Laser frequency stabilization to water vapour absorption lines using direct- and offset-locking techniques

* Laboratory of Nanophotonics and Metrology, NAM (EPFL), Lausanne, Switzerland
** Observatoire de Neuchâtel, Rue de l’Observatoire 58, CH-2000 Neuchâtel, Switzerland
daniela.werner@epfl.ch

Frequency stabilization is generally performed by using atomic or molecular absorption lines. However, it is sometimes necessary to lock a laser at a frequency located outside any absorption peaks. In this case, an offset locking configuration is necessary, in which a so-called slave laser is locked at a given frequency difference with respect to a stabilized master laser.

1 Introduction

Frequency stabilization of a laser is generally performed by using atomic or molecular absorption lines (on-line) for locking directly on it. However, it is sometimes necessary to lock a laser at a frequency located outside any absorption peak (off-line). In this case, an offset locking configuration is necessary, in which a slave laser is locked at a given frequency difference with respect to a stabilized master laser.

The first demonstration of stabilization on a water vapour absorption line was done with commercial telecommunications semiconductor lasers around 1519 nm. We stabilized one DFB laser directly on the water vapour absorption line at 1519.18 nm shown in the figure 1.

The main goal of this project aims to stabilize an off-line up to 20 GHz. We could stabilize slave laser on this off-line frequency by heterodyne detection (beating-technique) with the previously stabilized master laser. Further investigations on locking properties and different operating wavelengths will be done.

2 Experiment

The laser stabilization setup consists of two different stages, which are combined together. In the first part the light emitted by a modulated laser (the master laser in the figure 2) is injected into a 1 m long cell. This cell is filled with water vapour at a low total pressure of 30 Torr. At higher pressure the absorption lines are affected by the dominating pressure collision broadening effect (Lorentzian shape). For our purpose at 30 Torr a narrower water vapour absorption line with a Voigt shape is given for a precise stabilization.

The second part consists of the offset-locking of the non-stabilized slave laser on the already stabilized master laser.

2.1 Direct-locking by WMS

The direct-locking is based on the technique widely used in the Wavelength Modulation Spectroscopy (WMS), in which the zero-point of the first harmonic is used for the stabilization and the slope gives the direction of the correction for the drifting slave laser by Lock-In detection (see figure 3).

The modulation frequency \( \Delta \nu \) for the laser has to be much smaller than the half-width of the chosen absorption profile (\( \Delta \nu \ll \Delta \nu_{\text{line}} \)). In the WMS the instantaneous laser frequency interacts with an absorption line and is converted into an intensity modulation.
The amplitude of the modulated current of the laser $\Delta i$ is proportional to the amplitude of the modulation frequency $\Delta v$ and the modulation frequency normalized on the absorption line $m = \Delta v / \Delta v_{\text{line}}$ [1]. Thus the parameter were chosen for $\Delta v = 10$ kHz and for the $\Delta i = 3$ mA.

To evaluate the stability of this system a multi-pass cell of 20m length was added to the existing 1m-cell in the setup. The laser light was split and passed separately through both cells. For each cell the first harmonic was evaluated and the 20m cell signal was used as reference owing to its strong total absorption. As shown in figure 4. The free running laser can drift within 425 MHz and the stabilized laser by WMS is around 58 MHz.

So that the frequency difference between the two lasers exactly corresponds to the microwave generator frequency (see in figure 2).

3 Discussion

We have shown that in combination with the WMS-technique and an offset-locking on any water vapour absorption line is possible at least up to 18.95 GHz. We are confident that such a technique can be straightforwardly used in any spectral region. The locking range can be easily increased by using a broadband mixer and higher microwave oscillator. And a multi-stage configuration could broaden the locking range.

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Literatur
