Morphological Characteristics of Plasma-Etched Silicon Substrates Coated with Nickel Oxide Nanoparticles for Optoelectronics Applications

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Abstract

In this work, the morphological characteristics of the surfaces formed by deposition of nickel oxide nanostructures on silicon surfaces were studied. These structures are commonly used in optoelectronics and nanoelectronics due to their stability and functionality under high light intensity conditions. The morphology of the prepared samples was found to depend on the concentration of NiO nanoparticles deposited on Si substrate surface, which in turn would affect the overall characteristics of the heterojunction structures fabricated from these samples.

Keywords: Silicon devices; Nickel oxide; Nanostructures; Morphology

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1. Introduction

Currently, metal oxide nanoparticles represent an excellent candidate material for the fabrication of photonics, optoelectronics, and nanoelectronic devices due to their uncompetitive features when compared to the conventional materials and structures previously used [1,2]. When these nanoparticles are deposited on the surfaces of semiconducting substrates, they may play more than one roles at the same time. If these nanoparticles deposit on the flat or smooth surface, they can form a huge number of contact regions those may represent tiny junctions to contribute to the overall electrical and optical activities on such surface [3]. If the surface is not smooth, i.e., contains grooves, voids, pores, scratches, scars, etc., they may locate inside these surface irregularities and form similar junction regions as mentioned before [4]. The difference here is the increase in the surface area that can obtained from this phenomena due to the double effect of increasing the surface area by surface deformation as well as deposition of nanoparticles [5]. These phenomena can be successfully employed to fabricate highly-efficient devices by simply dropping metal oxide semiconducting nanoparticles (such as NiO) on a semiconducting substrate (such as Si) [6,7].

In this work, nickel oxide nanoparticles were prepared by dc reactive sputtering technique and deposited on the surfaces of silicon substrates. The morphological characteristics of these structures were introduced, compared and analyzed.

2. Experimental Part

Highly-pure sheet of nickel (99.99%) was used as sputtering targets. The target was maintained inside the deposition chamber on the cathode. Pure oxygen was used as reactive gas required to form the metal oxides. The quartz substrates on which the metal oxide thin films are to be deposited were carefully cleaned and then put on the surface of the anode. The temperature of the anode (and the substrate as well) could be controlled and a thermocouple was used to measure it.

The deposition chamber was first evacuated down to 10^{-3} mbar before filled with the gas mixture of argon and oxygen at a pressure of 0.1 mbar. The plasma required for sputtering was generated by the electric discharge of argon. Electrical power was provided by a high-voltage dc power supply. Several parameters of sputtering system, such as inter-electrode distance, deposition time, substrate temperature, total gas pressure and Ar:O_2 ratio, could be varied to determine their effects on the deposition process [8]. The film materials was extracted from the film samples by the conjunctional freezing-assisted ultrasonic extraction method [9].

A (111)-oriented n-type silicon wafer of 500µm thickness and 3 Ω.cm resistivity was used in this work. This wafer was cut into 1x1cm samples, placed on the anode inside discharge chamber to be subjected to glow-discharge plasma column for 30 min to etch their surfaces [10].

A 5 mg of the NiO nanoparticles were dispersed in distilled water with different concentrations (1.6-5) x10^{-4} g/mL. The solution was sonicated for 30 min to separate the nanoparticles as much as possible then dropped on the surface of silicon sample and left on the hot plate at 40°C to allow the distilled water to evaporate and left the NiO nanoparticles on the surface. The steps of the experimental part in this work are shown in Fig. (1).

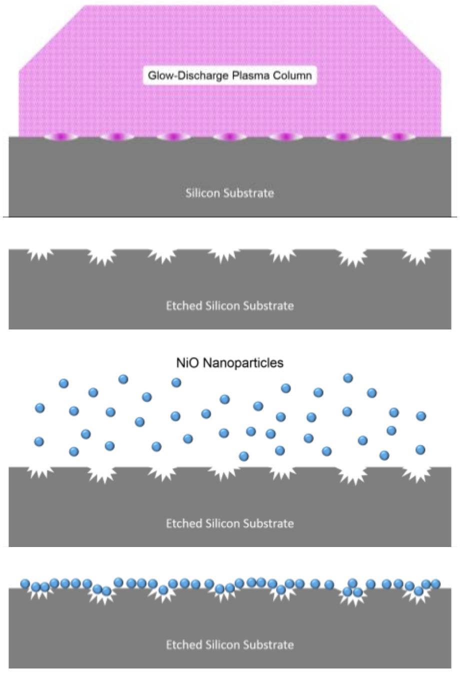


Fig. (1) The process of plasma etching and coating of silicon substrates with NiO NPs

3. Results and Discussion

Figure (2) shows the FE-SEM image of the NiO nanoparticles prepared in this work. The aggregation of the nanoparticles is clearly seen on the surface and the particle size is ranging within 20-30 nm.

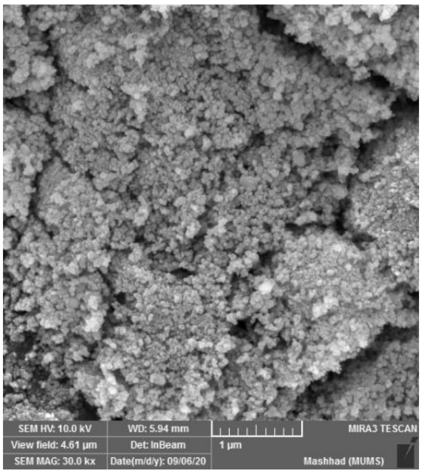
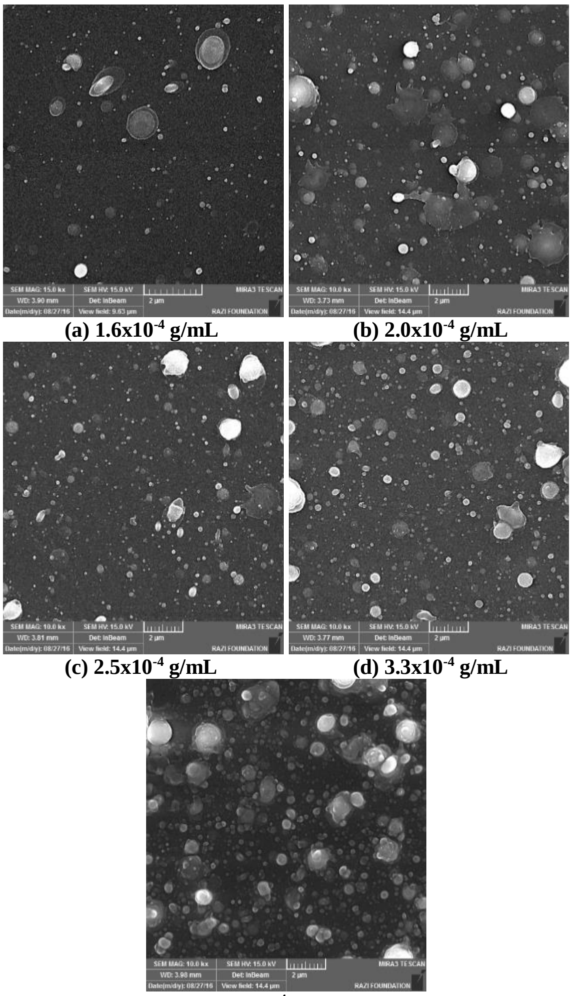


Fig. (2) FE-SEM image of NiO sample prepared in this work

Figure (3) shows the FE-SEM images of the samples prepared from dropping different concentrations of the prepared NiO nanoparticles on the surfaces of Si substrates. It is obvious that the lower concentration of NiO NPs in the solution would produce lower density of these NPs on the Si surface (Fig. 2a). The density increases with increasing the NiO NPs concentration to cover most area of the Si surface (Fig. 2b-e). The most important observation in figures (3b-d) is the increase in the coated area with keeping NiO NPs separated with no increase in the size, while larger particles can be apparently seen in Fig. (2e) due to higher concentration of NiO NPs.

Another observation to be seen is the residual water on the surface (Fig. 2a-c) while no such residual water is seen in the samples of Fig. (2d,e). This is attributed to the effect of heating the Si sample as well as the deposited NiO NPs, which lead to rise the surface temperature and hence evaporate all residual water. A drying step may be required to ensure no residual water exists on the surface of the final sample since it would negatively affect or degrade the performance of the devices fabricated from these structures [9-14].



(a) 1.6x10^{-4} g/mL **(b) 2.0x10^{-4} g/mL**

(c) 2.5x10^{-4} g/mL **(d) 3.3x10^{-4} g/mL**

5x10^{-4} g/mL

Fig. (3) FE-SEM images of NiO NPs dropped on Si surfaces at different concentrations in solution

4. Conclusions

In this work, the morphological characteristics of the surfaces formed by deposition of nickel oxide nanostructures on silicon surfaces were studied. The morphology of the prepared samples was found to depend on the concentration of NiO nanoparticles deposited on Si substrate surface, which in turn would affect the overall characteristics of the heterojunction structures fabricated from these samples.

References

[1] M.J. Schulz et al., "Optimization of Structural Phase of Cobalt Oxide Nanostructures Prepared by RF Sputtering Technique", Canad. J. Mater. Sci. Technol., 40 (2017) 111-120.

[2] O.A. Hammadi, "Characteristics of heat-annealed silicon homojunction infrared photodetector fabricated by plasma-assisted technique", Photon. Sens., 6 (2016) 345-350.

[3] M.H. Yaseen, R.J. Hameed and A.M. Jasim, "Energy Band Outline of Thin Film CoO:Au/Si Solar Cells", Iraqi J. Mater., 1(2) (2022) 89-94.

[4] J. Dresner and F.V. Shallcross, "Crystallinity and Electronic Properties of Evaporated CdS Films", J. Appl. Phys., 34(8) (1963) 2390.

[5] O.A. Hamadi, "Effect of Annealing on the Electrical Characteristics of CdO-Si Heterostructure Produced by Plasma-Induced Bonding Technique", Iraqi J. Appl. Phys. (IJAP), 4(3), 2008, 34-37.

[6] R.N. Khoshnaw, "Characteristics of CoO/Si Heterostructure Prepared by Plasma-Induced Bonding", Iraqi J. Appl. Phys. Lett., 7(2) (2024) 19-22.

[7] K.Z. Yahia et al., " Optical and electrical properties of selenium-antimony heterojunction formed on silicon substrate", Sharjah Univ. J. Pure Appl. Sci., 4(2) (2007) 1-11

[8] M.A. Hameed, S.H. Faisal and R.H. Turki, "Characterization of Multilayer Highly-Pure Metal Oxide Structures Prepared by DC Reactive Magnetron Sputtering", Iraqi J. Mater., 3(4) (2024) 1-8.

[9] O.A. Hammadi, "Production of Nanopowders from Physical Vapor Deposited Films on Nonmetallic Substrates by Conjunctional Freezing-Assisted Ultrasonic Extraction Method", Proc. IMechE, Part N, J. Nanomater. Nanoeng. Nanosys., 232(4) (2018) 135-140.

[10] A.K. Yousif et al., "Plasma-Induced Etching of Silicon Surfaces", Bulg. J. Phys., 35(3), 2008, 191-197.

[11] M.H. Abbas and H. Jabbar, "Structural and Magnetic Characteristics of Polyol Synthesized Cobalt Nanoparticles with Ruthenium and Samarium Additives: A First-Order Reversal Curve Analysis", Iraqi J. Appl. Phys., 20(2A) (2024) 305-311.

[12] O.A. Hamadi, "Characteristics of CdO-Si Heterostructure Produced by Plasma-Induced Bonding Technique", Proc. IMechE, Part L, J. Mater.: Design and Applications, 222, 2008, 65-71, DOI: 10.1243/14644207JMDA56.

[13] A.A.K. Hadi et al., "Optoelectronic Characteristics of As-doped Silicon Photodetectors Produced by LID Technique", Iraqi J. Appl. Phys. Lett. (IJAPLett), 1(2), 2008, 23-26.

[14] O.A. Hammadi, "Photovoltaic Properties of Thermally-Grown Selenium-Doped Silicon Photodiodes for Infrared Detection Applications", Photo. Sens., 5(2), 2015, 152-158.