REPETITION FREQUENCY STABILISATION OF PASSIVELY MODE-LOCKED SEMICONDUCTOR LASERS

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The repetition frequency of an external cavity mode-locked GaAs semiconductor diode laser has been stabilised by voltage controlled electrical feedback. The phase noise has been reduced by 40 dB at 1 kHz offset from the carrier and timing jitter reduced from more than 30 ps to 4 ps. This technique can be used to stabilise millimetre-wave mode-locked lasers.

Introduction: Passively mode-locked semiconductor diode lasers have demonstrated repetition frequencies up to 350 GHz [1]. However, most applications for optical pulses with a millimetre-wave repetition frequency require that the repetition frequency be stable, and synchronised to a low frequency reference. This stabilisation has been provided by hybrid mode locking, where current injection is used for gain modulation [2]. However, current injection is limited by the lowpass cutoff of the contact electrical parasitics.

We demonstrate for the first time feedback stabilisation of passively mode-locked semiconductor diode lasers. This technique is useful for stabilising millimetre-wave repetition frequency mode-locked devices as it is not limited by the laser contact electrical parasitics. Electrical feedback has previously been used to stabilise an actively mode-locked Nd : YAG laser using a microwave phase shifter before the modulation signal [3] and a passively mode-locked dye laser and colour centre-laser using a piezoelectric tuning element to adjust the cavity length [4]. The new stabilisation technique reported here is unique in that the photodetection and frequency tuning functions are monolithically integrated into the laser structure.

Experiment: The active device was a two-segment 360 μm long GaAs/AlGaAs bulk active region laser fabricated using impurity induced disordering [5]. The laser was antireflection (AR) coated on one facet and coupled to a 5 GHz external cavity (Fig. 1). A reversed biased 8 μm long segment was used as a saturable absorber to produce passive mode locking. The optical pulses had a pulsewidth of 3 ps and a spectral width of 3 nm. The absorber was also used as a photodetector to generate an electrical output at the pulse repetition frequency.

Feedback stabilisation requires control of the repetition frequency by a DC signal. Previously we demonstrated repetition frequency tuning by current injection of a short segment [6]. The two parameters that can be used for repetition frequency tuning of a semiconductor laser are forward current for gain sections and reverse voltage for absorbing sections.

The repetition frequency and power dependence on gain and absorber bias are shown in Fig. 2. The repetition frequency can be tuned with very little power variation using the absorber voltage, which reduces frequency noise to amplitude noise conversion in the stabilisation process. In contrast, varying the gain segment current causes a much laser change in output power and a smaller repetition frequency tuning range.

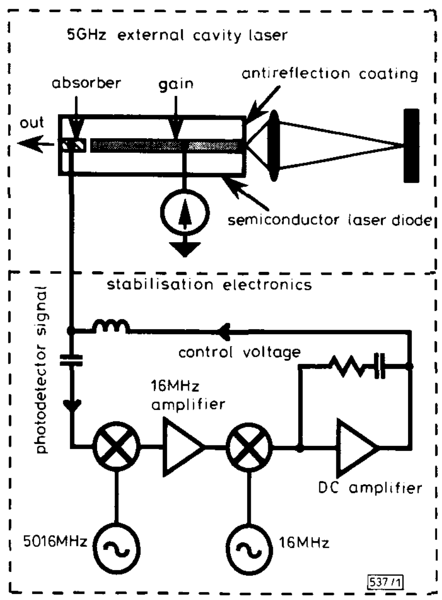

Fig. 1 *Experimental configuration for passive mode locking and repetition frequency stabilisation*

Several mechanisms can vary the pulse repetition frequency as a function of bias. One is carrier dependent changes in group velocity, which determines the pulse transit time through the laser. Another mechanism is a change in the gain or absorption saturation. Saturable gain and absorption

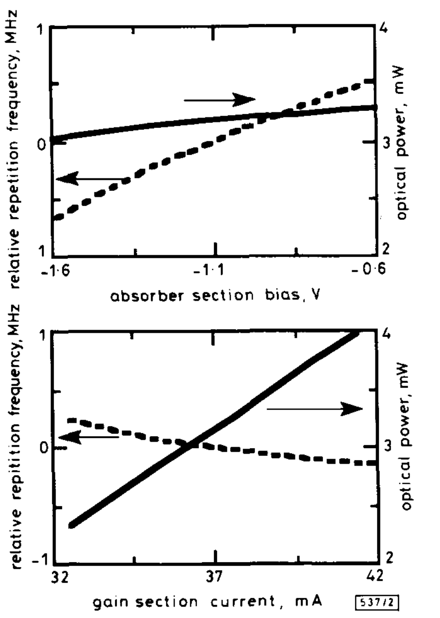

Fig. 2 *Measured repetition frequency tuning using control of gain section current and absorber section voltage*

changes cause a shift in the effective pulse centre and therefore the cavity round trip time.

The electrical network for feedback stabilisation is shown in Fig. 1. The short segment is used as a saturable absorber, photodetector, and a repetition frequency tuning element. The resulting phase noise was measured using an external high speed photodetector (Fig. 3). The phase noise after stabilisation was unchanged at carrier offsets much greater than the feedback loop bandwidth of 30kHz. For carrier offsets below the stabilisation loop bandwidth, the optical output tracks the electrical reference. The unstabilised phase noise has a slope of 20dB/decade, which is a result of frequency modulation by a white noise source. Unstabilised passively mode-locked lasers have an infinite timing jitter. The timing jitter that resulted from phase nose greater than 500Hz from the carrier was 30ps. With stabilisation, the total timing jitter was 4ps.

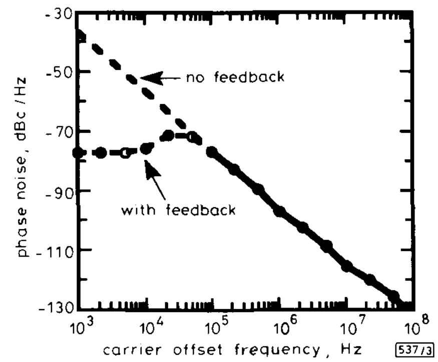

Fig. 3 *Single sideband phase noise with and without electrical stabilisation*

This electrical feedback technique can be extended into the millimetre-wave band using monolithic cavity devices. A high speed photodetector can be used in place of the integrated photodetector/saturable absorber. The integrated photodetector is strongly saturated, so its response time is reduced by carrier screening of the applied electric field. A low frequency reference signal can be used together with a harmonic mixer to allow stabilisation of an optically generated millimetre-wave signal by a low frequency reference.

Conclusions: We have demonstrated electrical feedback stabilisation of a passively mode-locked semiconductor laser. Jitter was reduced from more than 30ps to 4ps. This technique can be used to stabilise millimetre-wave mode-locked semiconductor lasers.

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