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Si-Au Hybrid Nanostructure Synthesis by Varying the Pulse Repetition of the ULPING Technique

Nishant Singh Jamwal, Amirkianoosh Kiani
Silicon Hall: Micro/Nano Manufacturing Facility, Faculty of Engineering and Applied Science, Ontario Tech University, 2000 Simcoe St N, Oshawa, Ontario, L1G 0C5, Canada
nishantsingh.jamwal@onatriotechu.net, amirkianoosh.kiani@ontariotechu.net

Abstract- The emphasis on synthesizing better nanomaterials for semiconducting applications, silicon was coated with a thin layer of gold and nanostructures were synthesized. ULPING, which is a novel technique was employed to synthesize the nanostructures on the gold coated silicon samples. Three samples were prepared by varying the pulse repetition of the laser source and it was observed that fibrous nanostructured samples were obtained with higher pulse repetition. The characterization was done with the help of SEM imaging and the optical spectroscopy was performed to analyze the optical properties of the samples. The sample with higher fibers had the higher band gap and refractive index and the band gap value was 1.44 eV. The optical conductivity was higher for the sample prepared with lower pulse repetition.

Keywords: Nanostructures, Green synthesis, laser processing, opto-electronics, hetero-structures.

1. Introduction:

The growing need for improved semiconducting materials has put forward the need to be inclined towards nanomaterials. Nanotechnology helps in creating materials with superior and varied properties than bulk materials. Silicon is one of the most used semiconducting materials. Transistor manufacturing has greatly employed silicon as well. Whilst silicon oxide has been used as the layer for the dielectric gate of the material, it has proved to be quite efficient. Although, addition of gold on the silicon oxide layer would allow the transistor to have metal contact points, which would allow for a good connection[1].

Here, the focus is on the fabrication of a composite nanostructured Au-Si/SiO2 material which does not compromise the dielectric property of gate material[2]. Au is used here as it provides a better contact surface for the charges. Currently, chemical vapor deposition (CVD), sputtering, molecular beam epitaxy is widely used for nano synthesis processes[3-5]. However, the processes require specialized chambers and are quite expensive. Thus, we have employed ultra short laser pulses for in-situ nanostructure generation (ULPING) technique instead, which is a single step, cost effective, green synthesis technique and has been used for other materials[6, 7]. The method is novel and thus, the effect of change of pulse repetition is noted on the samples. The variation of pulse repetition has been helpful in creating nanostructures of silicon; however, the observations will be based on the gold layer that is coated and how will affect the structure formation and optical properties of the material.

2. Methodology:

The samples were prepared using ULPING technique employing a pulsed laser, which focused the beam onto the surface of the material (silicon, which was coated by a thin layer of gold) through a Galvano scanner. Three different samples were created by varying the pulse repetition of the laser source. The parameters are listed in table 1. Material characterization was done using scanning electron microscopy (SEM) and energy dispersive x-ray spectroscopy (EDS). The optical properties were evaluated using optical spectroscopy (NIR; UV-VIS). Diffuse reflectance was measured and Kubelka-Munk theory was employed to determine the band gap, optical conductivity and refractive index of the samples[8]. The image processing was done using imagej and the graphs were plotted using OriginPro software.

Table 1: Illustrates the laser parameters for the samples.

Sample	Power (W)	Pulse repetition (kHz)	Scan Speed (mm/s)	Pulse duration (Picoseconds)
R1	15	600	10	150
R2	15	900	10	150
R3	15	1200	10	150

3. Results and Discussion:

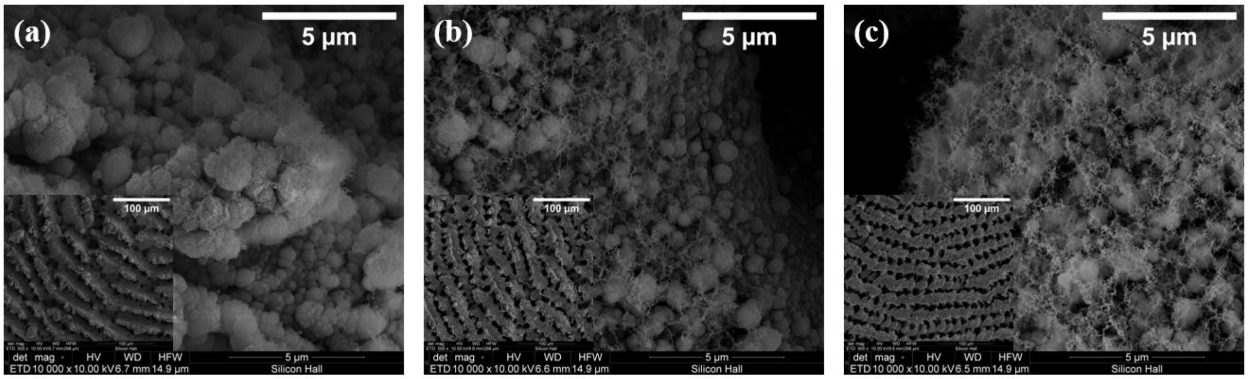

Fig. 1: shows the SEM images of the samples. (a) R1. (b) R2. (c) R3.

As the samples were synthesized by varying pulse repetition of the laser source, we observed a change in the colour of the surface, the surface of the sample with higher pulse repetition was brighter and the other two were slightly darker in shade. The SEM images here show that R3 has a more fibrous structure. R1 does not have any nanofiber, although it has a cluster of nanoparticles. We can observe a disintegration of the cluster to form fibers and smaller size particles as we increase the pulse repetition to 1200 kHz from 600 kHz. As the pulse repetition increases the energy density of laser pulses increases as well, this generates a higher ablation on the surface of the sample. The higher ablation leads to the formation of smaller nanostructures. The EDX in fig. shows the formation of silicon oxide and we can observe that the sample with smaller nanostructures have higher oxidation. Also, the EDX graph showed the presence of gold as well which was on the top layer. Here, we suspect a formation of gold nanostructures as well.

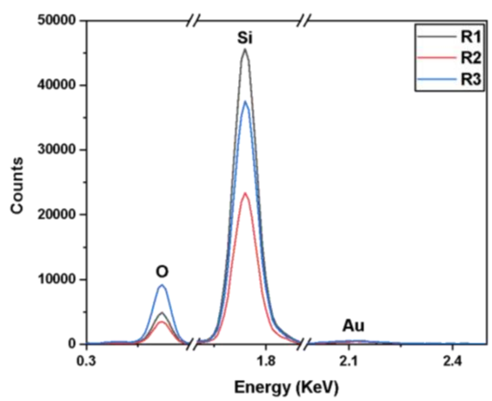

Fig. 2: Shows the EDX of the samples.

3.1. Band gap:

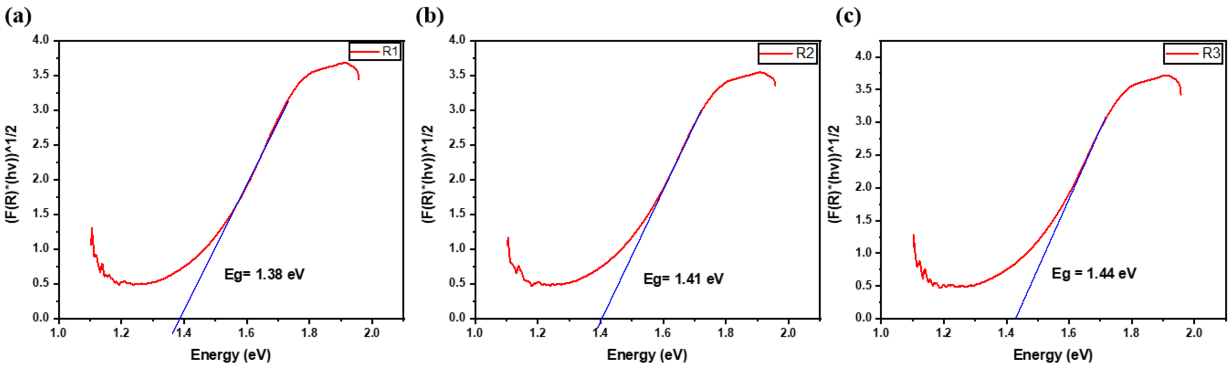

Fig. 3: Band gap of the samples. (a) R1 (b) R2 (c) R3.

The band gap was evaluated using optical spectroscopy and it can be noted that an enhanced band gap was observed for the samples. Here, R3 had a higher band gap of 1.44 eV. The band gap of the gold coated silicon sample is around 0.5 eV and here, it was increased. This was due to the formation of nanostructures.

3.2. Optical conductivity and refractive index:

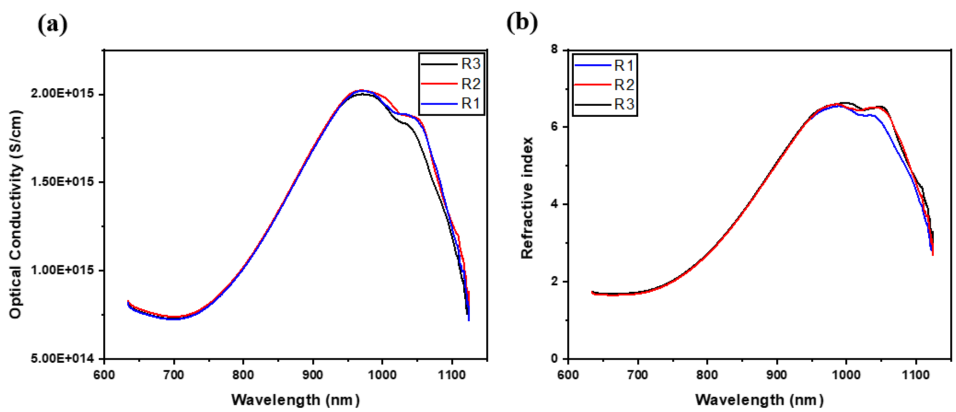

Fig. 4: Optical properties of the samples. (a) Optical conductivity (b) Refractive index.

The optical conductivity and refractive index were also determined using optical spectroscopy[8]. It was noted that the optical conductivity of the samples decreased with increasing band gap. Also, the general range of the optical conductivity is higher than that of silicon and this is due to the presence of gold. The refractive index on the other hand increases with the increasing band gap, as the band gap increases, the travel of light becomes slower in the material and thus the refractive index is higher as well[9].

4. Conclusion:

It can be concluded that the formation of nanostructures was observed on the gold coated silicon samples and nanofibers embedded structure was observed as the pulse repetition was increased. A higher oxidation was achieved in the sample with more nanostructures. The determination of optical properties showed an increase in the band gap of the samples and as the pulse repetition was increased the band gap increased as well. The refractive index of the samples increased with the band gap as well. The optical conductivity, however, decreased with the increased band gap. The presence of gold increased the optical conductivity value. We suspect the formation of hybrid Si-Au structure will be the future scope of the work.

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References

[1] C. R. Newman, R. J. Chesterfield, J. A. Merlo, and C. D. Frisbie, "Transport properties of single-crystal tetracene field-effect transistors with silicon dioxide gate dielectric," *Applied Physics Letters,* vol. 85, no. 3, pp. 422-424, 2004.

[2] W. Y. Choi and W. Lee, "Hetero-gate-dielectric tunneling field-effect transistors," *IEEE transactions on electron devices,* vol. 57, no. 9, pp. 2317-2319, 2010.

[3] R. Gago, L. Vázquez, R. Cuerno, M. Varela, C. Ballesteros, and J. M. Albella, "Production of ordered silicon nanocrystals by low-energy ion sputtering," *Applied Physics Letters,* vol. 78, no. 21, pp. 3316-3318, 2001.

[4] J.-H. Suk, S.-C. Hong, G.-S. Jang, and N.-M. Hwang, "Two-step deposition of silicon oxide films using the gas phase generation of nanoparticles in the chemical vapor deposition process," *Coatings,* vol. 11, no. 3, p. 365, 2021.

[5] S. Y. Jeong *et al.*, "Synthesis of silicon nanotubes on porous alumina using molecular beam epitaxy," *Advanced Materials,* vol. 15, no. 14, pp. 1172-1176, 2003.

[6] K. Khosravinia and A. Kiani, "Unlocking pseudocapacitors prolonged electrode fabrication via ultra-short laser pulses and machine learning," *Iscience,* vol. 26, no. 4, 2023.

[7] K. Khosravinia and A. Kiani, "Optimizing the Ultrashort Laser Pulses for In Situ Nanostructure Generation Technique for High-Performance Supercapacitor Electrodes Using Artificial Neural Networks and Simulated Annealing Algorithms," *ACS Omega,* 2023.

[8] N. S. Jamwal and A. Kiani, "Synthesis of 3D Nanonetwork Si Structures via Direct Ultrafast Pulsed Nanostructure Formation Technique," *Energies,* vol. 15, no. 16, p. 6005, 2022.

[9] V. Verlaan *et al.*, "The effect of composition on the bond structure and refractive index of silicon nitride deposited by HWCVD and PECVD," *Thin Solid Films,* vol. 517, no. 12, pp. 3499-3502, 2009.