Nanosystems and Technologies GmbH nanoplus		13. 10. 2011
document title:	Development of widely tunable lasers, properties and applications	
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1 Introduction

Compared to the tuning of the established nanoplus DFB diodes as exemplary shown in fig.1, widely tunable lasers offer more possibilities that will be explored in this short overview. A DFB laser around 2000nm has a continuous tuning range of around ± 2 nm of its "center" wavelength. The new widely tunable lasers aim at a maximum tuning range of 80+ nm, however (especially at this state of the development) this tuning is non-continuous, as is shown in the next section.

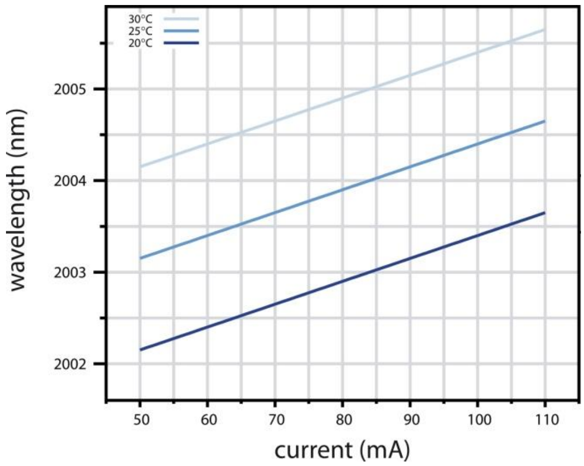

Fig. 1: tuning of a DFB diode. A change in the supply current changes the temperature inside the resonator yielding a wavelength shift. Due to the diode characteristic, a change in wavelength implies a change in output power.

For the customer, apart from the greater wavelength range, the most noticeable difference compared to a DFB laser will be the current supply. Widely tunable lasers consist of several active segments, which will require separate current drivers.

The number of segments required for wide tuning depends on the application demands with a minimum of two segments.

The output wavelength will be selected by applying defined currents to all the segments. Therefore, each laser is to be shipped with a detailed calibration table from nanoplus.

At the same time, nanoplus is developing a laser driver module that is able to control the temperature and currents of tunable laser diodes. This driver should be available within 2012.

2 example laser

To keep things simple, let us start with a two-segment laser. To demonstrate its tuning behavior, in fig. 2, the output wavelength is shown as a function of the drive currents in both segments. The dot color indicates the wavelength; in the uncolored stripes between the wavelength domains, the laser has a side-mode suppression-ratio only less than 30dB. The difference between minimum and maximum single-mode wavelength is 55.4nm.

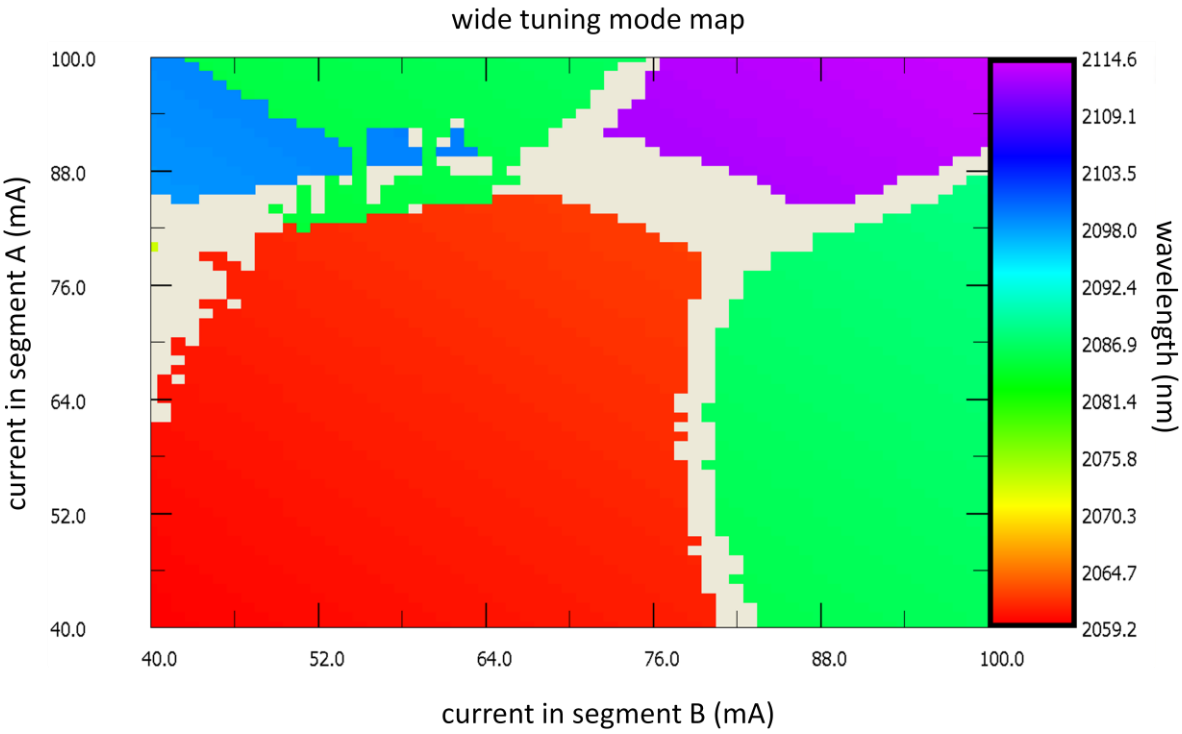

Fig. 2: mode profile of a two segment laser stabilized at 25°C. Altogether, this laser will emit at five distinct wavelengths in a 55 nm region. 87% of all 3721 measurements qualify as singlemode operation above 30dB side-mode suppression, and are shown in this plot. The remaining 13% of data points are not colored (grey). λ_{min}=2059.2 nm; λ_{max}=2114.6 nm.

Intrinsically, the output power is increasing with the currents, with least power in the lower left corner in fig. 2 and most power in the upper right corner of the laser.

For customers that are concerned with power stability, additional laser segments would have to be inserted to reduce this effect. The output powers in question are comparable to DFB lasers of the same wavelength, i.e. typically 10 mW and up to 20 mW.

Obviously, not every wavelength in the 55 nm interval of fig. 2 is covered by the laser. However, each singlemode domain **behaves like a DFB laser at this wavelength!** That means, in each domain, the laser output wavelength can be “fine-tuned” by changing the supply current.

Fig. 3 a/b illustrates this finetuning: the data of fig. 2 is plotted in one dimension. In fig. 3a, laser segment A is at a fixed current, with segment B varying, and vice versa in fig 3b.

In fig. 4 some typical spectrums are shown recorded with an optical spectrum analyzer.

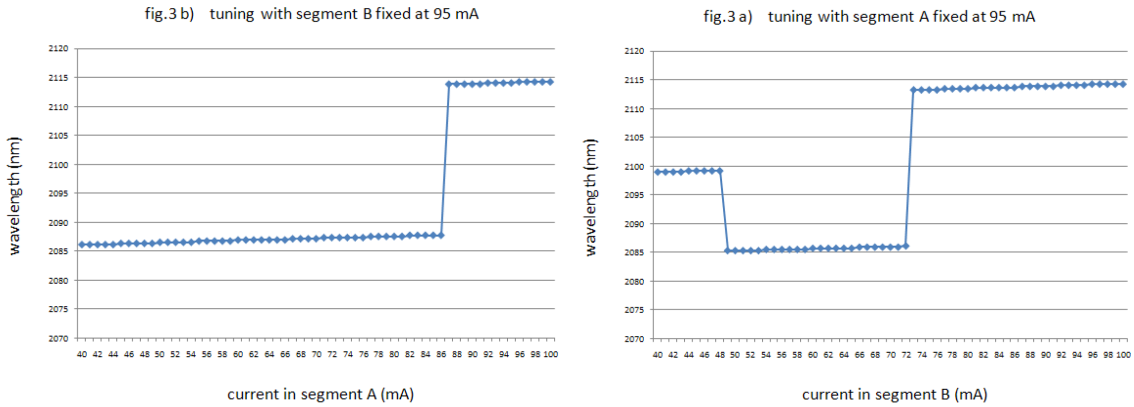

Fig. 3: output wavelength depending with a fixed current in one of the segments in 1 mA steps. These two plots are onedimensional cross sections through the twodimensional mode map (see fig.2).

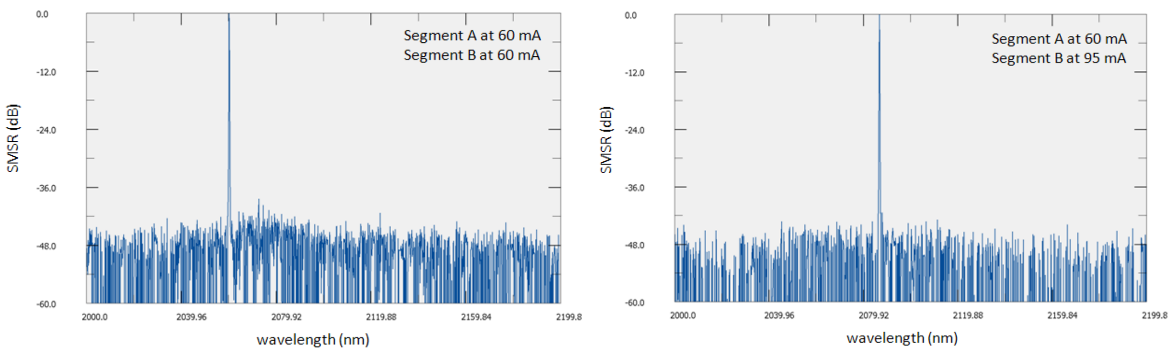

Fig. 4: typical spectrums at different supply currents. A widely tunable laser behaves like several DFB diodes at different wavelengths. The depicted linewidth of the emission peak is instrument limited. The previous fig. 2 and 3 were obtained by linking the peak wavelength of each spectrum with the combination of applied supply currents.

3 Application scenarios

The great advantages of the nanoplus wide-tuning concept are: monolithic integration of the laser on a single chip and quasi-DFB operation within wavelength domains.

Today, we have the following scenarios in mind, with many more possible:

1. Gas detection (fig.5), the laser is used like several conventional gas sensing DFB lasers. The only limit is that the absorption lines of the gases are with 80 nm. Work on extending this range is in progress.

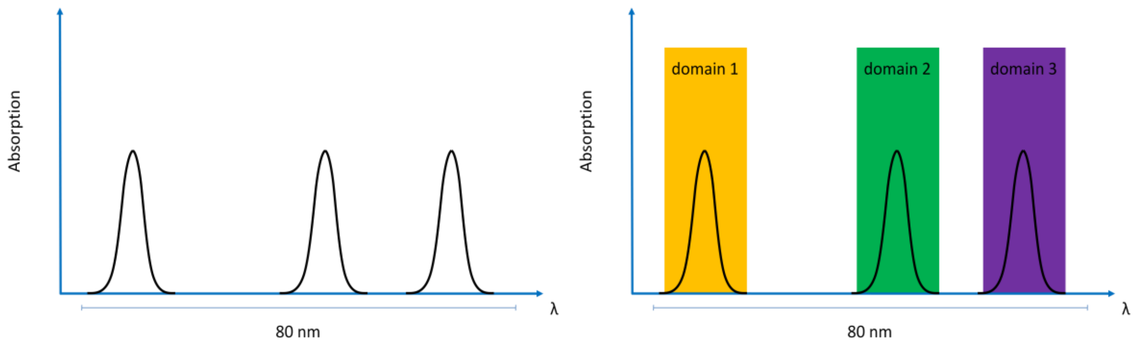

Fig. 5: (left) absorption lines of different gases (right) the tunable laser can be designed to cover all absorption lines with DFB-like operation.

2. Liquid detection (fig.6). In liquids, the challenge is to provide many sampling points without the requirement of tuning at each sample points.

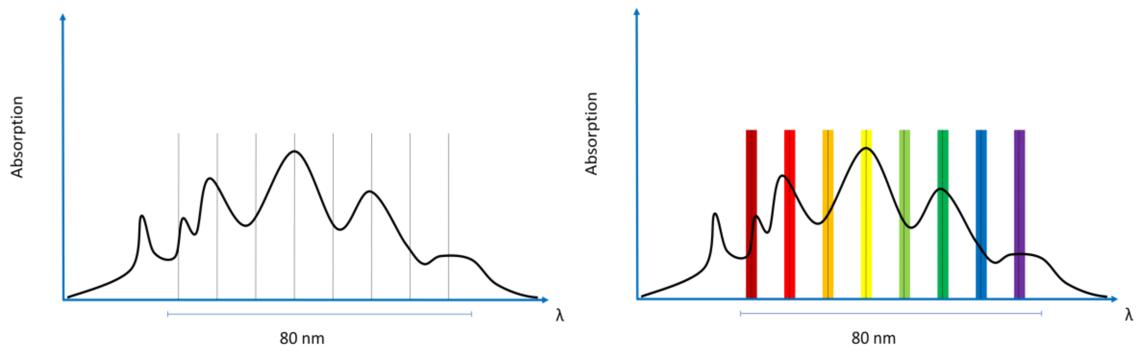

Fig. 6: (left) desired sampling points in a liquid (right) as many as possible domains are designed in the laser (that does not necessarily increase the number of active laser segments needed). The domains will be slimmer and can only be tuned in a range of say ± 0.2 nm. With this limited "fine-tuning range" it should be possible to include 10 to 20 domains in one laser.

This scenario with many equally-spaced emission points also applies for interferometry or distance measurements (see fig. 7)

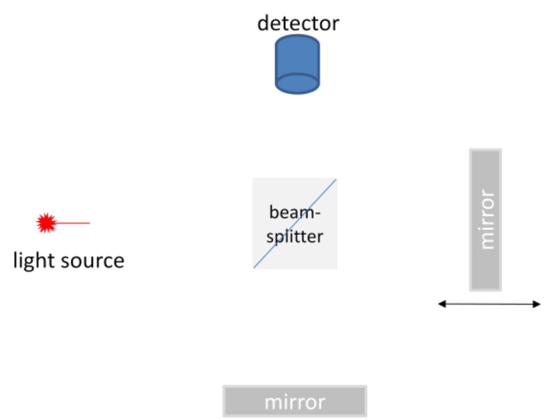

Fig. 7: Michelson interferometer with a movable mirror. Alternatively, the light source might be a tunable laser, so not mirror movement is needed.

3. Quasi-Continuous tuning over a given wavelength range (fig.8).
   As there can only be a finite number of wavelength domains present, where each domain has a finite extension, it will be a challenge to cover a larger wavelength interval.
   At the current level of development, we use the laser's heat sink temperature for coarse-tuning. Because the laser device is monolithic, an external temperature change affects all domains equally.

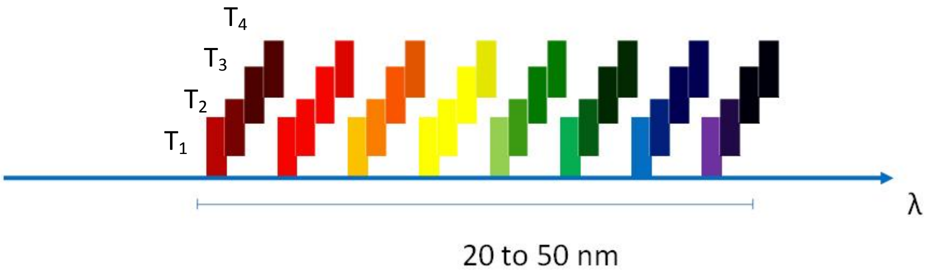

Fig. 8: symbolized quasi-continuous tuning using different temperatures.

Tuning by current only is very fast and one would expect around 300µsec delay to change the output wavelength by current only. Unfortunately, temperature stabilization is a slow process that will take in the order of seconds. Therefore, further development is required at this point.

4 perspective

The nanoplus wide-tuning concept has already been shown on every semiconductor materials that are used to manufacture DFB. The achievable maximum tuning is limited by the gain width of the respective material. The following table shows typical values

material	wavelength range (nm)	gain width at one temperature (nm)
[Al] GaAs	760-1400	15-25
InP	1400-1800	20-40
typical GaSb	1800-2900	≈50
nanoplus-developed widely-tunable GaSb	1800-2900	above 90
quinternary GaSb	2900-3400	≈50
Quantum Cascade Lasers	7000-20000	above 200

The development of widely-tunable lasers at all wavelengths is continuing. The infrastructure at nanoplus has been established, the next logical step is to seek out potential applications and adjust wide-tuning technology for the specifics of each scenario. These adjustments must be made together with the customers and researchers who will utilize the laser.

First-hand information is available from
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