1.1 Introduction:

In recent years, optical fiber communication has played a significant role in the rapid evolution of Information Technology. The ever-increasing and widespread use of data communications has stimulated the development of optoelectronic technologies for reliable photonic components and subsystems with adequate efficiencies and speed of response [1-3]. Integrated services like voice, still and motion picture, fax, e-mail, video conferencing, video on demand, etc. are the basic requirements of today. Because of the inherent high speed and high density data transfer capabilities of an optical communication system, many efforts have been devoted to move from electrical to optical system. Maximum benefit can be taken if the signal processing is also done optically. But, optical processing is not much matured like electronic processing. Also, in many cases signal is required in electrical form. For example, internally modulated optical source, external optical modulator, photodetector, etc., serve as interface between the electrical and optical signals. In this dissertation, the discussion is focused on the photodetector, which plays a significant role in the performance of an optical communication system. High-speed low-noise photodetectors are the demands in several applications including local area networks, chip-to-chip interconnects, fiber-to-the-home communications, etc. [1, 2, 4]. Commonly used wavelengths for long-distance data transmission are 1.3 μm and 1.55 μm, corresponding to the minimum dispersion and minimum attenuation respectively of silica optical fiber. Researchers all over the world are putting tremendous effort to build suitable optoelectronic integrated circuits (OEIC) working in wavelength range 1.3 - 1.55 μm [4-8]. The choice of material is critical for the design of photonic devices when large numbers of devices are
integrated on a single chip. The detectors commonly used for long-haul communication systems are based on III-V semiconductor materials [9-11]. Though III-V compound semiconductors and their alloys show superior performance, the main disadvantage of the material system is high cost, particularly for short-distance communication links. In this respect, Si based photodetectors seem attractive due to the following reasons. The cost of the material is low and Si is one of the natural elementary resources with the large quantity on earth. Besides, the insulators of Si, such as SiO$_2$ and Si$_3$N$_4$, have far better properties than other semiconductor insulators, and the processes to fabricate Si-based insulators are well-established than other insulators. Si has more than three times higher thermal conductivity than GaAs, which reduces the requirement of external cooling. This is important when large numbers of devices are integrated on a single chip and the clock frequency is increased, which raises the power consumption. Nowadays, apart from electronics industry, Si has become an important semiconductor material in photonic industry also [12, 13]. The recent explosion in Si photonics is driven primarily by the development of high-volume optoelectronic integrated circuit chips and secondarily by the development of practical photonic ICs which gives a large impact on the development of human civilization, society and daily life. To fulfill today’s requirement of high speed and compact devices, it is required that one OEIC chip contains all of the electronic and photonic components that are necessary to make a fast, bi-directional optical communication link with another OEIC chip. It has been demonstrated that interconnections between different modules in a multi-module chip can be efficiently implemented using optical communication system. The existing electrical interconnects can support a maximum of 200 MHz clock frequency whereas optical interconnects can support clock frequency in the order of GHz [14]. Optical interconnects for new generations of computers are the most important applications of silicon photonics. Sony and IBM jointly developed the eight-core processor which has an internal computation power of 256 Giga floating-point operations per second.
that can communicate with the peripheral graphics processor and memory at a speed of more than 25 Gb/s [15-17].

There are some fundamental problems in using Si as a photodetector material. The cut-off wavelength of Si being ~ 1.1μm, Si photodetectors are not suitable for operation around the long-haul wavelengths of 1.3 and 1.55 μm. Further, being an indirect band gap material Si exhibits poor absorption coefficient. The problems of very low absorption and low cut-off wavelength may be overcome by using lower bandgap Ge, another group IV semiconductor material [1, 4, 18-22]. Though Ge is also an indirect bandgap (E_g = 0.66 eV) material like Si, its direct bandgap (E_g = 0.8 eV) is only 140 meV above the dominant indirect bandgap. So, Ge offers much higher optical absorption in 1.3–1.55μm wavelength range, thus making Ge-based photodetectors promising candidates for Si photonics integration. However, the 4% lattice mismatch between Ge and Si places challenging obstacle towards monolithic integration of high-quality low dislocation density Ge devices through Ge on Si heteroepitaxy. A two step ultra-high vacuum / CVD process followed by cyclic thermal annealing has been developed, by which a high quality Ge epilayer on Si has been grown with substantially reduced threading dislocation density within the Ge film [8, 23]. Technological achievements in growth of high quality Ge films on Si wafers have opened up the possibility of low cost Ge-based photodetectors for near infrared communication bands and high resolution spectral imaging with high quantum efficiencies. Thus, Ge has emerged out as a promising material for the active layer of a photodetector.

In this thesis, we investigate the performance of Ge-based resonant cavity enhanced [8, 11, 24] Schottky photodetectors for optical communication. Schottky photodetectors are very attractive for their relatively simple fabrication process, which enables easy integration with discrete devices and integrated circuits [4, 25, 26]. The use of resonant cavity enhances the quantum efficiency and is discussed in detail in a later chapter. The analysis is made to study the bandwidth and quantum efficiency of the photodetector. The sensitivity of a
photodetector is largely controlled by noise [27, 28]. Noise performance of the Ge photodetector is also studied here. In all the models, the analyses include the important carrier confinement effect, which appears at Si/Ge hetero-interface of the photodetector. Based on the analysis, some optimum designs are suggested.
1.2 Scope of the Thesis:

Before describing the work in detail, it seems reasonable to give a suitable background on the materials under study and to highlight some works carried out in the field. So, a brief review on Ge based photodetector is given in Chapter 2. Photocurrent and, hence, Bandwidth of Ge-on-Si Schottky photodetector are calculated and discussed in Chapter 3, considering the effect of carrier confinement at the Si/Ge hetero-interface. Another important feature of photodetector is its quantum efficiency. Resonant cavity enhanced structure is used to improve the quantum efficiency of the photodetector. In Chapter 4, the quantum efficiency of resonant cavity enhanced Ge-on-Si Schottky photodetectors is discussed in detail. The noise performance including dark current, noise equivalent bandwidth, signal-to-noise ratio and minimum detectable power are investigated and discussed in Chapter 5. Some optimum designs of Ge photodetector for maximum bandwidth, quantum efficiency and bandwidth-quantum efficiency product are suggested in Chapter 6. Finally, in Chapter 7, a summary of the work and conclusion is given.
References:


