

## Chapter 3: Classical Electromagnetics and Lasers

The first two chapters illustrate the basic construction of semiconductor lasers. The construction incorporates the four fundamental components of the gain, pump, output coupler and feedback mechanisms. The phenomenological rate equations describe the operation of the laser in terms of fundamental mathematical quantities that represent the basic components (for example, the mirror loss  $\alpha_m$  or bimolecular recombination coefficient  $B$ ).

The present chapter delves deeper into the construction of the laser by discussing the dynamics of optical waveguiding and the flow of optical power through complicated optical systems. Maxwell's equations play a central role for those topics and for a classical description of the material gain. Not too surprising, the material gain can be described in terms of the polarization and susceptibility. Later chapters use the quantum theory to describe the material gain. The polarization and susceptibility provide the link between the classical and quantum mechanical treatments of lasers.

The first section in the present chapter reviews basic electromagnetic theory for Maxwell's equations. We then develop the wave equation and apply it to a classical gain medium in order to develop classical descriptions for the gain, absorption and index in terms of the susceptibility. The chapter shows how the internal energy of matter changes when it absorbs energy from electromagnetic waves. The absorbed energy can be (1) dissipated as heat, (2) stored as internal electric and magnetic fields, (3) stored in polarized atoms and molecules, and (4) stored in the magnetization of the material (however, we assume negligible magnetization). The chapter next discusses the boundary conditions necessary to solve the wave equation and applies the results to reflecting surfaces. The chapter continues the review of electromagnetic theory by discussing the Poynting vector in some detail and then applies it to the flow of optical power through complicated optical systems using the scattering and transfer matrices. The transfer matrices lead to the laser gain conditions, longitudinal modes and threshold conditions. The chapter finishes with the electromagnetic theory of waveguiding in rectangularly shaped waveguides. The transverse modes are discussed.

The final few sections lay the groundwork for advanced studies of the electromagnetic field and for the matter-light interaction. The first section reviews 4-vector notation in Minkowski space and the pseudo inner product developed to describe the "warping of space-time" encountered in the special theory of relativity. The subsequent section develops the connection between Maxwell's equation and the vector potential. Lastly, the chapter develops the Lagrangian and Hamiltonian for the electromagnetic field, shows how they reproduce Maxwell's equations, and how they yield the total energy of a system including the free field energy, particle energy and the matter-field interaction energy.