Chapter 1

Introduction

1.1 Introduction

Our everyday lives have been transformed by an advancement of electronic products such as television, computer, mobile phone, and satellite. All these products are contributed by the semiconductors technology. Especially, the development of the compound semiconductors provides a fruitful advantage. They allow a wide feature of device design that includes tunable energy gaps and an interested electronic property for any specific requirement. An example of the most important compounds is the III-V compounds; for example, GaAs, InP and GaN, and other typical compounds such as CdHgTe and SiGe. The devices which are based on compound materials have interesting properties such as high carrier mobility, low power consumption and high operational frequency. They play important roles in the research field of opto-electronic and high speed devices. Epitaxial techniques such as the molecular beam epitaxy allows the multilayer semiconductors to be fabricated with high accuracy in film thickness and composition concentration. Applications of semiconductor devices have been expanded by this new growth technique. The superlattice and modulation doping techniques are employed in order to improve electronic properties of devices via quantum wells. Electrical carriers which transport in quantum wells are considered as a two-dimensional carrier gas with high mobility especially at low temperatures. Examples of these advanced devices are

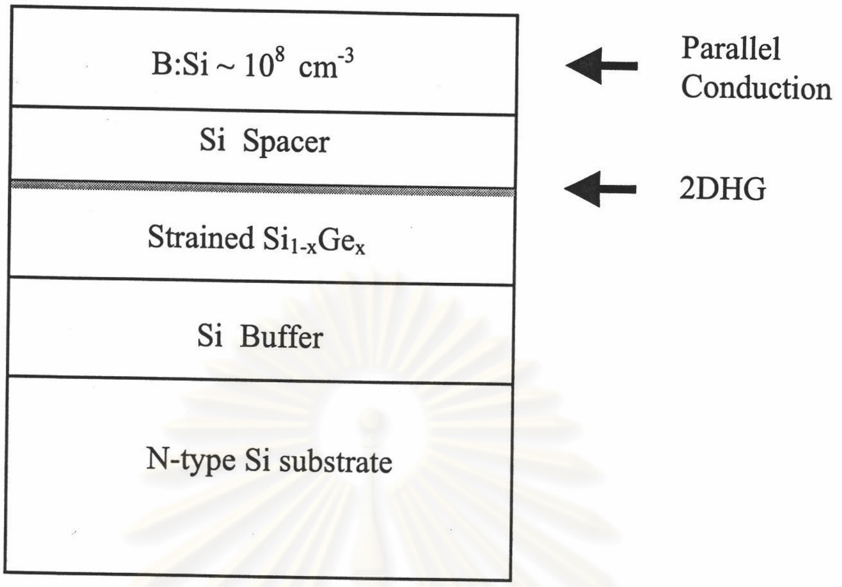

Figure 1.1: The modulation-doped $Si_{1-x}Ge_x/Si$ heterostructure contains 2DHG and a parallel conduction (after Kiatgamolchai(2000)).

heterojunction bipolar transistors (HBTs) and modulation doped field effect transistors (MODFETs).

To design electrical devices, required parameters are carrier concentration and mobility. They are used to explain the electrical transport in the interested material. The standard method for electrical characterization is a Hall measurement at single low-magnetic field with a simple model of electrical transport. This technique is generally used to identify types of semiconductor materials, mobility and carrier concentration. However, this technique can only be used to obtain net carrier concentration. It becomes inappropriate since the material is invented to have parallel conduction. The parallel conduction means that there is more than one conduction path within the material. Considering a diagram of modulation doped p-$Si_{1-x}Ge_x/Si$ in Fig. 1.1, there are a carrier group transports in a bulk boron-doped layer and another group in the quantum well at the interface between Si and $Si_{1-x}Ge_x$ layers. Those carrier groups have different mobilities. In this thesis, a carrier group that has a certain type of carrier and mobility is called a carrier species. Different carrier species respond to the magnetic field differently. As a result, the resistivity and Hall coefficient are varied with a magnetic field strength. To characterize these devices, the Hall measurement is performed at varying values of magnetic fields. Next, the pre-assumption about the number of species within a material is required. By fitting the required parameters to Hall data, the mobility and concentration of each species are estimated. This technique is called multi-carrier fitting technique [Colvard et al. (1989)]. However, using the fitting technique with a misassumption may lead to a wrong solution. The magnetic-field dependence of resistivity and Hall data are possible due to presence of the multi-carrier transport as same as an effect of energy-dependent relaxation time of one carrier species.

The mobility spectrum analysis is a calculation technique that the conductivity is described in terms of a continuous function of mobility. It does not require an initial guess of the number of carrier species. This non-destructive technique was firstly developed by Beck and Anderson (1987). It has been applied to a various number of semiconductor materials. The development of mobility spectrum with the discrete approach was proposed subsequently over the last 15 years in order to overcome the restriction and to improve the calculation accuracy such as the iterative method [Dziuba and Gorska (1992)], Quantitative Mobility Spectrum Analysis (QMSA) [Antoszewski et al. (1995)], improved-Quantitative Mobility Spectrum Analysis (i-QMSA) [Vurgaftman et al. (1998)], and Maximum-Entropy Mobility Spectrum Analysis (ME-MSA) [Kiatgamolchai et al. (2002*a*)]. Details of these mobility spectrum approaches are described in Chapter 3. However, the efficiency of mobility spectrum calculation is limited by the apparatus such as the maximum value of magnetic field strength and the level of experimental noise. The mobility spectrum is sensitive to the noise imposed on experimental data [Kiatgamolchai (2000)], and it usually leads to the misinterpretation of solution. Fig. 1.2 illustrates the mobility spectrum obtained from QMSA and ME-MSA for synthetic data sets

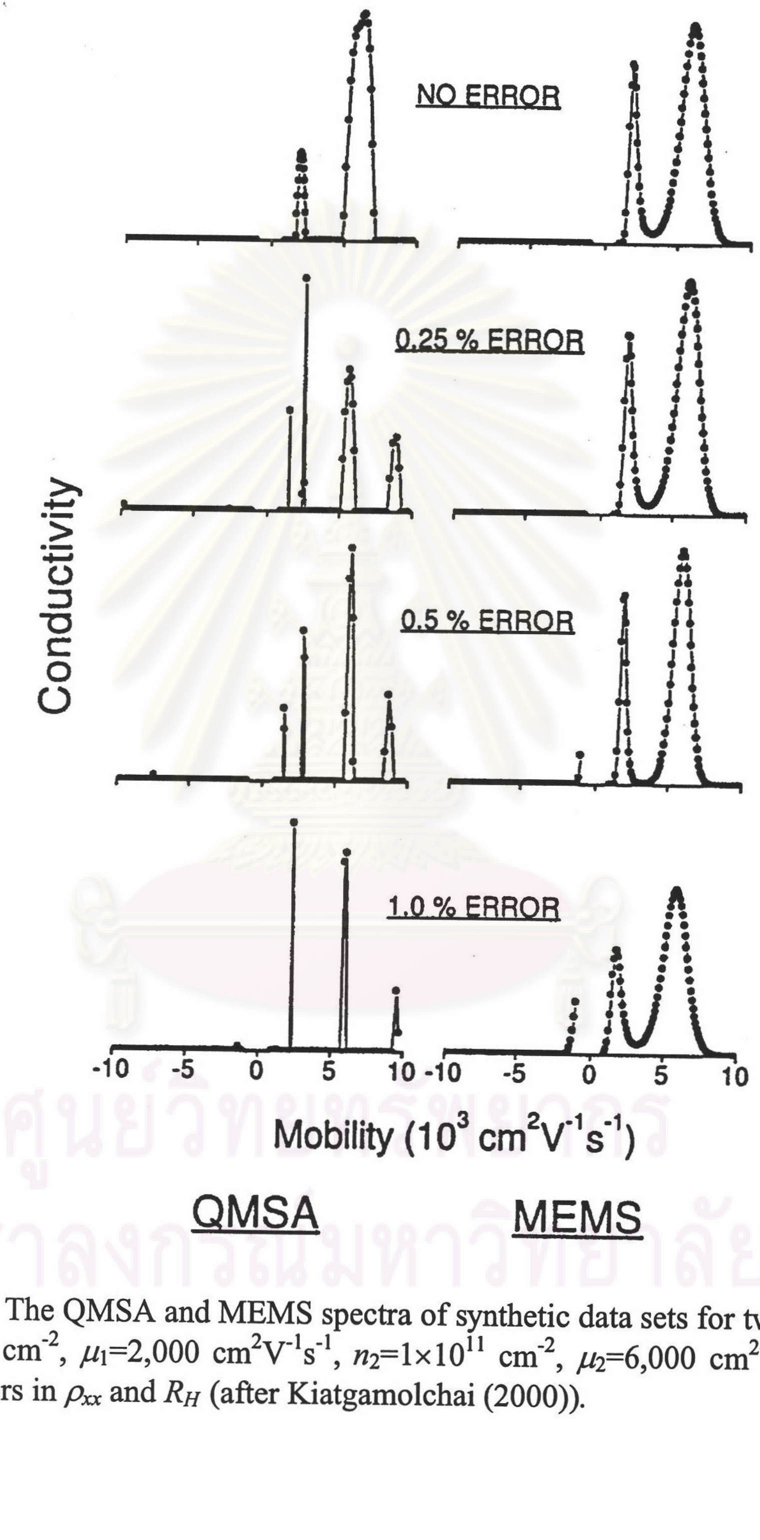

Figure 1.2: The QMSA and MEMS spectra of synthetic data sets for two carrier species (n_1=1×10^{11} cm^{-2}, μ_1=2,000 cm^{2}V^{-1}s^{-1}, n_2=1×10^{11} cm^{-2}, μ_2=6,000 cm^{2}V^{-1}s^{-1}) subject to various errors in ρ_{xx} and R_H (after Kiatgamolchai (2000)).

with different error levels. At high level of noise, the represented peaks in spectra do not correspond to the carrier configuration in data. Unfortunately, all existing mobility spectrum techniques do not provide an error bound of the solution. Thus the effect of noise in the data is hard to study directly through these calculation techniques.

1.2 Objective and scope of this thesis

This thesis is mainly concerned about the effect of the experimental noise in the data to the mobility spectrum calculation. For this purpose, a new calculation technique for mobility spectrum analysis is developed based on the Bayesian statistics and maximum entropy principle. By this new technique, the experimental noise is studied by a statistical point of view. Although there are many types of noise in measurement, we are interested only in a random noise; specifically, the voltage measurements. In addition, the error analysis will help analyze the obtained mobility spectrum with more confidence.

1.3 The structure of this thesis

The magnetotransport theory is explained in Chapter 2. The investigation of the magnetoconductivity tensor as a theoretical model of mobility spectrum problem and some background are presented. Next, in Chapter 3, a number of existing mobility spectrum techniques is described in details. Their usefulness and problems are discussed. Chapter 4 presents Bayes' theorem and information entropy as necessary tools which are used to develop the new mobility spectrum calculation technique. The formulation of a new technique based on Bayesian statistics and maximum entropy principle is presented. The calculation algorithm is also described with the demonstration on synthetic data. Chapter 5 is divided into three sections. The first section shows the result of synthetic data under various error conditions in order to test the efficiency of this method. Next section, comparison between the result of an experimental data obtained from our new method and from the maximum-entropy mobility spectrum method are considered. The error analysis is discussed in the third section. Conclusions and suggestions are in Chapter 6.