



## How to tune a QCL\*

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### 1 Short Pulses for narrow linewidth

The emitted wavelength of a DFB laser is given by the spacing of its Bragg grating, which is affected by temperature. In the case of a pulsed lasers, the sudden onset of electrical dissipation will increase the temperature during the pulse, which will create chirp. We give here some information on this behaviour.

At turn-on, this effect changes the emitted wavelength. The tuning rate is approximately 14 ppm/ns at the outset of the pulse and slows down rapidly after a few ns; the exact rates varying from one laser to another. It follows that, to obtain a narrow linewidth on a slow detector, the pulse length must be kept to a minimum.

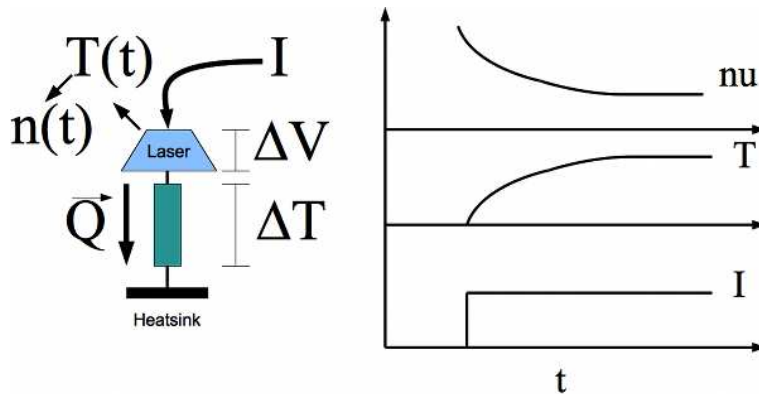


Figure 1: Behaviour at turn-on

The pulsed laser from Alpes Lasers are normally tested on their datasheet using a 50 ns pulse, which results in a noticeable linewidth shown on the datasheet spectra.

A shorter pulse can be used to reduce this linewidth. Using the QCL pulser provided by Alpes Lasers, pulses as short as 22 ns can be created. Dedicated electronics may be able to achieve even shorter pulses. However the non-linear electrical behaviour of QCL make the typical rise and fall-time of the pulse on the order of 8 ns, making very short pulses difficult to achieve.

As a final note, the effective linewidth can also seem to depend on the amplitude of the pulse. This is because there is typically an overshoot at the beginning of a pulse; this is especially pronounced at low

<sup>0</sup>CORID:6881\_ArchiveAL-87886

amplitude and very short pulses. It may therefore seem as though a pulse is very short, while it is in fact below threshold, with only a short overshoot being above threshold. An increase in amplitude will then show the true length of the current pulse. You can see on figure 2 a typical shape for a short pulse: the actual spectral behaviour will vary depending on the location of the threshold with respect to the shoulder appearing after 7.9 ns.

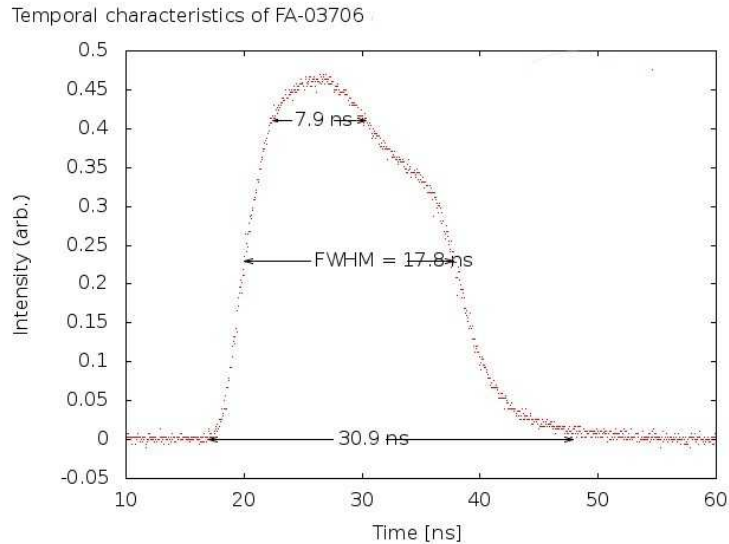


Figure 2: Typical light curve

## 2 Intra Pulse Modulation

The emitted wavelength of a DFB laser is given by the spacing of its Bragg grating, which is affected by temperature. In the case of a pulsed lasers, the sudden onset of electrical dissipation will increase the temperature during the pulse, which will create chirp. In the Intra-pulse modulation scheme, this chirp is resolved with a fast detector in order to scan through an absorption line.

The final resolution of this method depends on the scanning rate (which depends on the laser) and the detectors integration time. The scanning range can extend up to 2.5 cm<sup>-1</sup>.

For more information, we refer you to this article published in the Journal of the Optical Society of America B:

[http://www.alpeslasers.ch/fichier/papiers/interpulse\\_modulation\\_josab\\_20\\_8\\_1761.pdf](http://www.alpeslasers.ch/fichier/papiers/interpulse_modulation_josab_20_8_1761.pdf)

Typically, this method is used with pulses length ranging from 200 ns to 1  $\mu$ s. Not every laser chip can withstand such pulses! If you want to use the intra-pulse method, be certain to mention it in your request for quotation. Extra tests can be performed to ensure the suitability of a particular laser for this method.

## 3 Intermittent CW modulation scheme

One particular interest of quantum cascade lasers is their narrow intrinsic linewidths (down to <1kHz). To achieve a low effective linewidth, however, the driving scheme is important.

Three common driving schemes are inter-pulse modulation, intra-pulse modulation and CW modulation. They are described in more details elsewhere but each comes with their limitation:

short pulse schemes requires either fast current drivers (in the inter-pulse scheme) or fast detectors (in the intra-pulse scheme) to avoid the chirping inherent in pulsed lasers. CW modulation is more demanding on the laser itself and requires large heat dissipation.

We describe here a new scheme, dubbed Intermittent Continuous Wave (ICW) modulation, which allows one to perform spectroscopy with slow detectors and drivers while using lasers in TO-3 cans, which are less expensive than the LLH and HHL housing of true CW lasers.

This scheme was developed in collaboration with the Air Pollution / Environmental Technology group of EMPA.

### 3.1 Modulation schemes overview

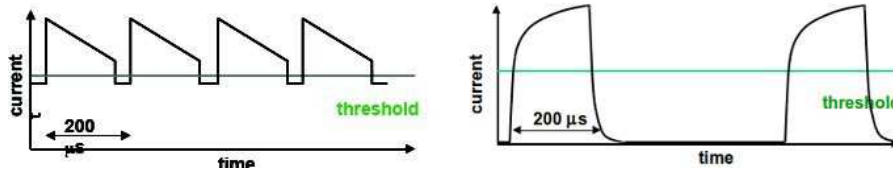


Figure 3: Driving scheme comparison

The image on the top-left shows a typical CW modulation scheme. The driving current is modulated in a saw-tooth pattern to create a frequency modulation over a 200 μs period, which is then followed by a short period below threshold and a repetition. This scheme allows for a slow frequency scanning: if the scanning range is 1 cm<sup>-1</sup>, then a detector with a 1 μs time resolution will yield a spectral resolution of 0.005 cm<sup>-1</sup>. The small current excursion ensures limited thermal effects.

Such CW modulation can be used with cooled lasers, for example in a HHL housing. However there are situations where the high footprint and power consumption required for running the laser in a constant-on mode are too high to be sustained.

The ICW scheme, shown on the top-right, diminishes the average dissipation in the laser by dropping the current to zero between pulses, and keeping a longer pause between pulses to allow the cooling down of the laser. Doing that, the overall dissipation is limited and the laser can be used in a TO-3 housing. The thermal excursion is larger which results in a faster transient tuning.

### 3.2 Requirements

ICW lasers must be lasers that would be capable of running in CW mode given enough cooling power. The ICW mode can be applied to any CW laser in a LLH or HHL housing. In addition, the ICW mode can be applied to a similar chip mounted in a TO-3 housing, but in this case a pure CW mode is not generally possible.

### 3.3 Ramps

The tuning rate can be controlled by applying a ramp to the current shape. In this case, the first 40 μs of the output is still discarded. Following that, the tuning rate can be increased or decreased by applying a current ramp to increase or decrease the thermal load on the active region of the laser. In this way, the total tuning range within a single pulse can reach up to 2 cm<sup>-1</sup>.

The following pictures show again typical results. Each lasers will be individually tested.

### 3.4 Parameter Dependency

The overall tuning is almost entirely independent of submount temperature, but is dependent on duty cycle. Figure 5 shows relative tuning for different temperatures and inter-pulse separation for an identical pulse length.

The tuning endpoints and the tuning rate are both dependent upon the duty cycle. Figure 6 shows absolute tuning with respect to duty cycle. As the pulse-to-pulse separation becomes smaller, the behaviour approaches the monochromatic CW result.

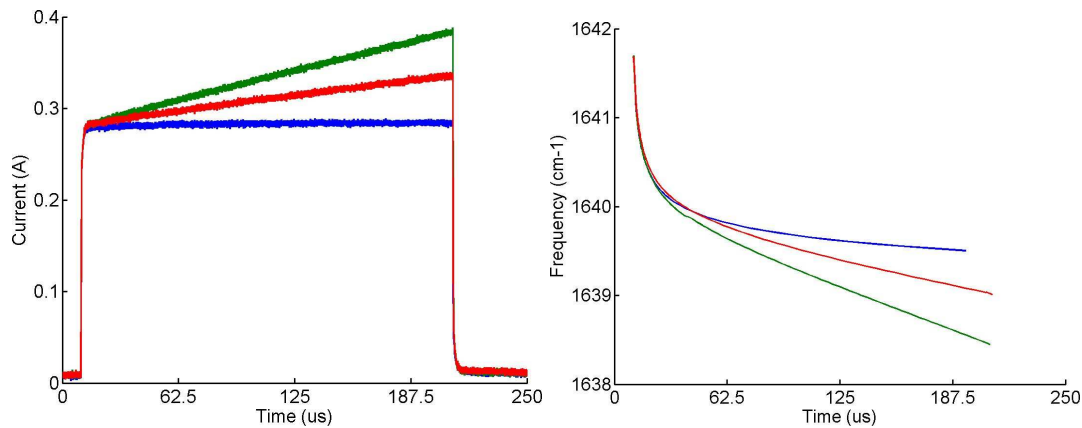


Figure 4: Effects of ramping

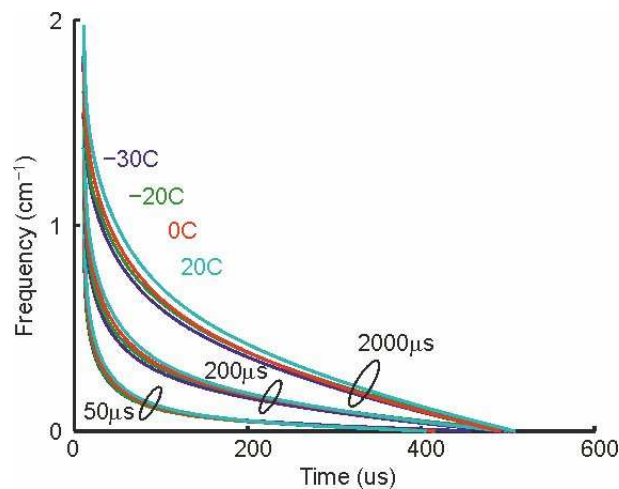


Figure 5: Temperature dependency

### 3.5 Hardware solutions

Square and sawtooth pulses can be created using programmable CW laser drivers. If you own such a driver you are welcome to use it and we will help you to find the best laser for such an application.

Alpes Lasers is also currently developing a driver fully dedicated to running lasers in the slow-chirp mode. We expect to be able to take orders for such drivers in 2014 - stay posted! Datasheets and Laser evaluation

Every CW laser mounted on NS mounts can be used in slow-chirp mode in a HHL or LLH housing. The datasheets shown on this website only reflects their performance in pure CW mode. If you enquire about these lasers, please precise the mode in which you intend to use them.

Since the long current pulse works by heating the laser, it is safe to assume wavelengths available in CW mode will also be available in ICW mode but with the base temperature being colder by about  $10\text{Å}^\circ\text{C}$ . The exact temperature shift will be affected by the current used in the laser and the duty cycle. The range available is typically greater than  $1.0\text{ cm}^{-1}$ . A specific slow-chirp mode test under your conditions can be performed prior to shipping.

Lasers on NS mounts cannot be mounted in a TO-3 housing. Therefore for a TO-3 laser, please enquire directly by sending us an email at [info@alpeslasers.ch](mailto:info@alpeslasers.ch)

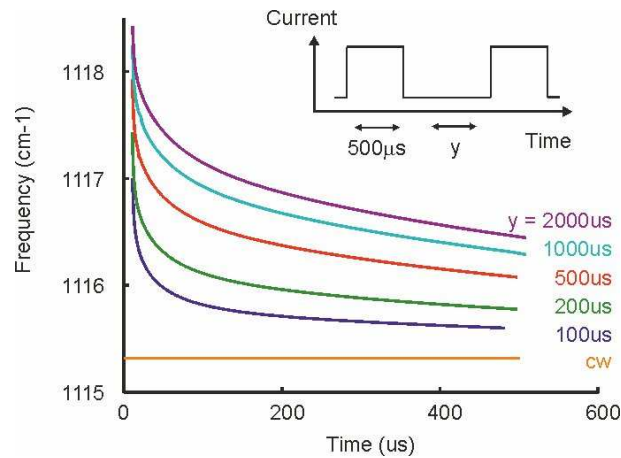


Figure 6: Duty Cycle dependency

## 4 Bias-T tuning

Since tuning of a QC laser is performed by changing the temperature of the active zone, a small sub-threshold DC bias current can be used to control the emission wavelength of pulsed laser via its heating effect. The LDD driver is equipped to accept a dual input, and this mode of operation is described in more details in Appendix B.3 of the Manual. If you have a gas cell available, you can also follow the sample start-up procedure.

Some of the first reported gas detection experiments were performed using the bias-T tuning method; such as for example the N<sub>2</sub>O and CH<sub>4</sub> detection experiment reported in the 1998 Optics Letter available here:

[http://www.alpeslasers.ch/fichier/papiers/tildas\\_ol\\_23\\_3\\_1998.pdf](http://www.alpeslasers.ch/fichier/papiers/tildas_ol_23_3_1998.pdf)

### 4.1 Sample Start-up Procedure

To start:

1. Start the laser. A good temp to dial in at first is  $\approx 15^{\circ}\text{C}$  so that any moisture inside the package does not condense on the laser chip. Use current settings as indicated in the Alpes test data. You should see energy if you monitor output with a detector.
2. Change the temp to one that should allow the highest frequency (shortest wavelength) of interest.
3. Reset the current to settings appropriate for that temp and wavelength and then reduce it a little bit further, but not below threshold (so you still see energy on the detector)
4. Put a gas cell between laser and detector and verify that you can still see the laser energy on the detector. Write down the value of the amplitude of the detector signal.
5. Turn on the bias T current to a low value (maybe 0.001A) and record the detector signal; repeat at 0.001A increments of bias-T current recording values for each increment until you have reached 0.060 A or some other value that has been discussed/agreed with Alpes.

What the above procedure has done is to generate a spectral scan of the laser over a wavelength region defined by the scan rate of the laser versus current (cm-1/A, a basic property of the laser). A 60 mA range might be equivalent to 1.2 cm-1 of wavelength change in the laser. If your starting point (temp, current) was right, you should see the line of interest in the data when plotted. If not, try again with new temp/pulse current. Continue to optimize the temp and drive parameters:

- Adjust the pulse length lower and higher and repeat the scan; thus learn about the effect of these parameters on power and laser linewidth; explore these to optimize the measurement

- If possible, repeat the measurement with a gas cell with the target gas at low pressure (1 Torr). This will narrow the line greatly and allow you to consider the apparent spectral resolution of the laser itself under the drive conditions and to learn whether the driver has any ringing or double pulsing (which will make the line width seem higher).

In the end you will have calibrated and optimized the laser spectrally as a function of temp and current and the values you have discovered will be much more precise than the values in the data supplied by Alpes (because there can be disagreements in calibration of current or temperature and because Alpes data is at a few discrete settings and your data is with your equipment against your target gas). You can use these optimized values to acquire your real gas data.

## 5 Direct CW modulation

A CW laser will settle to a fixed wavelength after a transient time of 10 ms; therefore you can modulate the laser with a signal slower than 100 Hz and expect the output wavelength to faithfully follow the input current with the relation measured in its datasheet.

CW lasers can also be modulated more quickly. The emitted power will follow the current amplitude faithfully at high speeds; for reference you can see this paper describing a free-space link functioning at 330 MHz:

[http://www.alpeslasers.ch/fichier/papiers/blaser\\_el\\_37\\_778\\_2001.pdf](http://www.alpeslasers.ch/fichier/papiers/blaser_el_37_778_2001.pdf)

However the wavelength modulation being a thermal effect, it will be suppressed at speeds exceeding 1 MHz, and will decrease monotonously between 100 Hz and 1 MHz. Graph 7 shows data for an amplitude a specific laser; the exact values will vary from one laser to the next.

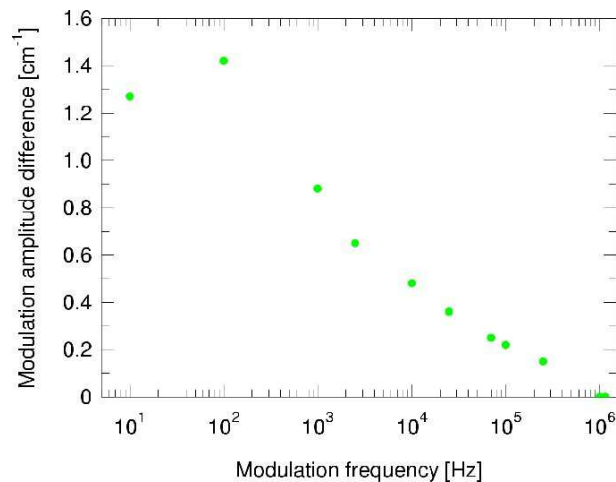


Figure 7: Modulation speed effect