Summary

This work concerns about the study of the Quantum Cascade Lasers' dynamics from theoretical and numerical point of view, by exploring different aspects of this vast field of study.
Firstly, the self-generation of optical frequency combs by exploiting these devices in the Fabry-Perot (FP) configuration has been studied by introducing the Effective Semiconductor Maxwell-Bloch Equations (ESMBEs), a model which encompasses the main features of semiconductors materials and includes in the case of FP cavity the Spatial-Hole Burning (SHB). The simulation study based on the integration of the ESMBEs has allowed the reproduction of relevant experimental achievements and the highlight of the role of some parameters such as the linewidth enhancement factor. Furthermore, this model has been retrieved for the case of ring Quantum Cascade Laser, and also in this case a simulation study has been performed.
The case of ring QCL have also been studied by introducing a reduced model based on a single master equation. This model, which is valid in the hypotheses of fast carriers and near threshold operation, presents a shorter simulation time, and showed an agreement with the ESMBEs results also for values of the current relevantly above the laser threshold.
The ring QCL with an optical injected field has also been considered and numerically studied, achieving the reproduction of experimentally found regimes such as temporal solitons and Turing rolls.
The last part of the work is dedicated to the study of a Terahertz (THZ)- QCL in presence of optical feedback, in a self-mixing interferometry setup which is combined with a probing-type microscopy technique, in order to produce a system for the nano-imaging of resonant materials, called Self-Detection scattering type near field optical microscopy (SD s-SNOM). A theoretical study based on the Lang-Kobayashi Equations and a simulation analysis of this setup have been performed in order to explore the possibility to retrieve the dielectric properties of materials with phonon resonances in the THZ region with a resolution far beyond the diffraction limit.