Politecnico di Torino

ELECTRICAL, ELECTRONICS AND COMMUNICATIONS ENGINEERING

Computationally guided design of ultrabroadband vertical-cavity surface-emitting lasers (VCSELs)

Funded By	Dipartimento DET

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Context of the research activity	The scope is to contribute to the development of a multiscale model of carrier transport and recombination processes in optoelectronic devices, with application to TCC-VCSELs. The candidate is expected (i) to advance in the understanding of the ultrabroadband mechanism by developing novel rate equation models; (ii) to develop simulation tools combining NEGF approach and the drift-diffusion approximation in DC and small-signal AC conditions; (iii) to contribute to the experimental characterization of TCC-VCSELs designed in collaboration with industrial partners.

	The unstoppable increase in the number and quality of entertainment and business online services is reflected in the research and development of ultrabroadband optical transceivers. The target of 200 Gbps intradatacenter optical communications requires, in addition to complex modulation formats such as PAM-4, to revolutionise each block of the communication chain. Focusing on the optical light source of the optical transmitter, vertical-cavity surface-emitting lasers (VCSELs) are emerging as great candidates as high-speed low-power data communications. In this framework, one of the hottest research topics is that of VCSELs featuring transverse-coupled cavities (TCC-VCSELs). These devices are based on introducing an interaction between the main VCSEL cavity and one or more additional cavities coupled to it, so that if one optical mode closely matches the resonant frequency of another mode, various nonlinear optical effects occur, such as a huge broadening of the intensity modulation (IM) bandwidth. In this framework, the scope of this Ph.D. program is to contribute to the development of TCC-VCSELs. The first part of the Ph.D. program will be dedicated to developing a basic understanding of TCC-VCSELs, on the basis of novel rate equation models. At present, there is not a general consensus about the model to be used, since the literature reports descriptions of the TCC-VCSELs operation

Objectives	exploiting analogies with similar devices, such as edge-emitting lasers with optical feedbacks, or lasers coupled according to a master-slave injection locking scheme. The first objective of the Ph.D. candidate is to disambiguate the interpretation of the mechanism underlying the ultrabroadband operation. Having advanced in the interpretation of the operation of TCC-VCSELs, the second part of the Ph.D. program will be dedicated to the development of simulation tools for high-speed infrared optoelectronic devices, combining the NEGF approach and the drift-diffusion approximation in DC and small-signal AC conditions. These models will be developed in collaboration with the Center for Semiconductor Materials and Devices Modeling (a cooperative initiative established by Boston University), within a collaboration supported by Office of Naval Research (ONR). This will involve both electromagnetic simulations, based on the coupled-mode theory solver Vcsel ELectroMagnetic (VELM), and multiphysics simulations, based on the Vcsel Electro-Opto-Thermal NUmerical Simulator (VENUS), developed at IEIIT-CNR and DET, Politecnico di Torino. Device-level simulation frameworks will allow to overcome phenomenological models, allowing to switch from a simple description of the ultrabroadband mechanism to its engineering based on technology computer-aided design (TCAD). Having developed competences and modeling tools, the Ph.D. candidate will interact with the Europe market leaders, to guide them towards the development and manufacturing of next-generation TCC-VCSELs, and will have the occasion to contribute to their experimental characterization, in the framework of the Excellence Research Center VCSELence, joining competences between DET-PoliTO, IEIIT-CNR and Links Foundation.

Skills and competencies for the development of the activity	The Ph.D. candidate is expected to have strong competences about photonic devices (in particular lasers and VCSELs), numerical methods, carrier transport in bulk (by semiclassical approaches such as those based on the Poisson-drift-diffusion equations) and nanostrucutred (by genuine quantum-kinetic approaches such as nonequilibrium Green's function methods) semiconductors.