Semiconductor laser Markov models in the micro-canonical, canonical and grand-canonical ensembles

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We are interested in semiconductor laser (SL) dynamics, namely its multimode stability. To that aim a microcanonical (MC) model was built and is very effective, but highly time-consuming to simulate [1]. We then question about the relevance of this statistical ensemble.

The model represents a SL by a Markov chain. It is composed of photon reservoirs figuring optical modes, and a finite number of electrons sharing a set of evenly-spaced energy levels. These states are split in two energy bands. Each energy level is occupied by zero or one electron, following the Pauli exclusion principle without spin consideration [2]. The system reaches its steady-state regime when pumping compensates exactly photon exits. Electron repartitions are directed by the Boltzmann thermalisation within each band. This photon flux is the main output of the model since it contains the laser noise. Photon absorption and emissions take place only at the laser energy level pair, one per mode. Their intensities are dictated by electron presence at each laser level. The way the latter occupation is coped with is determined by which statistical ensemble is favored.

The MC simulation takes into account the whole microstates, including electron thermalisation. It shows the laser multimode stability as expected and the possible occurrence of both the spectral hole burning and carrier heating [1]. Its main drawback is that one photonic event only occurs every 10^5 thermal ones.

To speed up calculations, we shift to a canonical (C) frame for electron thermalisation because the number of electrons in a band does not change except when photonics events occur. The C occupancies of the laser levels are obtained analytically [3], which allows to get rid of thermal events. As a main disadvantage, spectral hole burning and carrier-heating are now ignored. However a possible addition to the Markov framework may solve the question owing to an extension of the event set.

Finally, using the Fermi-Dirac distribution instead of the C ones is irrelevant for laser simulation purposes because carriers number fluctuations are ruled out. But it allows for a complete analytical description, which was shown to coincide with MC and C results for big systems.

The differences between the three ensembles will be discussed in this communication.

[l] L. Chusseau et al., Optics express **22**, 5312 (2014).
[2] J. Arnaud et al., Am. J. Phys. **67**, 215 (1999).
[3] F. Philippe et al., arXiv **math-ph**, 0211029 (2002).