Chapter 6

Conclusions

6.1 Conclusions

Studies on HW-PECVD deposition system for the preparation of silicon carbide thin films have been carried out successfully. The home-built HW-PECVD deposition system designed and built for this work has been shown to be able to produce good quality and reproducible silicon carbide thin films from pure silane and pure methane discharge. It was found that through all the deposition techniques, the deposition rate, optical energy gap and the Si-C and Si-H bonding configurations of the silicon carbide thin films are consistently influenced by methane to silane gas flow rate ratio, DC voltage applied across the electrodes and the presence of hydrogen atom during deposition.

The work has started by successfully designing and building a reaction chamber for a deposition system that can be utilized to produce silicon carbide thin films by multiple techniques. Thus, the first objective of this work was achieved at this stage. The second objective was achieved when the first part of the work has proven the ability of the newly built deposition system to produce silicon carbide thin films via RF-PECVD, DC-PECVD and HW-CVD techniques independently.

Characterization of the silicon carbide thin films prepared using RF-PECVD technique, DC-PECVD technique and HW-CVD technique were done via Optical transmission spectroscopy, Fourier Transform Infrared spectroscopy, X-Ray Diffraction spectroscopy and micro-Raman spectroscopy techniques. Studies involves the effects of methane to silane gas flow rate ratio on the film deposition rate, optical energy gap, Si-C and Si-H bonding configurations and formation of Si and SiC crystal structures. Studies in this part ensured that the home-built deposition system is in working order and is capable of producing good quality and reproducible silicon carbide thin films via different deposition techniques. Thereby, the third objective of this research is also met where the silicon carbide thin films prepared independently using RF-PECVD technique, DC-PECVD technique and HW-CVD technique were studied and compared.

The RF-PECVD technique developed in this system is able to produce silicon-rich amorphous silicon carbide thin films with deliberately high optical energy band gap. Increase in methane to silane gas flow rate ratio has enhanced the formation of Si-C bonds which in turn increases the optical energy band gap of the films. However, the concentration of Si-C radicals is still lower than that of Si-H radicals thus has made the film rich in silicon. At all values of R, the silicon carbide film prepared by RF-PECVD is mainly amorphous with the optical band gap values for the film stays within the band gap range of amorphous silicon (2.0-2.2 eV).

The DC-PECVD technique from the system provides the lowest rate of film deposition as compared to the other techniques. DC-PECVD technique is suggested for silicon carbide thin film preparation where low deposition rate is concern. By this technique also, the deposition rate of the silicon carbide films is least affected by methane to silane gas flow rate ratio. Nevertheless, the optical band gap energies for the silicon carbide thin films prepared by DC-PECVD technique are among the highest range and are enhanced by increasing value of R. The highest value obtained is 2.52 eV as prepared with R=14. This result is dedicated to the film microstructure where it is mainly built of amorphous silicon carbide. The film is dominated by Si-C based radicals but the concentration of Si-H_n bonds increases along with appearance of face-centered cubic-Si nanocrystals as R increases.

Compared to other deposition techniques, HW-CVD technique provides the highest growth rate of silicon carbide thin films. Like other techniques, methane to silane gas flow rate ratio also affected the deposition of silicon carbide thin films prepared by HW-CVD technique. By this technique, the film deposition rate increases rapidly as *R* increase for preparation with *R*>4. However, silicon carbide thin films prepared by HW-CVD had small optical energy band gap as compared to other techniques (1.63–1.85 eV). It is suggested that silicon carbide thin films deposited using HW-CVD technique in this work is mainly built of amorphous-Si and amorphous-SiC but traces of crystalline silicon were found for films prepared with low values of *R*.

Although the deposition system has successfully produced silicon carbide thin films with desired properties, works were continued to prove the availability of the system to cater to the importance of hydrogen gas. This has led to the second part of the work which revolves in deposition of silicon carbide thin films by HW-PECVD technique. This part involves utilization of both DC-PECVD and HW-CVD techniques to produce new quality silicon carbide thin films. This has accomplished the fourth objective of the work and lead to the novelty of this research work. Studies in this part include the role of hydrogen as an agent to produce crystalline nanostructures. In this work, it was proven that the built HW-PECVD system is capable of applying hydrogen gas either by gas dilution or by individual flow into the reaction chamber which later has let the hydrogen gas to act as surface treatment agent. Hydrogen surface treatment has helped to increase the carbon incorporation in the silicon carbide film produced by this technique.

Overall, the deposition system built in this work allows control over some properties of the thin film. The optical energy band gap of the silicon carbide films prepared in this work is varies in a large range from 1.63 eV to 3.26 eV. This result shows that the hybrid deposition technique developed in this system has enabled the production of silicon carbide thin films with large range of optical energy band gap and successfully satisfied the fifth and last objective of this research. The lowest optical energy band gap is obtained from HW-CVD technique while the highest value is obtained by HW-PECVD technique with applied DC voltage of 1000 V, without any assistance from hydrogen atoms. The film deposition rate can also be controlled using selected deposition techniques. Low deposition rate can be achieved by using DC-PECVD technique while high deposition rate can be performed by applying HW-CVD technique.

Over the multiple ranges of deposition parameters allowed by the system built in this work, a variety of silicon carbide thin film was produced. Spectroscopy analysis has shown that the system is capable of producing either totally amorphous silicon carbide thin film or multiphase silicon carbide thin film which has silicon nanocrystallites embedded within its amorphous silicon carbide matrix.

6.2 Suggestion for Further Works

Time constraint has put a pause to this work but given more opportunity, more experiments could be done and the study would be much improved. Studies on the silicon carbide film properties using HW-PECVD would have been more conclusive if technical constrains regarding the deposition system could be overcame more quickly. The time spent on building and testing the capability of the reaction chamber during the first phase was almost two years and was extended to another year when the second phase of the work was introduced. Much of the time was consumed in the process of determining the best suit parameters to comply with the maximum potential and overcoming drawbacks of the built system. This has lead to a very limited time for in depth studies on the prepared films.

However, the HW-PECVD system developed in this work will certainly benefit many researchers working on silicon carbide thin films or other materials. Despite several set-backs encountered during the process of completing this work, the most important objective of the work has been achieved. Studies on the influence of methane to silane gas flow rate ratio, applied DC voltage, hydrogen dilution and hydrogen surface treatment on the properties of the silicon carbide films will be useful for other researchers who would use this system in future and would probably obtain more beneficial results.

A clinch suggestion that could be put upon here is the production of SiC nanocrystallites which is highly possible by reducing the silane gas flow rate to a very small value thus providing a high value of R. This is trailed from the results of the hydrogen dilution experiment carried out using the HW-PECVD technique where the two extreme values of R were compared. The work done on the individual RF-PECVD, DC-PECVD and HW-CVD techniques also suggest increased properties with increasing values of R. Otherwise, manipulation of hydrogen gas flow into the reaction chamber could also be an interesting study in the search for nanostructures.

The effects of substrate bias on the produced silicon carbide thin films would be very significant since ion bombardment effects is an important factor in influencing the film properties. Layer-by-layer hydrogen plasma treatment on the film growth surface would progress this work into producing thin films with silicon nanocrystallites embedded within the amorphous silicon or amorphous silicon carbide structures. This kind of film will give many interesting properties and potential applications. Studying the morphology of the silicon carbide films using SEM and AFM would provide more significant findings. Auger and depth profile analysis would also be useful in analyzing the films deposited using different deposition time and thickness. In the constriction of time provided, these studies were not able to be done and presented in this work.

Indeed, there is no end to suggestions for further works because this work has a lot of potential for more interesting research findings. The home-built PECVD system developed in this work will benefit researchers in the institution and other researchers in Malaysia who are keen to study any thin film materials that can be deposited using this technique. The technology of building similar deposition system can always be transferred to other researchers in Malaysia. Technology developments such as this would definitely contribute to the nation’s development in Science and Technology. Therefore, contribution of this work in promoting further research in thin films especially silicon carbide thin films is indeed very significant and undeniable.