

AFOSR NLO Workshop 2007

Speaker Schedule

Tuesday, September 25th

7:45-8:00 am	A. Nachman	“Opening Remarks”
8:00-8:30 am	J.V. Moloney	“Quantum Design of High Power OPSL Lasers”
8:30-9:00 am	S.W. Koch	“Spontaneous Emission from Quantum Wells and Heterostructures”
9:00-9:30 am	G. Balakrishnan	“Interfacial Misfit Dislocation array based Growth of III-Sb active regions on GaAs/AlGaAs DBRs for High-power 2 μ m VECSELs”
9:30-10:00 am	M. Fallahi	“Vertical-External-Cavity Surface-Emitting Laser for 1170 nm and Yellow Emission”
10:00-10:15 am Coffee Break		
10:15-10:45 am	S. Yalisove	“Extreme light diagnostics for defense-critical advanced materials and processes”
10:45-11:15 am	M. Kolesik	“Dynamic Raman X-Waves”
11:15-11:45 am	T. Niday	“Modeling Ultraviolet Filament Propagation”
11:45-12:15 pm	M. Ablowitz	“Pulses and Dynamics in Mode Locked Lasers”
12:15-1:30 pm Lunch Break		
1:30-2:00 pm	D. Huang	“Ultrafast Scattering Model Applied to Laser-Driven Carrier Cooling by Non-Thermal Electron-Hole Plasmas in Intrinsic Semiconductors at Low Temperatures”
2:00-2:30 pm	J. Gallas	“Accumulations and Period-adding in Chaotic Phases of Optically Injected Semiconductor Lasers”
2:30-3:00 pm	V. Kovanis	“Dynamics of Quantum Dot Semiconductor lasers”
3:00-3:30 pm	Z. Chen	” Surface and defect states in optically-induced periodic structures”
3:30-3:45 pm Coffee Break		
3:45-4:15 pm	M. Mansuripur	“Radiation Pressure and the Linear Momentum of the Electromagnetic Field in Magnetic Media”
4:15-4:45 pm	J. Yang	“Analytic Studies of Gap Solitons and Defect Modes in two-dimensional Photonic Lattices”
4:45-5:15 pm	M.J. Potasek	“Large Broadband Nonlinear Semiconductor/Organic Nanostructured Materials: Experiments and Numerical Simulations+”
5:15-6:00 pm	POSTER SESSION & LAB TOUR	
7:30 pm	Workshop Dinner at the University Marriott	

Wednesday, September 26th

8:00-8:30 am	C. Chen	“Recent advances in magnetron theory and simulation”
8:30-9:00 am	R. Pakter	“Wave Breaking and Particle Jets in Intense inhomogeneous Charged Beams”
9:00-9:30 am	D. Kaup	“The Saturation Stage of a Magnetron”
9:30-10:00 am	J. Steinhoff	“Long Range in Numerical Simulation of Short Waves as Nonlinear Solitary Waves”
10:00-10:15 am	Arje Nachman	“Closing Remarks”

Quantum Design of High Power OPSL Lasers

J.V. Moloney

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Abstract

Optically-pumped surface emitting semiconductor lasers (OPSLs) provide a new class of compact, high power devices for generation high brightness of light ranging from UV to mid IR wavelengths. These external-cavity devices contain a complex semiconductor sub-cavity, consisting of a multiple quantum-well (MQW) resonant-periodic-gain (RPG) stack grown on a high reflectivity DBR mirror. A key step in power scaling such devices is to maximize the extracted optical power density before the device shuts off thermally.

We will review the key steps that enable us to fast track to a final OPSL device for a targeted wavelength operation. The quantum design approach¹ removes ad hoc parameterization of the problem, by pre-computing all of the critically important semiconductor optical properties such as wafer-level photoluminescence spectra (PL), inverted semiconductor gain spectra, spontaneous (radiative) and Auger (nonradiative) recombination losses. These microscopically-computed results are input to our optical/thermal modeling of the OPSL chip and external cavity. As specific examples, we will highlight the recent quantum design and demonstration of a yellow guidestar OPSL and our progress in designing a novel 2 μ m InGaSb OPSL. These latter QW designs are being grown at the University of New Mexico, Center for High Technology Materials and diagnostics are being carried out on grown QWs at the University of Marburg.

1. Quantum designs for the semiconductor sub-cavity are furnished by Nonlinear Control Strategies, Tucson, AZ.

Spontaneous Emission from Quantum Wells and Heterostructures

S.W. Koch

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Abstract

A fully microscopic theory for the photoluminescence of a quantum well in an arbitrary dielectric environment is reviewed. For strong-coupling configurations the full semiconductor luminescence equations (SLE) are solved. Under weak coupling conditions, it is shown that the externally measured luminescence can be related to the pure quantum-well emission in vacuum via a frequency dependent filter function. Using a systematic mode expansion, the filter function can be computed from the known structure of the dielectric environment. Numerical examples of the full SLE solutions and the filter-function approach are presented.

Interfacial Misfit Dislocation array based Growth of III-Sb active regions on GaAs/AlGaAs DBRs for High-power 2 μm VECSELs.

G. Balakrishnan, T.J. Rotter, A. Jallipalli, L.R. Dawson and D.L. Huffaker

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Abstract

We propose the growth of III-Sb InGaSb quantum well (QW) based optically pumped vertical external cavity surface emitting lasers (VECSELs) on GaAs substrates through the use of interfacial misfit dislocation arrays (IMFs). The IMF is a growth mode based on atomic self-assembly at lattice-mismatched interfaces. The characteristic feature of this growth mode is the 2-D matrix of 90° misfit dislocations that provides immediate strain relief by a periodically skipped inter-atomic bond. Subsequent growth on the IMF results in a completely relaxed and extremely low defect-density planar bulk material within a few monolayers of epitaxy regardless of the magnitude of the mismatch. We have realized very high quality IMF layers for growth of GaSb on GaAs and for AlSb on Si. The current growth of the III-Sb alloys using the IMF technology has already resulted in the demonstration of electrically injected room-temperature edge-emitters on GaAs at wavelengths of 1.8 to 2 μm and an electrically injected 77K edge-emitter on silicon at a wavelength of 1.55 μm .

This presentation will overview the growth of an IMF based VECSEL structure operating at 2 μm with an InGaSb QW active region ($a_0 = 6.09 \text{ \AA}$) on GaAs/AlGaAs distributed bragg reflectors (DBR) ($a_0 = 5.65 \text{ \AA}$). The use of the GaAs substrate instead of GaSb results in a significant reduction in the surface defect density while allowing the use of a mature GaAs/AlGaAs DBR technology. We shall provide photoluminescence results from 2 μm IMF based active regions grown on GaAs substrates and compare the results with the same active regions grown on GaSb substrates. We shall also provide extensive transmission electron microscopy, surface morphology and high-resolution x-ray diffraction analysis of the material grown.

Vertical-External-Cavity Surface-Emitting Laser for 1170 nm and Yellow Emission

M. Fallahi ¹, L. Fan ¹, C. Hessenius ¹, J. Hader ², H. Li ², J. Moloney ², W. Stolz ³, S. Koch ³, J. Murray ⁴, R. Bedford ⁵

1: College of Optical Sciences, University of Arizona

2: ACMS, University of Arizona, Tucson

3: Philipps Universität Marburg, Germany

4: Areté Associates, Longmont, CO.

5: Sensors Directorate, Air Force Research Laboratory.

Abstract

We have demonstrated a multi-Watt high-power InGaAs/GaAs vertical-external-cavity surface-emitting laser (VECSEL) with large tuning range in the 1150 nm to 1190 nm. The laser is then used to generate high-power multi-watts output in a wide yellow-orange band (575 ~595 nm) by the intracavity frequency doubling.

Extreme light diagnostics for defense-critical advanced materials and processes

Tresa Pollock, Steven Yalisove, J. Wayne Jones, Katsuyo Thornton, Roy Clarke, Almantas Galvanauskas, John A. Nees, and John F. Whitaker

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Center for Ultrafast Optical Sciences
Materials Science and Engineering
Applied Physics
Electrical Engineering and Computer Science

Abstract

The objective of this MURI program is to develop the scientific basis for use of ultrafast lasers as materials diagnostics and microfabrication tools for advanced aircraft engine materials and components. Single crystal nickel based super-alloy turbine blades and their thermal barrier protection systems have been studied with these lasers. Several methods are used to study the turbine blades including; terahertz radiation to study the thickness of the thermal barrier coatings, x-rays for phase contrast radiography of turbine blades, laser induced breakdown spectroscopy for chemical analysis of turbine blades, laser notching to study the fatigue characteristics of turbine blades, ultrafast pump probe microscopy to study the dynamics of femtosecond laser material interaction, and we have a comprehensive hydrodynamic simulation program to help interpret and predict ultrafast laser material interaction using Hyades and Flash codes. Additionally, a seed effort has started to study the use of the new class of high average power fiber lasers to make these goals economically viable. Recent results will be highlighted in this talk.

Dynamical Raman X-Waves

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and
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Abstract

Intense femtosecond laser pulses propagating in condensed or gaseous media can display dramatic spectral broadening features when they undergo critical collapse and become self-trapped. In normally dispersive media, this self-focusing collapse leads to a cascade of pulse splittings that result in the appearance of X shapes in the spectrally resolved far-field. Individual split pulses can be associated with individual arms of the X feature. Pump probe experiments where the weak probe pulse selectively collides with one or other sub-pulse can then selectively generate Raman Stokes shifted components from a specific arm of the X-feature

We will discuss the mechanism for generating such dynamical Raman X-waves and compare our simulation results with recent experiments. A robust 3-wave scattering picture of this and associated nonlinear phenomena in ultrashort pulse propagation will be presented.

Modeling Ultraviolet Filament Propagation

Thomas Niday and T. Jelaine Fondren

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Abstract

We investigate the propagation of long pulse (tens to hundreds of picosecond) ultraviolet filaments at 248 nm. Experimental groups have indicated meter-scale propagation of ultraviolet filaments by observation of the fluence profile, with potential for long-distance propagation through the creation of a long plasma channel. Previous theoretical work points to modulational instability occurring on the meter-scale in such pulses, which causes difficulty for time-independent models. We propagate with various values of nonlinear parameters of air to investigate the stability.

Pulses and Dynamics in Mode Locked Lasers

Mark J. Ablowitz

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Abstract

Mode-locked lasers can generate ultra-short optical pulses, with durations ranging from hundreds of picoseconds down to a few femtoseconds. Mathematical models include the so-called "master" laser equation and power saturation equation (PSE) models. Such power saturation equations are associated with Ti:sapphire and fiber lasers. The power saturation model admits localized pulse solutions and mode-locking under wide ranges of the parameters for both constant dispersion as well as dispersion managed systems.

Ultrafast Scattering Model Applied to Laser-Driven Carrier Cooling by Non-Thermal Electron-Hole Plasmas in Intrinsic Semiconductors at Low Temperatures

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Abstract

A dynamical model is proposed for studying steady-state laser-driven carrier cooling by non-thermal electron-hole plasmas in intrinsic semiconductors, in parallel with the finding of voltage-driven carrier cooling in doped semiconductors [see Phys. Rev. B **32**, 1112 (1985)] and tunneling-driven carrier cooling in doped quantum dots [see Phys. Rev. B **52**, 5714 (1995)]. Our model includes many-body effects such as the Coulomb renormalization of bandgap energy, screening and the excitonic interaction, on the optical absorption and spontaneous emission. It also includes a dynamical density equation and an energy-balance equation for the non-thermal-equilibrium between the electron-hole plasmas and the crystal lattice. The laser-driven carrier cooling is studied as functions of the lattice temperature, the photon flux and the photon energy. Furthermore, the importance of Auger scattering on carrier cooling will be compared for conditions with high-density/high-temperature, high-density/low-temperature, low-density/high-temperature, and low-density/low-temperature. In addition, we will illustrate our future direction of applying the coupled semiconductor Bloch equations and force-balance equation for the study of exciton transport.

Accumulations and Period-adding in Chaotic Phases of Optically Injected Semiconductor Lasers

Jason Gallas

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Abstract

We study the hierarchical structuring of stable periodic oscillations inside chaotic phases of single-mode semiconductor lasers with optical injection. Chaotic phases display remarkable accumulation boundaries or horizons: simple curves containing infinite an infinite number of accumulations of cascades of self-similar islands of periodic solutions of ever-increasing period. Individual cascades follow specific period-adding routes (not period doubling). The riddling of chaotic laser phases by such networks of periodic solutions may compromise applications operating with chaotic signals such as e.g.~secure communications. The next step is to investigate the impact of noise in the inner structuring of chaotic phases.

Dynamics of Quantum Dot Semiconductor Lasers

Vassilios Kovanis

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Abstract

I will present experimental results taken from a reconfigurable quantum dot monolithic multi-section passive mode-locked laser emitting at 1310 nm and injection locking dynamics optical power spectra taken from a 1550 nm Fabry-Perot quantum dash laser.

We investigated the dynamical response of a quantum dot photonic integrated circuit formed with a combination of eleven passive and active gain cells operating when these cells are appropriately biased as a multi-section quantum dot passively mode-locked laser. When the absorber section is judiciously positioned in the laser cavity then fundamental frequency and harmonic mode-locking at repetition rates from 7.2 GHz to 51 GHz are recorded. These carefully engineered multi-section configurations that include a passive wave-guide section significantly lower the pulse width up to 34 % from 9.7 to 6.4 picoseconds, as well increase by 49 % the peak pulsed power from 150 to 224 mW, in comparison to conventional two-section configurations that are formed on the identical device under the same average power.

Also the instabilities map of the injection strength versus optical detuning space will be presented for the case of Fabry-Perot quantum dash lasers and an comparison with legacy results will be discussed.

Surface and defect states in optically-induced periodic structures

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Abstract

Electromagnetic waves may propagate as stationary surface states at the interface between two different materials, or as stationary defect states in periodic bandgap materials such as photonic crystals. Recently it has been shown both theoretically and experimentally that the small refractive index change optically induced as periodic arrays of evanescently coupled waveguides can be used for defect state excitation [1, 2] as well as lower the threshold significantly for surface wave excitation [3-5].

In this talk, we will present our recent work on guiding light in optically induced PCF-like structures, and guiding light at the interface between continuous media and optically induced photonic lattices. We discuss the possibility of generating linear and nonlinear surface/defect states in reconfigurable optical photonic structures. Our experimental demonstration of linear defect states and nonlinear discrete surface states will pave the way for the study of a variety of new optical wave phenomena mediated by defects and surfaces, which may be relevant for such phenomena in periodic systems beyond optics. Moreover, these results may have potential applications in optical sensors, light routing and switching.

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J. Wang, J. Yang and Z. Chen, *Phys. Rev. A* **76**, 013828 (2007).
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A. Szameit et al., *Phys. Rev. Lett.* **98**, 173903 (2007).

Radiation Pressure and the Linear Momentum of the Electromagnetic Field in Magnetic Media

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Abstract

We examine the force of the electromagnetic radiation on linear, isotropic, homogeneous media specified in terms of their permittivity "epsilon" and permeability "mu." A formula is proposed for the electromagnetic Lorentz force on the magnetization M , which is treated here as an Amperian current loop. Using the proposed formula, we demonstrate conservation of momentum in several cases that are amenable to rigorous analysis based on the classical Maxwell equations, the Lorentz law of force, and the constitutive relations. Our analysis yields novel expressions for the density of the electromagnetic and mechanical momenta inside the media that are specified by their (epsilon, mu) parameters. An interesting consequence of this analysis is the identification of an "intrinsic" mechanical momentum density, $\frac{1}{2}E \times M/c^2$, analogous to the electromagnetic (or Abraham) momentum density, $\frac{1}{2}E \times H/c^2$. (Here E and H are the magnitudes of the electric and magnetic fields, respectively, and c is the speed of light in vacuum.) This intrinsic mechanical momentum, associated with the magnetization M in the presence of an electric field E , is believed to be the same "hidden" momentum that was predicted by W. Shockley and R. P. James nearly four decades ago.

Analytical Studies of Gap Solitons and Defect Modes in two-dimensional Photonic Lattices

Jianke Yang

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Abstract

Light guiding in two-dimensional photonic lattices and photonic crystal fibers is attracting a lot of interest these days. Most of such studies were numerical or experimental. In this talk, we will study this phenomenon analytically in 2D photonic lattices. First, we will analytically show that uniform periodic lattices support a wide array of nonlinear localized states (such as vortex-array solitons and dipole-array solitons) in various photonic bandgaps. Second, we will show that when the 2D lattice has localized defects, such defects can guide various types of linear defect modes such as vortex modes. Analytical calculations of such defect modes will be presented for the first time. These analytical results are in good agreement with our numerical results as well as preliminary experimental results.

Large Broadband Nonlinear Semiconductor/Organic Nanostructured Materials: Experiments and Numerical Simulations+

M. J. Potasek*

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And
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Abstract

Nanometer-sized semiconductor materials have attracted broad attention in the fields of physics, chemistry, biology and medicine for their unique chemical and physical properties. We developed a novel method, for the first time to our knowledge, for hybrid nanocomposites of surfactant-capped semiconductor nanoparticles embedded in polystyrene (PS) matrixes¹. TEM measurements showed that the quantum dot diameter was about 2 nm, and UV-VIS absorption spectra recorded an absorption band at about 370 nm.

The third and fifth order nonlinearity were measured, using a 25 ps Nd:YAG laser, at 532 nm and 1064 nm. We believe that the fabrication technique is applicable to many semiconductors, but so far we have fabricated CdS and CdSe surfactant-capped quantum dots (QD) embedded in the PS matrix. The cross-sections for two-photon and three-photon-absorption are three to five orders of magnitude bigger than those for the QD in solution or other host materials. To our knowledge, these are amongst the largest nonlinearities measured for any material to date.

The several orders of magnitude increase in the cross-sections for absorption indicate that the nonlinearity is due to other physical mechanisms, rather than just quantum confinement. Numerical and theoretical methods are used to investigate the physical mechanism for this large nonlinearity.

⁺Work funded in part by the Air Force Office of Scientific Research.

¹Y. Gao, A. Tonizzo, A. Walser, M. Potasek, and R. Dorsinville, submitted to Applied Physics Letters.

* In collaboration with Drs. Y. Gao, Dorsinville and Walser (CCNY)

Recent Advances in Magnetron Theory and Simulation

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Abstract

A planar magnetron model is developed to analyze the small-signal theory of a non-relativistic magnetron. The analysis includes a full Floquet expansion and fully electromagnetic effects. The present planar model avoids the problem of multiple poles (singularities) and the model is good provided that the A-K gap is small compared with the cathode radius. An analytical dispersion relation of such a planar magnetron is derived and the growth rate is calculated based on the dispersion relation. MAGIC simulations are performed on the planar magnetron and simulated growth rate reaches good agreement with the theoretic prediction. In addition, a relativistic treatment is presented for the equilibrium of a planar magnetron consisting of a planar cathode and a corrugated anode. The electron density in the electron layer is assumed to be constant, and the guiding-center approximation is employed. Properties of the equilibrium such as the electrostatic potential, flow velocity, and the self-magnetic field are determined analytically. An interesting result of the present analysis is the appearance of vortex structures near the cathode. Test particle studies are carried out to identify the parameter regimes in which the guide-center approximation is valid.

Wave Breaking and Particle Jets in Intense inhomogeneous Charged Beams

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Abstract

We analyze the dynamics of inhomogeneous, magnetically focused high-intensity beams of charged particles. While for homogeneous beams the whole system oscillates with a single frequency, any inhomogeneity leads to propagating transverse density waves which eventually result in a singular density build up, causing wave breaking and jet formation. The theory presented in this paper allows to analytically calculate the time at which the wave breaking takes place. It also gives a good estimate of the time necessary for the beam to relax into the final stationary state consisting of a cold core surrounded by a halo of highly energetic particles.

The Saturation Stage of a Magnetron

D.J. Kaup

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Abstract

We report on our recent studies of the saturation stage of the magnetron. The operation of a magnetron has been divided into two stages. The initiation stage which is where the electron sheath builds up and a nonlinear diffusion process initiates, causing a reshaping of the electron density profile into a non-Brillouin profile. As this initiation stage continues, the rf fields eventually reach their maximum amplitudes, the instability saturates and a vertical dc current (from anode to cathode) starts to flow. At this point, the device enters into the saturation stage. In this stage the growth rate vanishes, the nonlinear diffusion ceases and the density profile and the vertical current achieve their stationary form, with the device delivering rf power.

In our studies, we are seeking to find numerical solutions of this latter stage. Difficulties encountered in finding solutions for this stage include the existence of three additional fast rf modes, giving a set of fifth-order linear ODEs for the rf modes. A resolution for the required five boundary conditions will be given and discussed. Due to their linearity, solutions to these rf equations for various background density profiles can be obtained and also will be discussed. Other difficulties concern the dc background solutions. Here, the existence of the dc vertical current, which in the initiation stage could be neglected, must be included in lowest order. As a consequence of this, the structure of the equations for the dc background significantly changes and has been found to contain a potential instability at high vertical currents. Following the same successful principle used for solving the dc equations of the initiation stage, it will be shown that the stationary density profile in the saturation stage will again be determined by the ponderomotive forces. It is anticipated that sample numerical solutions of these density profiles will be presented and discussed.

Long Range Numerical Simulation of Short Waves as Nonlinear Solitary Waves

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Abstract

A new numerical method has been developed to propagate short wave equation pulses over indefinite distances and through regions of varying index of refraction, including multiple reflections. The method, “Wave Confinement”, utilizes a newly developed nonlinear partial differential equation that propagates basis function according to the wave equation. The discretized equation can be solved without any numerical dissipation. The method can also be used to solve for harmonic waves in the high frequency (Eikonal) limit, including multiple arrivals. The solution involves discretizing the wave equation on a uniform Eulerian grid and adding a simple nonlinear “Confinement” term. This term does not change the amplitude (integrated through each point on the pulse surface) or the propagation velocity, or arrival time, and yet results in capturing the waves as thin surfaces that propagate as nonlinear solitary waves and remain 2-3 grid cells in thickness with no numerical spreading. With the method, only a simple discretized equation is solved each time step at each grid node. The method can be contrasted to Lagrangian Ray Tracing: it is an Eulerian based method that captures the waves directly on the computational grid, where the basic objects are codimension 1 surfaces (in the fine grid limit), rather than rays. In this way, the complex logic of current ray tracing methods, which involve allocation of markers to each surface and interpolation as the markers separate, is avoided. With the new method, even though the surfaces can pass through each other and involve a nonlinear term, there is no interaction effect from this term on the variables of interest, allowing the linear wave equation to be accurately simulated. This absence of interaction is due to the form of the difference operators of the added term

The new method should be important in areas of wave propagation, from radar scattering and long distance communications to cell phone transmission.