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Relaxation Oscillation Dynamics in AlGaInP Diode Lasers

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1. Introduction

Diode lasers based on the AlGaInP system recently have been of large interest for high density optical storage devices. Although moderate modulation frequencies below 100 MHz generally are sufficient for these lasers, high frequency properties yield information on parameters for device optimization, like differential gain and carrier capture and diffusion times. This optimization has to be balanced between weak mode confinement for high optical damage threshold and low threshold current density for long term stability. Especially the weak optical confinement is expected to have strong implications on the dynamics of the carrier-photon system.

In this paper we study high speed relaxation oscillation dynamics in 680 nm laser diodes initiated by ps pulses from an external laser. This technique has the special advantage of not suffering from parasitics due to electrical connections [1-4]. We will show that the timescale for these oscillations and their damping are much longer than that of lasers with longer emission wavelengths.

2. Experimental

All experiments were performed on 680 nm AlGaInP lasers with uncoated facets. The lasers were biased with constant current. The ps pulses (repetition rate 80 Mhz) from a mode-locked Ti:Sapphire laser with subsequent frequency doubler (wavelength 420 nm) were focused onto one the facets with a microscope lens (spot size 1 micron) to excite electron hole pairs in the vicinity of the surface. These carriers induced relaxation oscillations in the emitted light of the diode laser. The light output was focused onto the entrance slit of a spectrometer through the same microscope lens. The signal was recorded spectrally and temporally resolved by a streak camera with two-dimensional readout. Spectral and temporal resolution were 1 nm and 40 ps, respectively. Since all high frequency processes took place in the optical domain, no diode lasers with high frequency connections were necessary.

3. Results and Discussion

Figure 1 shows the light output of a laser diode (output power 2.6 mW) after stimulation with ps light pulses for different levels of injected power. The curves are normalized to the output of the undisturbed laser diode. The locally increased carrier density due to the external perturbation starts relaxation oscillations that are in phase with the perturbation. Oscillations with opposite sign were observed in experiments in which the external laser pulses were tuned to the wavelength of the diode laser. In that case the external pulses reduced the carrier density and subsequently the photon density because the pulses were amplified when traveling through the waveguide [4]. The amplitude of the oscillations versus strength of the perturbation shows strong saturation. The amplitude of neighboring curves in Fig. 1 differs by roughly constant amounts although the injected light intensity is doubled in each step. This saturation is enhanced by the fact that the ps pulses (penetration depth below 1 μm) excite carriers very locally near one facet only. At high injection power the shape of the oscillations starts to change and the frequency of the oscillations drops. This behavior is opposite to that expected for increased carrier density and output power, and modeling has to take into account longitudinal variation of carrier density and light intensity.

Figure 2 shows the relaxation oscillations at 0.5 mW injection power for different values of the

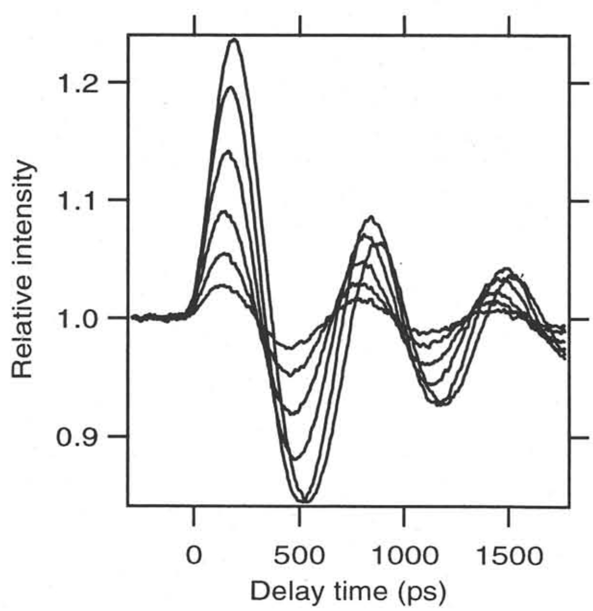

Figure 1: Relaxation oscillations in diode laser output for different power levels of the perturbing laser pulses (2, 1, 1/2, 1/4, 1/8, 1/16 mW).

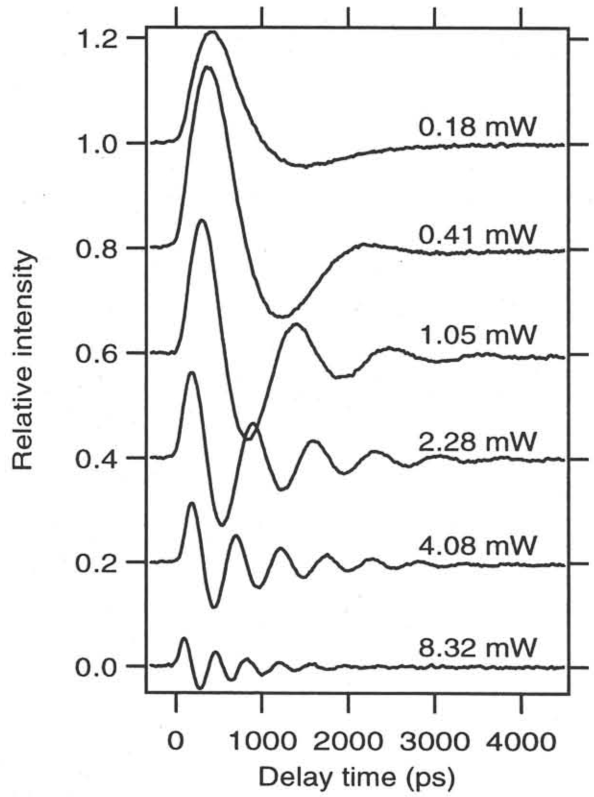

Figure 2: Relaxation oscillations for different values of the diode laser output power. The curves are offset vertically.

diode laser power. In the approximation of small perturbation and homogeneous carrier and photon densities the amplitude of the relaxation oscillations for time t>0 is

$$L = L_0 + B \exp(-t\gamma/2) \sin(t\,(4\pi^2 f^2 - \gamma^2/4)^{1/2}). \quad (1)$$

L_0 is the equilibrium intensity, B the strength of the perturbation, γ the damping of the oscillations, and f the resonance frequency. In our case the small signal solution yields much better results than the intermediate signal approximation described in [3], which yielded a good description of the dynamics in 1.5 µm lasers. We observe increased amplitudes during the negative oscillations half periods whereas the intermediate signal approximation, which assumes homogeneous longitudinal carrier and photon distribution, suggests the opposite behavior.

Figure 3 shows the squared relaxation oscillation frequency f^2 and the damping γ versus output power P. Frequency f and damping γ were determined from fitting Eq. (1) to the curves in Fig. 2. The diagram shows the expected linear variation of f^2 with P, but f^2 stays fairly low due to the optimization of the diode laser for low photon density and f^2/P yields 0.88 GHz^2/mW. The

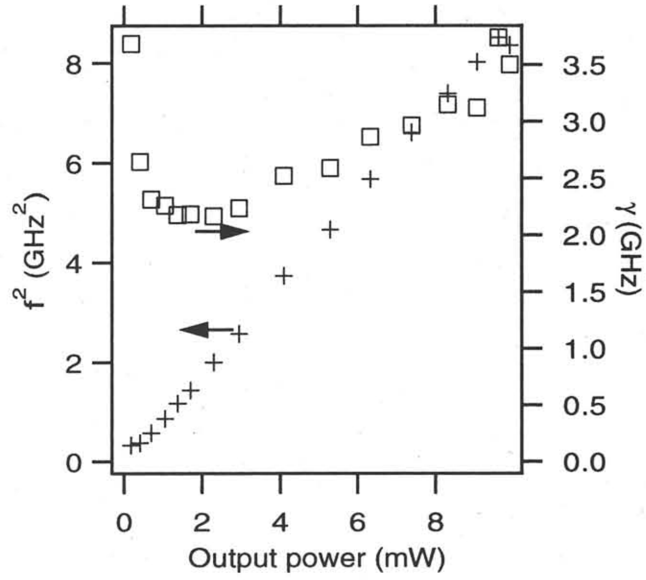

Figure 3: Relaxation oscillation frequency (crosses), and damping rate (squares) versus diode laser output power.

damping γ, which is also expected to vary linearly with P, shows a rather different behavior. Initially γ decreases with P and then shows a linear increase above 2 mW. From this increase we get a value of 4.8 ns for $K = \Delta\gamma/\Delta f^2$. Further work is underway to verify how much the above results are influenced by the inhomogeneous perturbation.

4. Conclusions

In conclusion we have investigated the relaxation oscillation dynamics in AlGaInP 680 nm diode lasers. The results show that the weak optical confinement generally used in these lasers has strong implications on the dynamic behavior, causing low relaxation oscillation frequencies, relative current independent damping rates, and a K-factor that limits the bandwidth to the sub Ghz range. This low bandwidth might be a problem for future ultra high speed storage devices.

References

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