grating-surface-emitting diodes coupled either as a linear array or in a ring configuration. A realistic model incorporating power saturation, saturable losses, and saturable dispersion effects is established. Optimization of operation by injection-current control and phase modulation is studied. Modeling of the general (nonsymmetric) ring geometry is more complicated than the corresponding linear array because the number of unknowns is four instead of two. We show an approach that reduces the number of general ring unknowns to two.

8:30am

FB3 Mode control of a blue Er:YLiF$_4$ upconversion laser using Zeeman tuning

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A number of visible upconversion lasers have been demonstrated using near-IR sources to pump short monolithic laser crystals doped with Er^{3+}, Nd^{3+}, or Tm^{3+} ions at low temperatures.[1,2] In many cases the spectral widths of the emission lines were comparable with the frequency spacing of the cavity modes, and the upconversion lasers operated in a single longitudinal mode. Recently, blue laser operation at 469.7 nm was achieved by using red or near-IR dye laser radiation for upconversion pumping of a 3.6-mm-long laser crystal of Er:YLiF$_4$ with mirror coatings directly applied to the spherically ($r = 2$ cm) polished end faces.[2] This laser operates on the $^2P_{3/2} \rightarrow {}^4I_{11/2}$ transition of Er^{3+}, which has a homogeneous linewidth of 16 GHz at low temperatures. The free spectral range (FSR) of the short monolithic laser crystal was 29 GHz. To achieve laser oscillation, the laser mode frequency must overlap with the narrow emission line and, consequently, the laser operates in the TEM$_{ijk}$ mode that exhibits the lowest pump threshold considering the frequency match of the cavity modes and the gain spectrum and the spatial overlap of the laser and pump profiles. Systematic studies of the laser mode selection were performed by applying a magnetic field to the Er:YLiF$_4$ crystal and observing the far field of the laser output and measuring the laser frequencies with a scanning Fabry–Perot interferometer. With appropriate adjustment of the magnetic field, Zeeman tuning of the blue Er^{3+} laser transition could be used to obtain laser operation in the TEM$_{00}$ mode. Sufficiently large detuning of the magnetic field resulted in TEM$_{01}$ mode operation, and further changes of the field led to a switching of the modes from TEM$_{0k}$ to TEM$_{0k+1}$ modes every 2.5 kG. The Zeeman tuning of the $^2P_{3/2} \rightarrow {}^4I_{11/2}$ emission line was 2.1 GHz/kG. The measured 5.2 GHz spacing of adjacent TEM$_{0k}$ modes is in good agreement with theoretical calculations for higher-order Gaussian modes in this geometry. The blue upconversion laser operated between 1.5 and 35 K, and in this range the laser mode frequency was measured to exhibit a temperature tuning rate of 140 MHz/K.

References

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2. T. Hebert, R. M. Macfarlane, R. Wannemacher, and W. Lenth, in *International Quantum Electronics Conference Technical Digest* (Optical Society of America, Washington, D.C., 1990), paper JWB3.

8:45am

FB4 RGB upconversion laser pumped by single IR pump

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Using a cw Ti^{3+}:sapphire laser operating near 800 nm, to pump Er:YLiF$_4$ and Er:BaY$_2$F$_8$ laser crystals, we have obtained laser oscillation from upper levels $^4I_{13/2}$, $^4I_{11/2}$, $^4F_{9/2}$, $^4S_{3/2}$, $^2H_{9/2}$, $^4G_{11/2}$, and $^2P_{3/2}$ of the Er^{3+} ion. We will summarize the observations to date, covering 0.47–2.7 μm. Five of the upper laser levels are above the pumped level and therefore must require that cooperative energy sharing processes be occurring or involve a sequential absorption of two, three, or more pump photons, or both. To our knowledge, the laser at 470 nm is the first blue laser to be excited with a single IR pump. Previous reports of blue operation have required either a pair of yellow pump photons or a combination of a visible and a near-IR pump to achieve a cascade absorption pumping pathway. An examination has been reported by Xie and Rand[1] of the appearance of instabilities that occur under conditions of nonlinear coupling between the several state populations. It appears likely from our observations, that for many of the above systems, an accurate description of the laser behavior will need this complex nonlinear analysis.

References

1. P. Xie and S. C. Rand, "Pair pumped, continuous solid state laser," in *Advanced Solid State Lasers Digest* (Optical Society of America, Washington, D.C., 1990), p. 179.

9:00am

FB5 FM mode-locked laser-diode-pumped Nd:glass laser

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The mode-locked Nd:glass laser is of interest as a source of short pulses because of its large fluorescence bandwidth (5.3 THz). This lasing medium is particularly suited to pumping by laser-diode arrays, and the performance of several AM mode-locked laser-diode-pumped Nd:glass lasers has been reported.[1,2] We present what we believe to be the first report of an FM mode-locked laser-diode-pumped Nd:glass laser. The laser cavity used in our experiment was an astigmatically compensated 3-mirror cavity. The active medium, a 1.2 mm thick disk of highly doped LG760 glass, was inserted at the focus of the cavity at Brewster's angle. With 1.5% output coupling we have obtained a power of 35 mW for 400 mW incident on the glass. The FM modulator was a Brewster-angled LiNbO$_3$ crystal. Its insertion loss was determined to be 3%. The modulator was driven at a 235 MHz, by 1–2 W of rf power. The phase retardation was 0.7 rad. The pulse duration, which was measured by means of standard autocorrelation techniques, was 9 ps (assuming a Gaussian pulse shape), and the laser bandwidth when mode-locked was 71 GHz. The maximum mode-locked power output was 14 mW. Detailed performance characteristics of this laser will be presented, and future development of this system will be discussed.

References

1. S. Basu and R. L. Byer, Opt. Lett. 13, 458 (1988).
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9:15am

FB6 Stochastic mode-locking theory of external-cavity semiconductor lasers

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A stochastic mode-locking model has been developed to study the effect of intrinsic spontaneous noise and carrier shot noise on the phenomenon of active mode-locking in external-cavity semiconductor lasers. This frequency-domain numerical model includes nonlinear carrier dynamics, population pulsation, and self- and cross-saturation of the gain and is sufficiently flexible to account for coupling of multiple harmonic field components. The computer simulation of noise follows Marcuse's approach[1] except that, because of active modulation, the Langevin noise strengths are allowed to depend on the time evolution of the gain and photon number. The resulting numerical simulation models the pulse-height probability distribution and the correlation of pulse height deviations under various operating conditions, such as the bias level, modulation strength, modulation type, and frequency detuning. The array of optical pulses are also numerically sampled and averaged to reveal the detailed stable structure of pulses, including possibly the reproducible satellite peaks, as have been evidenced in other experiments.

Reference

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