# Chapter 1

## *Introduction*

## 1.1 The Significance of Silicon Carbide

The technology of silicon carbide had reached tremendous development since the last decade. Silicon carbide has emerged as a potential material for high temperature, high voltage, and high frequency semiconductor devices fabrication due to its high saturated electron drift velocity, junction breakdown electric field and thermal conductivity. Silicon carbide crystallizes in several polytypes. Among the most common are 3C cubic or β-SiC, 6H hexagonal, and 4H hexagonal SiC. Each polytype exhibit its own characteristics. The cubic β-SiC has an appropriate band gap of 2.2 eV and electron mobility for high temperature and high power devices and can be deposited on silicon substrate (Calcagno *et al.,* 2002).

Being the most elaborated wide band gap semiconductor material, silicon carbide (SiC) became the best candidate to replace conventional semiconductors in hard electronics applications. Naturally, the physical and chemical properties of silicon carbide are excellent for use in high temperature electronic devices, high-power switching and high-frequency power generation.

In optoelectronic applications, hydrogenated amorphous silicon carbide (a-SiC:H) were applied as optical coating for solar cells, as well as in light-emitting diodes and X-ray lithography masks. Laser annealing of a-SiC:H could be used to produce microcrystalline silicon carbon (μc-SiC) alloy at low substrate temperatures in order to develop further applications in solar cells and light-emitting diodes (Kaneko *et al.,* 2005).

A variety of high power devices, short wavelength optoelectronic devices and circuits demonstrations have been produced in addition to volume production of LED's fabricated on silicon carbide wafers. The main advantage of silicon carbide compared to other materials such as gallium nitride and diamond is the availability of substrates allowing homoepitaxial growth of layers and structures needed for fabrication of different devices. The growth of epitaxial layers is also possible with high growth rate to a thickness of over 100 µm (Yakimova *et al.,* 2001, Kordina *et al.,* 1998, Syvararvi *et al.,* 2000). The availability of silicon carbide as wafers especially of 6H and 4H polytypes has been the encouraging factor to the growth of these devices. On the other hand, crystalline silicon carbide films are also grown on silicon substrates. Besides being relatively economic, the coalition of silicon carbide with the low cost silicon substrate is very advantageous because it combines the excellent properties of silicon carbide with the well known silicon technology. However, the production of this combination still requires solution for some technological problems.

## 1.2 Problem Statement and Motivation of Research

Silicon carbide thin films definitely have great potential in various technological and commercial applications. The unique properties of silicon carbide thin films arise from the strong dependence of their properties on the bonding configurations and the incorporation of carbon in the films. The structure and incorporation of carbon in silicon carbide films are determined by the composition of the gas mixture in the deposition process which in turn determines optical properties of the film. Optical energy band gap can be changed by varying the deposition parameters. The influence of deposition parameters like deposition temperature, pressure, discharge power, gas flow rate ratios on the film properties of silicon carbide film is crucial. Therefore, it is possible to obtain silicon carbide thin films with a wide range of properties by varying the deposition parameters during the growth process. In order to study the effect of the deposition condition on the film properties, it is very important to be able to produce the silicon carbide thin film in-house.

In the past years, numerous innovations in the use of Chemical Vapour Deposition methods have been established for the synthesis of silicon carbide thin films. However, a commercialized deposition system is technically expensive and lacks the flexibility of design modification for future research. Building an in-house deposition system would open the possibility to close re-adjustment and custom made to satisfy to various demands and applications. This is based on the belief that a home-built deposition system does not limit the feasibility of modifying the system to suit the research requirements. Building an in-house deposition system also provide expertise to researchers with the technology of deposition systems besides the technology of fabricating new functional material.

In order to fulfill this, a deposition system which could adopt multiple plasma-enhanced chemical vapor deposition techniques is worked out in this research. The system should be made feasible to the use of Radio Frequency (RF) and Direct Current (DC), and also be able to accept the presence of Hot-Wire. The novelty of this work will lie on the building of a hybrid plasma enhanced chemical vapour deposition system which comprises Direct Current and Hot-Wire.

## 1.3 Focus and Objectives of Research

This dissertation is mainly focused on the preparation techniques that would provide the desired qualities of silicon carbide thin films to be used as active layers in optoelectronic devices and applications. For this, a deposition system is designed, built and utilized. The system is made flexible to adopt multiple plasma-enhanced chemical vapor deposition techniques which include the utilization of Radio Frequency (RF) and Direct Current (DC). Hot-Wire (HW) chemical vapor deposition is also adopted into the system to provide as one of the deposition techniques. In later works, a hybrid plasma enhanced chemical vapour deposition system comprising of Direct Current and Hot-Wire was designed as an innovative attempt in order to investigate the outcome of combining the two techniques. This method of thin film deposition is thus referred to as Hot-wired Plasma Enhanced Chemical Vapor Deposition or HW-PECVD technique. Hydrogen atoms were then introduced as an added factor to more promising results. Other deposition parameters such as the gas flow rate ratio and applied DC voltage were also utilized in each of the deposition technique. The effects of these parameters on the growth mechanism and optoelectronic properties are investigated through this research.

Therefore, the first phase of this research is focused on designing and building the reaction chamber for a Plasma Enhanced Chemical Vapor Deposition (PECVD) system which is able to produce silicon carbide thin films. The reaction chamber is designed to be powered by RF and DC and is also feasible to the use of hot-wire.

The second phase of the work is focused on ensuring that the home-built PECVD system is in perfect working order and is therefore able to produce good quality and reproducible silicon carbide thin films. For this part of the work, silicon carbide thin films produced by RF-PECVD technique at a fixed RF power are studied. This technique is used since it is widely used in producing silicon carbide thin films and is known to produce high quality films and at high deposition rates. The next phase of this work involves silicon carbide thin films prepared using DC-PECVD technique. This technique is used because very few researches have been done on silicon carbide thin films deposited by this method. It offers easier operation and is more economical, and therefore the research could be done in laboratories with limited research funding. HW-CVD technique is also adopted into the research due to its prosperous traits with regards to silicon carbide.

In the third phase of the work, a HW-PECVD technique is designed and utilized because it is found that the results from DC-PECVD and HW-CVD deposition techniques have compromising qualities that would compliment each other in the path towards desired thin film qualities. The effects brought by hydrogen atom in providing interesting results have not been left behind. Therefore, the final phase of this work includes hydrogen dilution and hydrogen as surface treatment agent which is expected to produce silicon carbide thin films with nanostructures.

In characterizing the prepared thin film samples, the optical transmission spectra of the films was obtained using the ultra-violet visible near-infrared (UV-Vis-Nir) spectrophotometer to estimate the deposition rate and to study the optical properties of the films. Chemical bonding and vibration properties of the films were studied through Fourier Transform Infrared (FTIR) spectroscopy, micro-Raman scattering spectroscopy and X-ray diffraction (XRD) spectroscopy techniques.

In the exertion of establishing all of the above mentioned, the objectives of this research is outlined as the followings;

1. Build a reaction chamber for a deposition system that is able to produce silicon carbide thin films with the feasibility of applying multiple techniques using radio frequency (RF), direct current (DC) and hot-wire (HW).
2. Prepare and characterize silicon carbide thin films using RF-PECVD technique, DC-PECVD technique and HW-CVD technique independently.
3. Compare the independently prepared silicon carbide thin films using RF-

PECVD technique, DC-PECVD technique and HW-CVD technique.

4. Build a novel hybrid HW-PECVD system comprising of DC-PECVD technique and HW-CVD technique.
5. Produce silicon carbide thin films with large range of optical energy band gap using the novel hybrid HW-PECVD system.

## 1.4 Outline of the Thesis

Chapter 1 begins with a brief introduction on the research title. It is followed by research background which outlines the production of silicon carbide thin films in this work. Chapter 1 also outlines the research goals by describing the focuses and motivation of the studies and importance of the research. A brief description of each subsequent chapter is also presented in this section, which gives the outline of the thesis.

The literature review done by the author in the attempt of providing basic information on the current scenario of the materials research is presented in Chapter 2. Chapter 2 provides useful information on the previous works done in the field of research. This is followed by a discussion on the influence of deposition parameters in silicon carbide thin films and the literature review on growth techniques and growth mechanism of silicon carbide thin films. Common characterization used to analyze the silicon carbide thin films along with its discussion on the main issues are also presented in Chapter 2.

Configuration on the experimental set-up and design of the chamber and the whole PECVD system is done and described in Chapter 3. Here, the experimental details for this work are explained. The analysis methods, characterization procedures and calculation techniques used to analyze results obtained from the measurements for their optical and chemical bonding properties are described. Chapter 3 also covers the scope of work and experiments done in pursuing the objectives of this dissertation.

Chapter 4 unveils the experimental results of optical and chemical bonding properties of the silicon carbide thin films prepared in the early phases of this work. Results include the spectroscopic analysis provided by the Ultra-Violet (UV), Infra-Red (IR), micro-Raman and X-Ray Diffraction (XRD). The results are presented in the sequence of deposition technique starting with RF-PECVD, followed by DC-PECVD and HW-CVD. The effects of methane to silane gas flow rate ratio on the deposition rate, optical energy band gap, bonding configurations and structure of the films produced in this work are discussed in this chapter.

Chapter 5 reports the result of the optical and chemical bonding properties of the silicon carbide thin films prepared using the HW-PECVD technique. The effects of applied DC voltage, hydrogen dilution and hydrogen surface treatment on the deposition rate, optical energy band gap, bonding configurations and structure of the films produced were discussed in this chapter.

Finally, Chapter 6 concludes the overall research findings which are previously discussed in Chapter 4 and Chapter 5. Some suggestions for the advancement of this research for future researchers and other possible applications of the deposition system are also mentioned in this chapter.