High power semiconductor laser modules

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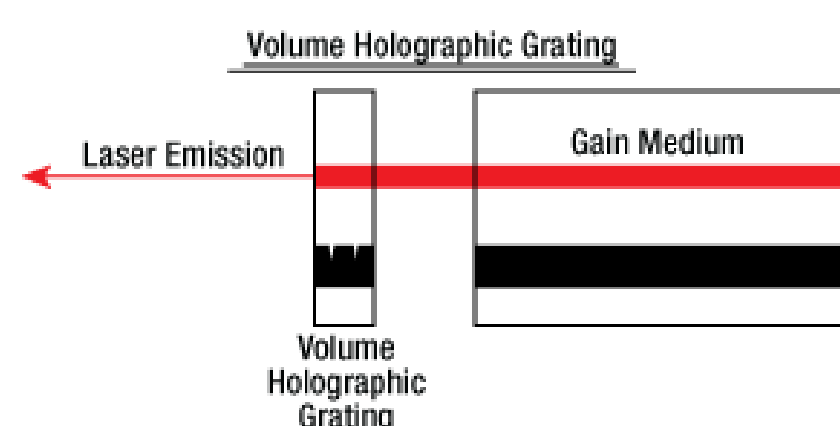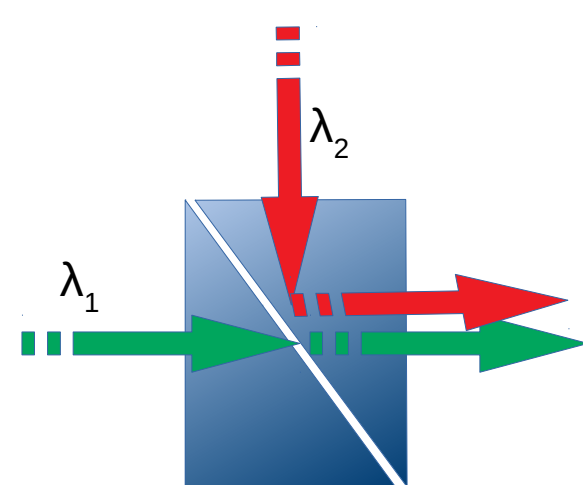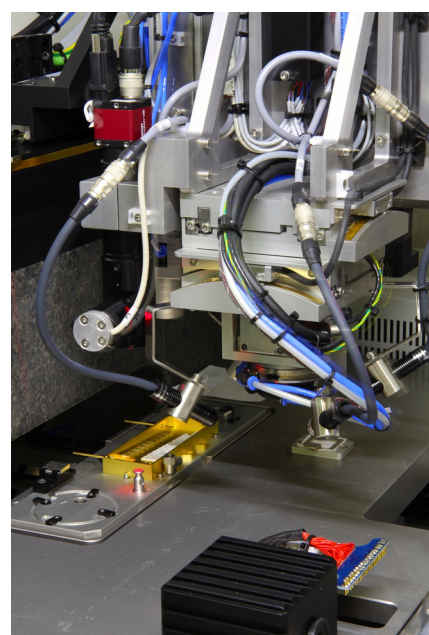
Research context and motivation

- Semiconductor laser diodes are the fundamental building block of any modern high power laser for industrial or medical applications. Indeed, even if a single high power laser diode chip is limited to a maximum emitted power of few watts, tens of these chips can be assembled in compact laser modules capable of delivering up to more than 200 W. Then, several of these high power modules can be further combined to achieve an output power in the order of some kilowatts to be used both in direct diode applications or for pumping fiber lasers.

- The market competitivity continuously pushes for improving the throughput of the laser processes while reducing the operative costs; in turn, this requires optimizing the so-called "cost-per-watt" of the modules. This can be obtained only by increasing the emitted power, while preserving the beam quality, the volume manufacturability and the long-term reliability.
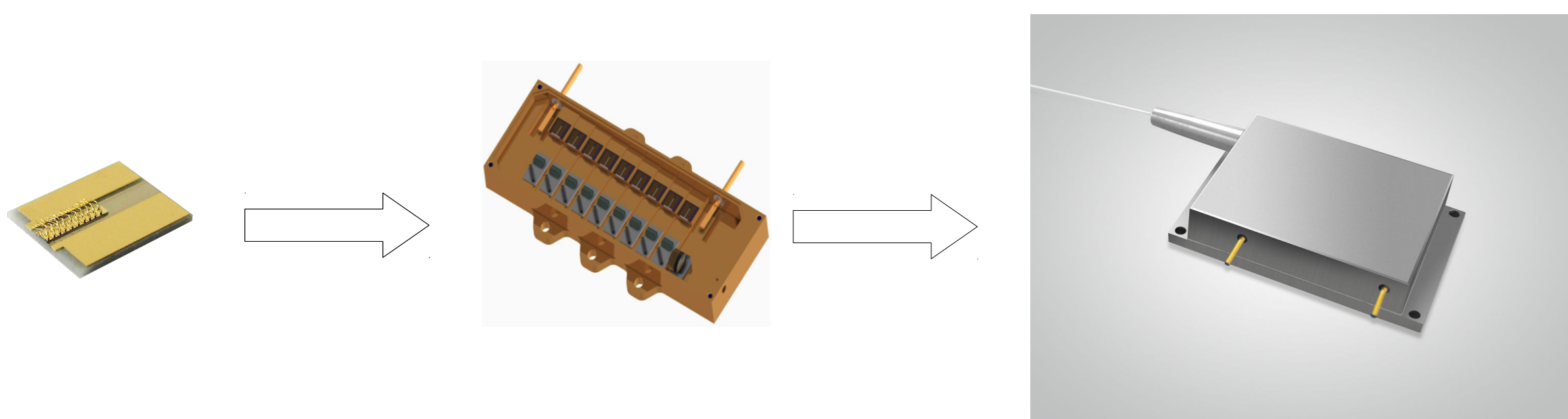
Addressed research questions/problems

The optimization of high power laser diode module performance requires three specific actions:

- Study of new **strategies for the automatic assembly.** One of the main costs of semiconductor laser modules is in the time needed to assemble them since each of the tens of lasers diodes output a divergent beam that needs to be collimated and routed through a set of diffractive elements with strict positioning tolerances.

- Development of **multiplexing technologies for power scaling**. Typical module power scaling is obtained by combining spatial and polarization multiplexing. However these approaches are quickly reaching their limit, particularly for higher beam quality applications. Further emitted power increases can be obtained by adding an additional level using dense wavelength multiplexing.

- Study of techniques for **narrowing and stabilizing the beam spectrum**. Many applications – including fiber laser pumping and wavelength multiplexing – require that the laser module emission spectrum peaks at a well defined wavelength, with very small deviations with current, temperature and external disturbances. A possible solution is to use externa stabilization gratings.

Submitted and published works

Paper on modeling the beam propagation through arbitrarily oriented planes has been submitted for journal publication

Novel contributions

- Design of an **automatic lens alignment system based on artificial neural networks**. First a code based on the non uniform angular spectrum method has been developed to simulate the beam propagation through arbitrarily oriented diffractive elements. This code has then been used to generate a synthetic dataset of images to train a convolutional neural network to automatically align the diffractive elements.
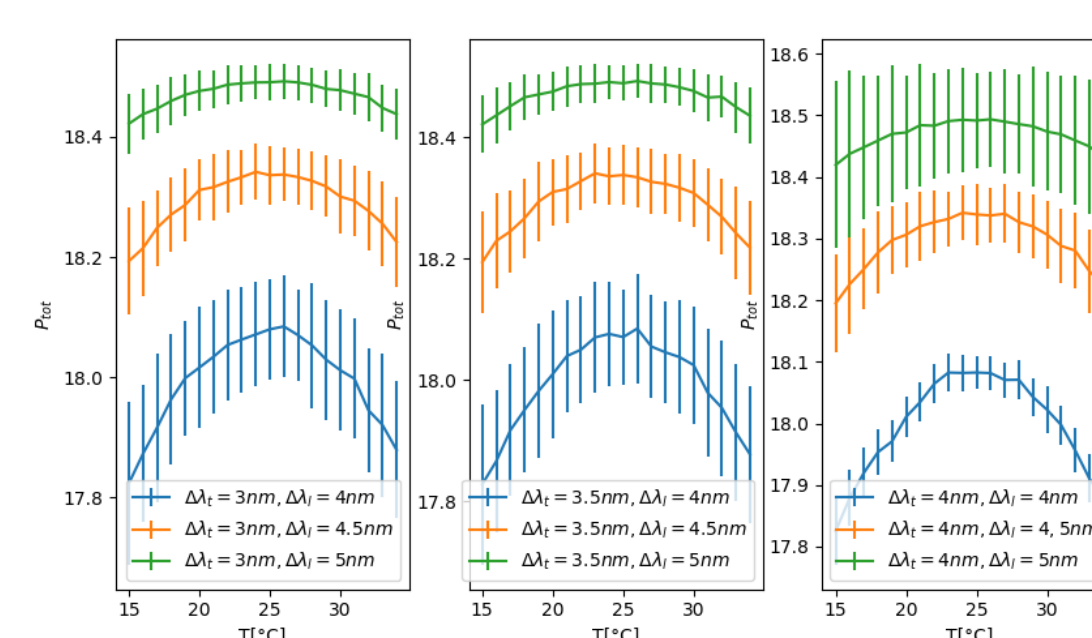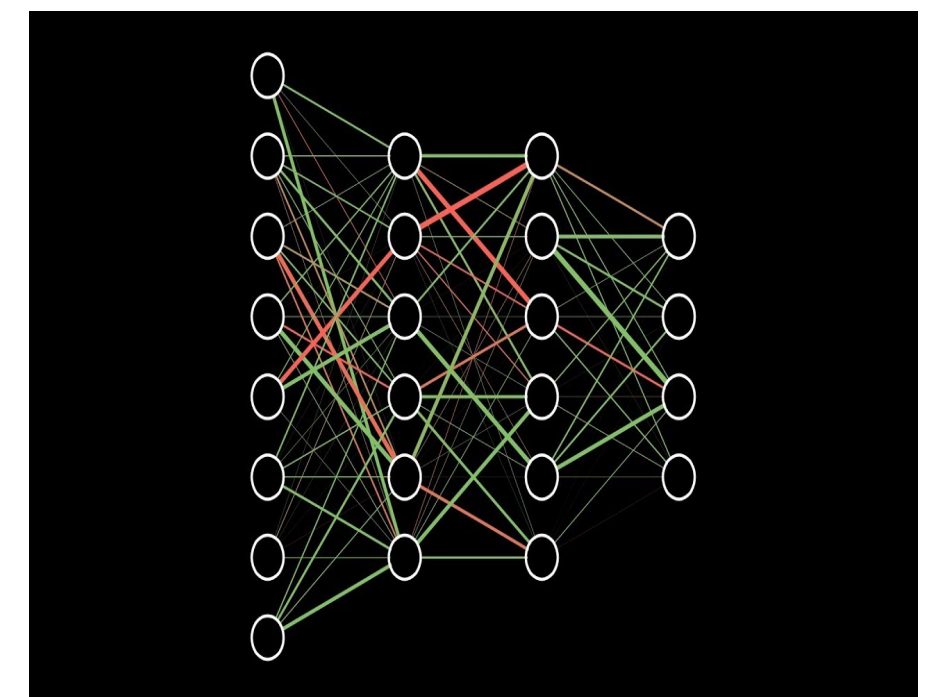
- **Spectral multiplexing of two sets of high power diodes**. First a stochastic model of the single diode output has been used in order to study the tolerances and find out the parameters that best suits the spectral multiplexing in a real semiconductor laser module. The design and fabrication of a specific dichroic mirror is currently ongoing.
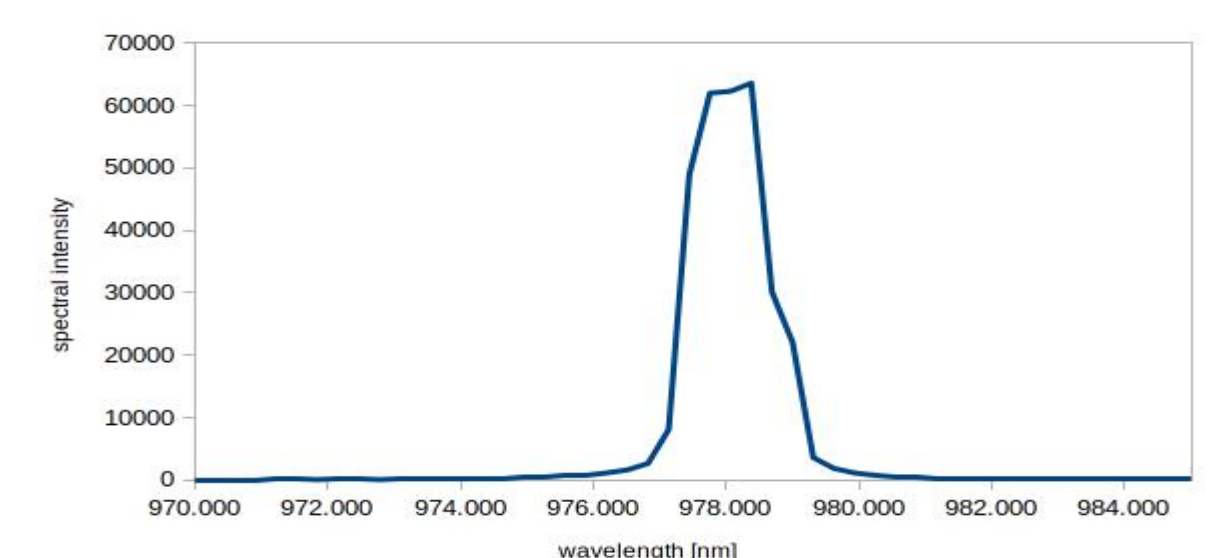
- **Wavelength stabilization of a whole module** using an external volume holographic grating, obtaining a stability of the peak wavelength of 976 nm and spectral width reduced to less than 1 nm

Adopted methodologies

- The laser beam propagation has been numerically studied in non-paraxial cases to understand the effect of misalignment of the refractive elements with respect to the optical axis, merging together the band limited angular spectrum and the non uniform fast Fourier transform in an extremely fast and parallelized code. Then, a neural network has been implemented and used to compute the misalignment from propagated beam images. The system has been experimentally validated using ad-hoc developed lab setups.

- In order to design the dichroic mirror a stochastic method based on a Montecarlo approach has been implemented; this takes into account temperature dependent wavelength fluctuation as well as real spectral distribution to compute accurate prediction of the module efficiency

Future work

- Further validation of the code result against experimental results in case of multiple refractive elements.
- Spectral multiplexing of more than two wavelength in order to further scale up the modules output power.
- Laser wavelength stabilization using gratings integrated in optical fibers.

List of attended classes

- 01TEVRV – Deep learning (04/06/2019, 6)
- 01RRPRV – Lean startup and lean business for the innovation management (06/08/2019, 4)
- 01TBCRT – Ottimizzazione stocastica e apprendimento ottimale (05/07/2019, 3)
- 01QFDRV– Photonics, a key enabling technology for engineering applications (12/07/2019, 5)
- 01SOVAB– Statistical learning and neural networks (08/02/2019, 6)