3.1 Introduction:

The basic physics governing the properties of heterostructures and quantum wells have been discussed in Chapter 2. Various pairs of semiconducting materials are used for fabricating these heterostructures of which Si-SiGe and GaAs-AlGaAs are most widely used. These semiconducting pairs have great advantage in device applications and the growth techniques are fairly advanced. Many devices like the high speed MODFETs, optical devices like stark effect modulators, infrared detectors are developed on SiGe and GaAs-AlGaAs systems. In this Chapter a review of the work already undertaken on the transport and thermoelectric properties of heterostructures fabricated using these two semiconducting pairs, has been presented.

3.2 Work on Si-SiGe Heterostructures:

Advances in SiGe heteroepitaxy have opened up prospects of integrating high speed heterojunction devices with conventional Si technology. Properties of bulk crystalline $\text{Si}_{1-x}\text{Ge}_x$ alloys were investigated many years ago by Glickmann (4), Paul and Warschauer (2), Dismukes et al (3), Feldman et al (4), Kline et al (5) etc. Recent work on bulk SiGe alloys has been done by Mitchard and McGill (6) in 1982, Takeda et al (7) in 1983, Krishnamurthy and Sher in 1985 (8) and Alonso et al in 1989 (9).

Extensive work has been done on hot compressed alloys by Amano et al in 1987 (10) because they are useful for thermoelectric applications. Paul et al (2) have shown that depending on the composition, the band gap of $\text{Si}_{1-x}\text{Ge}_x$ alloy varies from 1.1eV to 0.7eV corresponding to the wave length range of about 1.3$\mu$m to 1.5$\mu$m. This is very useful range for discrete optoelectronic devices for integrated optoelectronics on Silicon.

SiGe layers have properties appropriate for device applications. The first good quality pseudomorphic layers of $\text{Si}_{1-x}\text{Ge}_x$ on Si were grown by Kasper et al (11) in 1975. Si-Si$_{1-x}$Ge$_x$ heterosystems provide flexibility in
designing new devices because parameters of the materials on the two sides of the heterojunction can be varied. Si\textsubscript{1-x}Ge\textsubscript{x} structures improve existing devices.

A review of the experimental work already done on the fabrication of SiGe-based strained layer structure is given by Jain et al (49). The various devices based on SiGe structures and their performances are discussed in the review. The different devices already in existence are the Modulation Doped Field Effect Transistors (MODFETs), PIN photo detectors, Heterostructure Bipolar Junction Transistors (HBJTs), Double Heterostructure Bipolar Transistors (DHBJTs) etc. The properties of the carriers confined in Si\textsubscript{1-x}Ge\textsubscript{x} strained layer MODFETs are being thoroughly investigated as this will lead to an improvement in the device performance and their characterisation. When a Si\textsubscript{1-x}Ge\textsubscript{x} strained layer is sandwiched between two Si layers (p-type or n-type), holes or electrons migrate to the Si\textsubscript{1-x}Ge\textsubscript{x} layer where they form the two dimensional carrier gases. This type of structure is of great interest because the carriers confined in the structure are characterised by high mobility.

The n-channel SiGe MODFETs were fabricated by Daembakes et al (12) in 1986. Recently theoretical studies of the properties of 2DEG supported by Si-SiGe heterostructures have been done by Gold (13), Paul and Basu (14) etc. Gold has analysed the different scattering mechanisms such as impurity scattering, surface roughness scattering in Si-SiGe quantum wells. Paul and Basu have studied in detail the alloy scattering mechanism in Si-SiGe quantum wells. Experimental studies have also been carried out. Holzmann et al (15) have shown by magnetotransport studies that two spatially separated electron channels exist in Si-SiGe-Si heterostructures. Tobben (16) has established the presence of high mobility 2DEG confined in Si-SiGe heterostructure.

The p-type Si-Si\textsubscript{1-x}Ge\textsubscript{x} MODFETs are also gaining interest because they promise of high hole mobility. The transport and magnetotransport properties of these structures have been studied by Guldner et al (17), Loo et al (18) etc. Experimental values of hole mobility at different temperatures have been reported by Wang et al (19), Cheon et al (20), Loo et al (18), Guldner et al (17) and many other groups. The magnetotransport studies of the Si-Si\textsubscript{1-x}Ge\textsubscript{x}-Si heterostructures reveal the presence of two parallel highly
equivalent channels when the thickness of Si$_{1-x}$Ge$_x$ alloy layer is wider (>40nm) and a single channel for narrower alloy layer thickness (≤15nm). Therefore, the carrier distribution inside the Si$_{1-x}$Ge$_x$ layer is dependent on the width of the layer. It can be described by Fang Howard wave function for wider wells and Sinusoidal wave function for narrow wells. The aim of the present work is to develop a new well width dependent wave function which can suitably describe the carrier distribution in the SiGe layers at all well widths and can also explain the experimental values of hole mobility.

3.3 Work on AlGaAs-GaAs Systems:

Due to the various advantages of AlGaAs-GaAs system, this system is widely studied. Much investigations have already been done both experimentally as well as theoretically on AlGaAs-GaAs quantum wells and heterojunctions. The two dimensional electron gas systems supported by AlGaAs-GaAs heterostructures have been studied extensively. Theoretical work on 2DEG systems have been undertaken by many groups (23-27). The transport properties of the electrons along the plane of free motion have been well analysed by Riddoch and Ridley (24), Xu et al (25) Shah et al (26), Fischetti and Dimaria (27), Lei et al (28) etc in the mid 1980's. The theoretical models on which these studies are based (21-23,29,30) assume constant density of states function, parabolic E-K relation and mostly scattering at low temperatures where only one subband is occupied by electrons. The scattering mechanisms effective at low temperatures viz., deformation potential acoustic phonon scattering, background and remote impurity scattering, alloy and surface roughness scattering have been studied by Walukiewicz et al (31), Ridley (32) etc. Lee and Shur (33) have also calculated the low field mobility of 2D electron gas in modulation doped AlGaAs-GaAs layers. They have studied the scattering mechanisms operative at all temperatures. These include scattering by remote donors, interface charge, polar optic, acoustic deformation potential and piezoelectric scatterings. Theoretical studies on thermopower of 2D electron gas has been done using Mott formula (34). Thermopower has also been calculated by Kundu et al (35) using the formula predicted by Nag (36). The cyclotron resonance line width and transport properties at high fields have also been studied by different groups (28-30, 37,39). Investigation of the effect of magnetic field
on two dimensional electron gases have revealed the novel phenomena of QHE and Fractional QHE (40,41).

Experiments on 2D electron mobility in AlGaAs-GaAs systems were first reported by Dingle et al (42) in 1978. Later in 1984 Inoue and Sakaki (43) reported two dimensional electron mobility of much higher value than those reported earlier. Experimental work on 2DEG mobility was also carried out by many other groups (44) and mobility as high as 11.9 m^2 V^{-1} s^{-1} at 77K has been reported. The measurement of thermopower has been done by Nicholas et al (45).

The performance of the electrons in one dimensional systems were expected to be better than their two dimensional counterpart. Attempts were, therefore, made to fabricate structures supporting one-dimensional electron gases. Sakaki (46) was the first to prepare GaAs QWW supporting 1DEG. Thereafter, studies on one-dimensional electron gas were undertaken by many groups. The low field electron transport in 1DEG supported by GaAs QWW embedded in AlGaAs has been studied by Lee and Vassell (47) in 1984. They have analysed the different scattering mechanisms in one dimensional electron gas. Yuh and Wang (48) have also studied the scattering mechanisms in GaAs QWW and have proposed a novel one dimensional electron gas FET with high electron mobility. Lee et al (50) and Fishman (51) have studied the screening effect in GaAs QWW.

Recent studies on AlGaAs-GaAs quantum wires has been undertaken by Usagawa et al (52), Sato et al (53) etc. Work on the fabrication of GaAs quantum wires has been done by Hasegawa et al (54), Wang et al (55) etc. The photoluminiscence spectra in GaAs quantum wires has been studied by Someya et al (56).

Scattering theory of 1DEG supported by GaAs quantum wire surrounded by Al_xGa_{1-x}As has been studied more recently by Mickevicius and Mitin (57), Telang and Bandopadhyay (58,59) etc. Mickevicius and Mitin have demonstrated that acoustic phonon scattering becomes inelastic in quasi one-dimensional systems in contrast to that in bulk materials. The literature on the work of low-dimensional hole gases is quite limited. The physics of low-dimensional hole gases is relatively unexplored due to the complexity of the valence band structure. Therefore, further investigation of the properties of low-dimensional hole gases is important for better
understanding of the valence band structure. Moreover, the hole effective mass is anisotropic and selection of proper growth direction in low dimensions reduces the hole effective mass from bulk values. In strained layer structures, due to modification of energy band, the light hole bands get preferentially populated. Therefore, further study of the properties of low-dimensional hole gases may lead to the emergence of devices where the hole mobility will be comparable to electron mobility.

The study of low-dimensional hole gases have already been undertaken by different groups. Walukiewicz (60) have studied the transport properties of 2DHG in modulation doped AlGaAs-GaAs heterostructures. The variation of hole mobility with temperature and spacer width for different scattering mechanisms has been studied. Leo et al (61) have studied the resonant tunnelling of holes in AlGaAs-GaAs quantum well structures. Ekenberg and Altarelli (62, 63) have analysed the valence band structure of AlGaAsGaAs heterojunction. The E-K relationship has been obtained and the hole effective masses for different subbands have been determined. Stormer et al (64) have also obtained effective mass of holes. It has been found (65) that the effective masses given by Ekenberg give better agreement with experimental results.

Experimental works on 2DHG supported by GaAs-AlGaAs heterostructures have also been undertaken by many groups. The hole mobility, conductivity, drift velocity and field dependence of drift mobility has been studied experimentally by Reemtsmaa et al (66). Wang and Mendez (67) have also measured the hole mobility in AlGaAs-GaAs modulation doped structures. But the hole mobilities reported in these samples were much lower than the electron mobility. The hole mobility was expected to increase in strained layer structures but the reported mobilities (68) in these structures were also much lower than their electron counterpart. Later it was shown by Suemune and Coldern (69) that the effective mass of holes in one-dimensional quantum wires is very much reduced if proper growth direction is chosen. They have proposed a value of effective mass of holes in a GaAs quantum wire which is comparable to the effective mass of electrons in GaAs systems. In the present work the different scattering mechanisms limiting the 1DHG mobility, the screening effect and thermopower of 1DHG in a GaAs quantum wire has been studied and hole mobility has been calculated using the
effective mass proposed by the Suemune and Coldren. The hole mobility has been compared with the electron mobility for identical systems.
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