Phase and amplitude stability of an external cavity laser diode modelocked by optoelectronic feedback

M.O. Ziegler, M. Hofmann, J. Sacher, W. Elsäßer and E.O. Göbel

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The authors have investigated the stability of an external cavity laser diode modelocked by optoelectronic feedback. The measured picosecond pulses at repetition frequencies of up to 1.2 GHz exhibit an amplitude and phase jitter of the order of a few percent, increasing with increasing repetition frequency.

Introduction: Coherent trains of picosecond pulses from mode-locked semiconductor lasers are promising sources of applications such as optical data transmission systems. Many groups have reported on pulsewidths in the picosecond range, at repetition rates of up to a few gigahertz, by active modelocking of external cavity laser diodes via injection current modulation [1, 2]. Still higher repetition frequencies can be obtained by modelocking long monolithic devices with no external cavity [3]. Usually, external modulation by stable frequency synthesisers is a basic requirement for the active modelocking of laser diodes. Recently a scheme was proposed allowing active modelocking without external modulation by the use of optoelectronic feedback [4, 5]. The knowledge of its stability properties is of fundamental importance to future applications. This Letter reports on investigations of the amplitude and phase stability of this system at repetition frequencies in the gigahertz range.

Experimental setup: The complete experimental setup is shown schematically in Fig. 1. The antireflection coated laser diode is a

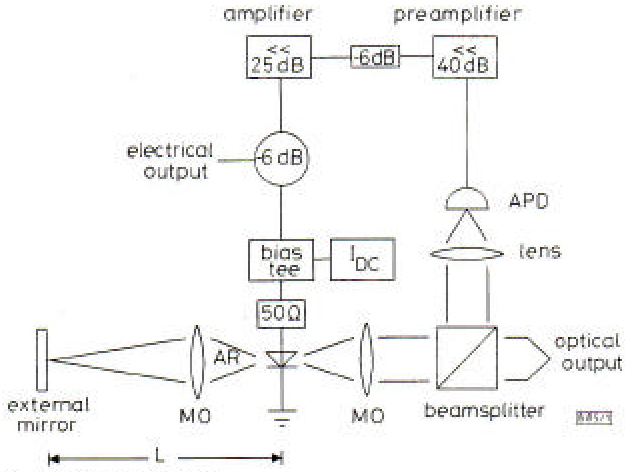

Fig. 1 *Experimental setup*

MO: microscope objective; AR: antireflection coating; APD: avalanche photodiode

BH structure emitting at 1.3μm. It is placed in an external cavity consisting of a microscope objective (MO) and a highly reflective mirror. The light output is collimated with a microscope objective and divided by a beamsplitter: one beam is taken for the optoelectronic feedback (OEFB) and the other one allows analysis of the optical output. The feedback beam is focused on to a fast (4.5 GHz bandwidth) avalanche photodiode (APD). The electrical APD signal is amplified by two commercial high bandwidth (10 GHz) amplifiers and superimposed on to the DC current of the laser diode via a bias tee. The 6dB power divider inside the electrical feedback loop allows analysis of the electrical signal with a spectrum analyser or a sampling oscilloscope. Furthermore, it provides the trigger signal for a synchroscan streak camera, which is used for time resolved measurements of the optical output. The use of an optical spectrum analyser yields information on the spectral properties of the optical output.

The optical cavity roundtrip frequencies are chosen as multiples of 150MHz, which corresponds to the length of the optoelectronic feedback loop. The repetition frequency of the modelocked output pulses is equal to the optical roundtrip frequency in all cases discussed below.

Experimental results: Modelocking by OEFB has been obtained at repetition frequencies from 75MHz up to 2.4GHz, with optical pulsewidths between 20 and 40ps. In the following, we investigated the phase and amplitude stability of our system at three representive repetition frequencies of 600MHz, 900MHz and 1.2 GHz. The measured pulsewidths were 23, 22 and 21ps, respectively. The amplitude jitter is defined as the ratio $\Delta E/E$ of the mean pulse energy fluctuations to the absolute pulse energy, while the phase jitter (or timing jitter) is assigned to be the ratio $\Delta t/T$, T being the repetition period and Δt being the average uncertainty of the temporal pulse position.

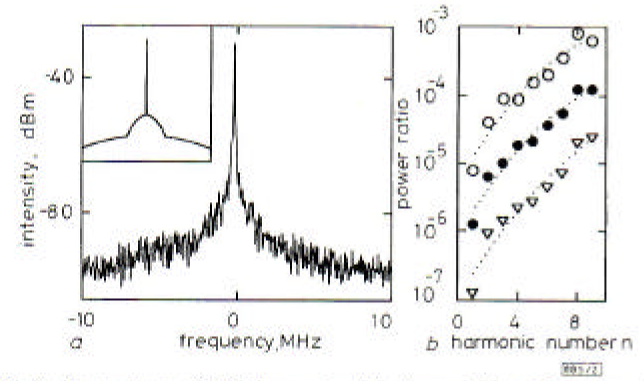

Fig.2 *RF spectrum of fifth harmonic of fundamental beat frequency of 1.2GHz, and power ratio*

a RF spectrum
Measurement interval: 50s: resolution bandwidth: 100Hz; inset shows evaluated jitter contributions schematically
b Power ratio against harmonic number *n*
Widths of noise bands are: ∇: 5MHz; ●: 1.5MHz; ○: 0.7MHz
Dotted lines show proposed quadratic dependence of power ratio on *n*

Information about the magnitude of the amplitude and timing jitter is obtained by investigation of the measured power spectra. The power spectrum consists of a set of carriers at harmonics of the fundamental repetition frequency. These carriers are surrounded by broad noise bands which are caused by amplitude and phase jitter [6]. For example, Fig. 2*a* shows the measured RF spectrum in the vicinity of the fifth harmonic of the fundamental beat frequency of 1.2GHz. The noise bands originating from amplitude and phase jitter can be distinguished in the following way: the phase noise contributions can be identified by the quadratic increase in the power ratio between the power of the noise bands and the carrier, while the amplitude noise power ratio is constant for all harmonics [6, 7]. The power ratio between the noise sidebands and the carrier was measured and plotted against harmonic number in Fig. 2*b* for a repetition frequency of 1.2GHz. From the quadratic frequency dependence of their power ratios three different phase jitter contributions can be identified. Note that jitter contributions below 100Hz cannot be evaluated due to the finite spectral resolution of the spectrum analyser. The amplitude jitter contributions were determined from the zero-order intercepts of the parabolic fits to the noise band power ratios. The ultimate jitter values can be obtained from integration of the noise bands [6, 7]. The values we determined from our measurements are summarised in Fig. 3*a* and *b* for the three repetition frequencies we investigated. We found the amplitude jitter to be less than a few percent and the phase jitter to be less than 1.5%. The exact maximum values of the absolute timing jitter were 3.3, 9.4 and 9.6ps at 600MHz, 900MHz and at 1.2GHz repetition frequency, respectively. Accordingly, timing jitter is of minor importance at the lowest repetition frequency while it becomes a considerable portion of the optical pulsewidth at the higher repetition frequencies. All amplitude and phase jitter contributions increase considerably at higher repetition frequencies, indicating a reduced stability when the ratio of the cavity roundtrip frequency to the OEFB frequency increases.

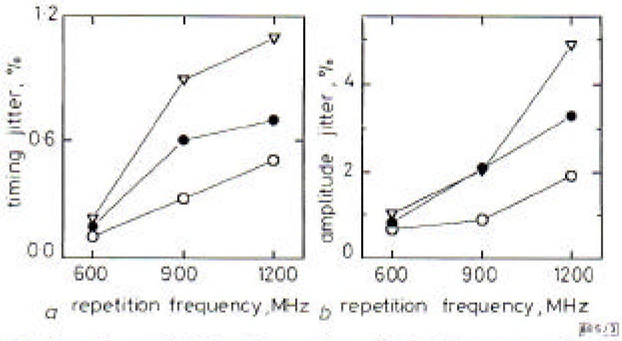

Fig.3 *Dependence of timing jitter and amplitude jitter on repetition frequency*

a Timing jitter
b Amplitude jitter

Further investigation is required to clarify the influence of the loop delay on the jitter and to determine the origin of the different jitter contributions. In particular, the reason for the considerable increase in both amplitude and timing jitter has to be determined, since at higher repetition frequencies the timing jitter plays a dominant role in the system's performance.

However, comparing our results for the phase stability to those for active and passive modelocking, we find that the timing jitter is comparable to that of passively modelocked diode lasers [7], while it is larger than the timing jitter we observed for active modelocking of our laser diode by at least a factor of 3.

Conclusions: We have presented the first results of our investigations into the stability of an external cavity laser diode modelocked by optoelectronic feedback. The results show both amplitude and timing jitter to be in the order of a few percent. These results for the jitter are higher than those observed for active modelocked external cavity laser diodes but better than those obtained for passive modelocking [7]. Stability decreases when the ratio of the cavity roundtrip frequency and optoelectronic feedback frequency increases. For this reason integration of the feedback loop will be a useful means of achieving much higher repetition rates with improved stability.

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M.O. Ziegler, M. Hofmann, W. Elsäßer and E.O. Göbel (*Fachbereich Physik und Zentrum für Materialwissenschaften der Philipps Universität Marburg, Renthof 5, D-35032 Marburg, Germany*)

J. Sacher (*Joachim Sacher Lasertechnik, Nikolaistraße 9a, D-35037 Marburg, Germany*)

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