SYMPOSIUM MM
Ultrafast Lasers for Materials Science

November 30 - December 1, 2004

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* Invited paper
8:30 AM *MM1.1 Phase Change Mechanisms in Laser-Matter Interaction. Nianfan Xu, Purdue University, West Lafayette, Indiana.

Laser micro-machining is finding many applications in materials processing and manufacturing. At Purdue, various laser techniques are being used to fabricate sensors, micro-fluidic systems, bio-MEMS, and nano-structures. This presentation will mainly deal with the fundamental issues involved in laser-matter interaction. Our studies are focused on laser induced thermal and thermomechanical phenomena and phase change mechanisms that determine the materials removal behavior during laser machining, as well as the non-linear laser-material interaction in dielectric materials. It is shown that during nanosecond laser heating, explosive phase change could occur, during which the liquid is superheated to close to the thermodynamic critical point, followed by an explosive, homogeneous phase transformation. On the other hand, it is observed in the experiment that the time for nucleation during laser induced phase explosion is on the order of one nanosecond. Thus, when a laser with pulsewidth of one picosecond or less is used, it is likely that the material can be heated above the critical point, and another type of phase change, spinodal decomposition becomes possible. The time scales obtained from the fundamental studies, i.e., the time scale of non-linear optical response in ultrafast laser-dielectrics interactions, non-equilibrium energy transfer between electrons and the lattice, and the time scales of lattice melting and removal provide a good guidance for synthesizing pulse trains with specific temporal waveforms to improve the results of ultrashort laser micro-machining. The experimental studies are aided with numerical simulations. We have developed finite difference (FD) and molecular dynamics (MD) simulation techniques. Results from these studies emphasize the explosive nature of pulse laser-matter interaction. Our current effort is on large-scale hybrid FD/MD type of numerical studies to develop parallel computational techniques, which may provide a better understanding of the material removal process.

9:00 AM MM1.2 Polaritonic Materials Fabricated and Tested with Ultrashort-Pulse Lasers. David W. Ward, Eric Statz, Thomas Feurer and Keith A. Nelson, Department of Chemistry, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Using ultrashort-pulse laser machining, we have fabricated guided-wave, photonic bandgap, effective index, and apertonic structures designed to control propagation of phonon-polaritons in ferroelectric crystals with thicknesses from 10 microns to 500 microns. Broadband and narrowband polaritons were generated with impulsive stimulated Raman scattering (IRS) using an ultrashort laser pulse. The spatial and temporal evolution of the polaritons were recorded as they propagated through the structures. Functional devices such as near-field THz waveguide tips and slabs, tunable THz filters, waveguides, and resonators as well as the design and fabrication procedures for these devices will be demonstrated.


There has been rapid progress in research and development of lab-on-chip device that is used for field-deployable chemical analysis with high-efficiency, high-accuracy, and high-performance. The lab-on-chip device is composed of microfluidic components, such as microcell, and microchannel for infusion of reagents and storage of reactants, micromechanical components, such as microvalve, micromixer, and micropump for control of reagent flow and reaction, and microoptical components, such as micromirror, microlens, micrograting, waveguide and microoptical sensor, for in-situ analysis of the reactants. These components are integrated in a small chip and then infused, mixed, and reagents and reaction of the reagents and analysis of the reactants are successively conducted. Consequently, the lab-on-chip device makes it possible to reduce reaction and analysis time in human gene and protein analysis, medical inspection, new drug development, and environmental monitoring by measuring a trace amount of reagents. For the lab-on-chip device manufacture, development of fabrication technique of three-dimensional (3-D) hollow microstructures is in great demand. Since it is well known that ultrafast laser processing is the most promising candidate for such application. Therefore, we use such a laser would be a promising and simple approach for embedding 3-D hollow microstructures inside the materials. In fact, the internal modification of glass by ultrafast laser followed by selective wet etching of the modified regions can fabricate such structures. In the present paper, fabrication of 3-D hollow microstructures in glass is demonstrated for the lab-on-chip device application. We use a commercially available photostructurable glass (Foturan glass) from Schott Glass Corp. The fabrication process includes three steps: (1) direct writing of latent images in the glass by tightly focused fs laser beam (770 nm, 150 fs); (2) baking of the laser irradiated sample in a programmable furnace for formation of modified regions; and (3) etching of the modified sample in a 10% diluted solution of hydrofluoric acid for the selective removal of the modified region. The time for etching is determined by experimentally etching contrast ratio of about 50 in etching rate compared with unmodified regions, resulting in formation of 3-D hollow internal microstructures. By using this technique, we fabricate a variety of microfluidic structures. Mixing of two different fluids in solutions in a microchannel is demonstrated using the fabricated structure. Then, we fabricated a freely movable micropipette inside the microfluidics that has a function of microvalve controlling flow direction of fluids. We also apply the present technique to integrate microoptics, such as a micromirror and a micro beam splitter, and micro laser inside the glass for optical analysis of reactants in the lab-on-chip device.


New nanomaterials such as nanobump, nanomesh, and nanobelt were generated from thin film processed by interfering femtosecond laser beams. To split and correlate femtosecond laser beams through free space, a combination of glass or semiconductor materials is used. We have fabricated a conical nanobump array on an SiO2 film using a fs laser with a pulsewidth of one picosecond or less. It is found that the time for nucleation during laser induced phase explosion is on the order of one nanosecond. Thus, when a laser with pulsewidth of one picosecond or less is used, it is likely that the material can be heated above the critical point, and another type of phase change, spinodal decomposition becomes possible. The time scales obtained from the fundamental studies, i.e., the time scale of non-linear optical response in ultrafast laser-dielectrics interactions, non-equilibrium energy transfer between electrons and the lattice, and the time scales of lattice melting and removal provide a good guidance for synthesizing pulse trains with specific temporal waveforms to improve the results of ultrashort laser micro-machining. The experimental studies are aided with numerical simulations. We have developed finite difference (FD) and molecular dynamics (MD) simulation techniques. Results from these studies emphasize the explosive nature of pulse laser-matter interaction. Our current effort is on large-scale hybrid FD/MD type of numerical studies to develop parallel computational techniques, which may provide a better understanding of the material removal process.

10:45 AM *MM1.5 Femtosecond-Laser-Encoded Distributed-Feedback Color Center Laser in Lithium Fluoride Single Crystal. Ken-ichi Kawamura1, Toshio Kamiya2 and Hideo Hosono3,1; IHosono Project, Japan Science and Technology, Yokohama, Japan; 2Kanazawa University, Kanazawa, Japan; 3Tokyo Institute of Technology, Yokohama, Japan.

Lithium fluoride (LiF) offers good physical and chemical properties including high photothermal stability of laser active color centers, which can be used for any applications in which a stable and unique color is needed. Initially, F2 and F3+ centers in LiF were very promising candidates for stable laser action. Recently, Montecchi1 has reported enhancement of the refractive index due to the formation of the color centers and fabricated active channel waveguide. However, high-energy deposition techniques such as ion implantation, electron beam and γ-ray irradiation are generally needed for producing the color centers in LiF because of its large optical bandgap (14 eV). To our knowledge, producing the color center in LiF using optical light has not been demonstrated. Here we report the fabrication of three-dimensional active optical devices inside LiF by holographic encoding method using an infrared fs laser.2 We present gratings, waveguides and a distributed-feedback (DFB) color-center laser. The femtosecond laser pulses were generated by a Ti:sapphire laser and 230 fs pulses with a repetition rate of 1 MHz were used. The laser could write spots with a spot size of 50 micrometer in diameter. As a result, formation of F2, F23+ and F2+ color centers were observed by optical transmission measurements. Estimated concentration of the F2+ color center was 2x1014 cm−2. The color of the laser beam changed about 1%. Then, we fabricated DFB F2 center laser.

A femtosecond Ti:sapphire laser from Spectra Physics was frequency doubled to a wavelength of 400 nm, pulse width of 180 fs, and a repetition rate of 1 kHz. The laser was used with a computer controlled galvo head to write periodic structures on Si <100> samples, which were fixed on a high resolution X- Y stage. Laser pulses generated by interaction of fs-laser radiation with Silicon energy of 100 nJ were focused using an objective lens of 0.65 NA. Laser diode pumped, compact, high energy efficient Cr:LiSAF femtosecond laser system is used which generates laser pulses with a pulse length of 130 fs in pulse length are generated from a Ti:sapphire femtosecond laser system and focused at the surface of these Co reactive foils are made using magnetron sputter deposition on thermally oxidized silicon wafers and released as a free standing film. Laser assisted surface texturing of silicon surfaces, especially a-Si:H thin film solar cells, light trapping has been sought as a means of enhancing absorption. Here we present results for surface texturing of 2 micron a-Si:H thin film solar cells, has been reported by many research groups as a means of enhancing absorption. We have proposed a "gholographic encoding technique by an interference infrared femtosecond (fs) laser pulse" in this technique, holographic gratings are encoded on the surfaces of various nonphotovoltaic materials as a consequence of the interference of two fs pulses split from a single pulse. Furthermore, we have succeeded in encoding refractive index-modulated volume-type gratings deep inside transparent materials if we use a single-chirped (500 fs) pulse laser. This technique provides a fast method applicable for encoding gratings and for fabricating optical devices such as distributed-feed-back (DFB) lasers. DFB F2-color center lasers were fabricated using en coded volume type gratings in LiF single crystal and oscillated at room temperature. These results prove that our fs laser interference technique has good applicability to produce unique devices. However, the technique has still a few points to be improved. In this study, we have tried to control shapes of gratings and to reduce power densities for the encoding by employing a pre-excitation technique. Furthermore, we observed ultrafast electron dynamics related to optical permanent damages occurring during the encoding.
of the gratings in femtosecond regime. Generally, laser damages in transparent materials is described in terms of three major processes: (I) the multiphoton ionization (MPI), (II) laser heating of the conduction band electrons by absorbing the residual laser pulse, and (III) transfer of the plasma energy to the lattice. We separated the contributions to these processes at a wavelength of 800nm and generating 150fs-long pulses by using a high-performance analyzer with a 5pm resolution. The grating length was set by changing the ratio of the translation speed to the period. The fibre was placed on a high-precision, two-coordinate translation stage. The stage moved at a constant speed along the focal point of the beam. Each laser pulse produced a grating pitch. The grating period was set by changing the ratio of the translation speed to the pulse repetition rate. Reflection and transmission were monitored in-situ by using two optical spectrum analysers. Gratings were later characterized using a tunable laser with 1pm resolution and a high-performance analyzer with a 5pm resolution. The grating length ranged from 10nm to 55nm. Gratings of first, second and third order were inscribed at speeds of 0.335nm/s and 1.075nm/s and 1.695nm/s, respectively for a characteristic resonance at a wavelength of 1550nm. Second order grating presented the strongest response. We believe this is a consequence of the femtosecond inscription technique without a pre-pulse. We observed that threshold energy was drastically reduced by a pre-pulse and irradiation diffraction efficiency of the gratings strongly depended on the delay time. Furthermore, we have studied the shape of the diffraction pattern by inserting two optical spectrum analysers. The procedure of the pre-pulse was repeated with time delays varied from 0 to 10 ps. The pulse energies of both the pre-pulse and interfered pulse were always below the threshold energy for the encoding by a single pulse technique without a pre-pulse. We observed that threshold energy was drastically reduced by a pre-pulse and irradiation diffraction efficiency of the gratings strongly depended on the delay time. Furthermore, we have studied the shape of the diffraction pattern by inserting two optical spectrum analysers. The procedure of the pre-pulse was repeated with time delays varied from 0 to 10 ps. The pulse energies of both the pre-pulse and interfered pulse were always below the threshold energy for the encoding by a single pulse technique without a pre-pulse. We observed that threshold energy was drastically reduced by a pre-pulse and irradiation diffraction efficiency of the gratings strongly depended on the delay time. Furthermore, we have studied the shape of the diffraction pattern by inserting two optical spectrum analysers. 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Femtosecond Laser Pulses. Chen-Hsiung Cheng and Ming Li; Panasonic Boston Laboratory, Cambridge, Massachusetts.

Nano-meter scale surface topology modification has been demonstrated using NSOM (near-field scanning optical microscopy) delivered femto-second pulses. The ablation laser has a pulse width of 150 femto-second and wavelength of 387-nm. The laser pulses are coupled into the free end of a multimode optical fiber that a nanometer-size NSOM probe was fabricated on the outer end with small orifice. The transmitted laser pulses from the probe orifice illuminates and machines the substrate surface when the probe is in contact with the substrate. The produced feature on Silicon surface is as least 200-nm deep with hole diameter around 200-nm. Near-field coupling of the laser has the potential to achieve ablation of feature size less than diffraction limit. Using NSOM delivery method also allows us to take advantage of nanometer metrology in precision surface ablation or other type of surface modification. The ability of monitoring surface topology of substrate in real time enables us to accomplish the in-situ surface process monitoring. This unique technique of drilling 200-nm air holes on a pre-formed 600-nm wide wave guide. This method can be used to fabricate one-dimensional photonic crystal on a waveguide in ambient environment. The experiment design and performance evaluation will be discussed. Acknowledgements This work was performed under the Femtosecond Technology Research Association (FESTA), which is supported by the New Energy and Industrial Technology Development Organization (NEDO) in Japan.

Tuesday Evening, November 30, 2004
Exhibition Hall D (Hynes)

SESSION MM3: Poster Session
Chair: Alberto Pique
Tuesday Evening, November 30, 2004
8:00 PM
Exhibition Hall D (Hynes)

MM3.1 ZnO nanowire synthesis using femtosecond laser, Lei Luo; Yanfeng Zhang, Richard Russo, Liwei Lin and Samuel S. Mao; Lawrence Berkeley National Laboratory and Department of Mechanical Engineering, University of California at Berkeley, Berkeley, California.

One-dimensional semiconductor nanostructures have attracted much recent interests for their potential in realizing nanoscale electronic, optical, and mechanical devices. ZnO nanowires, due to their unique properties such as wide band gap and large piezoelectric coefficient, are under intensive investigations for applications such as lasers, sensors and actuators. While thermal evaporation remains a standard approach for growing ZnO nanowires, no alternative method for making high quality ZnO nanowires has been reported. Using high power femtosecond laser pulses, we successfully synthesized ZnO nanowires based on vapor-liquid-solid process. In our experiments, a ZnO target was ablated using the femtosecond laser pulse, whereas a silicon substrate was placed a few mm away from the target. Gold catalysts, which promote the formation of Zn-Au alloy droplets that help initialize one-dimensional growth, were prepared near the ablation target. Using femtosecond laser pulses, we successfully synthesized different oxide semiconductor nanowires on silicon substrate without any metallic catalyst. We will discuss the influence of electrical growth parameters, such as the growth temperature, oxygen partial pressure, and laser power on nanowire growth. We will propose an alternative three stage vapor-solid growth model for oxide semiconductor nanowire growth.

MM3.2 Catalyst-free Growth of Oxide Semiconductor Nanowires by Pulsed Laser Deposition. Yanfeng Zhang, Richard Russo and Samuel S. Mao; Lawrence Berkeley National Laboratory, Berkeley, California.

Owing to their potential in nanoscale device applications as well as in fundamental research, one-dimensional oxide semiconductor nanowires have attracted substantial interest. In this presentation, we report on recent progress in synthesizing oxide nanowires using femtosecond pulsed laser deposition (PLD) approach. PLD is a widely used method for fabricating oxide thin films; it has also been applied to synthesize different types of nanowires based on vapor-liquid-solid (VLS) one-dimensional growth model. A standard VLS process requires the presence of metallic catalysts such as Au, which promote the formation of alloy droplets that help initialize one-dimensional growth. Nevertheless, our recent oxide nanowire growth experiments suggest that catalyst-free VLS technique may not be the only mechanism for nanowire growth. By using femtosecond laser pulses, we successfully synthesized different oxide semiconductor nanowires on silicon substrate without any metallic catalyst. We will discuss the influence of electrical growth parameters, such as the growth temperature, oxygen partial pressure, and laser power on nanowire growth. We will propose an alternative three stage vapor-solid growth model for oxide semiconductor nanowire growth.

MM3.3 Carrier Dynamics in Sr2RuO4. Prasenjit Guptaarma1, Marshall Onellion2, Michael Schneider2, Steve Sendelbach2 and Greg Taft3; 1Physics, University of Wisconsin-Milwaukee, Milwaukee, Wisconsin; 2Physics, University of Wisconsin-Madison, Madison, Wisconsin; 3Physics, University of Wisconsin-Stevens Point, Stevens Point, Wisconsin.

Using femtosecond pump-probe methods to measure the transient optical reflectivity, we report on the carrier dynamics of Sr2RuO4 in the normal state, from 7K to room temperature. At room temperature, there is a single fast relaxation (time constant 70 fs) and a single fast relaxation (120 fs). As the temperature decreases, there are two qualitative changes. First, a second, slower, component to the relaxation develops and becomes dominant. The slower component of the relaxation is as slow as >500 ps time constant at 7K. Also, the increase in reflectivity, usually attributed to carrier thermalization, develops two components. The second component becomes slower (time constant 10 ps at 7K) and larger at low temperatures. The data are in direct conflict with the idea, arising from electrical resistivity measurements, that Sr2RuO4 is an anisotropic three-dimensional Fermi liquid below 25K. Sr2RuO4 is also qualitatively different from the cuprates in that both the thermalization and the relaxation develop two components at low temperatures. We discuss implications of the data for modeling carrier-carrier interactions in Sr2RuO4. 1. Y. Maeno et al., J. Phys. Soc. Jpn. 66 (1997) 1405. 2. A.W. Tyler et al., Phys. Rev. B 58 (1998) R10107.

MM3.4 Excited Sates Dynamics of Silicon Clusters and Nanowires in Intense Laser Fields Studied Quantum Mechanically. Anna Maria Mazzone and M. Bianconi; IMM, Sezione di Bologna, CNR, Bologna, Italy.

Dynamical processes at the molecular level occur on ultrafast time scales and are often associated with structural as well as electronic changes. In poly-atomic structures these excitations result in the rapid mixing of vibrational and electronic motions. Though this non-adiabatic coupling is a key step in photochemical and photobiological processes, the notion of distinct and readily observable electronic and vibrational states becomes obscure. Therefore particular attention has been given in theory and experiments to the smallest molecular systems and intense, femtosecond laser irradiation has been adopted as a powerful experimental tool to improve the current understanding of excited ion-electron dynamics by breaking the linear regime usually dealt with by perturbative expansions. The purpose of this work is to extend this study to structures of current interest in nanoscience and it centres on crystalline silicon clusters and atomic wires under femtoseconds laser pumping. The study is performed within a real-space, real-time implementation of the Dynamical Hamiltonian functional theory. The non-adiabatic demonstrative growth is possible to obtain detailed insights into ultrafast non-adiabatic processes as well as on their dependence on the irradiated structure.

MM3.5 Transient Photoconductivity of vertically aligned crystalline TiO2 nanorod arrays. Abul K. Azad4, W.-L. Zhang5, S.-H. Li2 and Yiping Zhao2; 1Physics and Astronomy, University of Georgia, Athens, Georgia.

Yiping Zhao'; 'Physics and Astronomy, University of Georgia, Athens, Georgia.
Dye-sensitized solar cells based on nanocrystalline TiO2 films have attracted enormous interest because of their high photo-current and conversion efficiencies [1]. The transient photocurrent of sensitized TiO2 nanoparticles has been shown to be sensitive to the temperature with a relative thick nanoparticle layer (3 um) [2]. However, the operation of a solar cell usually is at room temperature or higher. Here, using incandescent halogen white light as the photocurrent excitation source, we have studied the photocurrent of vertically aligned TiO2 nanorod arrays at room temperature. The TiO2 nanorod sample is a 0.42-7m-thick film deposited on 1-mm-thick quartz substrate by glancing angle deposition [3]. It has been annealed in vacuum for 4 hrs at ambient, and the XRD shows that there is only Anatase phase TiO2. The TiO2 sample was sensitized in ethanol solution of Ru-535 in order to broaden its absorption from the visible through the FIR along with broadband THz radiation. The new facility offers simultaneous synchrotron light extraction. The new facility offers simultaneous synchrotron light generation of light sources based on an Energy-Recovered, electro dynamical theory becomes as important as the acceleration term (synchrotron radiation). The sub-picosecond pulses of light offer unique capabilities in 2 specific areas, namely time-resolved dynamics, and imaging. High resolution THz spectroscopy has recently revealed sharp vibrational modes for many materials including malignant tumor tissues, DNA, pharmaceuticals and complex polymer units. Energetically the THz range embraces superconducting bandgaps, and regions of intense interest in the understanding of systems in which correlated motions of electrons are important both in metallic and superconducting nanomaterials, and high-Tc materials. The very high power levels of the new source will allow non-linear effects to be observed as well as the creation of novel states of materials, including electric-field driven localization[4]. We will give examples of current work in these areas and present opportunities afforded by the new source. 1. G.L. Carr, M.C. Martin, W.R. McKinney, K. Jordan, G.R. Neil and G.P. Williams "High Power THz Generation from Sub-ps Bunches of Relativistic Electrons, Steve Benson, Dave Douglas, Joe Gubeli, Kevin Jordan, George Neil, Michelle Shinn, Shukui Zhang and Gwyn P. Williams; Jefferson Lab, Newport News, Virginia.

We describe a > 100 Watt broadband THz source that takes advantage of the relativistic enhancement of the radiation from accelerated electrons according to the formula assigned the name of Sir Joseph Larmor[1,2]. This is in contrast to the typical 1 milliwatt source available in a laboratory. Spectrally, the enhancement is the result of the energy transferred from a relativistic electron to the wave in a collision process or from the fact that the emission is enhanced by the fourth power of the electron's momentum. For example, the enhancement is > 10^6 for 100 MeV electrons, for which the mass increases by a factor of 200, the enhancement is > 10^9. The experiments use a new generation of light source called an energy recovery linac (ERL) [3], in which bunches of electrons circulate once, but in which their energy is increased by a factor of 200. The experiments use a new generation of light source called an energy recovery linac (ERL) [3], in which bunches of electrons circulate once, but in which their energy is increased by a factor of 200. The experiments use a new generation of light source called an energy recovery linac (ERL) [3], in which bunches of electrons circulate once, but in which their energy is increased by a factor of 200. The experiments use a new generation of light source called an energy recovery linac (ERL) [3], in which bunches of electrons circulate once, but in which their energy is increased by a factor of 200. The experiments use a new generation of light source called an energy recovery linac (ERL) [3], in which bunches of electrons circulate once, but in which their energy is increased by a factor of 200. The experiments use a new generation of light source called an energy recovery linac (ERL) [3], in which bunches of electrons circulate once, but in which their energy is increased by a factor of 200.

Since the laser ablation and deposition of intact poly(ethylene glycol) (molecular weight 1.5 kDa) was first reported in 2001, it has been demonstrated that other polymers can be ablated substantially into the gas phase by resonant infrared excitation of bulk substrates using a picosecond micropulse free-electron laser (FEL). In most of this work, the ablated polymers were deposited for subsequent analysis by resonance-enhanced multiphoton ionization (REMPI) analysis by Fourier-transform infrared spectroscopy, size-selective chromatography and mass spectrometry. Preservation of local electronic structure and of the polymer mass distribution were noted in most, though not all, resonant excitation experiments with poly(tetrafluoroethylene) (PTFE) have demonstrated the even more interesting result that crystalline PTFE can be deposited by the same technique at substantially lower temperatures than can be achieved using ultraviolet laser deposition or femtosecond near-infrared (800 nm) laser ablation. The crystallinity was confirmed by X-ray photoelectron spectroscopy and X-ray diffraction; the smoothness of the films, observed by atomic-force microscopy and electron microscopy, was excellent. Ablation yields and thresholds were compared at wavelengths resonant with PTFE vibrational modes (4.2 and 8.56 µm) and off-resonance (7.1 µm). PTFE is a particularly interesting case because of its technological importance, and the fact that its insolubility means that other thin-film growth techniques, such as spin-coating, are not feasible. In order to more fully understand how picosecond resonant vibrational excitation can lead to intermolecular bond-breaking and vaporization of relatively large polymeric units, we have characterized the PTFE ablation plumes on and off resonance by pulsed laser shadowgraphy. The results show that the ejection of the polymer target material by off-resonance irradiation has substantially longer incubation time before the formation of a plume compared to on-resonance irradiation (6.8 µs vs 4 µs). Given the high photon flux density characteristic of the FEL micropulses, this probably reflects the efficient vibrational pumping of the anharmonic resonant modes of the polymers in resonant excitation. Photographs of the PTFE ablation target show clear evidence of damage (carbonization) in off-resonance ablation, damage that is absent in the case of resonant FEL excitation. Taken together with the shadowgraphy data, this suggests that the resonant excitation has a non-thermal component, while the off-resonance laser irradiation proceeds thermally. This research was supported by grant FA9550-04-1-0045 from the DOD MFEF Program.


SESSION MM4: Chair: Ming Li Wednesday Morning, December 1, 2004 Room 305 (Hynes)


A new THz/IR/UV source at Jefferson Lab is the first of a new generation of light sources based on an Energy-Recovered, (superconducting) Linac (ERL). The machine has a 150 MeV electron beam and an average current of 10 mA in high repetition rate bunches that are in the hundred femtosecond regime. These electron bunches pass through a magnetic chicane and therefore emit synchrotron radiation. For wavelengths longer than the electron bunch the electrons radiate coherently a broadband THz half cycle pulse whose average brightness is > 5 orders of magnitude higher than synchrotron IR sources. Previous measurements showed 20 W of average power extracted[1]. The new facility offers researchers accessible synchrotron light from the visible through the FIR along with broadband THz radiation. The sub-picosecond pulses of light offer unique capabilities in 2 specific areas, namely time-resolved dynamics, and imaging. High resolution THz spectroscopy has recently revealed sharp vibrational modes for many materials including malignant tumor tissues, DNA, pharmaceuticals and complex polymer units. Energetically the THz range embraces superconducting bandgaps, and regions of intense interest in the understanding of systems in which correlated motions of electrons are important both in metallic and superconducting nanoparticles, and high-Tc materials. The very high power levels of the new source will allow non-linear effects to be observed as well as the creation of novel states of materials, including electric-field driven localization[4]. We will give examples of current work in these areas and present opportunities afforded by the new source. 1. G.L. Carr, M.C. Martin, W.R. McKinney, K. Jordan, G.R. Neil and G.P. Williams "High Power THz Generation from Sub-ps Bunches of Relativistic Electrons, Steve Benson, Dave Douglas, Joe Gubeli, Kevin Jordan, George Neil, Michelle Shinn, Shukui Zhang and Gwyn P. Williams; Jefferson Lab, Newport News, Virginia."
the critical self-focusing threshold in SF57 glass. Victor Diez1, Jan Siegel1, Fabian Negredo2 and Javier Solis3; Instituto de Optica, CSIC, Madrid, Spain; Depto. Optica y Optomecansia, UPC, Terrassa, Spain.

Waveguide writing with fs-laser pulses in glasses can be hampered by the appearance of uncontrollable non-linear propagation phenomena. This occurs when the pulse power exceeds a certain threshold, \( P_{\text{crit}} \), above which critical self-focusing takes place and leads to catastrophic damage. In a first approach, \( P_{\text{crit}} \) is inversely proportional to the linear and non-linear refractive indices, \( n_0 \) and \( n_2 \), which makes the processing of materials with high \( n_0 \) and \( n_2 \) values to become a challenge. The aim of the present work is to analyze the behavior of one of these materials, Schott SF57 glass, when it is processed with 800 and 1200 nm, 10 fs laser pulses to produce waveguide structures. SF57 is a commercial glass essentially formed by \( \text{SiO}_2 \) and \( \text{PbO} \) having a 40-50% cationic content of \( \text{Pb} \) and that shows large linear \( (n_0=1.85) \) and non-linear \( (n_{2}=10^{-18} \text{m}^2/\text{W}) \) refractive indices. Two types of structures have been produced inside this glass, transversal (t- and longitudinal (l-) ones, depending on whether the sample was perpendicular or parallel to the writing laser beam. In the t-structures, extremely elongated damaged zones are the result of critical self-focusing. Off-center light guiding is observed nearby the damaged filaments indicating the formation of a refractive index increased region in the vicinity of this damaged zone. In the l-structures, the damaged zones shows a circular shape, corresponding to the focal volume of the critical self-focused writing beam. In this case, off-center light guiding is again observed nearby the damaged region. We attribute the formation of these off-center guiding regions, in both the l- and t- structures, to the high local pressure generated by the ultrafast temperature increase at constant volume that takes place in the focal volume of the critical self-focused beam. This pressure can be high enough to compress the material nearby giving rise to the observed refractive index increase in the guiding region \( (\Delta n=5\times10^{-4}) \). For both l- and t-structures, critical self focusing effects appear for pulse energies just above the structural modification threshold, and the size of the increased refractive index region is conditioned by the pulse energy and wavelength used; for instance, when writing at 1200 nm, the size of this latter region is not large enough to support a guided mode at 633 nm. As an alternative means to produce efficient waveguides with a controllable guiding zone size, the use of multiple structures has been investigated. The basic idea relies on writing several l-channels that do not individually support a guided mode. However, when they are written close enough to each other the resulting multiple structure effectively supports a guided mode with a gaussian profile, as it has been shown for a writing wavelength of 1200 nm.

11:30 PM AM4.5
Investigation of Femtosecond Laser Irradiation on Fused Silica HF Etching Selectivity. Yves Bègue1, Ali A. Said2, Mark Dugan3 and Philippe Bado4; C'TI, Resenaher Polytechnic Institute, Troy, New York; Translume, Ann Arbor, Michigan.

Femtosecond laser irradiation has various noticeable effects on fused silica. It can locally increase the index of refraction or modify the material chemical selectivity. Regions that have been exposed to the laser are etched several times faster than unexposed regions. Various observations reported in the literature seem to show that these effects are possibly related to a combination of structural changes and the presence of internal stress. However, a detailed analysis of the contribution of both effects is still lacking. In this paper, we present systematic SEM-based investigations performed on fused silica substrate (a-SiO2). Line-patterns were first scanned on the substrate using femtosecond laser (Ti-Sapphire, repetition rate 250 kHz and pulse width 100fs) and then etched in a low-concentration HF solution. The effects of various laser parameters such as the power and the scanning speed are analyzed and we show further evidence of an interface between two different etching regimes.

11:45 AM AM4.6
Waveguide Structures Written with Fs-Laser Pulses above the Critical Self-Focusing Threshold in SF57 Glass. Victor Diez1, Jan Siegel1, Fabian Negredo2 and Javier Solis3; Instituto de Optica, CSIC, Madrid, Spain; Depto. Optica y Optomecansia, UPC, Terrassa, Spain.

Waveguide writing with fs-laser pulses in glasses can be hampered by the appearance of uncontrollable non-linear propagation phenomena. This occurs when the pulse power exceeds a certain threshold, \( P_{\text{crit}} \), above which critical self-focusing takes place and leads to catastrophic damage. In a first approach, \( P_{\text{crit}} \) is inversely proportional to the linear and non-linear refractive indices, \( n_0 \) and \( n_2 \), which makes the processing of materials with high \( n_0 \) and \( n_2 \) values to become a challenge. The aim of the present work is to analyze the behavior of one of these materials, Schott SF57 glass, when it is processed with 800 and 1200 nm, 10 fs laser pulses to produce waveguide structures. SF57 is a commercial glass essentially formed by \( \text{SiO}_2 \) and \( \text{PbO} \) having a 40-50% cationic content of \( \text{Pb} \) and that shows large linear \( (n_0=1.85) \) and non-linear \( (n_{2}=10^{-18} \text{m}^2/\text{W}) \) refractive indices. Two types of structures have been produced inside this glass, transversal (t- and longitudinal (l-) ones, depending on whether the sample was perpendicular or parallel to the writing laser beam. In the t-structures, extremely elongated damaged zones are the result of critical self-focusing. Off-center light guiding is observed nearby the damaged filaments indicating the formation of a refractive index increased region in the vicinity of this damaged zone. In the l-structures, the damaged zones shows a circular shape, corresponding to the focal volume of the critical self-focused writing beam. In this case, off-center light guiding is again observed nearby the damaged region. We attribute the formation of these off-center guiding regions, in both the l- and t- structures, to the high local pressure generated by the ultrafast temperature increase at constant volume that takes place in the focal volume of the critical self-focused beam. This pressure can be high enough to compress the material nearby giving rise to the observed refractive index increase in the guiding region \( (\Delta n=5\times10^{-4}) \). For both l- and t-structures, critical self focusing effects appear for pulse energies just above the structural modification threshold, and the size of the increased refractive index region is conditioned by the pulse energy and wavelength used; for instance, when writing at 1200 nm, the size of this latter region is not large enough to support a guided mode at 633 nm. As an alternative means to produce efficient waveguides with a controllable guiding zone size, the use of multiple structures has been investigated. The basic idea relies on writing several l-channels that do not individually support a guided mode. However, when they are written close enough to each other the resulting multiple structure effectively supports a guided mode with a gaussian profile, as it has been shown for a writing wavelength of 1200 nm.
Laser cutting and welding are well established industrial applications. To maintain productivity and to guarantee product quality, the industry tries to introduce monitoring and control systems. The long term goal is the autonomous laser machine. Signal assessment is advancing by monitoring and simulation of the dynamical processes. Applying the advanced results about diagnosis and modeling broadens the potential to cope with productivity and quality features in drilling, trepanning and fine cutting. As result, in cutting two mechanisms for the formation of adherent dress are revealed theoretically, identified by the monitoring system and can be avoided by modulation of the laser beam power. In welding, the dynamic model predicts the formation of pores sets in or is suspended depending on modulation frequency for the laser power. In drilling the mechanisms governing the maximum depth of the drilled hole – still showing efficient melt removal – are identified experimentally and can be related to the processing parameters theoretically.

2:15 PM *MM5.3 Micro- and Nano-Structured Optical Fibers - Artificial Media for Amplification of Light. Andreas Liem1, A. Tunnemann1,2 and H. Zellmer1; 1Friedrich Schiller University Jena, Institute of Applied Physics, Jena, Germany; 2Fraunhofer Institute for Applied Optics and Precision Engineering, Jena, Germany.

Rare-earth-doped fibers have established themselves as an attractive and power scalable solid-state laser concept. In continuous-wave operation output powers approaching the kW-regime with diffraction-limited beam quality have been demonstrated. Ytterbium-doped fibers provide also several key advantages regarding the amplification of short optical pulses. The gain bandwidth supports pulses as short as ~30 fs, the saturation fluence allows for the generation of high energy pulses and high optical pumping efficiencies (up to 80%) make an ytterbium-doped fiber amplifier to an outstanding gain medium. However, power and energy scaling of single-mode fiber amplifiers is restricted due to nonlinear pulse distortions. Novel fiber geometries based on micro- and nano-structured fiber-cores allow for a significant scaling of power in continuous and pulse operation. The optical properties of these artificial media are discussed, scaling laws are presented.

3:15 PM MM5.4 Ultrafast generation and detection of shear and longitudinal acoustic phonons in GaAs. David Howard Hurley1, Osnam Matsud1, Oliver B. Wright2 and Vitali E. Gusev2; 1Physics Department, INEEIL, Idaho Falls, Idaho; 2Department of Applied Physics, Hokkaido University, Sapporo, Japan; 3Université du Maine, Le Mans, France.

Gaining a better understanding of the way in which electrons interact with the vibrational modes of a lattice (phonons) is of fundamental importance for controlling quantum processes in semiconductors. For example, devices that rely on the coherent control of excitons are limited by decay, which is mediated by electron-phonon coupling. Coupling between electrons and phonons is described in terms of deformation potentials that relate shifts in the energy of band extrema to strain. For semiconductors that lack inversion symmetry, electron-phonon coupling can also arise through changes in electric polarization caused by electron motion, that in turn give rise to strain via the piezoelectric effect. Ultrafast optical techniques provide an opportune means to probe directly the interaction of photoexcited electrons and phonons. In this study we make use of ultrashort optical pulses to generate and detect acoustic phonon pulses in (411) GaAs. Unlike previous studies involving ultrafast phonon generation in semiconductor surfaces cut in high-symmetry orientations, the reduced symmetry of the (411) GaAs surface allows shear as well as longitudinal phonon generation. The role of anisotropy in relation to phonon generation through thermelasticity, deformation potential coupling, and piezoelectric effects caused by screening of built-in electric fields by photoexcited carriers is considered in detail. In addition, the pump power dependencies of the various generation mechanisms are discussed.

3:30 PM *MM5.5 Fundamental Mechanisms and Applications of Ultrafast Laser Ablation of Solids. Michel Meunier1, Laurent J. Lewis2, A. V. Kabashin3, J.-P. Sylvestre1 and E. Sacher1; 1Laser Processing Lab, Department of Engineering Physics, École Polytechnique de Montréal, Montreal, Quebec, Canada; 2Department of Physics, University of Montreal, Montreal, Quebec, Canada.

Recent works on the fundamental mechanisms of ultrafast laser interaction with solids and applications of fs laser ablation towards the fabrication of nanomaterials will be reviewed. In the first subject, we will address the physical pathways to laser-induced matter removal from surfaces by studying the routes to ablation of silicon under UV pulses with duration ranging from 500 fs to 100 ps. The detailed electronic and atomic dynamics are described by the Monte Carlo and molecular-dynamics methods, respectively, and the density, temperature, and pressure of the system are computed during heating, cooling, and expansion. By mapping these results onto the phase diagram of silicon, the complete thermodynamic evolution of the system can be obtained. Under ultrashort pulses (~1 ps), isochoric heating and rapid adiabatic cooling of the system below the binodal line provide a natural pathway to phase explosion while under "long" (~10 ps) pulses, matter removal is, rather, driven by a fragmentation process within the supercritically expanding matter [Phys. Rev. Lett. 91, 225502 (2003)]. In the second subject, we consider the fs laser ablation of metal targets in aqueous solutions and the resultant formation of colloidal metal nanoparticles. The distribution of ablated particles give evidence for two different mechanisms of material ablation in liquid environments. The first mechanism, associated with thermal-free fs ablation, leads to very small (2.5 -10 nm), almost monodisperse, gold colloids. The second, attributed to the subsequent plasma-induced heating and ablation of the target, gives rise to much larger particles, with broad size distributions [J. Appl. Phys. 94, 7941, 2003]. Chemically active products (e.g. cyclodextrins, etc.) are also used to surround and stabilize the particles on formation, permitting the fabrication of contamination-free, almost monodisperse, 2-3 nm colloidal particles, whose surfaces could be modified for specific biochemical interactions [J. Phys. Chem. B, 107, 4527 (2003)].