Quantum Design of Semiconductor Devices

Philipps Universität Marburg

Fast track from design to actual device

With information and communication technologies forming an integral part of our daily lives, demands to their speed, compactness and ease of integration keep rising. Consequently, increasingly small and elaborate devices are produced in more and more complex processes. Modelling these devices realistically presents a special challenge, but also yields multiple rewards in aiding to reach an optimal design and obtaining information about the production process at an early stage.

The semiconductor theory group at the Department of Physics, Philipps-Universität Marburg, has developed the microscopic theory needed to quantitatively model optical properties of semiconductor heterostructures. In tiny devices such as modern semiconductor lasers and photodiodes, it is mandatory to take into account the quantum mechanical nature of the system. That is, contrary to our daily experience, the classical laws of physics have to be replaced by quantum many-body physics. The microscopic model is used to calculate optical luminescence, gain and loss spectra that constitute the critical input into predictive laser analysis and design. Figure 1 shows an example for the excellent agreement between calculated and experimentally measured spectra.

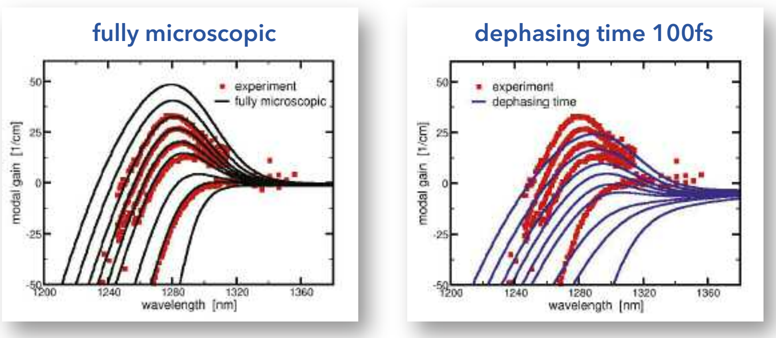

Fig. 1: Comparison of measured and calculated gain for (left) the microscopic and (right) a simpler phenomenological model. Obviously, agreement improves considerably with the microscopic theory.

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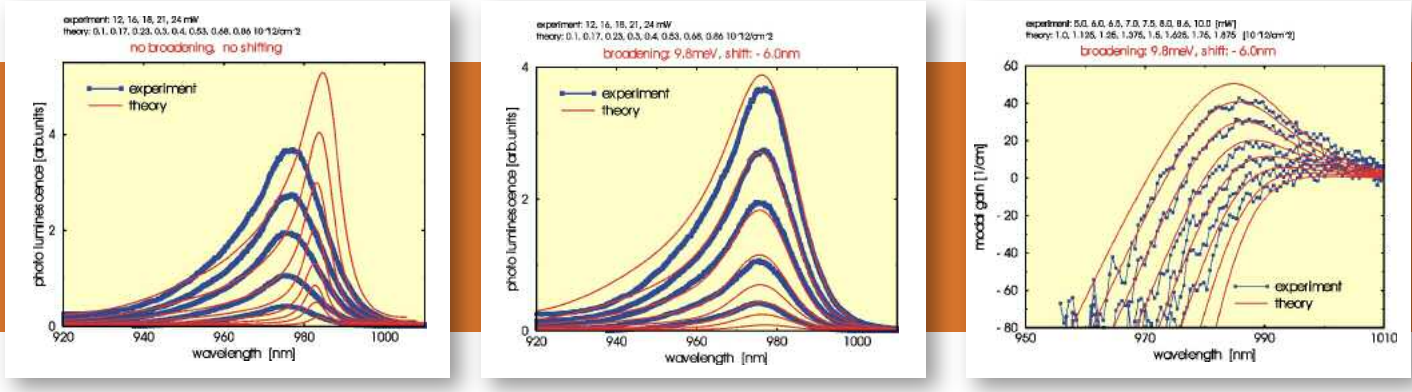

Fig. 2: Example of a luminescence analysis in a quantum well structure.
Left: Measured luminescence compared to a calculation using the nominal structural parameters. **Middle**: Measured luminescence compared to a calculation which was corrected for growth uncertainties as well as disorder introduced in growth. **Right:** Measured and calculated gain without further adjustable parameters as compared to the picture in the middle. Obviously, no phenomenological parameters are required to get good agreement.

- Applications of the theory include the quantitative luminescence analysis of actual structures. Without any sample processing, the wafer quality may be tested by scanning measurements of the photoluminescence and realtime comparison with pre-computed spectra yielding systematic deviations from the nominal structure as well as local variations (inhomogeneous broadening). On the basis of this analysis, important laser properties can be predicted without further measurements. An example of such a luminescence analysis is shown in Fig. 2
- Another application of the microscopic model is the computer design of new structures with desired optical properties (e.g. emission wavelength, output power, etc.) in order to expedite the development and optimization of novel devices. Significant cost savings can be expected by replacing replacing some steps in the usual device development by predictive microscopic calculations.
- The analysis of existing devices may point to possible improvements of the design.

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