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Semiconductor lasers

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Abstract

In this short-course, we described simply the physics of semiconductor lasers. After a few reminders of basic solid state physics on electronic states in semiconductors, how a semiconductor can emit light has been considered. The p-n junction is the basic mechanism for obtaining the population inversion required for stimulated emission gain. We presented the principles and fundamental equations governing the optical gain in these structures. The threshold conditions is then determined and the various improvements over the basic p-n junction (double heterostructure laser, quantum well laser) are set in historical perspective. Then, the variety of semiconductor lasers is illustrated by some examples: distributed feedback (DFB) lasers, distributed Bragg reflector (DBR) lasers, mode-locked lasers (MLL). Finally, an attempt to put into perspective some advanced semiconductor lasers, in particular the quantum dot lasers, has been made.

Introduction

Semiconductor lasers, invented in 1962, today have considerable importance in our societies. They are found in optical fibre telecommunications (internet, telephone, TV,...), for storing information on optical discs (CD, DVD, Blu-ray), on photocopiers, laser printers, in medical and industrial applications. They are, by economic standards and the degree of its applications, the most important of all lasers.

The main features that distinguish the semiconductor laser are: a) small physical size (< 1μm), b) direct pumping by low-power electric current (few tens of mW), c) high efficiency (> 50%), d) ability to modulate its output by direct modulations of the pumping current at rates exceeding 20 GHz, e) possibility of integrating it monolithically with electronic and optical devices in III-V semiconductors to form integrated optoelectronic circuits.

1 - Basic principles of semiconductor lasers

The purpose of this section has been to provide a qualitative understanding of the physics behind the semiconductor lasers. Conditions required to operate a laser are discussed. The heart of a semiconductor laser is the p-n junction, which is why is also referred as diode laser. From this basic structure, the main characteristics of laser semiconductors have been deduced: the emission wavelength, λ, the threshold current density J_{th}, the modal optical gain G and the external differential quantum efficiency η_D. Then, the p-i-n double-heterostructure (DH) is introduced. Semiconductor materials for DH diode lasers and epitaxial growth technologies are presented.

2 - Special semiconductor lasers structures

In this section, we intended to describe monomode lasers such as distributed feedback (DFB) lasers, distributed Bragg reflector (DBR) lasers, which utilizing a fine periodic structure, i.e. an optical Bragg grating, formed in the semiconductor structure. The Bragg grating is formed in the active section in DFB lasers, and outside the active section in DBR lasers.
Then, effects of size quantization in diode lasers are analyzed. We introduced the quantum well structures (QWL), and the phenomenological approach to the threshold current estimations through the gain parameters were studied. Also, the gain characteristics to the density of states of the active layer in connection with its dimensionality were correlated.

3 - New trends in semiconductor lasers

In this last section, latest advances in semiconductor lasers using quantum dots in the carrier recombination zone are presented (QDL). With these structures, it is expected: a) a significant reduction of the threshold current density in comparison to quantum well-based lasers and b) temperature-independant properties.
Finally, current trends on new structures such as quantum cascade lasers and monolithically integrated photonic circuits are presented.

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