FIRST PAGE OF THE ARTICLE

Comments and Corrections

Comments on "The Spontaneous Emission Factor for Lasers with Gain-Induced Waveguiding"

J. ARNAUD

Newstein[1] introduces a new definition for the power in the fundamental mode of a laser resonator excited by a radiating dipole J. His expression is P_2 = real part of $J^*E_0/2$, where E_0 denotes the fundamental mode field at the dipole location. E_0 is obtained as in Petermann's work from a modal expansion of the form $E(x) = E_0(x) + E_1(x) + \cdots$, where $E(x)$ denotes the total radiated field and the integral of $E_0E_1, \cdots$, over x (without complex conjugation) is taken to be zero. The power P_2 so defined is drastically smaller than the one (P_1) that results from Petermann's definition, namely the integral of $|E_0(x)|^2$ over x. As was explained [1], [2], in the presence of higher order transverse modes, or radiation modes, the so-called "power in the mode" depends on the definition used. Newstein, in my opinion, fails to demonstrate in his paper that his P_2 is more relevant to the problem at hand than Petermann's P_1. I believe that the opposite is true.

Indeed, what really matters in a semiconductor laser oscillator is the optical field intensity in the active region (e.g., if we are interested in the time-evolution of the electron density). Using a thin slab approximation (as in [2]), I was able to show that, well-above threshold, the total field intensity in the active region (which includes both the fundamental mode and the radiation modes) is almost equal to the fundamental mode-field intensity alone. This is intuitively understandable because, in that region, there is strong spatial filtering of the higher-order transverse modes. Thus, following the reasoning of [1] (which I will not repeat here), I conclude that Petermann's K-factor fully applies when $I >> I_{th}$ for conventional semiconductor lasers with plane end facets. Near or below threshold, however, spatial filtering is not so strong and Petermann's factor may need revision.

Finally, I would like to note that K in (5) and (23) of[1] is only the square root of the K-factor. A square is also missing in (15).

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The author is with Equipe de Microoptoelectronique de Montpellier, Unité Associée au CNRS, USTL, Pl. e. Bataillon, 34060 Montpellier Cedex, France.

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Further Comments on "The Spontaneous Emission Factor for Lasers with Gain-Induced Waveguiding"

MAURICE NEWSTEIN

This note is a response to the comments by Arnaud [1]. The expression I used for the spontaneous power P_2, radiated by a point dipole current, J, into the fundamental mode E_0 of a laser, namely $P_2 = \mathrm{Re} J^* \cdot E_0/2$, is not new. It follows from the modal resolution of the field, E, in the $\mathrm{Re} J^* \cdot E_0/2$, which represents the *total* power spontaneously radiated. If one uses Poynting's Theorem to derive a rate equation for the field energy in the dominant mode of a laser oscillator this is the term that one identifies as the total spontaneous emission power times the spontaneous emission factor [2].

One may also compute the *total* power spontaneously radiated by a point dipole current by integrating the normal component of the Poynting vector over a surface surrounding the source [3, (7)]. This surface should be close to the source in order to avoid including the induced emission contribution from the active medium in the region between the source under consideration and the surface. This procedure leads to an expression which is quadratic in the total field. If one expresses the total field as a linear superposition of modes, E_n, one gets diagonal terms $|E_n|^2$ as well as cross-terms, $E_n^* E_m$ *with* $n \neq m$. If the modes are power orthogonal [3], the cross-terms vanish and the contribution to the Poynting vector integral from the dominant mode is the same as our P_2. For the case of interest (gain-guided modes) the cross-terms do not vanish, and the particular term involving only the dominant mode contribution, i.e., involving $|E_0|^2$, is different from P_2. If one, nevertheless, interprets the term involving $|E_0|^2$ as the power coupled into the dominant mode, one gets Petermann's [4], expression for the K factor. I believe I have demonstrated that the first method of calculation is more relevant since the second method involves dropping terms (those involving $E_0^* E_n$) which are not negligible.

Arnaud [1] claims that if one considers a laser oscillator well-above threshold, then Petermann's K factor applies because the field is almost entirely in the dominant mode. This result follows from the reasoning in [5]. In terms of my formulation of the problem, using Poynting's Theorem, one might be led to argue that under these conditions, the term with $|E_0|^2$ dominates the Poynting vector surface integral. This is not true for the following reason: in an oscillator resonator containing a gainy medium and a prescribed dipole current source,

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The author is with the Polytechnic Institute of New York, Long Island Center, Farmingdale, NY 11735.

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