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NOVEL MEASUREMENT TECHNIQUE OF α FACTOR IN DFB SEMICONDUCTOR LASERS BY INJECTION LOCKING

Indexing terms: Measurement, Semiconductor lasers

A simple and accurate method to measure the linewidth enhancement factor α in DFB semiconductor lasers is proposed. This method, based on the principle of external optical injection locking, does not require the knowledge of the absolute value of optical injection level.

Introduction: A special feature of semiconductor lasers is the coupling between carrier-induced variations of real and imaginary parts of susceptibility, which is commonly referred to as the linewidth enhancement factor, α.[1] Many properties that are unique to semiconductor lasers can be traced back to this α parameter which, unfortunately, cannot be measured directly.

In the last decade, many attempts have been made to determine the value of α.[2] According to present data, the accuracy of the result of α measurement is not yet reliable. Light injection was proposed as a notable method to perform the measurement of the α parameter.[3,4] In injection locked Fabry-Perot (FP) lasers, the multi-longitudinal-mode tendency arousing for small detuning prevents an easy measurement of the α parameter. Usually knowledge of the injected optical power is required, but this parameter is difficult to precisely determine.[2]

In this letter we propose an alternative method to determine the α value in distributed feedback (DFB) semiconductor lasers in which the side modes are highly suppressed. Although based on the principle of optical injection locking, it does not require knowledge of the absolute amount of the injection level.

Theory: The starting point of our analysis is based on the following well known Van der Pol equations:[5]

$$d\beta(t)/dt = [-i\omega_c + \Delta G(1 + i\alpha)/2]\beta(t) + \beta_1(t)/\tau_i \qquad (1a)$$

$$dN(t)/dt = R - N/\tau_s - G|\beta(t)|^2 \qquad (1b)$$

where $\beta(t) = I^{1/2} \exp[-i(\omega)t - \phi)]$ is the normalised electric field of the slave laser (SL) and $\beta_1(t) = I_1^{1/2} \exp(-i\omega_1 t)$ is that injected from the master laser (ML), I and I_1 are the field intensities of SL and that coupled from ML, G is the material gain, $\Delta G = G - 1/\tau_p$, is the net gain, τ_p is the photon life time, ω_c is the modal frequency of the slave cavity, ω_1 and ω are the frequencies of ML and SL, $N(t)$ is the carrier density, R is the carrier injection rate, ϕ is the phase, τ_s and τ_i are the spontaneous life time and the group roundtrip time of SL, respectively.

In the stable locked state, the frequency of the slave laser is locked to that of the master, so that, the stationary solutions are

$$\Delta G = -2\rho \cos\phi \qquad (2a)$$

$$\Delta\omega = \rho(\sin\phi - \alpha\cos\phi) \qquad (2b)$$

where $\Delta\omega = \omega - \omega_c$, is the frequency detuning and $\rho = (I_1/I)^{1/2}/\tau_i$ is the normalised injection level. From eqns. 1 and 2, the relative change of the output optical power can be found to be proportional to $2\rho(\tau_p/\tau_i)I\cos\phi$ and the half locking bandwidth to be equal to $\Delta\omega_m = (1 + \alpha^2)^{1/2}\rho$.[5] The zero change in the output optical power happens when $\phi = \pi/2$, which corresponds to a detuning $\Delta\omega_0 = \rho$. The α value can then be easily determined from

$$\alpha = [(\Delta\omega_m/\Delta\omega_0)^2 - 1]^{1/2} \qquad (3)$$

Experimentally, both the values of $\Delta\omega_m$ and $\Delta\omega_0$ can be measured precisely if the stable injection locking is maintained. Previous studies revealed that most of the injection locked range is dynamically unstable.[5] Instability might strongly affect the accuracy of the measurement of $\Delta\omega_0$.

A stability analysis was carried out for DFB lasers using the linearised form of eqn. 1 as in Reference 5. The upper and lower detuning limits are shown in Fig. 1, the former being determined by locking/unlocking condition and the latter by the onset of dynamic instability. There is an unconditionally

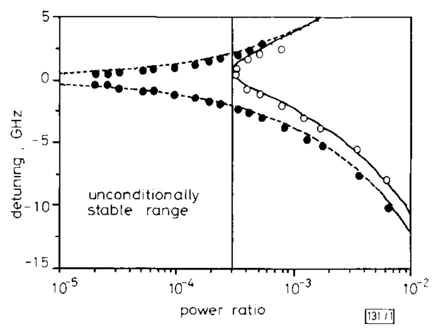

Fig. 1 *Locking bandwidth against power ratio*

——— theoretical upper limit
– – – – theoretical lower limit
●●● measured upper limit ○○○ measured lower limit

stable range where the injection level is below a certain critical value which depends on the spontaneous life time as well as the nonlinear gain saturation effect. We have also found that this stable locking band is symmetrically centred around the frequency of free-running SLs. This was verified by a computer simulation using the nonlinear eqn. 1.[6] The stable locked optical output is increased for negative detuning and decreased for positive detuning as shown in Fig. 2*a*. The symmetry of this stable locking band is difficult to find in FP laser diodes where the gain margin between the main and the side longitudinal modes is too small and the gain decrease in the locked main mode for positive detuning will result in multi-longitudinal mode operation.[4,7,8]

Experiment: Two identical DFB-BH laser diode (Fujitsu FLD 150) with a wavelength of 1554 nm were used. The SL was biased at 1·75 times its threshold, which corresponds to 3 mW of optical output. Two diffraction limited lenses with 0·65 NA

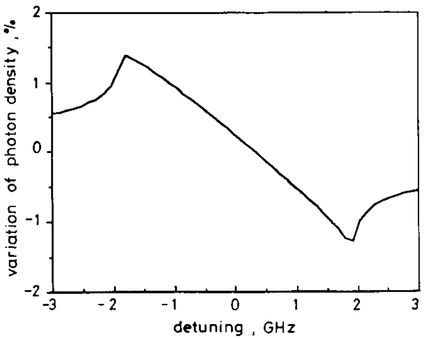

Fig. 2A *Relative photon density variation against detuning obtained through computer simulation*

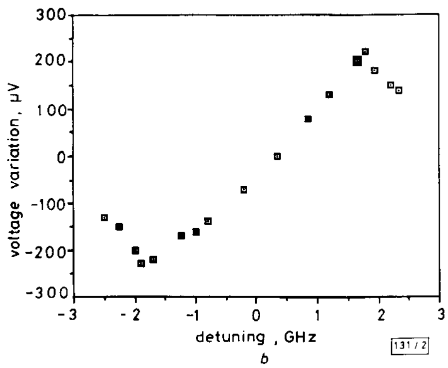

Fig. 2B *Experimental values of the junction voltage variations*

were used for beam coupling. Two optical isolators, inserted between ML and SL, provided more than 50 dB isolation and a $\lambda/2$ plate was used to match the polarisation of the two lasers. The coupled optical power was roughly evaluated from the photo-current induced in the SL at zero bias. Frequency matching and adjusting was accomplished by controlling the heat-sink temperature of the lasers. The spectrum of SL output was measured by a FP scanning interferometer and an isolator was used to prevent optical feedback from the interferometer.

The measured stable locking range in our experiment is shown in Fig. 1, where the definition of stable locking is that in which the side peaks of relaxation oscillation or spurious free-running slave modes are less than 20 dB of the locked main peak in the SL spectrum. In order to get the information of the photon density variation against detuning in the SL, we measured the electric voltage across the diode junction, as this voltage variation is directly proportional to the variation of carrier density, and therefore inversely proportional to that of photon density inside the cavity. In this way, we were able to get rid of the problem of field interference between the SL output and the directly transmitted or reflected light of ML outside the SL waveguide. Usually, it was difficult to entirely eliminate this interference if a photodiode was used to directly detect the slave optical output power. A typical result of the measurement of the voltage variation across the junction, shown in Fig. 2*b*, qualitatively agrees with that of the computer simulation.

Several measurements of α, performed at different injection levels within the unconditionally stable locking range, using eqn. 3 are reported in Fig. 3. From this Figure, α can be estimated to be $5·5 \pm 0·6$ in this case.

Conclusion: A simple and accurate method of estimating the linewidth enhancement factor α was proposed. The symmetric stable locking band in the low injection level in DFB laser confirms the accuracy of the α measurement method proposed

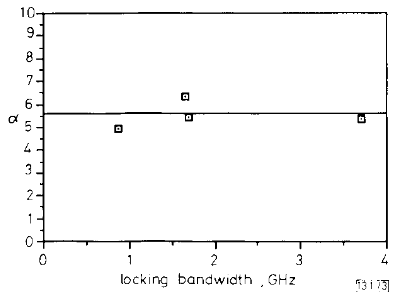

Fig. 3 *Values of α measured at different optical injection levels*

in this letter. It must be noticed that this method is effective for DFB semiconductor lasers, but not for FP lasers where the side-mode suppression ratio are usually less than 20 dB which is strong enough to affect the accuracy of measurement of $\Delta\omega_0$.

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UNSLOTTED CSMA-CD PROTOCOL WITH COMBINED RETRANSMISSION STRATEGY FOR FIBRE OPTIC BUS AND RING NETWORKS

Indexing trems: Fibre optic networks, CSMA-CD, Priority queue

An efficient unslotted 1-persistent CSMA-CD protocol for fibre optic bus and ring networks is presented. It provides stability and good delay performance.

Introduction: Several carrier sense multiple access with collision detection (CSMA-CD) protocols for the fibre optic bus and ring networks have been studied.[1–3] Unlike slotted proto-