Stabilization of an InP-based laser using the Pound-Drever-Hall technique deploying electro-optic tuning for the electrical feedback

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ABSTRACT

In this work, we present results from the stabilization of an integrated single frequency InP diode laser with an extended cavity using the Pound-Drever-Hall locking technique. The laser is a multi-section DBR laser with an intra-cavity ring resonator. It is locked to a 1 MHz wide resonance of a highly stable Fabry-Perot etalon via electrical feedback which is applied on the rear DBR section. The DBR section is used in reverse bias to tune the lasing mode thus avoiding any thermal effects. We show measurements that confirm the drift stabilization of the laser to an etalon resonance for over 10 minutes and linewidth measurements using the delayed self-heterodyne method. The latter show a reduction of the laser linewidth below 50 kHz which is at the moment limited by the time delay of the current feedback loop.

Keywords: InP, laser, stabilization Pound-Drever-Hall locking, phase modulator.

1. INTRODUCTION

Lasers with high short- and long-term stability are essential in sensing [1], spectroscopy [2] and metrology [3]. Their stability however is degraded by environmental disturbances (temperature and pressure fluctuations, mechanical, vibrations, flicker noise from electronics) while many times their intrinsic linewidth [4] is not sufficiently low either. Active stabilization schemes are required in order to dramatically improve the stability of free-running lasers. Such schemes may deploy electrical or optical feedback or can even be feedforward techniques.

One of the most powerful and widely used techniques is the Pound-Drever-Hall (PDH) frequency locking technique [5]. In PDH locking the laser is locked to a resonance of usually a high-finesse optical cavity which acts as an absolute reference. The laser output light is phase modulated and from the reflection of the side-bands a frequency discriminator-like signal is generated. This is often called the error signal and it is fed to a PID controller which applies a negative electrical feedback to the laser. The laser in this way is locked to the resonance. If the feedback loop has sufficient bandwidth and gain it can furthermore reduce the linewidth of a laser by suppressing its phase noise. The electrical feedback is usually applied on the SOA section of semiconductor lasers or heaters that tune the lasing mode.

In this work, we investigate and demonstrate the stabilization of an InP-based diode laser using PDH locking by applying the electrical feedback on a reverse biased DBR section of the laser to tune the lasing mode. This

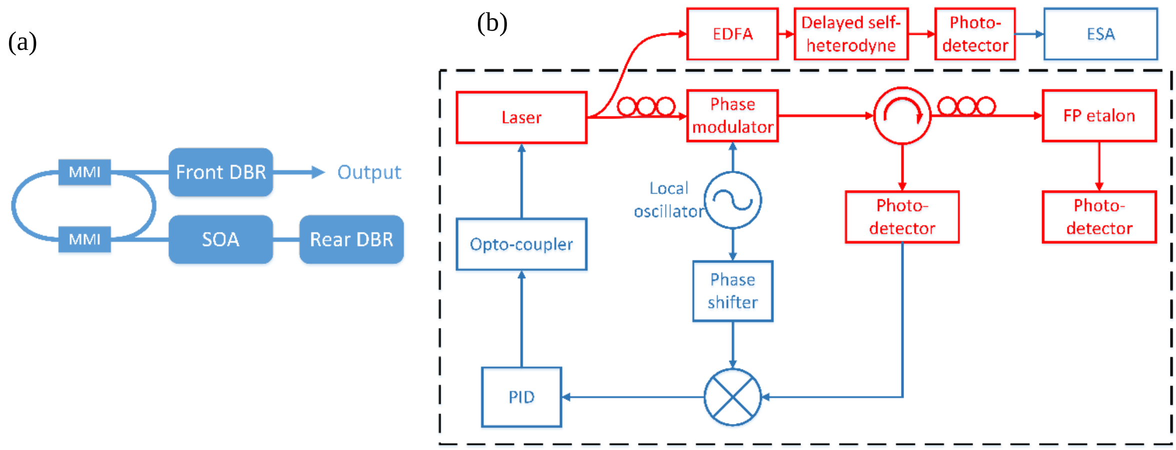

Figure 1. (a) Schematic of the laser. The cavity is formed by two DBR mirrors (300 μm and 400 μm) and the intra-cavity components are an SOA (500 μm), a ring resonator (80 μm radius) and passive waveguides, (b) Schematic of the Pound-Drever-Hall frequency locking technique used in the black dashed box.

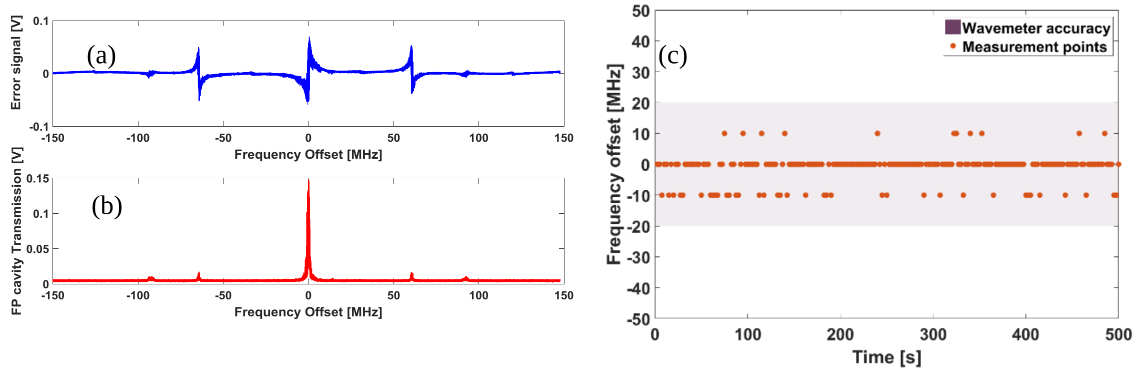

Figure 2. (a) The error signal as a function of frequency offset from the resonance transmission (the modulation frequency is 60 MHz and the FWHM of the resonance 700 kHz), (b) The transmission of the scanning laser through the Fabry-Perot etalon, (c) The lasing frequency of the locked laser measured using a wavemeter (40 MHz). The measured points are within the measurement accuracy of the instrument.

implementation avoids any significant thermal effects contrary to tuning laser tuning using carrier injection. In the first part information about the laser and the implementation of the PDH locking are given and in the second its results. The drift is stabilized by locking the laser to a stable reference etalon and confirmed by using a wavemeter to record the lasing wavelength. The observed frequency fluctuations are associated with the wavemeter and its accuracy indicating that the laser is locked to the resonance over this time interval. Linewidth reduction below 50 kHz is observed from the electrical spectra of the delayed self-heterodyne method. The bandwidth of our current feedback loop however is probably the limiting factor.

2. POUND-DREVER-HALL IMPLEMENTATION WITH THE InP-BASED LASER

A schematic of the InP-based laser fabricated using an active-passive integration technology [6] is shown in Fig. 1(a). It is a multi-section DBR laser with an intra-cavity ring resonator [7]. The semiconductor optical amplifier (SOA) is 500 μm long and the front and rear DBRs are 300 μm and 400 μm long respectively. The ring resonator has 80 μm radius. The DBR sections can be used to tune the lasing wavelength in reverse or forward bias. Here, we only use the gratings in reverse bias voltage in which the change of the effective index results from mainly electro-optic-effects. Since the current levels are typically less than 1 μA thermal effects are avoided. This is an important issue because thermal tuning has wavelength shift of opposite sign compared to electro-optic tuning therefore two different control signals are not necessary.

The chip was fabricated by Smart Photonics [6] in the multi-project wafer technology. The chip is mounted on an aluminium sub-mount and kept at 18°C using a water-cooler. Light is coupled from the chip using a single mode lensed fibre. A schematic of the used PDH locking is depicted in Fig. 1(b) in the black dashed box. The laser output is phase modulated at 60 MHz using a lithium niobate modulator. The modulated light falls through a circulator on a Fabry-Perot cavity with full-width at half-maximum (FWHM) of 700 kHz and free spectra range of 3 GHz. Its finesse is about $4{\cdot}10^3$ and it is made out of ultra-low expansion material thus it experiences very

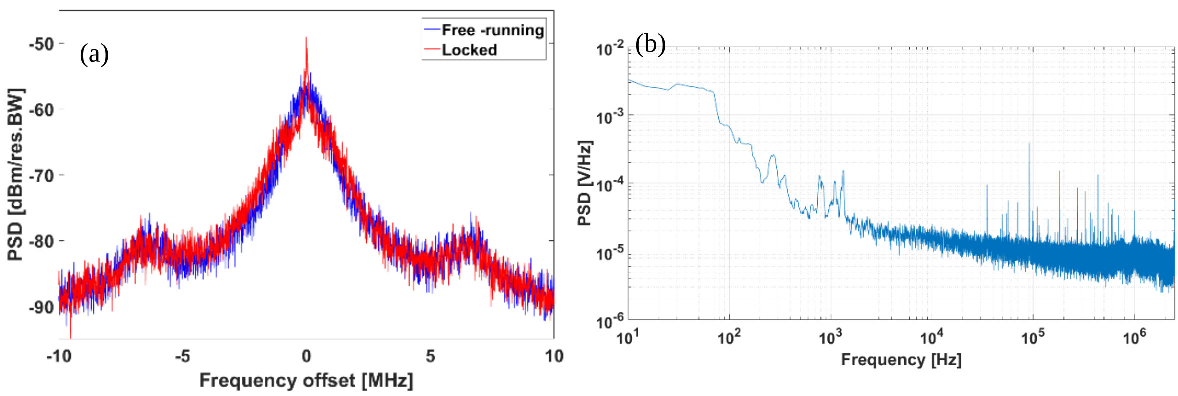

Figure 3. (a) The laser linewidth is measured using the delayed self-heterodyne method (25 km delay line) under locked (red) and free-running (blue) conditions. The linewidth is narrowed down at the peak of the mode, (b) The spectral content of the feedback trace applied on the rear DBR mirror.

small drift over time (<1 MHz per day). The reflection signal is directed to a low-noise photodetector with a transimpedance amplifier, then down-converted and fed to the PID controller. At the output of the PID controller we use an opto-coupler which has a dual purpose. The first is to electrically isolate the laser and avoid electromagnetic interference but it is also used to scale the PID output. The electrical feedback signal is then applied on the rear DBR of the laser. The scanning signal that produces the error signal (Fig. 2(a)) was applied on the front DBR grating.

3. STABILIZATION RESULTS

The error signal in the scanning mode is shown in Fig. 2(a) as a function of the detuning frequency from the resonance transmission maximum. The resulting slope of the error signal around zero frequency offset is 3 mV/kHz. The sensitivity of the laser is also estimated from the error signal and it is 700 kHz/mV. The transmission through the FP cavity is shown in Fig. 2(b). First the absolute wavelength stability of the laser is measured using a wavemeter with 40 MHz absolute frequency accuracy. The frequency variations of the locked laser lasing frequency over 500 seconds is shown in Fig. 2(c). The variations are within the wavemeter accuracy and attributed to the instrument therefore confirming that the laser is locked to the same resonance peak of the stable reference etalon. The long-term drift of the laser is then the same as the etalon's.

In Fig. 3(a) the linewidth of both free-running (blue) and locked laser (red) were recorded on the ESA (resolution BW 30 kHz and video BW 1 kHz) using the delayed self-heterodyne (DSH) method. The delay-line of the DSH setup is 25 km and a low-noise EDFA for optical amplification was used. The FWHM of the free-running laser shows a laser linewidth of about 500 kHz which includes technical noise as well. Turning on the PDH locking drastically reduces the width of the peak (red trace) indicating a linewidth less than 50 kHz. The effect of the locking is visible on the linewidth from the top of the lineshape and down to about 15 dB lower from the top. At this point the shape becomes the same as the free-running laser indicating that the control loop has no effect in that range. Further increasing the gain does not result in further suppression of the noise. We attribute this to the delay of our feedback loop. In Fig. 3(b) the power spectral density of the electrical feedback is shown. It indicates that the feedback loop bandwidth is about 500 kHz where the power spectral density of the feedback signal becomes flat.

4. CONCLUSIONS

We demonstrate the locking of a monolithically integrated single frequency InP-based extended cavity laser with DBR mirrors and an intra-cavity ring filter to an optical cavity using the PDH locking by applying the electrical feedback to a reverse bias voltage on the rear DBR grating of the laser. The locking is implemented by operating the DBR grating in reverse bias. We confirm its long-term drift stabilization and also observe linewidth narrowing which is however limited probably due to the time delay of the feedback loop.

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