

# Linewidth Enhancement Factor of Semiconductor Lasers: Results from Round-Robin Measurements in COST 288

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**Abstract:** Round-Robin measurements on the linewidth enhancement factor are carried out within several laboratories participating to EU COST 288 Action. The  $\alpha$ -factor is measured by applying up to 7 different techniques. The obtained results are compared.

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## 1. Introduction

The linewidth enhancement factor ( $\alpha$ -factor) [1], has a great importance for semiconductor lasers (SLs), as it is one of the main features that distinguishes the behavior of SLs with respect to other types of lasers. The  $\alpha$ -factor influences several fundamental aspects of SLs, such as linewidth, chirp under current modulation, mode stability, laser dynamics, laser behavior in presence of optical feedback and injection, the occurrence of filamentation in broad-area devices. A low  $\alpha$ -factor is generally considered good.

As reported by Osinski and Buus [2], several different techniques have been proposed to measure the  $\alpha$ -factor, without any comparison between the results achieved by different methods. This statement is still valid nowadays. Moreover, the number of the proposed measuring methods has increased, and several SL novel designs have become commonplace, for which the determination of the  $\alpha$ -factor can be particularly critical (e.g., VCSELs, Quantum Dot Lasers, Quantum Cascade Lasers).

## 2. Round-Robin Measurement within COST 288 Action

The COST 288 Action “Nanoscale and Ultrafast Photonics” [3] is an initiative sponsored by the European Commission and the European Science Foundation, within the frame COST – “European Cooperation in the field of Scientific and Technical Research”. In Working Group 2 “Physics of Photonic Devices” of COST 288, it was decided to set-up a Round-Robin (RR) measurement activity on the SL  $\alpha$ -factor, with the main goal of comparing different

measurement methods and assessing their consistence and repeatability, using the same set of laser devices circulating in sequence among different Laboratories. The continuous flow of experimental results is supplying interesting results that will be completed by mid-year 2007. In the present work we summarize the results achieved to date, by illustrating the measurement techniques that have been implemented in the RR, and by comparing preliminary data.

### 3. Experimental Results

The different measuring methods that have been considered for the RR are hereby listed.

1. The *Hakki–Paoli method* [4] relies on direct measurement of the refractive index change (measured through detection of the frequency shift of longitudinal Fabry–Perot mode resonance) and the differential gain as the carrier density is varied by slightly changing the current of a SL in sub-threshold operation.
2. The *Linewidth method* relies on the measurement of SL linewidth, and on fitting the results to known SL parameters, so that the  $\alpha$ -factor can be extracted by applying the Henry formula (equation (26) of [1])
3. The *Modified Linewidth method* relies on the measurement of SL linewidth as a function of emitted power in the threshold region, and the ratio of the slope of the curve linewidth vs inverse power gives directly the  $\alpha$  value [5]
4. The *FM/AM method* [6] relies on high-frequency SL current modulation which generates both amplitude (AM) and optical frequency (FM) modulation. The ratio of the FM over AM gives a direct measurement of the  $\alpha$ -factor. Corrections for the so-called adiabatic chirp shall be taken into account [7].
5. The *Fiber Transfer Function method* exploits the interaction between the chirp of a high-frequency modulated SL and the chromatic dispersion of an optical fiber, which produces a series of minima in the amplitude transfer function vs. modulation frequency. By fitting the measured transfer function, the  $\alpha$ -factor can be retrieved [8].
6. In the *Optical Injection method*, light from a master SL is injected into the (slave) SL under test, causing locking of the slave optical frequency to that of the master. The locking region is characterized in terms of the injected power level and frequency detuning, showing an asymmetry in frequency due to the non-zero  $\alpha$ -factor [9,10].
7. The *Optical feedback method* is based on the self-mixing interferometry configuration and, according to the Lang–Kobayashi theory, the  $\alpha$ -factor is determined from the measurement of specific parameters of the resulting interferometric waveform, without the need to directly measure the feedback strength [11].

The above methods have been applied to two specimen of commercial high-power DFB SLs (JDSU CQF935/808) that come in a butterfly package with optical isolator. In addition to the comparison of methods, other relevant aspects are being studied, such as the high-power behavior of the  $\alpha$ -factor due to non-linear effects [12], which can be studied with methods 4–7, the influence of the adiabatic chirp [7] on methods involving modulation (4,5) or the interaction with other non-linear effects.

While the complete results will be made available on the COST 288 website [3], preliminary results to-date can be summarized as follows. (i) The Hakki–Paoli method is difficult to be applied to commercial DFBs, due to the lack of knowledge of laser parameters. (ii) The FM/AM method requires modulation well above the relaxation frequency of the SL, and it can be difficult to be implemented with some SL types. (iii) The Fiber Transfer Function method appears to be the most reliable, provided a precise measurement of fiber dispersion is preliminarily made using a LiNbO<sub>3</sub> M–Z modulator, and the power along the fiber span is kept below +3 dBm to avoid non-linear effects. (iv) Methods 6–7 can be applied to a variety of devices, and give the effective  $\alpha$  in operating conditions above threshold.

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