motion of the two coupled modes. The antiphase dynamics, which are especially evident below the relaxation oscillation frequency of the laser, can include both periodic and chaotic frequency components. Modelling and possible applications of the coupled mode system with optical injection are discussed.

All-optical noninvasive control of semiconductor lasers

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Multisection semiconductor lasers provide numerous applications, e.g. in optical communication schemes. Their dynamics comprise cw emission, selfpulsations, and even chaotic emission on picosecond timescales.

In this context, stabilization of an intended (unstable) regime of operation can be required, necessitating ultrafast all-optical control methods where the ultimate speed limit is set by the speed of light.

The time-delayed feedback control (TDFC) method introduced by Pyragas plays an outstanding role among other control schemes, being self-adapting and noninvasive.

An all-optical implementation of this method has been proposed early [1] but not yet realized.

In proof-of-concept experiments, we demonstrate all-optical TDFC of unstable cw emission [2] and selfpulsations up to 26 GHz in a multisection laser.

The experimental device, fabricated by Fraunhofer HHI, combines two distributed feedback lasers and a passive waveguide section on the same chip. Each section is separately addressed by injection currents. Reproducible access to various bifurcations is provided within the codimension 4 parameter space spanned by the three currents and the device temperature.

In different regimes, unstable states are stabilized by direct resonant feedback from a plane Fabry-Perot cavity. The optical round trip phase shift provides an additional new control parameter compared to standard TDFC, requiring careful adjustment of the relevant cavity on a sub-wavelength scale.

Device specific simulations agree well with the measured data and give a systematic study of the relevant control parameters.

[1] J. E. S. Socolar, D. W. Sukow, and D. J. Gauthier, Phys. Rev. E 50, 3245 (1994)

[2] S. Schikora, P. Hoevel, H.-J. Wuensche, E. Schoell, and F. Henneberger, Phys. Rev. Lett. 97, 213902 (2006)

Optical bistability and flip-flop operation in DFB laser diodes injected with a CW signal

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All-optical flip-flops draw more and more attention as potential parts of all-optical packet or burst switching schemes. Recently several schemes for such all-optical flip-flops have been proposed, e.g. mutually coupled laser diodes, Mach-Zehnder interferometers with fed back output and ring lasers. All flip-flops are based on bistable behaviour and on the possible switching between the two stable states using short optical pulses.

Previously, we have shown numerically that a DFB laser diode in which a CW signal is injected can exhibit a bistability in the input power dependence of the amplification and of the laser output power. A condition for this bistability was that the injected light is not reflected inside the laser diode. The wavelength of the injected light must therefore be not too close to the Bragg wavelength and the laser must be AR coated.

In this contribution, we present additional modelling results as well as some experimental results for lambda/4-shifted DFBs. We show numerically that for a certain bias current the bistability only occurs when the carrier lifetime and the series resistance of the laser diode are not too small, such that sufficient spatial hole burning can exist inside the laser. Experimental results show that bistability is observed in some lasers but not in others, something which may be related to the series resistance and carrier lifetime.

We will also discuss the dynamic, all-optical flip-flop operation, which is possible by injecting short pulses on either facet of the laser.

6997-24, Session 5

Bifurcation analysis of a multi-transverse-mode VCSEL

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We investigate a multi-transverse-mode vertical-cavity surface-emitting laser subject to optical feedback. Starting from a partial differential equation (PDE) description of the spatial optical mode profiles and the carrier diffusion, we show how eigenfunction expansion techniques can be used to resolve the spatial dependence. The addition of optical feedback results in a model in the form of a system of delay differential equations (DDEs), where the delay represents the propagation time of light in the external cavity. The resulting DDE system is amenable to a full nonlinear bifurcation analysis by means of numerical continuation techniques.

We investigate here the dependence on parameters of the steady states, known as external-cavity modes (ECMs), and bifurcating periodic solutions for a VCSEL with two transverse modes. Specifically, we consider the effect of cross-coupling of the two modes via the external round-trip. We study the transition from a degenerate case, in which both optical fields receive feedback only from themselves, through to the case where both fields receive feedback only from each other. Between these two extremes we identify a number of changes in the steady state structure and the bifurcations of the periodic solutions. In particular, we find a number of coexisting stable ECMs, as well as coexisting stable periodic solutions with vastly differing frequencies.

6997-25, Session 5

Asymmetric square-waves in mutually coupled semiconductor lasers

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Two edge-emitting lasers coupled through polarization-rotated optical injection exhibit square-wave oscillations provided the roundtrip time from laser to laser and back is sufficiently large. If the pump parameters of the two lasers are different, the two plateaus of the square-waves exhibit different durations even though the total period remains close to the roundtrip time. This asymmetry progressively disappears as the feedback strength is increased. The experimental observations are confirmed by numerical simulations using rate equations similar to those studied in Gavrielides et al. (Opt. Lett. 31, 2006 (2006)) for a single edge-emitting laser. The simulations also reveal that the square-wave regimes appear through a series of complex bifurcations and that a sufficiently large roundtrip time is needed. To our knowledge, it is the first experimental example of asymmetric square-waves induced by a delayed feedback.

6997-26, Session 6

3.5 W GaInNAs disk laser operating at 1220 nm

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The practical interest in developing optically pumped semiconductor disk lasers is rapidly growing as such sources are proving to offer unique opportunities for generating high-brightness radiation at visible wavelengths. Although intra-cavity frequency doubled 940 nm-1040 nm InGaAs/GaAs disk lasers are able to generate multi-Watt power at blue and green, the generation of high-power red laser light still remains a challenging task that requires an efficient source emitting around 1.2 μm.

This presentation reports an essential progress towards development of efficient semiconductor disk lasers operating at 1220 nm using GaInNAs/GaAs quantum-well structures. The gain mirror was fabricated by molecular beam epitaxy using an RF-plasma source for incorporating the nitrogen. The structure consisted of a 30-pair GaAs/AlAs distributed Bragg reflector and 10 GaInNAs/GaAs quantum-wells with relatively low content of nitrogen. The growth parameters and the composition of the structure have been optimized to reduce the detrimental effect of nitrogen on the emission efficiency. We have achieved a maximum output power of 3.5 W and a differential efficiency of 17.6%. These parameters represent the best performance reported to date for a GaInNAs disk laser.

Technical Programme

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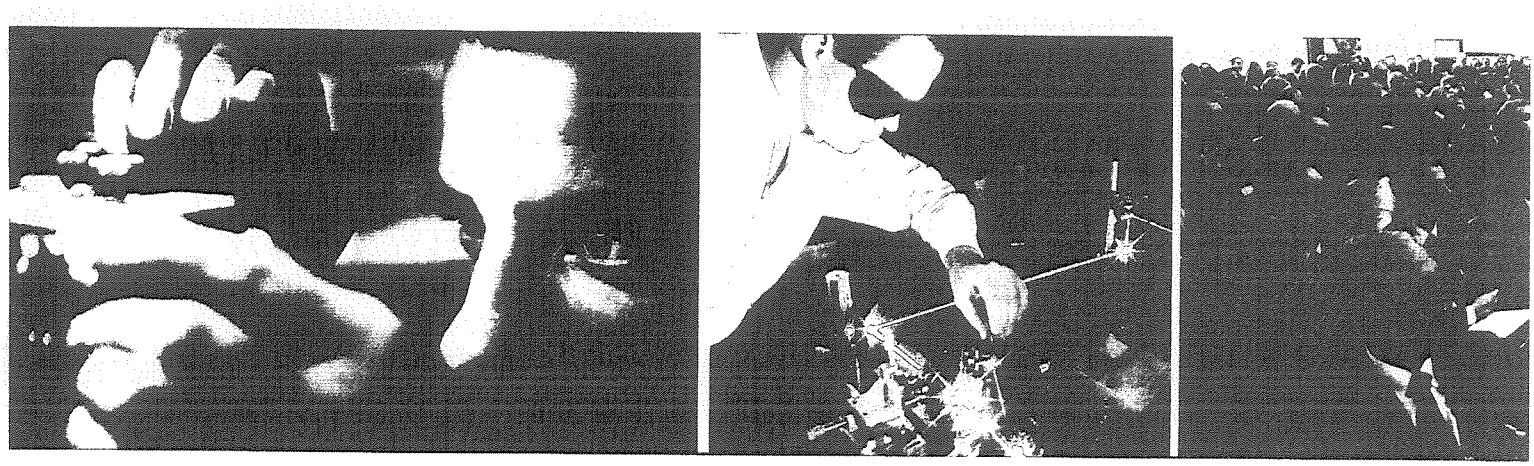

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