput over conventional square and round apertures producing the same optical spot size. The second application is a 100-1000 fold increase in SPR sensor sensitivity by using the Goosch-Hanchen effect and a surface plasmon resonance effect. In the presentation storage and bio-sensor applications involving both sub-wavelength structures are presented.

S6

Frequency-domain phase conjugator for a few cycle optical pulses

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We will discuss on frequency-domain phase conjugation (FDPC) expressly to correct a few cycle (10 fs) optical pulse distortion in an all-optical system. The FDPC wave forms a time-reversed replica of a temporally phase varied (frequency chirped) pulse. When the phase distortion is given by a group-delay-dispersive (GDD) element, the time-reversed replica regenerates a transform-limited pulse after passing though again the same GDD element. In principle, the FDPC operation requires frequency-selective phase-conjugation mechanism (for example, in the photon-echo system, Fourier phases are stored as coherences in an inhomogeneously broadened medium, and are conjugated by the π-area-pulse flipping). In this paper, we demonstrate ultrabroadband (>80 THz) FDPC in a nonresonant material. Each angular frequency and Fourier phase of the laser pulse has been recoded as spatial frequency and phase in a diffractive optics. The Fourier phase discrimination was carried out by making second-order cross correlation with a gate pulse. The 1^{st} and -1^{st} order diffractions of the optically programmable diffractive optics generate the genetic and the time-reversed replica, respectively.

S7

Near-field laser tweezers

Min Gu

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Optical tweezers employ the forces of radiation pressure of light to trap and manipulate microscopic particles, and have enormous applications in various disciplines ranging from physics to biology. While one deals with very small biological specimens like single cells or molecules, a reduced trapping volume is desirable, which would ideally be provided by a near field trap. Near field trapping employs the evanescent field to manipulate microparticles, and hence reduces the axial trapping volume down to tens of nanometres. Although a nano-aperture and a metallic tip have been proposed to perform near-field trapping and manipulation but these mechanisms have not been experimentally confirmed because these they are located too close to the sample. We have recently reported on a new near-field trapping method based on the focused evanescent spot. When this method is combined with femtosecond-pulsed illumination, we can achieve simultaneous near-field tweezing and two-photon induced morphology dependent resonance spectra from a trapped particle.

S8

Optical properties of warm dense matter created with ultra-short-pulse laser

Hitoki Yoneda[1,2] and Richard M. More[3]

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We describe experiments on warm dense matter created with an ultra-short pulse UV laser, and probed with short pulses of various frequencies. The reflected probe pulse is analyzed to give the three Stokes' parameters which describe its elliptic polarization. Comparing between experiment and model of analytical or numerical hydrodynamics, we can approximately determine the dielectric function. We have measured Au, Cu, Al, W, Mo, Fe, Sn, SS304, and SiO_2. Some warm-dense expanding metals can be interpreted by assuming a surprising low electrical conductivity. We find the free electron contribution to the dielectric function is often much less than expected from the usual Spitzer-Drude theory. These results suggest that we are observing a plasma equivalent of localized or quasi-localized states of low-energy free electrons. In this research, many of the most important questions are issues of electronic structure: how are atomic excited-state energies modified by high density? Do low-energy conduction electrons behave like a simple Fermi gas? Are there localized or quasi-localized electron states near the boundary between atomic bound-states and the continuum? In addition, we propose new method to measure the critical point for high melting point metals. These measured data will be useful for testing Solid and plasma physics models.

Session 3: Laser and Photonic Devices

S9

Optical waveguides in crystalline oxide materials: Growth, structuring, characterization, and applications

Markus Pollnau

University of Twente, Netherland

This seminar will review our recent work at the Swiss Federal Institute of Technology Lausanne on optical planar and channel waveguides in sapphire and Ti:sapphire as well as rare-earth-ion-doped $KY(WO_4)_2$. Growth by liquid phase epitaxy, structuring and refractive-index modification by reactive ion etching, ion beam implantation, and femtosecond laser writing, optical waveguide characterization by propagation-loss, dark m-line, and luminescence measurements, as well as applications as waveguide lasers and broadband light sources for interferometry will be discussed.

S10

Physics and Application of Highly Charged Ions

NAKAMURA Nobuyuki[1], TONA Masahide[2], NAGATA Kazuo[1], TAKAHASHI Satoshi[1], YOSHIYASU Nobuo[3], YAMADA Chikashi[3], and OHTANI Shunsuke[1]

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Highly charged ions (HCIs) are the ions which have only a few electrons. One of the notable characteristic points of HCIs is that they have huge potential energy even if they do not have kinetic energy at all whereas the size is as small as 'sub-nanometer'. Thus HCIs can modify the local area of material surfaces drastically, and as a result, nanometer-sized structure can be created on the surface with a quantum efficiency of 1.

In order to apply this characteristic point of HCIs to nanotechnologies including the creation of photonic devices, we are studying fundamental processes in the interaction of HCIs and surfaces by using a highly charged ion source called Tokyo electron beam ion trap (Tokyo-EBIT). Recent experimental activities and plans are presented after brief introduction of HCIs.

S11

Directional lasing from micro-cavities

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In this presentation, we will report our recent works on directional lasing from various kinds of mciro-cavities. The micro-cavities include 1-D photonic band gap cavity with high scattering gain media as the defect layer, and several extremely deformed micro-ring cavities. All these cavities show very narrow linewidth lasing and narrow emission divergence behavior.

S12

Big impact of fiber lasers onto the solid state technology

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High power fiber lasers have made great progress last ten years. We developed >1kW output fiber lasers in 2002 for the first time in the world. This was a demonstration of the real industrial fiber-disk laser. Our laboratory has developed a wide variety of fiber lasers like highly stabilized fiber MOPA system, ultra-narrow-band fiber laser with loop mirror resonator, arrayed fiber laser for coherent summation, blue output fiber laser through the upconversion mechanism, and the high energy pulse fiber lasers by large core photonic fibers. We review and talk about the big impact of fiber lasers onto the solid state laser technology.

Poster Presentations

Coherent Manipulation and Control

PS1

Superluminal Transmission through a DFB Cavity with Intracavity EIT Medium

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We study pulse propagation through a high finesse distributed feedback cavity containing an electromagnetically induced transparency (EIT) medium. The EIT medium is modeled by an effective susceptibility at the probe frequency and depends on the pump strength and frequency. We show that the pump laser parameters (like frequency and strength) can be used as efficient handles to control the velocity of the transmitted pulse. In particular, we demonstrate significant superluminal transit with very low attenuation. This is in sharp contrast to the usual use of EIT for slow light. Moreover, we show a significant enhancement of the group index mediated by the cavity. We believe that the results may find important application in optical signal processing and computation.

PS2

Gyroscopic effects in interference of matter waves

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A new gyroscopic interference effect stemming from the Galilean translational factor and *quantum Foucault effect* in the matter wave function is pointed out. In contrast to the well-known Sagnac effect that stems from the geometric phase and leads to a shift of interference fringes, this effect causes slanting of the fringes. We illustrate it by calculations for two split cigar-shaped Bose-Einstein condensates under the conditions of a recent experiment, see Y. Shin *et al.*, Phys. Rev. Lett. **92**, 050405 (2004). Importantly, the measurement of slanting obviates the need of a third reference cloud.

PS3

Pump-probe analysis of doubly excited states of He

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Recent advances in the experimental techniques of subfemto- or atto-second laser pulses make it possible to observe the motion of the electrons in atoms and molecules in the real time domain. In this work, we investigate the feasibility of observing the correlated motions of doubly excited states of He in real time by atto-second pump-probe experiments. We study *ab initio* photo electron spectra by using the time-dependent Hyperspherical close-coupling (TDHSCC) method. We implemented pilot calculations with several sets of the laser parameters, and found that it is possible to extract the real time information on the molecule like ro-vibratioanl motions of the two electrons of He from time-resolved single ionization spectra by atto-second pump-probe lasers.

PS4

On the Minimization of the Depth of Certain Quantum Circuits

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A logic circuit model of computation is a basis for every kind of computation, and also takes an important role in quantum computation. Thus it is important to study how to evaluate logical functions on quantum circuits, and how to minimize or simplify those circuits. In this paper, we show how to automatically generate a certain kind of shallowest quantum logic circuit without ancilla, a so-called *f*-C-NOT gate, which computes an arbitrary logic function, *f*. We will, moreover, show that this circuit generation problem is strongly related to the minimization problem for a logical expression, called ESOP. Furthermore, in order to generate the desired *f*-C-NOT gates as quickly as possible, we reduce this minimization problem to an NP-complete problem, the so-called Maximum Clique. Having applied this reduction, we can use a well-known, efficient program to solve the Maximum Clique problem to generate a desired *f*-C-NOT gate with the minimum depth.

PS5

Quantum Electric-Current Mirrors Based on Small Tunnel-Junction Systems

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We study quantum electric-current mirrors, which duplicate direct electric currents accurately to the degree of a passage of a single elementary charge through the devices. The devices are composed of capacitively coupled two arrays of small tunnel junctions, and the duplication is based on the self regulation of the single charge tunnelings due to the charging effect and correlation of the tunnelings in the two arrays via the electrostatic interaction. We propose two versions of current mirrors: one is slantingly coupled arrays with superconducting electrodes, and the other is coupled long and short arrays of normal conducting electrodes. In the former device, each electrode in one array is capacitively coupled with two electrodes in the other array, and, in the latter device, the arrays are coupled only through the central electrodes, and the short array acts as a so called single-electron turnstile. We present experimental and simulational results of the current duplication in the devices.

PS6

Manipulating Atoms Using Sub-Wavelength Diameter Optical Fiber

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We propose various schemes for microscopic trapping of atoms around a sub-wavelength diameter fiber e.g. using single red-detuned or two color (red and blue-detuned) evanescent waves. Also we found red and blue-detuned magic wavelengths for state insensitive trapping so that we can use MOT for efficient loading of these traps and also we can afford continuous observation during trapping interval. Recently we study the spontaneous emission of a Cs-atom in the vicinity of a sub-wavelength diameter fiber. We show that the confinement of the field in the guided modes and the degeneracy of the excited and ground states substantially affect the spontaneous emission process. When the fiber radius is about 200nm, a significant fraction of spontaneous emission by the atom can be channeled into guided modes. Regarding the experimental realization, laser-cooling and thin-fiber technologies must be combined. Among them, the key technology is to prepare ultra-thin silica fiber with diameter in sub-wavelength range. We have developed techniques to make tapered fiber adiabatically maintaining the single mode condition. We prepare tapered fibers with diameter less than 400 nm with very low tapering loss.

PS7

Dual optical lattice for the study of controlled cold-atom collisions and quantum computation

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A three dimensional array of ultra-cold atoms trapped in an optical lattice is an attractive system for the quantum computer. The atom can be placed in a single motional quantum state of the lattice potential, and its internal state can be manipulated by coherent light providing single-qubit operations of the quantum computer. However, atoms are too closely packed in an optical lattice to optically manipulate individual atoms. We propose and are constructing a dual lattice system, in which the second atoms are trapped in an independent lattice with the same lattice constant, select the lattice cite to do single-qubit operation and intermediate two-qubit operations. The system can be used to study inter-atomic interactions under completely controlled external motion.

High-Precision Optical Control

PS8

Generation of a 10-THz ultrahigh-repetition-rate train by synthesizing phase-coherent Raman-sidebands

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A train of highly-stable, high-beam-quality ultrashort pulses is successfully produced by synthesizing phase-coherent rotational-Raman-sidebands in parahydrogen. The intensity-waveform of this ultrashort-pulse-train is directly evaluated in time domain based on a sum-frequency-generation autocorrelation-technique. It is shown that a 10.6-THz ultrahigh-repetition-train of short pulses is formed with an effective-duration of 20 fs and a high peak-power of 2 MW.

PS9

Ultraviolet self-pumped phase conjugation by stimulated photorefractive backscattering in $LiNbO_3$:Mg

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With increasing demands for high-resolution photolithography and laser-beam control in short wavelength regions all-optical manipulation of ultraviolet coherent optical waves by nonlinear optical means has paid much attention. Here we report on the demonstration of self-pumped phase conjugation (SPPC) in the ultraviolet by stimulated photorefractive backscattering in a highly Mg-doped $LiNbO_3$. We used a $LiNbO_3$:Mg (5 mol%) sample and the measured coupling gain at 351 nm was 16 cm^{-1}. We found that stimulated photorefractive backscattering took place only when the incident beam propagated toward the +c-axis direction as a result of the unidirectional energy transfer. Backscattered speckle patterns were dependent on the distance between the focused beam position and the sample. At a certain distance, all the speckles merged into a single spot that was found to be a phase-conjugate replica of the incident beam, which was verified by the phase-distortion correction measurement. The SPPC reflectivity of approximately 10% was obtained.

PS10

Dispersion-free absolute interferometry with a spatial-frequency-tunable light source

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Conventional absolute interferometry suffers from a dispersion problem because it makes use of a broadband optical frequency spectrum generated from a white-light source or an optical-frequency-tunable light source. From the space-time analogy, we note that spatial frequency can play the same role as optical frequency, and propose an alternative technique for absolute interferometry that makes use of a monochromatic spatial-frequency-tunable light source created by a computer-controlled spatial light modulator. The proposed system can perform two different modes of operation for absolute interferometry, one being the synthesis of a spatial coherence function for the selective acquisition of a depth-sectioned image, and the other the spatial frequency scan for absolute profilometry. Quantitative experimental results will be presented that demonstrate the validity of the principle.

PS11

Beam deformation in holographic generation of Laguerre Gaussian beam caused by hologram distortion

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The Laguerre-Gaussian(LG) beam is an optical beam that has doughnut-shaped intensity distribution and phase

singularity. Applications of LG beam are optical trapping and rotational manipulation. Generation of LG beams has been realized through computer holograms. The profile of beam generated by hologram is often more important than its diffraction efficiency. Low diffraction efficiency can be compensated by high power light source. A high power distorted beam may cause serious problems. However, the beam profile has not bean discussed in detail. We have found through experiment that the profile of beams generated by off-axis holograms are deformed into triangular shape. We deduce that the source of this beam deformation is that the grating pitch of hologram varies with location. A numerical simulation for analysis of this effect is also reported.

PS12

Observation of the isotropic conical diffraction in holographic photopolymers

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A coherent light beam focused into a photorefractive crystal such as $LiNbO_3$ or $BaTiO_3$ suffers from nonlinear scattering under a certain condition. The origin of this phenomenon is attributed to the recording of numerous noisy dynamic phase gratings formed by the incident wave and scattered waves in such a crystal. The resultant diffraction pattern sometimes consists of symmetric cones centered in the crystal, which is called the conical diffraction.[1,2] Here we report on the observation of a similar isotropic conical diffraction pattern from thick dry photopolymers including binder photopolymers, nanoparticle-dispersed photopolymers[3,4] and holographic polymer-dispersed liquid crystals.[5] We discus its origin, its influence on volume holographic recording and reduction methods.

[1]M.D. Ewbank, P. Yeh and J. Feinberg, Opt. Commun. **59**, 423(1986). [2]Z. Zhang et al., Opt. Commun. **69**, 66(1988). [3]N. Suzuki and Y. Tomita, Appl. Opt. **43**, 2125(2004). [4] Y. Tomita, N. Suzuki and K. Chikama, Opt. Lett. **30**, 839(2005). [5]R.L. Sutherland et al., Chem. Mater. **5**, 1533(1993).

PS13

Direct writing of two-photon-induced volume grating by a mode-lock oscillator

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Two-photon gated 10 fs optical pulse recording and frequency-domain phase conjugation have been demonstrated with a few nJ laser pulses from a mode-lock oscillator. Because diffraction efficiency is proportion to square of pulse width a nonlinear material having deep refractive index modulation is required for a few-cycle recoding. The material should be highly photo-sensitive to avoid self-phase modulation. A 72 μm thick dye-doped film having an absorption cross-section of 10^{-16} cm^2 and OD=11 at the two-photon wavelength has been developed as the recording material. Figure 1 is showing diffraction efficiency of a two-photon-induced 8-groove volume grating. The maximum diffraction efficiency of 3.3 % corresponding to a refractive index change of 0.03 has been obtained. This result is the highest index modulation by two-photon writing.

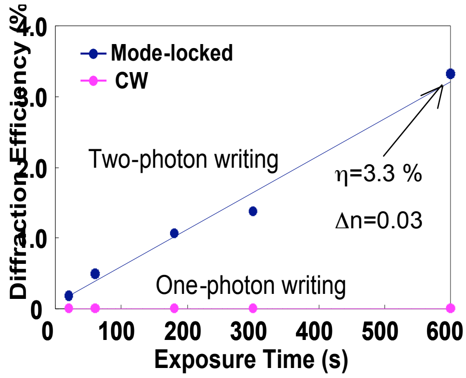

Fig.1 Diffraction efficiency of two-photon recorded 8-grooves grating as a function of exposure time.

PS14

Optimization of compression factor and diffraction efficiency in the two-photon-gated diffractive optics

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The total conversion efficiency of two-photon gated femtosecond pulse recording is given by the product of contrast ratio of the phase-sensitive 2nd order cross-correlation and the diffraction efficiency. In this paper, we have numerically optimized these parameters.

The result shows that optimum gate pulse energy ratio was proportional to squire root of the compression factor i.e. a gate pulse fraction corresponding to 1 % of signal pulse energy was the optimum value at a compression factor of 10,000.

When signal pulse has linear chirp, the diffraction efficiency was proportion to coherent length in contrast to monochromatic case, as shown in Fig.1. The diffraction efficiency of 69% was possible when the signal and gate pulse width are 10 ps and 10 fs, respectively.

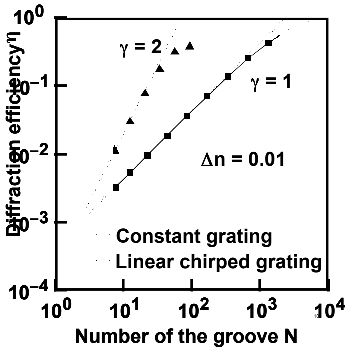

Fig.1. Diffraction efficiency of the gratings versus number of the grooves.

PS15

Characterization of Methacrylate Photopolymer Films doped with Silica Nanoparticles and Transparent Plastics

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Transmission volume holograms recorded in methacrylate photopolymer films doped with silica nanoparticles and transparent plastics are studied. It is found that poly-methylmethacrylate (PMMA), which is a well-known host material for plastic dye lasers, works as an efficient host binder material and that the refractive index modulation as high as 0.005 is possible with PMMA of 50 vol.%. It is also shown that concentrations of silica nanoparticles as high as 30 vol.% can be uniformly dispersed into the monomer-PMMA mixture to form a volume holographic grating with the refractive index modulation as high as 0.005. This value is higher than that formed in typical fiber Bragg gratings and is enough for DFB lasers requiring a short and strong Bragg grating.

PS16

Phase-Crossing Algorithm for White-Light Fringe Analysis

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White-light interferometry is widely recognized as a technique that allows high precision measurement of objects with discontinuous shape structure. During the last decades, several techniques have been developed for the analysis of white light fringes. Among others, the most popular are the envelope detection techniques. We propose a spectral phase-crossing algorithm for the analysis of white-light fringes obtained by use of a color-insensitive camera. The technique searches for the zero optical path difference (OPD) position from a crossing point of two phases of spectrally resolved fringes, which are obtained from the Fourier spectra of white-light interferograms. A detailed principle and the results of preliminary experiments will be presented to demonstrate the performance superior to the conventional envelope detection techniques.

PS17

Broadband Wavelength Conversion by Utilizing Multi-Stage Cascaded SOA-based Wavelength Conversion

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As transmission data of optical transmission systems increase, optical networks operating at a wider wavelength region will be required. In such networks, all-optical wavelength converters with wide wavelength tuning range are very useful to enhance network flexibility. So far, various widely tunable wavelength converters by semiconductor optical amplifier (SOA) have been demonstrated. However, no fully tunable SOA-based wavelength converter that can operate over a wide tuning range is reported. In this work, we have proposed a novel widely tunable wavelength conversion by utilizing multi-stage cascaded SOA-based wavelength converters. Widely tunable wavelength conversion experiment was successfully demonstrated over 160 nm up-conversion using two-stage wavelength converters for the first time. The technique is useful for developing broadband flexible optical networks.

Photonic Devices

PS18

Hydrogen Evolution from p-GaN Cathode in Water under UV Light Irradiation

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Hydrogen is evolved at a zero bias when a p-type GaN cathode in an electrolyte solution is irradiated with UV light, although both hydrogen evolution rate and photocurrent decrease during irradiation. Spontaneous hydrogen evolution indicates that the conduction band-edge of p-GaN is above the reduction potential of H^+(aq). From the relationship between the volume of generated hydrogen and the amount of electrons traveling from the Pt anode to the p-GaN cathode, the reaction efficiency of electrons injected from the conduction band of the p-GaN cathode with H^+(aq) in a neutral Na_2SO_4 electrolyte solution is larger than 70%. As a result, the overall quantum efficiency for the hydrogen generation before degradation is estimated to be 4-6% at a wavelength of 340 nm by considering the incident photon-to-current efficiency of p-GaN.

This work is partly supported by a Grant-in-Aid for Scientific Research (B) (Grant No.16310085) from the Ministry of Education, Culture, Sports, Science and Technology.

PS19

Fabrication of luminescing nanowire structures by vapor-liquid-solid processes

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Semiconductor microstructures were fabricated by vapor-liquid-solid processes. ZnO needles with ~100-nm diameter and ~100-μm length were grown. These needles were densely accumulated on a substrate, and intense blue photoluminescence due to exciton-exciton scattering process was observed. Si nanowires were also fabricated. Copper sulfide sealed in a silica-glass ampule with a silicon substrate helped to form Si-wire structures. Wires with a variety of their sizes were grown on the substrate. In addition to large wires with ~1-μm diameter and ~100-μm length, small ones with ~3-nm diameter were observed. By doping rare-earth ions, visible photoluminescence from Si-wire structures was obtained at room temperature.

PS20

Optical Absorption, Photoelectrochemical, and Carrier Dynamic Investigations of TiO_2 Electrodes :Composed of Different Size Mixture of Nanoparticles Sensitized with CdSe Quantum Dots

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Significant progress in solar cell application has been made since 1990`s using nanostructured TiO_2 electrodes adsorbed with organic dyes (dye sensitized solar cell : DSSC). In addition to organic dyes, semiconductor quantum dots (QDs) have also attracted significant interest as light harvesters in DSSCs. In this study, we investigate the effects of different size mixture of TiO_2 nanoparticles (15nm and 27nm) in nanostructured anatase-type TiO_2 electrodes sensitized with CdSe QDs on optical absorption measured with photoexcited carrier dynamics using a lens-free heterodyne detection transient grating (LF-HD-TG) technique. The transient grating signal shows a fast and slow decay, corresponding to the photoexcited hole and electron relaxation processes respectively. Ultrafast decay time of excited electrons in the CdSe QDs around 30ps decreases with the increase of the content of 27nm particles.

PS21

Effect of Crystal Structure on Carrier Dynamics of TiO_2 Films Studied Using Lens-Free Heterodyne Detection Transient Grating Technique

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A great deal of attention has been devoted to TiO_2 nanoparticles for photocatalytic activity, solar enegy conversion, and so on. Photoexcited carrier dynamics on TiO_2 and charge transfer processes between TiO_2 and adsorbed molecules are important factors affecting the photocatalytic activity and solar energy conversion efficiency. It is known that the crystal structures of TiO_2, like other nature such as particles sizes, defects, and impurities, are very important for photocatalytic reactivity and solar conversion efficiency. Because charge carrier dynamics is linked greatly to photoactalytic activity, it is necessary to understand the relation between photoexcited carrier lifetimes and the TiO_2 structural parameters. In this paper, we studied ultrafast carrier dynamics of anatase and rutile TiO_2 nanostructured films using lens-free heterodyne detection transient grating technique. We find that the crystal structure has a great effect on the carrier dynamics of TiO_2 films.

PS22

Optical Absorption and Photoelectrochemical Investigations of Inverse Opal TiO_2 Photonic Crystals

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Titanium dioxide (TiO_2) is an attractive material considered for the fabrication of photonic crystals due to its the high refractive index and good transparency under visible light. This study present a simple fabrication method, wherein inverse opal TiO_2 is made by filling the voids in an artificial opal latex sphere (diameter 309nm) with nanosized TiO_2 particles. Several drops 2% $TiCl_4$ in methanol is put into the latex matrix, hydrolyzed then heated at 80°C after each drop. Calcination of the original latex matrix and the annealing of TiO_2 were conducted at 450°C. XRD show an anastase structure and honeycomb structure had 270 nm pore diameter as seen using SEM. The transmittance and reflectance spectra indicate that sample may be a photonic crystal, with a photonic band gap of 425 nm. The incident photon-to-current conversion efficiency (IPCE) spectrum shows that the inverse opal TiO_2 electrode yielded up to 20% conversion efficiency.

PS23

Ultrahigh-frequency mode-locked pulse generation with an all-optical semiconductor gate

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The purpose of this research is to develop an innovative optical pulse generation scheme, which was first experimentally proposed in 2001 by one of the present authors[1)]. Relying on an original ultrafast, all-optical semiconductor gate (DISC)[2)] and other chemically stable optics instead of conventional nonlinear mode-locking mechanisms, we are studying this brand-new scheme and trying to realize monolithically integrated, mass-producible, stable, precise, and universal pulse sources that generate transform-limited optical pulses. Regarding the nonlinear gate inside the generator, 1.5-ps, 160-GHz gated waveforms have experimentally been observed since 2000[2)].

In this symposium, the latest research results in this Course of Coherent Optical Science are presented where the *threshold condition* for generating our nearly-transform-limited mode-locked 1555-nm, 5-ps, 10-GHz pulses was clearly observed for the first time[3)].

References: 1) Y. Ueno et al., Appl. Phys. Lett. **79** (2001) 2520, 2) Y. Ueno et al., Jpn. J. Appl. Phys. **39** (2000) L806, 3)

R. Suzuki et al., *just published in digest of CLEO-Pacific Rim*, paper number CFM1-4, Tokyo, July 11-15, 2005.

PS24

Numerical Analysis of Scattering of Electromagnetic Waves Using Green's Function

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To analyze the scattering of electromagnetic waves by photonic crystals, source codes have been developed. The Dyson equation of the Green's function is solved numerically in the discretized real space by the method developed by Martin, Girard, and Dereux, who applied it for analysis of Scanning Near-Field Optical Microscope. Test runs have been done to reproduce their results successfully. The calculations of the scattering by photonic crystals, combined with the band calculations, are expected to help us understanding the detail and the relation to their band structures of experimental results of reflection and transmission spectra.

PS25

Single frequency fiber laser MOPA system with <2kHz linewidth

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Narrow linewidth single frequency lasers at 1083nm have important applications in atomic and molecular spectroscopy and other fields. In our experiment, in order to produce high power, narrow linewidth single frequency 1083nm laser, we used a fiber master oscillator power amplifier (MOPA) configuration. The laser oscillator was linear cavity with loop mirror filter (LMF), which generated stable single frequency 1083 nm laser. The linewidth of the laser was as narrow as 2 KHz (or less than 2KHz). Output from the laser oscillator, the single frequency signal was coupled into 5 m Yb fiber amplifier, which was pumped by pigtail coupled laser diode at 976nm. From the MOPA fiber laser system, 177mW single frequency laser was produced under the launched pump power of 332 mW, the according gain is about 16 dB**.**

PS26

Blue Up-conversion Fiber Laser Pumped by a 1120nm Raman Fiber Laser

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An 1120nm Raman fiber laser pumped Tm^{3+} doped ZBLAN fiber laser was demonstrated with blue output power levels up to 116mW. Photodegradation and photocuring effects were investigated in the operation of blue fiber laser. Our experimental results indicate that a competition between photodegradation and photocuring greatly affects the maximum output power of a blue up-conversion fiber laser. Power scaling of Tm^{3+} doped ZBLAN blue up-conversion fiber laser was investigated by a simple model. The optimal parameters (including fiber length, fiber core diameter and the reflectivity of the coupler mirror) for the operation of high power (>1W) blue fiber laser were presented through simple numerical simulations, which is valuable for the future design of high power blue up-conversion fiber laser.

PS27

High Power Fiber Laser Development in ILS/UEC

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Starting from the first 1-kW fiber laser based on fiber-embedded disk concept, we have investigated various kinds of fiber lasers for high power, high quality, and high functionality. For power and brightness scaling, coherent beam combining of many fiber lasers has been proposed and demonstrated, realizing not only efficient power summation of as many as ten single-mode fiber lasers, but narrowband (<12 MHz) operation and coherent beam steering. Power scaling of femtosecond fiber laser is also investigated by use of an erbium-ytterbium-codoped large-mode-area photonic-crystal fiber, chirped-pulse fiber amplification with an air-core photonic bandgap fiber compressor, and a new coherent array method. New wavelength fiber lasers based on fiber Raman laser and ytterbium-doped fiber laser, linearly polarized fiber laser and amplifiers, and their frequency conversion by periodically-poled nonlinear crystals and highly nonlinear fibers will also be reported.

PS28

Proton Sputtering from Si(111)1x1-H Suface Irradiated with Highly Charged Ions

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The emission of sputtered ions from a hydrogen-terminated Si (111) 1×1 surface has been measured for impact of slow ($v < 0.25\ v_{Bohr}$) highly charged Xe ions. Proton sputtering yields increase strongly with projectile charge q (q^{γ} ; $\gamma \sim 4$) and reach to the value greater than one for Xe^{q+} impact ($q \geqq 44$). Yields of Si^{+} remain constant (~ 0.1) for lower q ($14 \leqq q \leqq 29$) but increase with q for higher q region which shows that the apparent Coulomb explosion-like potential sputtering might set in and enhances the sputtering yield drastically over q = 29.

PS29

Nanostructure Formation on Graphite Surface by Impact of a Single Slow Highly Charged Ion

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Radiation effects of highly charged ions (HCIs) on highly oriented pyrolytic graphite (HOPG) surfaces have been investigated with Raman spectroscopy and scanning tunneling microscopy. The xenon-HCIs, Xe^{q+} ($q \leq 48$), were incident on HOPG surfaces and each collision event was monitored with detection of secondary electrons. In Raman spectra, disorder induced peaks (D peak) appeared in addition to narrower, persistent peaks (G peak) which are

characteristic of unirradiated HOPG. The intensity ratio of the D peak to the G peak is much larger than that of HOPG irradiated with singly charged ions (SCIs) at the same fluence. On the other hand, observation with scanning tunneling microscope revealed that a protrusion nanostructure was induced by a single HCI impact. The diameter of the structure increased with the potential energy, for example ～1.5 nm for Ar^{8+} and ～7 nm for Xe^{46+}, while the height of the structure was less sensitive and kept constant (～0.5 nm).

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PS30

Nanoscale processing using highly-charged ions

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The deposition of potential energy from slow highly-charged ions (HCI) on solid surfaces makes highly localized energetic regions due to intense electronic excitation. The relaxation of such an excitation induces nanoscale-sized deformation of the surface as well as very high yield of both secondary electrons and particles. Detecting the emitted secondary electrons allows us to confirm the one by one implantation of HCI. We are trying to apply these characteristics of HCI to nanoscale surface modification such as a single atom array. Experimental plans and the present status will be shown at the poster.

PS31

Light-Induced Magnets from Organic and Organic-Inorganic-Hybrid Approaches

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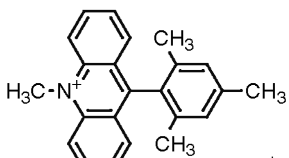
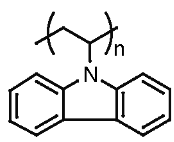
We have attempted to synthesize and fabricate photo-switchable magnets from purely organic systems. The Acr^+-Mes dyad has attracted current attention, since the corresponding light-induced charge-transferred state has been reported to be remarkably long-lived [Fukuzumi *et al.*; but some refutations arose (Harriman *et al.*)]. We fabricated a thin film of Acr^+-Mes dispersed in PVK and measured light-induced magnetization in situ on a SQUID magnetometer. The specimen was changed to be paramagnetic upon UV-irradiation at 4 K or 100 K and recovered to be diamagnetic on annealing at 300 K. As for hybrid materials, we prepared polymeric transition-metal complexes containing azide bridges. UV-irradiation of powdered specimens of $[Fe(pyrimidine)(N_3)_2]$ (*T*c



Acr^+-Mes



PVK

= 39 K) appreciably enhanced the spontaneous magnetization below *T*c. The spectroscopic studies on the product suggest that the azide group reacted to afford additional magnetic moments.

PS32

Theoretical modeling of laser produced Xe and Sn EUV sources

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The atomic processes and radiative transfer in the hot dense laser produced plasmas are investigated. Efficient extreme-ultraviolet (EUV) emission from Xe and Sn plasmas is considered as a light source for the next generation semiconductor technology. In the present study, detailed atomic structure and atomic processes of Xe and Sn ions are investigated using the atomic data calculated by the HULLAC code. The resonant 4d-5p transition of Xe^{10+} as well as 4d-4f and 4p-4d transitions of $Sn^{8\text{-}12+}$ contribute to the emission in the 13.5nm band. In addition, the satellite lines are found to contribute to the EUV emission, especially in the case of Xe. Irradiation of the laser pulse produces dense plasma with the electron temperature around 20eV, where the level population of the Xe and Sn ions becomes close to the LTE, and the resonance lines becomes optically thick, resulting in the significant emission through satellite lines. It is shown that the high conversion efficiency can be achieved with the unit optical thickness of the plasma at the 13.5nm wavelength region.