CHAPTER 1

Introduction

Light and its interaction with matter has been timelessly a fascinating subject of interest throughout the human history. To a very large extent, this is due to the crucial importance of the visual sense of human beings (and of animals as well) for perceiving the world around us. Equally important, the physical world is bathed with light. Besides, plants on the earth draw energy from light. Without exaggeration, the human race cannot live without light.

Before 20^{th} century, the scientific work on light had long been conducted by many prominent scientists and it formed the foundation of what is now called classical optics including geometrical optics and wave optics [Hecht 2002]. Optics would probably be the oldest field of Physics just second to mechanics. Starting from early 20^{th} century, the formulation of quantum mechanics, in particular the idea of light energy quanta or photons, provided new understanding about light and its interaction with matter. In fact, the quantum theory of light and matter interaction was given a profound name called quantum electrodynamics (QED) [Feynman 1990].

Up to early 21^{st} century now, the scientific study of light-matter interaction has brought a multitude of fruitful results leading to various technological applications. Indeed, the technologies of light tremendously permeate almost every aspect of our daily life. It ranges from the lighting technologies [Tsao 2004] for illumination to various information-related technologies such as fibre optics and semiconductor lasers for telecommunications, optical discs for high density low-cost information/data storage, imaging as in digital cameras, flat-panel displays for visually displaying information in various consumer products. Various optical methods are also used in the practice of medicine such as for medical diagnosis and surgery. Optical lithography techniques underpin the manufacturing of the electronic integrated circuit chips [Kenyon 2008] which are essential in all electronic consumer goods. The technology of light also includes energy-harvesting photovoltaic applications which become increasingly important in our energy-concerned age. Light also has its vital role as a versatile tool to explore the frontiers of science [Slusher 1999, Grier 2003]. In all the above cases, light is exploited with its energy either as a vehicle/carrier for information or its energy directly. It is under exploration to exploit photons of light for information processing and storage, namely utilising the quantum mechanical properties of photons to build photonic qubits and quantum network for quantum information processing [Cirac 1997].

Nowadays, light and its interaction with matter has still been a highly topical subject of intense research in various fields such as quantum optics, photonics, electromagnetic induced transparency (EIT), metamaterials, plasmonics in science and engineering disciplines [Barnes 2003, Fleischhauer 2005, Atwater 2007, Shalaev 2007, Valentine 2008]. In science and engineering disciplines, the physical properties, the generation, the transmission or propagation and the absorption of light are studied and to be controlled in desirable ways, spectrally, spatially and temporally. In this thesis, it is mainly concerned the generation and propagation of photons and the manipulation of these optical processes using semiconductor nanostructures, spectrally, temporally and spatially, respectively in terms of the emission wavelength, the spontaneous emission rate and the propagation direction.

1.1 LIGHT AS ELECTROMAGNETIC WAVES AND PHOTONS

Light, defined here in a broad sense, includes not only visible light but also far infrared (IR) light to deep ultra-violet (UV) light. Light exhibits both wave and particle properties. It behaves obviously as a wave in some situations while in other situations as particles. The wave property of light is evident from interference and diffraction experiments. The most conclusive one is the double slit experiment [Hecht 2002]. On the other hand, the particle nature of light is evident in the photoelectric effect and the Compton scattering [Bransden 2000]. These two seemingly contradicting facts are summed up by the well-known wave-particle duality.

1.1.1 Electromagnetic Radiations

Electric fields are produced by electric charges while magnetic fields are produced by electric currents which are basically flows of moving charges. When the charges accelerate, electromagnetic (EM) radiations are produced and propagate in space as waves. Figure 1.1 shows a pictorial illustration of an EM wave travelling in space showing the oscillating electric and magnetic fields.