OPTICAL PROPERTIES MEASUREMENTS OF NANOCRYSTALLINE SILICON THIN FILMS

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For my ever-supportive family

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ABSTRACT

Nanocrystalline silicon (nc-Si) thin films on 7059 corning glass substrate were prepared using Very High Frequency Plasma-Enhanced Chemical Vapour Deposition (VHF-PECVD) at different deposition temperatures. The nc-Si properties films were analyzed using spectroscopic ellipsometer, ultra violet (UV-VIS) spectrophotometer and luminescence spectrometer (PL). The thickness and optical constants of the films were investigated as a function of deposition temperature (T_d) as T_d increased the thickness and refractive index increased whereas the extinction coefficient decreased. Based on the transmission spectra, the nc-Si films found to have transmission percentage above 40% for the red visible spectrum wavelength. The photoluminescence spectra of nc-Si films excited at 498 nm showed a single peak in the range of 1.84 - 1.95 eV (636 - 675 nm) and excited at 388 nm also showed a single peak in the range of 2.15 - 2.30 eV (539 - 578 nm). Both of these peaks were at energy higher than the band gap energy (E_{band}) obtained by using Tauc plot method which was around 1.7 - 1.8 eV. The peak energy was found to be shifted as T_d changes. It was found that the decrease in T_d acts to increase the values of E_{band} and the PL peaks showed red shift.

ABSTRAK

Filem tipis nanokristalin silikon (nc-Si) di atas substrat kaca Corning 7059 telah disediakan dengan menggunakan teknik deposisi wap kimia dengan plasma yang berfrekuensi yang tinggi (VHF-PECVD). Sampel-sampel disediakan dengan suhu deposisi (T_d) yang berbeza. Filem-filem nc-Si dianalisis menggunakan spektroskopi ellipsometer, ultra violet (UV-VIS) spektrofotometer dan luminescence spektrometer. T_d didapati adalah sebagai fungsi bagi ketebalan dan pemalar-pemalar optik. Ketika T_d meningkat, ketebalan dan indeks bias meningkat sedangkan indeks penyerapan berkurang. Berdasarkan spektrum penghantaran, filem nc-Si mempunyai peratusan penghantaran yang tinggi pada panjang gelombang spektrum merah, iaitu melebihi 40%. Spektrum fotoluminesen (PL) bagi nc-Si diuja pada gelombang 498 nm menunjukkan puncak tunggal sekitar 1.84 - 1.95 eV (636 - 675 nm) dan diuja pada gelombang 388 nm juga menunjukkan puncak tunggal sekitar 2.15 - 2.30 eV (539 - 578 nm). Tenaga bagi kedua-dua puncak tersebut adalah lebih tinggi daripada jurang tenaga optik (E_{band}) yang diperolehi dengan kaedah Tauc, iaitu sekitar 1.7 – 1.8 eV. Puncak tenaga ini didapati berubah mengikuti perubahan T_d, didapati bahawa penurunan T_d bertindak untuk meningkatkan nilai E_{band} dan puncak PL menunjukkan pergeseran merah.

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T_d	-	Deposition temperature
E_{band}	-	Energy band gap
E_{PL}	-	Photoluminescence energy
I_a	-	Anodization current
A	-	Absorption
R	-	Reflectance
T	-	Transmittance
ρ	-	Complex reflection coefficient
I_0	-	Intensity of the incident light
α	-	Absorption coefficient
c	-	Light speed
k	-	Extinction coeffiecient
v	-	Photon frequency
λ	-	Wavelength
h	-	Planck's constant
E	-	Photon energy
n^*	-	Complex refractive index
ψ	-	Arc tangent factor
Δ	-	Phase difference
P_1	-	First polarizer reading
P_2	-	Second polarizer reading
A_1	-	First analyzer reading
A_2	-	Second analyzer reading

CHAPTER 1

INTRODUCTION

1.1 Introduction

Thin film is a layer of material deposited on a substrate with thickness in range of 10 to 1000 nm (Chopra, 1969). Groove (1852) discovered the sputter phenomena in which thin film can be generated in a vacuum environment. The physical properties of films such as optical, chemical, magnetic and electrical are important in industrial and technical applications.

Silicon has been widely used in semiconductor industry for the past several decades but not in optoelectronics. This is due to the indirect band gap in the electron energy structure and low photoluminescence (PL) efficiency (Pavesi et al.,2000). Semiconductors in group III-V, like GaAs have very good optical and electronic properties due to the direct band gap, but they are very expensive in manufacturing. However, in nanocrystal form of silicon, the silicon properties change drastically presenting a direct band gap with emission in the wavelength range of 600 to 1000 nm in which depending on the nanocrystal size distribution. Due to the specific optical properties of nanocrystalline silicon (nc-Si), it has been widely used in electronic application and as replacement for other materials to save costs. Recently, nc-Si has been intensively studied due to the potential applications in silicon based optoelectronics because nc-Si exhibits a quantum size effect.

Nc-Si can be produced with several different techniques such as ion implantation, ion beam sputtering, HF sputtering, RF sputtering, RF magnetron sputtering, pulsed laser deposition, low pressure chemical vapor deposition (LPCVD) and plasma enhanced chemical vapor deposition (PECVD). Compared with other fabrication methods, PECVD has been extensively used in large area of thin film technology and industrial applications. This is because nc-Si thin films formed by PECVD have shown strong and stable photoluminescence, strong structure and good surface passivation (Ali, 2008).

1.2 Research Background

Deposition of nanocrystalline silicon thin film was first reported in 1967 by Veprek and Maracek, in which the silicon was sputtered and the product was transferred to substrate in low temperature condition. Nc-Si is the most potential material in solar cell thin film manufacture due to its high efficiency photoluminescence and low cost production. When light incident on an nc-Si thin film, some of the lights are reflected, some absorbed and some are transmitted. Transmission is the main parameter which makes a basic to their optical characterizations. The transmission will be reduced if the films thickness is thicker due to large size of grain boundaries (Karim Deraman, 1997).

Ali *et al*. (2006) had carried out experiment on hydrogenated nanocrystalline silicon (nc-Si:H) produced by PECVD technique using $SiF_4/SiH_4/H_2$ gas mixtures. They examined the photoluminescence (PL) of nc-Si:H by varying the deposition temperature (T_d) from 95 to 250°C under two different hydrogen flow rate conditions. They found out that the PL exhibited two peaks at around 1.7 - 1.75 and 2.2 - 2.3eV. The peak energy (E_{PL}) of the 1.7 - 1.75eV PL band was found to shift as T_d or flow rate changes. The decrease in T_d acts to decrease the average grain size, $<\delta>$, and to increase both the optical band gap, E_{band} , and the E_{PL} values. By contrast, the increase in flow rate decreased the $<\delta>$ value, while increased the values of E_{band} , and the E_{PL}. They proposed that the use of both low T_d and high flow rate conditions would allow to grow nc-Si:H films with small grains. They reported that the first 1.7 - 1.75eV peak is related to nanostructure in the films and the 2.2 - 2.3eV peak was associated with SiO related bonds.

Toshihiko *et al.* (1997) had investigated the optical and structural properties of nc-Si thin film exhibiting blue-band PL at room temperature. The nc-Si was grown by rapid thermal annealing (RTA) at 800 - 1200°C for l - 5 min in vacuum on crystalline Si substrates. They found out that PL intensity is increased with the annealing time and temperatures, while the peak energy of 2.5 - 2.7eV which is almost independent of the rapid thermal annealing temperature and time.

Ghriba *et al.* (2010) had studied optical properties of nc-Si deposited by PECVD on porous aluminum (PAL) structure. They found out that the PL emission lies in the orange region of the visible spectral range. The PL band peak position varies from 616nm to 624nm or 2 to 1.98eV as the anodization currents I_a increases from 200 to 400 mA. They reported that PL does not seem to have its origin only from silicon nanocrystals embedded in the porous aluminum matrix, as proposed by Ong and Zhu (2002) but it is due to the contributions of the two materials that is the Si incorporated in

PAL. They also shown the PL peak position represents a blue shift as the nc-Si size decrease.

Choi *et al*. (1998) reported that the PL spectra of nc-Si films excited by the 488nm line of an Ar laser show a single peak at about 2.1 eV which similar to the optical band gap. The nc-Si films in their research were deposited on Corning 7059 glasses in a remote plasma chemical vapor deposition (RPCVD) reactor. They also found that the PL spectra of nc-Si films excited by 325 nm line of HeCd laser were similar to those of thermally grown silicon oxide films. It shows three peaks at about 1.6, 2.5, and 3.1eV. They reported that the PL excited at 325 nm is produced by Si-O related effects in the surface oxide layer of nc-Si films, while the PL excited at 488 nm is caused by light emission in the amorphous silicon-like bulk region of nc-Si films.

1.3 Problem Statement

The nc-Si can be prepared by several deposition methods such as PECVD, RPCVD, RTA and pulsed laser deposition. The PL spectra depend on the conditions of deposition process and the material of substrates. Some deposition method require high deposition temperature, for example, high quality silicon dioxide films can be deposited at 300 to 350^{o}C with PECVD while CVD requires temperatures in the range of 650 to 850^{o}C to produce similar quality films. This shows that the deposition method and deposition temperature will affect the properties of the films such as refractive index, thickness and other optical properties of thin films. In order to control the structure and properties of thin film for specific purpose in application, it is important to study the relation between the deposition temperature with the optical properties and thickness of thin film. The issue is that the previous research only highlights the deposition temperature which is lower than 200^{o}C but very seldom consider for higher deposition temperature. Thus, this experiment will attempt to investigate the optical properties of nc-Si films which deposited by PECVD method at different deposition temperatures.

1.4 Objectives

The deposition temperature will affect the optical properties and thickness of nc-Si, this project is to study the relation between them. Nanocrystalline silicon (nc-Si) will be deposited by using very high frequency plasma enhanced chemical vapor deposition (VHF-PECVD) with temperature between 200^{o}C to 450^{o}C. Ellipsometer will be used in this project to study the optical constants of nc-Si. The transmission, reflectance and absorption spectrum are analyzed by using ultra violet visible near infrared (UV-VIS-NIR) spectrophotometer. The photoluminescence spectrometer will be used to study the E_{PL} of nc-Si. The objectives of this project are:

i) To grow the nc-Si thin films by VHF-PECVD at deposition temperature of 200^{o}C to 450^{o}C.
ii) To determine the thickness (d), refractive index (n), and extinction coefficient (k) of nc-Si films using ellipsometer.
iii) To analyze the effect of deposition temperatures between optical constants of nc-Si (thickness, refractive index, and extinction coefficient).
iv) To determine the optical parameters (absorption coefficient and energy band gap) using UV-VIS-NIR spectrophotometer and LS55 Luminescence spectrometer.

1.5 Scope of Work

The scope of work is divided into following parts:

1. Preparing the nanocrystalline silicons by VHF-PECVD method at deposition temperatures of 200^{o}C to 450^{o}C.
2. Using the ellipsometer to measure thicknesses, refractive indices, and extinction coefficients of nc-Si films.
3. Plotting graph to show the relation of deposition temperatures with thicknesses, refractive indices, and extinction coefficients of nc-Si films.
4. Using UV-VIS-NIR Spectrophotometer to plot reflectance, transmittance and absorptance spectra of nc-Si films.
5. Using the absorptance spectra to calculate the energy band gaps of nc-Si films.
6. Using luminescence spectrometer to determine the energy band gaps of nc-Si films.

1.6 Thesis Outline

Chapter 1 reviews some previous works done related on optical properties of nc-Si films. The objectives and scopes of the study are also discussed.

Chapter 2 covers the literature review related to the study. This includes the structure of silicon, thin film deposition techniques, ellipsometry, UV spectrophotometer, photoluminescence spectroscopy and basic theories on optical properties.

Chapter 3 describes the preparation of the materials and the method of experiments to collect data and method to analyze data.

Chapter 4 shows the data of the experiments and the way that the data are presented. By using appropriate data analysis, the relation of deposition temperatures with optical properties are presented and discussed.

Chapter 5 concludes the results of this study and suggests the works to be carried out in future related to this research.

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