

Research or Thesis on Quantum Dot and Qwell Semiconductor Lasers and Monolithically Integrated Photonic Devices

Research or Theses Subject: The group (Semiconductor Integrated Optoelectronics and Photonics) is working on modeling and design of new optoelectronic devices for various applications, such as optical communications, medicine and sensing. The devices studied by the group are all realized in the main research labs in Europe or USA and are at the state of the art in the field of semiconductor lasers and integrated photonics. Several devices designed by the group have been realized in other research labs, after the realization the devices are characterized and the results of characterization are interpreted by the group using the numerical tools developed. The group has several collaborations in the framework of European projects with leading industries in the field (Alcatel Thales III-V Lab in Paris, Innolume in Dortmund, Merge Optics in Berlin, Modulight in Tampere) and research labs in Europe and outside (University of Wurzburg, University of Darmstadt, Kassel University, University of Sheffield, Cambridge University, Technical University of Denmark, ORC in Tampere, Technion Haifa, Dundee University, Wroclaw University, University of Rennes, University of New Mexico, University of Athens).

Tools: the group has several PCs available for undergraduate and PhD students and three high performance workstations for very demanding computations. Several simulation and design tools are already available. The group would also like to start the optimization of some codes in terms of computation efficiency applying grid-computing techniques.

What does a student do during the Thesis/PhD program?

- understanding fundamentals of optoelectronic devices
- modelling of quantum well or quantum dot semiconductor material and understanding the basic physics
- modelling, simulation and design of new devices
- interpret/simulate measured characteristics
- development of design and simulation codes
- optimize codes in terms of computation time (if necessary)
- mount/use simple benches for characterization of devices

Which are the topics proposed to the students?

Here are a few examples:

- study of innovative Quantum Dot lasers for generation of ultra-short pulses, dark pulses or THz radiation
- study of quantum dot lasers and amplifiers for emission at 1.55 μm
- study of quantum dot solar cells

SEE NEXT PAGE FOR COMPLETE LIST
OF TOPICS AND DETAILED
DESCRIPTION

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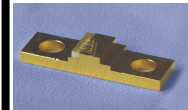
Ivo Montrosset - Dipartimento di Elettronica tel: 011 564 4059

Let's give an example...

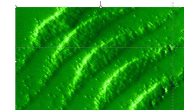
Quantum Dot SLDs

Device realized by University of Sheffield +Thales III-V Lab
Device design and modeling: our group at PoliTO

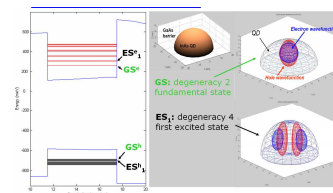
SLD mounted



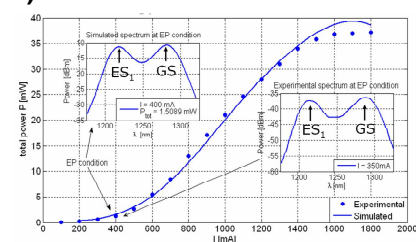
Quantum Dot Technology



Modelling of QD material (SIOP)



Device simulation (SIOP) and characterization (III-V Lab)



LIST OF TOPICS

1) **Modeling and design of Quantum Dot solar cells:**

QD solar cells are a new and very recent generation of solar cell properly developed to optimize the efficiency of standard solar cells based on p-i-n junctions.

Students working on this topic will:

- develop simple models with Matlab to understand and analyze the basic principle of QD solar cells
- use commercial simulation software for the simulation of optoelectronic devices and test the validity of the software for the simulation of QD solar cells
- validate the models through comparison with experimental data found in the literature

2) **Study of new QD semiconductor lasers for emerging applications:**

Quantum dot semiconductor lasers are the last generation of semiconductor lasers developed in the 90's. These lasers use the quantum dots as active materials and exploit the properties coming out from the confinement of carriers in these nano-structures. QD technology is now quite well established and new kinds of lasers are going to be realized.

Students working on this topics will use and update simulation tools already existing in the group with the purpose of studying new QD lasers such as:

- **QD comb lasers:** This is a single Fabry-Perot semiconductor laser that emits many wavelengths, each of which can be modulated at high speed and combined into an optical fiber or silicon photonic network. The comb laser is an essential enabler for future computer optical interconnects, allowing the low-cost migration of telecom's wavelength-division multiplexing (WDM) technology into the computer.
- **QD lasers for THz generation:** multi-section QD lasers can be properly design to realize a THz source thanks to the beating of two cavity modes well separated in wavelengths.

There are several approaches for the generation of THz radiation but one possible and promising approach is to use a dual-mode semiconductor laser that features a device with two longitudinal modes simultaneously emitting at two different frequencies from a single or combined laser cavity. The use of the dual-mode laser has the advantage of being free of optical alignment issues since there is no need to align two laser beams, which is critical for photomixing efficiency. Several optical cavity approaches have been studied that achieve simultaneous two-color generation from a compact, monolithic system based on bulk or quantum well material. In this thesis the students will analyze the possibility and advantages of using a QD material.

- **QD lasers for generation of short pulses:**

These kinds of lasers have been successfully studied and design by the group in the last years. The thesis will continue the existing activities and start the analysis of new pulse generators (MOPAs, dark pulse lasers etc ...).

- **QD lasers for space applications:** it has been observed that QD lasers and other QD based devices (photodiodes, solar cells, optical amplifiers) can be very promising for space applications and/or for operation in very high temperature environments. Due to the specific properties of the gain material and thanks to the improved carrier confinement, the QD lasers should result more insensitive to high energy radiation with an enhancement of the reliability of these lasers in space borne applications. The student working on this topics will explore the findings on this field reported in the literature and will analyze the possibility of

including into existing numerical models the effects of space radiation and/or the operation at extremely high temperatures (150-200C).

3) **Quantum dot material and devices for emission at 1.55 um and above**

Quantum dots were originally grown on GaAs substrate for emission in the first and second optical communication windows, but in the last years there is a significant need of QD devices emitting in the third window and also beyond.

The thesis on these topics will study QD grown on InP substrate with the aim of:

- calculating the band structure of QDs grown on InP
- calculate the gain properties of this material
- insert the results of the previous calculations in simulation tools (already existing) for studying laser and optical amplifiers
- compare the results obtained with the available experimental results and compare the performance with those of analogous devices grown on GaAs for emission at 1.3um.

4) **Feedback effects in QD FP and QD DFB lasers:**

From an ideal point of view QD lasers should be completely insensitive to weak external optical feedback since their alpha-factor is ideally very close to zero. This is very attractive for industrial applications because the packaging of the lasers could get rid of the expensive external optical isolator. However realistic QD lasers have several limitations respect to the full insensitivity to the optical feedback. The thesis will study realistic QD lasers subject to external optical feedback and will compare them with similar lasers realized in quantum well technology. Are the ideal expectations coming to be true??

5) **Traditional devices based on Qwell material:**

Several topics are available on this subject; all the topics mainly aim to find and design new laser structures for improving the performance of the traditional QWell-lasers. Particular attention is devoted to the extension of the modulation bandwidth beyond 40GHz (maximum modulation speed of traditional QW-lasers is around 15-20 GHz).

6) **Miscellanea of very advanced topics:**

This is a collection of very new and emerging topics in the field of semiconductor lasers and photonic devices. Students working in this subject will start the study of new devices never studied before in the group. Possible topics are:

Transistor lasers, nanostructure lasers with photonic crystal cavity, single photon emitters, Fabry-Perot nano-plasmonic lasers, lasers and photonic devices for Si-photonics (ie: photonic technology on silicon), semiconductor lasers in optical PLLs, etc...