Active and Passive Elec. Comp., 1998, Vol. 21, pp. 293–296

Published by license under
the Gordon and Breach Science
Publishers imprint.
Printed in India.

ANALYSIS OF THE DENSITY OF ELECTRON-HOLE PAIRS FOR MINIMAL PUMP ENERGY IN A LASER DIODE WITH COHERENT FEEDBACK

M. A. GRADO-CAFFARO* and M. GRADO-CAFFARO

Scientific Consultants, C./Julio Palacios, 11, 9-B, 28029-Madrid, Spain

(Received 22 June 1998; In final form 4 September 1998)

The average value in the time domain of the density of electron-hole pairs in a semiconductor laser with coherent feedback is calculated under conditions of minimal pump energy. This value is found to be finite; the significance of this result is discussed as well as the asymptotic value of the above carrier density.

Keywords: Density of electron-hole pairs; laser diode; coherent feedback; minimal pump energy

1. INTRODUCTION

Optical coherent feedback is a relevant phenomenon in the context of semiconductor lasers; this phenomenon is strongly connected with AM and FM noises and coherence collapse, and a number of questions related to this subject remain open from the theoretical point of view since a considerable part of the literature only contains empirical techniques which, in practice, have achieved a scant success. However, in recent years, some authors as Refs. [1–4] have obtained important results; in particular, we refer to AM and FM noises and minimal pump energy. This last subject has been treated in Ref. [4] in a manner that can be considered as a singular source of fruitful future investigations within the frame of optical coherent feedback in laser

*Corresponding author.

diodes. At this point, we can claim that the aim of the present paper is to analyze the electron-hole density in a semiconductor laser with coherent feedback under conditions of minimum pump energy; these conditions have been considered in Ref. [4]. The relevance of pump energy minimization is clear since minimum pump energy corresponds to maximum quantum efficiency and it is obvious that this optimal efficiency represents a crucial problem.

2. THEORETICAL CONSIDERATIONS

For minimal pump energy in a laser diode with coherent feedback, the density of the electron-hole pairs $n(t)$ is given by the following relation (see Ref. [4]):

$$n(t) \approx \left(\frac{n_0 - \Gamma_0 P_s T}{1 + T\zeta P_s}\right) \exp\left[-\frac{1}{2}(\sqrt{5}+1)(T^{-1} + \zeta P_s)t\right] + \frac{(\Gamma_0 - \zeta n_0)P_s}{T^{-1} + \zeta P_s} \tag{1}$$

where t stands for time, $n_0 = n(0)$, T is the lifetime for spontaneous recombination of electrons and holes in the active layer, Γ_0 is the rate of optical power emission, ζ is the gain coefficient, and $P_s = |E|^2$ is the density of photons in the active layer; $E(t)$ is the slowly varying envelope of the complex electric field in the active layer. Here, harmonic solutions to Eq. (2) of the form $E(t) = \sqrt{P_s}\,e^{i\Omega t}$ are considered so that P_s does not depend on time (see previous refs.); Ω denotes feedback-induced frequency shift. The above mentioned Eq. (2) is the following Lang-Kobayashi equation namely [5]:

$$\frac{d}{dt}(E(t)) = \frac{1}{2}[G(n(t)) - \Gamma_0]E(t) + \gamma E(t-\tau)\exp(-i\omega_0\tau) \quad (i = \sqrt{-1}) \tag{2}$$

where ω_0 is the optical angular frequency which is near the laser angular frequency, γ is the feedback rate, τ is the feedback delay time, and $G(n(t))$ is the complex gain function which depends upon $n(t)$. Now, from Eq. (1) we get:

$$n_\infty \equiv \lim_{t\to\infty} n(t) = \frac{(\Gamma_0 - \zeta n_0)P_s T}{1 + \zeta P_s T} \tag{3}$$

On the other hand, note that also from Eq. (1) it is deduced the existence of a relaxation time given by:

$$\tau_r \approx \frac{2T}{(1+\sqrt{5})(1+T\zeta P_s)} \tag{4}$$

so that from Eqs. (3) and (4) it follows:

$$n_\infty \approx 1.62\, P_s \tau_r (\Gamma_0 - \zeta n_0) \tag{5}$$

Next we shall evaluate the average value of $n(t)$ as follows:

$$\langle n \rangle = \lim_{t_0 \to \infty} \left[\frac{1}{t_0} \int_0^{t_0} n(t)dt \right] \tag{6}$$

Then, by taking into account formulae (1) and (6) as well as L'Hôpital's rule with respect to parametric differentiation, we obtain:

$$\langle n \rangle = n_\infty + \left(\frac{n_0 - \Gamma_0 P_s T}{1 + T\zeta P_s} \right) \times \lim_{t_0 \to \infty} \exp \left[-\frac{1}{2}(1+\sqrt{5}) \times (T^{-1} + \zeta P_s) t_0 \right] = n_\infty \tag{7}$$

Notice that result (7) coincides with n_∞ (see formula (3)), that is, time-averaged electron-hole density is exactly equal to the asymptotic value of this density in the time domain.

3. DISCUSSION

We have found that $\langle n \rangle = n_\infty$, this value being dependent on relaxation time τ_r; at this point, note that τ_r does not depend on the feedback delay (for details on this delay, see Refs. [2, 4]). In addition, we must emphasize that our results refer to minimal pump energy which constitutes a very interesting circumstance since this situation is related to crucial problems in the context of chaotic phenomena. It is well-known that these phenomena are not at present well understood so very important research efforts are needed. Finally, we can mention Refs. [5, 6] as basic work in this context.

References

[1] Grado-Caffaro, M. A. and Grado-Caffaro, M. (1994). *Act. Pass. Electronic Comp.*, **16**, 101–103.
[2] Grado-Caffaro, M. A. and Grado-Caffaro, M. (1994). *Optik*, **98**, 74–78.
[3] Grado-Caffaro, M. A. and Grado-Caffaro, M. (unpublished).
[4] Grado-Caffaro, M. A. and Grado-Caffaro, M. (1994). *Mod. Phys. Lett. B*, **8**, 819–822.
[5] Lang, R. and Kobayashi, K. (1980). *IEEE J. Quantum Electron*, *QE*, **16**, 347.
[6] Yasaka, H., Yoshikuni, Y. and Kawaguchi, H. (1991). *IEEE J. Quantum Electron*, *QE*, **27**, 193–204.