Design and Simulation of 2 um VECSELs

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Christina Bückers, Angela Thränhardt, and Stephan W. Koch
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Philipps Universität Marburg, GermanyDesign and Simulation of 2 micron VECSELs

Abstract

2-um vertical-external-cavity surface-emitting lasers (VECSELs) based on InGaSb-AlGaSb quantum wells (QWs) are designed and simulated using microscopically computed optical gain databases and a coupled optical/thermal analysis scheme. Two QW designs, a standard one and an optimized one, and two types of distributed Bragg reflector (DBR) are first analyzed and used to devise 2-μm VECSEL semiconductor chips. The coupled optical/thermal analysis is then conducted to obtain the performance of the VECSEL designs, where the semiconductor chip is combined with a highly reflective concave mirror to form a two-mirror laser resonator. The simulation results show that the laser characteristics such as slope efficiency are highly dependent on the thermal resistance of the VECSEL designs. It is also shown that the VECSEL incorporating the optimized QW design has much better performance than the one using the standard QW design.

Enforcing Interface Conditions in the Galerkin Finite Element Framework

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Abstract

In Galerkin Finite Element Method the interface conditions are satisfied by selecting appropriate basis functions. For example, when the field is continuous across the interfaces, nodal elements are chosen as the basis functions. Similarly when the tangential component of the field is continuous across the interfaces, edge element basis is chosen. This approach has the drawback that, not all interface conditions can be enforced this way. For example, it is not possible to enforce the interface conditions on the derivative of the field in addition to the interface conditions on the field itself. As a consequence of this one obtains incorrect solutions for scattering problems.

To remedy this, we suggest augmenting the linear system obtained from Galerkin discretization with additional constraints that would enforce the interface conditions in an integral sense. However one ends up with a rectangular linear system that should be solved in a least square sense. We apply this method to test scattering problems in 1d (plane parallel cavity) and 2d (infinite cylinder) and show that the method computes correct solutions. We are currently studying the application of this method to 3d scattering problems.

As an application, this method makes the study of electromagnetic scattering properties of structures with discontinuous magnetic permeability, using FEM, feasible.

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Two posters Abstracts:

1. Analytical model of N+1 - core fiber laser

Linear coupled mode equations for a multicore (one core at the center of a circle of N others) fiber laser resonator are solved in closed form. Of the N+1 eigenvalues N/2 (N even) or (N-1)/2 (N odd) are doubly degenerate. Reflection at the ends causes coupling of in-phase and anti-phase modes. Because of gain the diagonal as well as off-diagonal elements of the coupling matrix are complex, and non-reciprocality of central & ring cores is also included in the model. In addition, the interdependence of coupling elements is taken into account and modeled by coupled mode theory (Hardy & Streifer, 1984). We obtain conditions for which the in-phase supermode has largest gain, and the effect of mode mixing due to reflection is given. A linearized stability analysis, including differential rate equation s for the gain media, is under way and partially completed.

2. Novel ideas for high-mode area, antiguiding, single-mode fiber laser and "all in-air" waveguides, and other applications involving the reflection and guiding of high –intensity radiation.

Reflection coefficients and loss constants are derived for Bragg reflection of a stack of loss-free dielectric media separated by media of low index ("HLHL---LH"), and designs found that are suitable for potentially "revolutionary" single mode as well as multimode waveguide applications. An example of the former is the prevision of an 80 μm slab waveguide with loss of 0.046 dB/m for the fundamental mode and 0.46 dB/m for the next higher mode. The model at present is for slab geometry, with the intention of future extension to cylindrical geometry.

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Four poster Abstracts:

1. **Title: X wave generation by Cross-Phase-Modulation induced spatio-temporal reshaping and amplification within optical filaments.**

Ultrashort laser pulse filaments are shown to induce strong Cross-Phase-Modulation (XPM) effects on weak seed pulses. Driven by the pump, the seed pulse undergoes pulse slitting with the daughter pulses slaved to their pump counterparts. They undergo strong spatio-temporal reshaping and are transformed into X waves traveling at the same group velocities as the pump split-off pulses. In the presence of a gain mechanism such as Four-Wave-Mixing or Stimulated Raman Scattering, energy is transferred from the pump filament leading to amplification of the seed X wave and formation of a temporally compressed intensity peak.

2. Supercontinuum and Third-Harmonic Generation accompanying Optical Filamentation as First-Order Scattering Processes

It is demonstrated numerically that the supercontinuum generation and third-harmonic generation that accompany optical filamentation in nonlinear dispersive bulk media can be described as first-order scattering processes akin to the first Born approximation. In particular, for an incident ultrashort pulse the angularly resolved spectrum of the transmitted pulse is shown to be accurately determined using first-order scattering of the incident field from the nonlinearly modified refractive-index due to the optical filament. Thus, although an optical filament is a highly nonlinear object, the accompanying supercontinuum generation and third-harmonic generation are driven parametrically
by the filament and have negligible back action upon it.

3. Conditional femtosecond pulse collapse for white-light and plasma delivery to a controlled distance

Collisions between ultrashort pulses with different wavelengths are studied numerically. The relative delay, wavelength difference, focusing geometry and chirp are used to accurately control the distance at which pulses undergo conditional collapse and generate plasma and white light. Wide supercontinuum spectrum is achievable even with pulses that by themselves do not have sufficient power for filament formation.

4. Intensity fluctuations and pattern formation in broad-area semiconductor lasers

Statistics of light intensity fluctuations in a broad-area semiconductor laser is studied numerically. It is shown that even in a steady state regime, the light intensity exhibits strong fluctuations with probability distribution close to Poisson. Peak intensities are typically several times higher that the mean intensity. The characteristic time scale of these fluctuations is sub-picosecond. On the other hand, on nano-second and slower time scales, static filament patterns appear in the averaged intensity and carrier density spatial profiles.

Electromagnetic Interaction between Nanoparticles and Optical Subwavelength Devices

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Abstract

We present an approach for calculating the force on a quantum dot in sub-wavelength structures. As application we show that a quantum dot can be either pushed into or pushed away from the center of a quadrupole-like metallic bowtie.

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Two posters Abstracts:

1. Carrier Recombination in Semiconductor Lasers: Classical Myths vs. Microscopic Truths

We use fully microscopic manybody models to investigate important dependencies of the dominant carrier loss mechanisms in semiconductor lasers, spontaneous emission and Auger recombination. It is shown that the classically assumed dependencies for the density dependence of these losses (N^2 and N^3), temperature dependence (1/T and exp(-E_a/T)) and well width dependence (const. and $1/w^2$) generally fail dramatically to describe the dependencies correctly.

2. Structural Dependence of Optical Gain and Carrier Losses in InGaN Quantum Well Lasers

Fully microscopic models are used to investigate the structural dependence of InGaN/GaN quantum-well gain media. Due to the inherent piezoelectric fields, the amplitudes and spectral positions of gain and spontaneous emission strongly depend on the structural details. It is shown how quantitative experiment/comparisons can be used to determine the fields. As a general trend, it is found that the loss current due to spontaneous emission at the threshold decreases with well width and indium composition.

Dual-band laser transmitter for above- and under-water communications using third-harmonic generation of fiber-laser system at $1.5\mu m$

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Abstract

We report a viable dual-band laser transmitter for free-space optical above- and under-water communications. An all-fiber, picosecond, Watt-level master-oscillator-power-amplifier (MOPA) system at 1.5 m based on rapid amplification of modelocked pulses in heavily Er:Yb co-doped phosphate fiber is combined with a fiber-pigtailed lithium niobate intensity modulator (pulse picker), to construct a fully integrated eye-safe transmitter operating at 65Mbps data rate, for intermediate-range (few km) atmospheric communication links. For under-water use, the output of the MOPA system is frequency-tripled into the blue-green transparency window of ocean water. The wavelength conversion occurs in a simple single-pass setup utilizing a sequence of two periodically poled lithium niobate (PPLN) crystals, both of which are operated at room temperature. The conversion efficiency from fundamental to third harmonic reached 14% and resulted in generation of 140mW of average power at 518.5nm. The conversion efficiency can be straightforwardly tripled by using properly AR-coated optics in the free-space part of the system, and the data rate can be scaled up into the Gbps range by using a faster modelocked oscillator in the MOPA system.

Role of the Coulomb effect on the spectrum of Harmonic Generation

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Abstract

Using a quantum mechanical three-step model, we have investigated the influence of the Coulomb effect of the binding potential on the spectrum of harmonic generation in atomic systems. We have extended the Lewenstein model by modifying the plane-wave Volkov solution to an approximate Coulomb-Volkov wave function to account for the asymptotic Coulomb effect. This wave function describes, in an approximate manner, an electron in the simultaneous presence of the static Coulomb field of the residual ion and the oscillating laser field. In the absence of the Coulomb effect, our model reduces to Lewenstein model. The numerical results have been obtained for the different short laser pulses. A comparison of our results with the Lewenstein's data shows that the Coulomb effect is prominent in the low-order harmonics. We are grateful for financial support by AFOSR under grant No. FA9550-07-1-0010.

Tunable Frequency-Doubled Yellow-Orange VECSEL

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Abstract

Optically pumped semiconductor vertical-external-cavity surface-emitting laser (VECSEL) potentially provides an innovative approach to low-cost frequency agile lasers engineered for specific applications in infrared and visible range. In this poster, we present the development and demonstration of a multi-Watt highly strained InGaAs/GaAs vertical-external-cavity surface-emitting laser (VECSEL), which can be tuned from 1147 nm to 1197 nm. Based on this tunable InGaAs/GaAs VECSEL and intracavity frequency doubling, we develop multi-Watt frequency-doubled tunable VECSEL in a wide yellow-orange band (575 ~595 nm). This compact high-power yellow-orange laser provides an innovative approach to an affordable guidestar laser (~589.1 nm) solution, and has a lot of important applications in biomedicine.