Studies of Si Quantum Dots synthesized at different working pressure

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Abstract

This research paper describes the synthesis and characterization of Si quantum dots prepared by PVCT at the working pressures of 10 Torr and 20 Torr with substrate temperature at 77 K using liquid nitrogen. The synthesized quantum dots were characterized by high resolution travelling electron microscope (HRTEM) and UV-visible spectroscopy. HRTEM images of synthesized quantum dots suggest that the size of quantum dots varies from 8-10 nm. On the basis of UV-visible spectroscopy measurements, a direct band gap has been observed. The temperature dependence of the dc conductivity of thin films of Si quantum dots in the temperature range 300 K to 450 K have also been studied. It is evident that the dc conductivity (σ_{dc}) increases exponentially with increasing temperature, indicating that conduction in these quantum dots is through an activated process which also shows the semiconducting behavior of these quantum dots.

Key words: Si quantum dots, Thin Films, optical properties, electrical properties

1. Introduction

In the recent era of nanoscience and nanotechnology, nanostructured semiconductor has acquired great deal of attention by the researchers in both theoretical and experimental fields. Now the challenge is to produce nanomaterials with controlled size distribution, shape, tuned properties and interfacing with substrates. The physical properties of nanomaterial can be controlled by modifying the particle size. The semiconductor quantum dots (QDs) have got extensive concentration because of their modern technological applications. It can be realized in physics having structure of zero-dimension. These quantum dots are promising materials because of their excellent electrical and optical properties which can be changed according to the choice of devices. The semiconductor QDs also exhibit the effect of quantum confinement. The quantum dots (QDs) offer the impressive ability to harvest sunlight, advantageous features of photo stability, high molar extinction coefficients, size dependent optical properties and low costs. In the near future, the single-electron nanodevices and molecular devices will be manufactured as higher integrated circuits [1]. The optical interconnects are expected for the higher integrated circuits and three-dimensional circuits. Many different types of optical interconnect have been developed and discussed: optical interconnects between circuit boards in the computer, between chips, and between individual elements within in a chip [2]. The study towards a full understanding the synthesis and properties of Si nanoparticles is still under way [3].

Several studies have been done on up-conversion and down-conversion processes to change IR and UV photons in photons having energy in the useful spectrum range [4]. Due to this reason, attention has been made on semiconductor quantum dots. Zhen et al [5] have prepared semiconductor quantum dots solar cells with enhanced efficiency, Yu et al [6] have synthesized Mn-doped CdS quantum dots for solar cell application, Wang et al [7] have studied the size dependence semiconductor quantum dots with power conversion efficiency of dye cosensitized solar cells. Several other researchers [8-16] have used different semiconductor quantum dots for the enhancement of power conversion efficiency of Solar cells. The present research work describes the synthesis and characterization of Si quantum dots prepared at different working pressure

2. Experimental

Si quantum dots were synthesized by physical vapor condensation technique (PVCT). Silicon chips were placed in a boat of graphite in a chamber. The chamber was evacuated to 10^{-6} Torr. with the help of turbo molecular pump. After this vacuum, the chamber was purged with argon gas at two different pressures of 10 and 20 Torr. with substrate temperature at 77 K using liquid nitrogen and then the quantum dots were grown directly on silicon wafer substrate. The quantum dots of different sizes were obtained under different argon pressure. The amorphous nature of the quantum dots were confirmed by X-ray diffraction studies. The size of the Si quantum dots were examined by High Resolution Travelling Electron Microscope (HRTEM). The absorption of the prepared Si quantum dots were studied by UV-VIS spectroscopy (Carry 5000, Agilent).

For dc conductivity measurements, silver paste was used as thick electrode on the thin films. The prepared thin films were then mounted in a specially designed metallic sample holder, where a vacuum of about 10^{-3} Torr could be maintained throughout the measurements. A dc voltage was applied across the sample and the resulting current was measured by a digital electrometer (Keithley, Model-617). The temperature of the film was increased from 300 to 450 K by a step value of 5 K and correspondingly the current was read by the electrometer.

3. Results and Discussion:

Fig. 1 shows the HRTEM images of silicon quantum dots deposited at different working pressure. HRTEM images also confirm the size of quantum dots varying from 8 to 14 nm.

Optical absorption of Si quantum dots prepared at different working pressure has been studied at room temperature within the wavelength range of 400-1000 nm. Fig. 2 shows the variation of absorption against wavelength for Si Quantum dots prepared at different working pressure.

The optical density recorded using UV-VIS spectrophotometer can be converted in to absorption coefficient (α) using the relation [17-18].

$$\alpha = \text{Optical Density/ Film Thickness} \qquad (1)$$

The absorption coefficient is calculated using above relation which is found to increase exponentially with the increase in photon energy for both samples.

To calculate the optical band gap of a material, we use the following relation

$$(\alpha h\nu)^{1/n} = B\,(h\nu - E_g) \qquad (2)$$

where, ν is the frequency of the incident beam, h is Planck's constant, B is a constant, E_g is the optical band gap and n is an exponent. The values of n can be taken as 1/2, 3/2, 2 and 3 for different electronic transitions responsible for absorption [19-21].

The present system of as-deposied silicon quantum dots follows the rule of direct transition at the extremum, lying at the same point of k space. On the basis of direct transition, equation (2) is rewritten as given below [22-23].

$$(\alpha\, h\nu)^2 \propto (h\nu - E_g) \qquad (3)$$

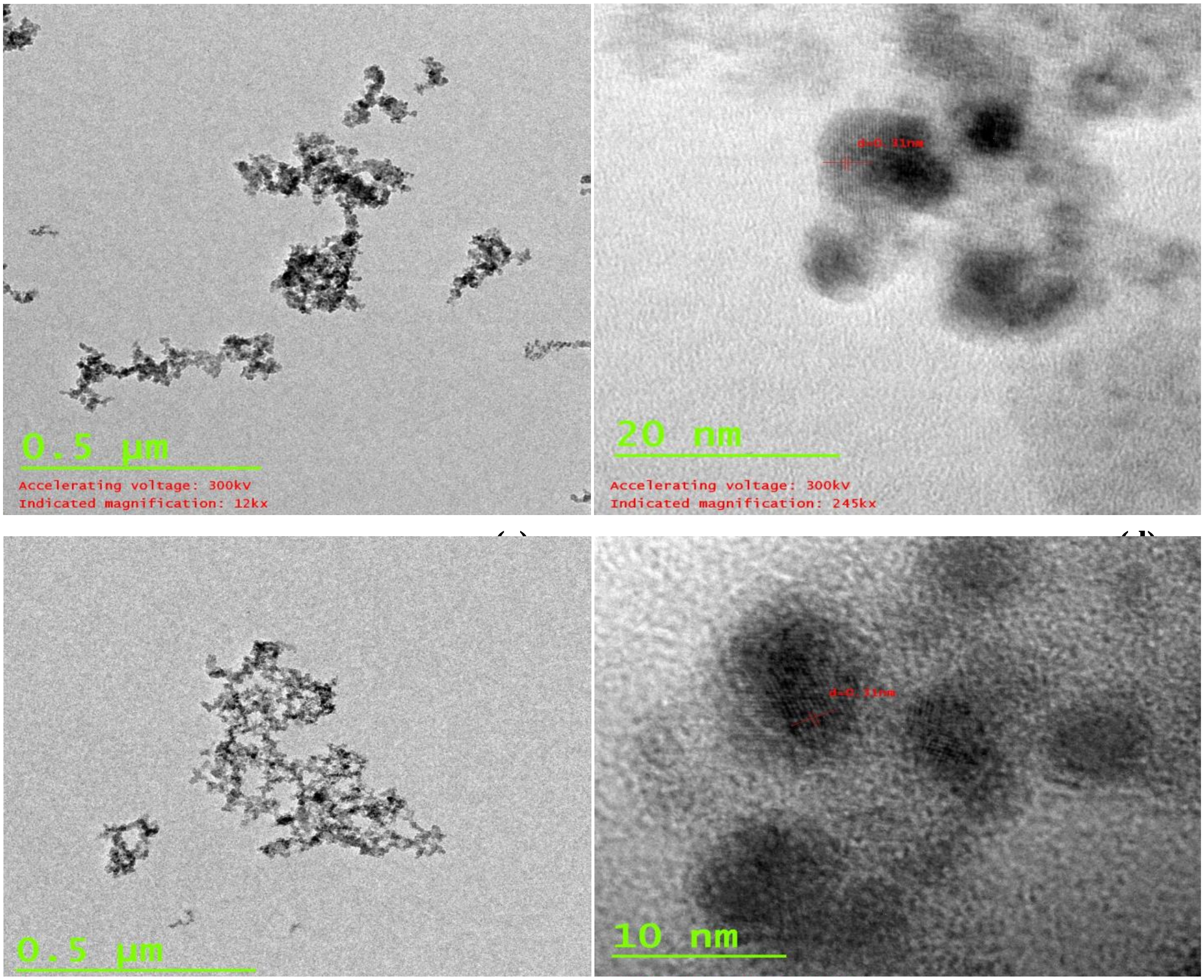

Fig. 1: HRTEM images of Si quantum dots (a-b) prepared at 10 Torr and (c-d) prepared at 20 Torr working pressure with different magnification.

The dependence of $(\alpha h\nu)^2$ with photon energy (hν) for as-deposited silicon quantum dots is presented in Fig. 3. The value of energy gap has been calculated by taking the X-axis intercept of the plot $(\alpha h\nu)^2$ versus *hν.*

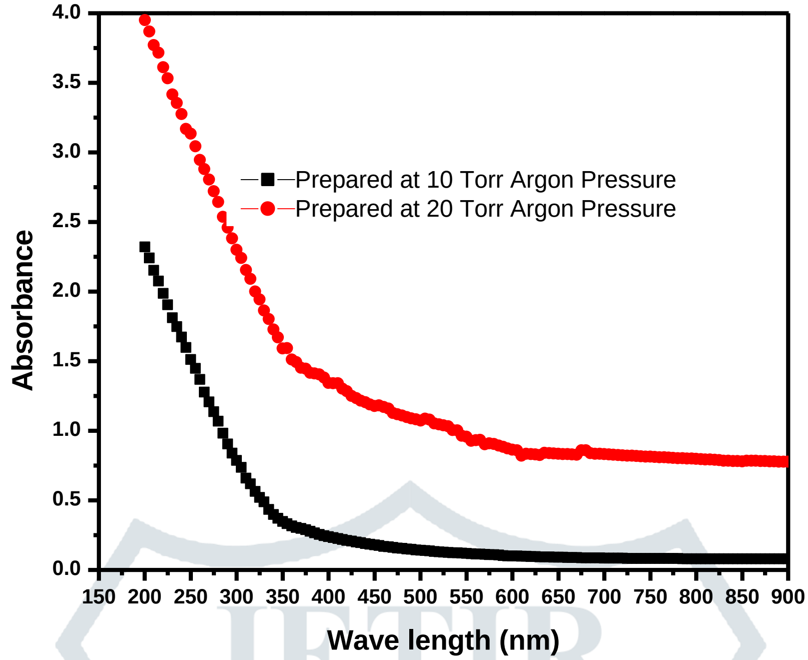

Fig. 2: Absorbance against wavelength for Si Quantum dots prepared at different working pressure.

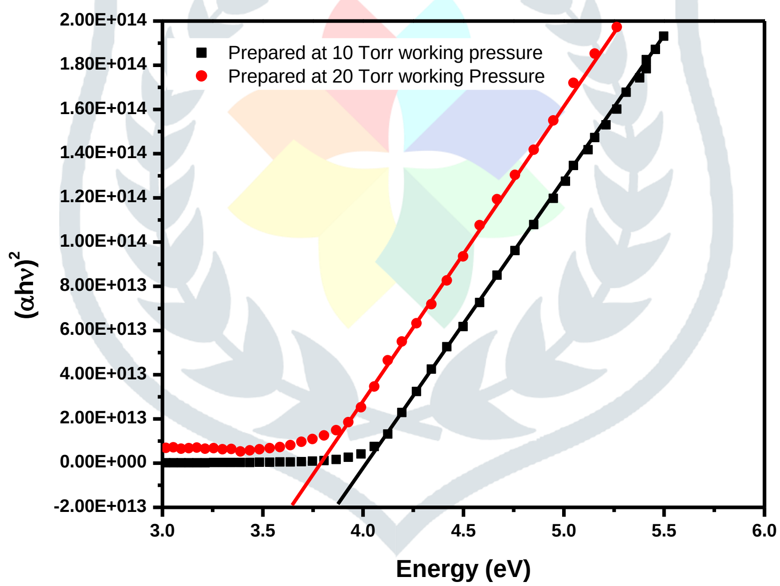

Fig. 3: $(\alpha h\nu)^2$ versus hν (eV) for Si quantum dots for Si Quantum dots prepared at different working pressure.

The calculated values of E_g are given in Table 1. The estimated values of optical gap of the quantum dots prepared at 10 Torr and 20 Torr chamber pressure are 3.2 eV and 3.7 eV respectively.

The dc conductivity can be expressed by the relation,

$$\sigma_{dc} = \sigma_0 \exp (- \Delta E_c / KT) \qquad (4)$$

where, σ_0 and ΔE_c represents the pre-exponential factor and activation energy respectively, T is temperature, K is Boltzmann constant.

We may write equation (4) as,

$$\ln \sigma_{dc} = \ln \sigma_0 - (\Delta E_c / KT) \quad (5)$$

or

$$\ln \sigma_{dc} = -(\Delta E_c / 1000\ K)\ (1000/T) + \ln \sigma_0 \quad (6)$$

When we plot a graph between ln σ_{dc} and 1000/T, a straight line is obtained having slope (ΔE_c/1000 K).

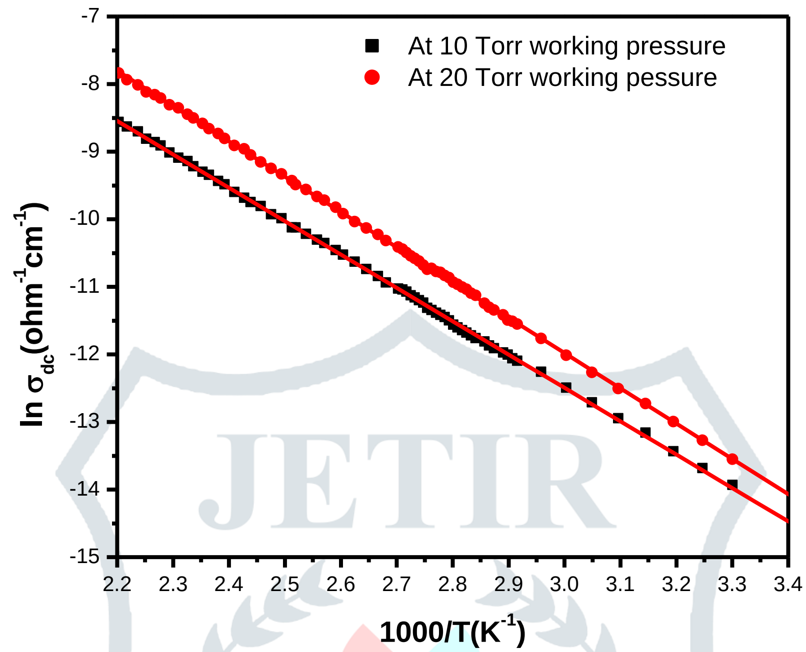

Fig. 4 : Temperature dependence of dc conductivity in the temperature range (303 to 454 K) of Si Quantum dots prepared at different working pressure.

We may calculate the activation energy (ΔE_c) as follows,

$$(\Delta E_c) = 1000\ K \times \text{slope of straight line} \quad (7)$$

The temperature dependence of the dc conductivity of thin films of Si quantum dots prepared at 10 Torr and 20 Torr working pressure in the temperature range 300 to 450 K have been studied and are shown in Fig. 4.

Table-1

Optical and electrical constants in Si Quantum Dots prepared at different working Pressures

Working Pressure	*Absorption Coefficient (cm^{-1}) at λ= 650 nm*	*Optical Band Gap (eV)*	*σ_{dc} ($\Omega^{-1}cm^{-1}$) at T= 368 K*	*ΔE_c (eV)*
10 Torr	138.56×10^4	3.2	2.47×10^{-5}	0.53
20 Torr	193.27×10^4	3..7	3.59×10^{-5}	0.64

It is evident from this figure that the dc conductivity (σ_{dc}) increases exponentially with increasing temperature, indicating that conduction in these quantum dots is through an activated process which also shows the semiconducting behavior of these quantum dots. The variation of dc conductivity and the activation energy with different working pressure is shown in Table 1.

4. Conclusion

The research work presented here focuses on the structural, optical and electrical properties of Si quantum dots prepared by physical vapor condensation technique at different working pressure. HRTEM investigations suggest the formation of silicon quantum dots of average size~8 nm. An enhanced optical band with increasing working pressure is reported in the present result which is due to the formation of very small size quantum dots. The dc conductivity (σ_{dc}) increases exponentially with increasing temperature, indicating the conduction in these quantum dots is through an activated process which also shows the semiconducting behavior of these alloys.

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