Chapter 1

Introduction

1.1 Background

In the past research on III-V compound semiconductor, epitaxial layers were grown by using Liquid Phase Epitaxy (LPE) technique. This technique, in which an epitaxial layer is grown on a single-crystal substrate by deposition from a molten solution saturated at the growth interface (e.g. growth of GaAs epilayer from a Ga-rich solution saturated with As) originated by Nelson in 1963 [1], is matched to processes of thick layer devices. An important limitation of the LPE technique is the difficulty of growing layers that differ in lattice constant by more than ~1% from the substrate. From the requirements of ultrathin layers growth technology, evaporation technique became in interest. From the late 1950's until 1960's, many evaporation techniques were introduced for growing epitaxial layer of III-V compound. However, most of the epitaxial films showed texture or twinning. Crystal structures could only be reported with electron and X-ray diffractions. Therefore, in general, the films were too poor to measure carrier mobilities or optical properties such as photoluminescence (PL) [2].

Molecular beam epitaxy (MBE) is an improved form of evaporation technique by using ultra-high vacuum (UHV) environment that can distinguishes from other evaporative crystal growth methods. This technique allows high quality epitaxial layers with excellent optical properties as well as carrier transport to be prepared. The term "molecular beam epitaxy" was first announced in crystal growth paper in 1970 by A.Y. Cho. [3]

The unique feature of MBE is the ability to prepare single crystal layers with atomic dimensional precision. MBE became in the front line of the crystal growth technologies when it prepared the first semiconductor quantum well and superlattice structures that gave unexpected and exciting electrical and optical properties.

Many materials have been crystallized as epitaxial thin films by MBE, but semiconductor of the III-V group in general GaAs and $Al_xGa_{1-x}As$ in particular have received most attention. This comes from the high-frequency properties and the unique optical properties of the III-V compounds comparing to Si. The ability to fabricate high quality lattice-matched AlGaAs/GaAs thin films as well as bulk crystal has made it possible to explore a large number of interesting intrinsic as well as extrinsic phenomena associated with the structural, optical and vibrational states of the system.

The alloy system AlGaAs/GaAs is potentially of great importance for many high-speed electronics and optoelectronic devices, because the lattice parameter difference between GaAs and AlGaAs is very small, which promises an insignificant concentration of undesirable interface states.

A number of interesting properties and phenomena, such as high-mobility low-dimentional carrier gases, resonant tunneling and fractional quantum Hall effect, have been found in the AlGaAs/GaAs heterostructure system. New devices, such as quantum-well lasers, modulation-doped FETs, heterojunction bipolar transistors, resonant tunneling transistors, and other photonic and quantum-effect devices, have also been developed recently using this material system. These areas are recognized as now being the most interesting and active fields in semiconductor physics and device engineering.

Most of the devices that described before need etching processes to make device forming so-called "Mesa structure" for creating device-separation and/or lateral confinement. Two mainly etching processes that are used in device fabrication are wet chemical etching and dry etching, such as reactive ion etching. These processes create "damage" onto the crystal surface and remove atomic site in the reactive area. The damages may still remain until to the end of device fabrication processes and may cause unexpected result on device properties.

One problem of the etching process is a practicality to fix number of atomic layer etched. Etching depth by using wet-chemical etching has not enough precision. It is hardly to control all the chemical conditions for reproduction. Undercut is also make complexity on lithography process due to the size compensation of the mask is required. Although plasma etching with biasing can solves the undercut problem. Faceting, trenching, and redeposition are three effects that arise from physical sputtering and can influence edge profiles in reactive etching [4].

At the present time, submicron and nanostructure technologies are being investigated. Normal lithography and etching seem to be not suitable for fabricating process. To leave remaining resist as dots or very narrow stripes with large spacing is too hard and undercut from etching procedure affects the mesa structure catastrophe. The advance techniques have been introduced but all of them mainly in novel lithograhy and etch controlling process research. When the lateral size of mesa structure becomes smaller than its height, etching process is then so complicate to control yield of the structures.

1.2 Objective

This research work proposes to introduce a novel technique to grow mesa structures of compound semiconductor, typically GaAs and related compounds through micro-*shadow mask*. By the shadow mask technique, the growth areas are selectable with openning the mask where we need. This shadow mask technique has many advantages comparing with other techniques. Mesa sidewalls have no any mechanically contact with anything during the growing process. By using MBE, the mesa structures could be grown with precise layer thickness and after the growth no mesa-etching process is needed. Without after growth etching means that the mesa structure sidewalls should have no etching defects that cause an improvement of the structure property.

The aim of this dissertation is to utilize the shadow mask technique for growing multi-quantum well structure of GaAs/AlGaAs on the GaAs substrate and to verify the selective epitaxial growth crystallography by using Photoluminescence as a main inspection technique. The quality of the selective growth epitaxy will be compared with the same structure that grown on the bare surface as conventional MBE.

Figure 1.1 compares the normal mesa structure fabrication process with an idea of shadow masked mesa growth. However, the substrate surface has been etched before the growing process to open the mask spacer as shown. This area could be treated by heating or annealing process in the UHV condition before MBE regrowth.

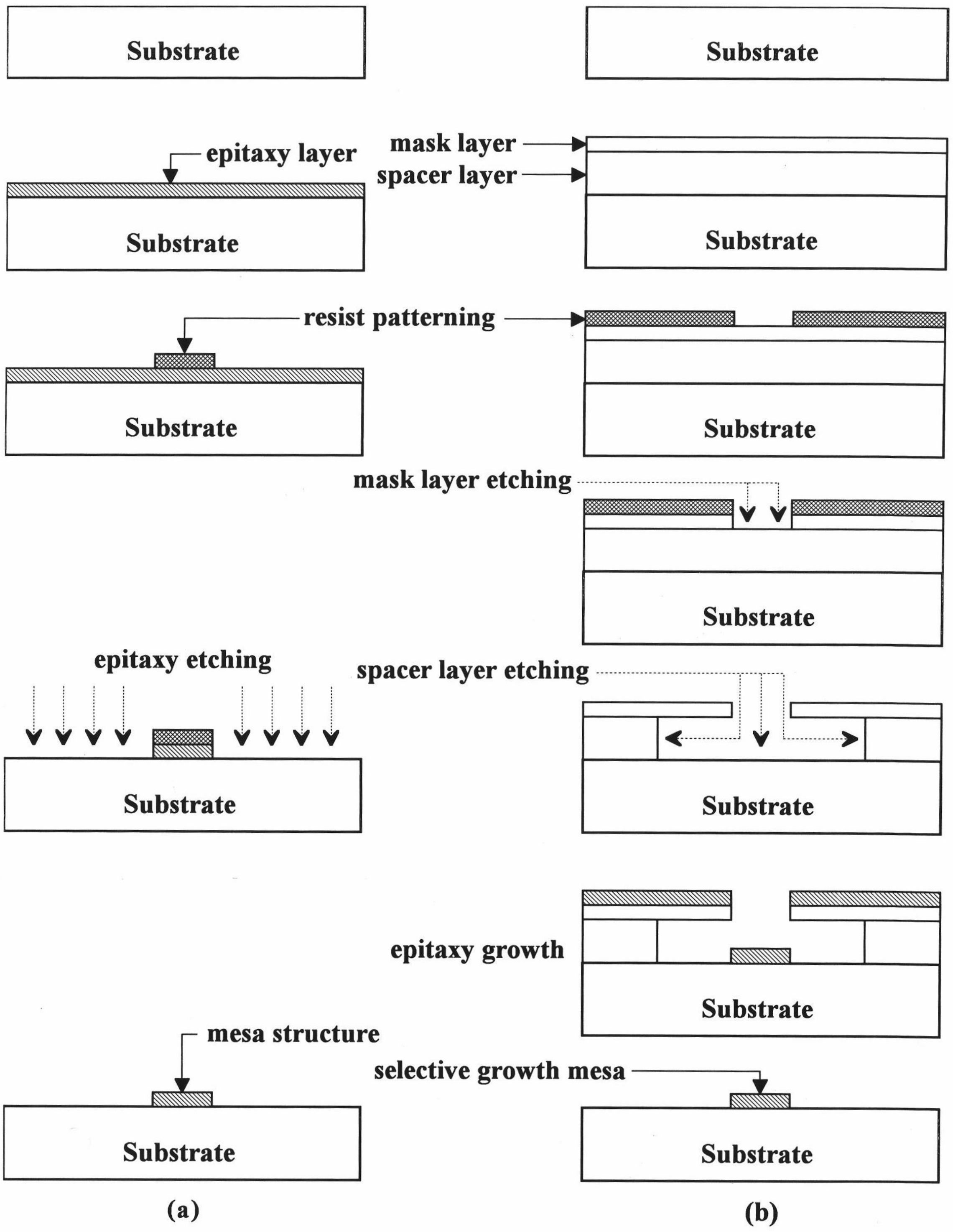

Figure 1.1 Mesa structure fabricated by conventional etching process (a) comparing with an idea of shadow mask technique (b).

1.3 Dissertation Contents

In chapter 2, the basic of the molecular beam epitaxy technique is described. The preliminary works on growing the GaAs, AlGaAs, bulk layers and multi-quantum well structures are recounted in chapter 3.

The details for the shadow mask preparation process will be described in chapter 4. This is the main controlling idea of this thesis. The research work for growing GaAs compound semiconductor by shadow mask onto GaAs substrate is emphasized.

Not only growing shadow masked GaAs/AlGaAs on GaAs substrates but also GaAs layer grown on Si substrate was studied in this research. The epitaxial growth of GaAs on the Si substrate is interested because it can mix together the excellent optical properties of GaAs and other III-V compounds with a comparative very low price and vigorous property of Si. Unfortunately, GaAs could not be easily epitaxial grown onto the Si substrate due to different physical properties. The shadow mask technique is adapted to prove the idea of selective growth of high lattice mismatch materials. These works are explained in chapter 5 and 6.

In chapter 7, the proposal for futher researchs on selective growth of the epitaxy by using shadow mask method is presented. The optoelectronic devices are mainly in the range of applications. The prelayer grown techniques by other groups show that significantly small effect of the lattice mismatch between GaAs and Si could be applied to the selective growth of III-V compound structures on Si substrates.

In the final chapter, the results attained from this dissertation work are concluded.