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Enhancement of Optical Conductivity and Band Gap of 3D Nanostructured Si Induced By Ultra-Short Laser Pulses

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Abstract **-** Silicon is a commonly used semiconductor material. In this research, we synthesized nanostructures on silicon wafers with a thickness of 250 µm. Direct ablation in the ambient air technique was employed. The scan speed of the laser was varied and thus we observed the formation of nanoparticles. The nanostructures were more at lower scan speed. Optical test showed an increase in the band gap of the structure and the optical conductivity was measured as well.

Keywords: Direct Laser ablation, Nanostructures, band gap, optical conductivity, silicon.

1. Introduction

Silicon is a semiconductor material with a band gap of 1.1 2 eV[1]. Also, due to the abundance of Silicon on earth, it is also the most used material for present day devices. The usage of silicon is high yet, there is a limit till what we can use silicon as a material[2]. To enhance the abilities of silicon, researchers have delved to nanotechnology. Nanoparticles of silicon offer better properties than the bulk material[3]. A lot of synthesis techniques have been employed to produce the nanoparticles of silicon[4-6]

Here we have employed direct laser ablation on silicon to synthesize nanostructures and examined the synthesized samples to determine the optical properties.

2. Experimental Setup:

The samples were prepared using Pulser Fiber Laser (IPG Model: YLPP-1-150V-30) by the process of direct laser ablation. Silicon wafers of Si-100 orientation and a thickness of 20 µm. The laser was processed through various lenses and ablated the surface of the wafer which was on the mount. The power and frequency of the laser was kept constant for all 4the samples. Four samples were created by varying the scan speed of the laser as listed in table 1.

The samples were subjected to light spectroscopy (Ocean Optics STS-NIR) to examine the optical properties of the samples. The reflectance data is collected from the spectroscopy.

Band gap is calculated using the reflectance data and then employing the Kubelka-Munk theory. The function is calculated and a graph is plotted[7].

$$1 \quad h\nu \text{ v/s } F(R)*h\nu \qquad (1)$$

The optical conductivity is measured using the reflectance data as well and by employing the following equation[8]:

$$2 \quad \sigma = \alpha nc/4\pi \qquad (2)$$

Here, α is the absorption coefficient, n is the refractive index of the material, c is the velocity of the light.

Table.1 Machining parameters for the samples.

Sample	Power (w)	Frequency (KHz)	Scan Speed (mm/s)	Band Gap eV
S-10	20	1200	10	1.83
S-50	20	1200	50	1.48
S-100	20	1200	100	1.31
S-200	20	1200	200	1.30

3. Results and Discussion:

Upon visual inspection of the four samples, it was clearly seen that there was higher fiber growth in the S-10 samples, which was ablated at a lower scan speed. As can be seen in the fig.1. The sample with a brighter color means that it was more ablated. Over the period in the samples, the growth in nanostructures was dynamic and at lower scan speed. Also, at higher scan speed, we can observe the ablation in the samples. However, the ablation is very less. If we compare the sample S-10 and S-200, the difference in color is the first aspect that can be noticed and shows the difference.

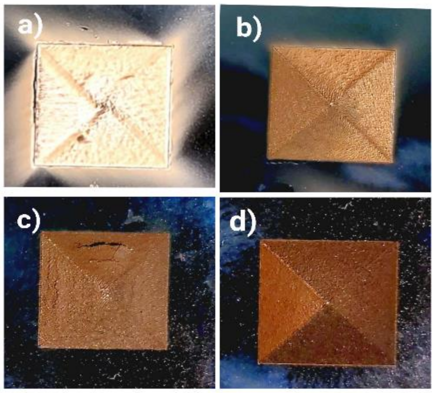

Fig.1. shows laser-ablated silicon samples. a) S-10 b) S-50 c) S-100 d) S-200

3.1. Optical Properties:

The band gap of the samples as can be seen in the table 1 one has been enhanced for all the samples. Fig.2. shows the band gap plot using the Kubelka-Munk function, the graphs are plotted against the photon energy. There was an increase in the band gap with a decrease in the scan speed of the laser. As the power and frequency was constant for all the samples, the slower the laser moved over the surface the higher was the ablation. This also, can be attributed to the fact that, an equal amount of energy but at lower pulse rate is applied for low scan speed.

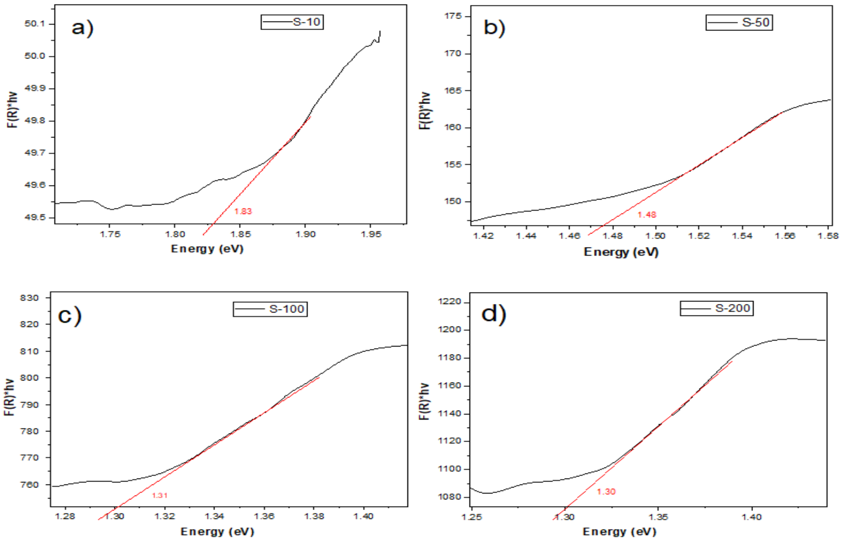

Fig.2. shows the band gap plots. a) S-10 b) S-50 c) S-100 d) S-200

The optical conductivity of the samples which is also shown in the fig.3. shows a decreasing trend for the samples. Here, the optical conductivity of the samples decreased with the increase in the band gap[9]. This is because as the band gap of the material decreases, the ability of the material to conduct increases. There are freer electrons that are charged and thus more electrons can be excited to the conduction band.

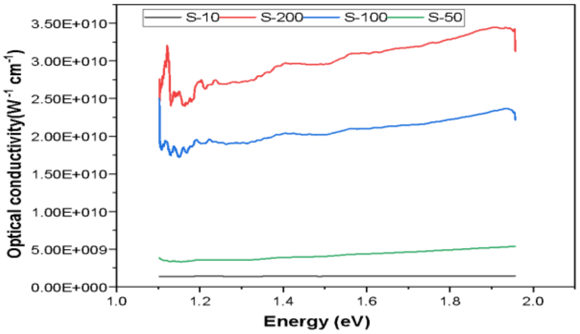

Fig.3. shows the optical conductivity of the samples.

4. Conclusion:

The nanostructures on the samples were successfully synthesized employing the direct laser ablation method and it was observed that decreasing the scan speed and at a higher power and frequency of a laser, the nanostructure formation is higher. Also, the band gap of the material increases with the increase in the nanoparticles in the material.

The optical conductivity of the material decreases with the increasing band gap of the material.

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