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Fabrication based porous silicon photo-detector and improving its spectral responsivity by depositing IZO thin films

صناعة كاشف ضوئي بالاعتماد على السليكون المسامي وتحسين استجابته الطيفية بترسيب اغشية اوكسيد الخارصين الرقيقه المشوبه بالانديوم

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Abstract:

In this work porous silicon was prepared by electrochemical etching, then IZO thin films were deposited on porous silicon. SEM pictures showed different morphology for all from porous silicon and IZO films deposited on porous silicon. The pores diameter ranges from (0.5-1 μ m). AFM pictures showed the smoothness increased with depositing IZO films. The average roughness is (34.12 nm), (23.4 nm) and the root mean square is approximately (41.88 nm), (28 nm) for porous silicon and IZO film deposited on porous silicon respectively. The results showed increasing of the spectral responsivity with depositing IZO film. Spectral responsivity for photo detractor is about (0.69 A / Watt) then it improved by depositing IZO films and becomes (0.84 A / Watt).

Keywords: porous silicon, thin films, ZnO, spectral responsivity.

الخلاصة:

في هذا العمل تم تحضير السيليكون المسامي بالتنميش الكهروكيميائي، ثم تم ترسيب اغشية اوكسيد الخارصين المشوبة بالأنديوم على السيليكون المسامي. صور المجهر الالكتروني الماسح لكل من السيليكون المسامي و اغشية اوكسيد الخارصين المشوبة بالأنديوم المترسبة على السيليكون المسامي تظهر اختلاف في طبيعة السطح، تتراوح اقطار المسامات (0.5-1) مايكرو متر. بينت صور مجهر القوة الذرية زيادة النعومة مع ترسيب اغشية اوكسيد الخارصين المشوبة بلانديوم. متوسط الخشونة (34.12نانو متر)،(23.4نانومتر) ومتوسط الجذر التربيعي تقريبا (41.88نانو متر)، (28نانو متر) للسيليكون المسامي و اغشية اوكسيد الخارصين المشوبة بلانديوم المترسبة على السيليكون المسامي على التوالي. بينت النتائج ازدياد الاستجابة الطيفية مع ترسيب اغشية اوكسيد الخارصين المشوبة بلانديوم. الاستجابة الطيفية للكاشف الضوئي (0.69 امبير\واط) ثم تحسنت بترسيب اغشية اوكسيد الخارصين المشوبة بلانديوم واصبحت (0.84امبير \ واط).

Introduction:

Photon detectors are solid- state devices that operate under the influence of photon effects. The photon detectors essentially measure the rate at which quanta are absorbed, thus they respond only to that photon of short wavelength; therefore, their response at any wavelength is proportional to the rate at which photons of that wavelength are absorbed. In photon detectors, the radiation is absorbed directly by the electronic system to cause changes in the electrical properties [1]. Porous silicon (PS) was discovered in 1956 by Uhlir [2]. Porous silicon (PS) can be defined as a silicon crystallite having a bunch of nanosized pores in it. It has been proven that porous silicon is one of the most promising materials, because it can emit visible range of light at room temperature. One of the most important characteristics of the PS layers is its very large and reactive internal surface so that, one should expect, that this internal surface would play an important role in those specific properties of PS layers which make this material so different from bulk one [3]. By increasing the porosity, the size of the silicon (Si) structures in (PS) layer reduce, which affects the properties of the (PS) layer [4]. ZnO is one of the most important transparent conducting oxide (TCO) materials; it is an intrinsic n-type semiconductor which was regarded as one of the important transparent conducting oxide (TCO) with an energy band gap of (3.4eV), is of great use owing to its significant technology applications such as photo-catalysts, solar cells, transparent conductive films and chemical sensors. ZnO can easily be doped n-type, but is difficult to doped p-type [5]. The crystalline growth of ZnO thin film is improved in the structural stability of (PS) substrate [6].

Spray pyrolysis deposition is particularly attractive since it is relatively fast, vacuum less, simple and more economics. Typically, group III (Al, Ga, and In) elements are used to dope ZnO with donor impurities [7]. Responsivity is defined as the ratio between the electrical signal output (voltage or current) to the incident radiation power or is defined as the r.m.s. single voltage to the r.m.s. value of the incident radiation power. The responsivity for monochromatic light of wavelength incident normally is given by [8, 9].

$$R_\lambda = \frac{I_{Ph}}{P_{in}} \quad or \quad R_\lambda = \frac{V}{P_{in}} \qquad \text{--------} (1)$$

Where:

R_λ : the responsivity

I_{ph} : the measured photocurrent

P_{in} : the incident optical power

Experimental:

Porous silicon substrate was formed by electrochemical etching, p-type silicon wafer with orientation (100) and resistivity of (1.5- 4 Ω.cm). The silicon substrate was cleaned before the etching process. This process can be summarized as following:

1-The silicon wafers are cleaned in ethanol alcohol with (99.99%) purity in the ultrasonic bath for 15 minutes to remove the oil dirt's.

2-The wafers are rinsed with a distilled water to remove the dust on the surfaces of the samples.

3-The wafers are put for five minutes in an HF acid solution which is diluted with distilled water (HF: H_2O) with a ratio (1:10).

4- As soon as the samples are taken out of the (HF) solution, they are rinsed in distillated water and then in ethanol alcohol solution. This process decreases the possibility of the oxide growing again on the surfaces of the wafers, and then the samples are dried with a clean cloth of silk.

The electrochemical cell is made from Teflon which has a circular aperture with a radius of 0.4 cm, the cell consists of a two-electrode system with the silicon wafer as the anode and gold as the cathode, the wafer was placed in an electrolyte solution HF-Ethanol (1:3) with a current density of 25 mA / cm^2 at an etching time of 40 min. After etching, all samples were rinsed with ethanol and air-dried.

To prepare (IZO) films, which used zinc nitric (Zn $(NO_3)_2$) (purity 99.99) with concentration (0.1M) and procures material ($InCl_3$) is a solid material which has a white color, the Indium chloride ($InCl_3$) was added with doping concentrations (3wt.%), and also dissolved in 50 ml of distilled water. The IZO films deposited by chemical spry pyrolysis technique at temperature (400±10) $^\circ$C and distance between substrate and nozzle equal 30±1 cm, the gas will be evaporated; IZO will be deposited on substrate. The surface morphology was observed by an atomic force microscopy (AFM) and scanning electron microscopy (SEM).

Detector characteristic measurement:

The detector performance is characterized by the responsivity and response time of the fabricated detector. In order to determine the detector parameter of porous silicon and IZO films deposited on porous silicon and deposited the mask is used the samples in experimental arrangement for measurements of characteristic of photovoltaic detector.

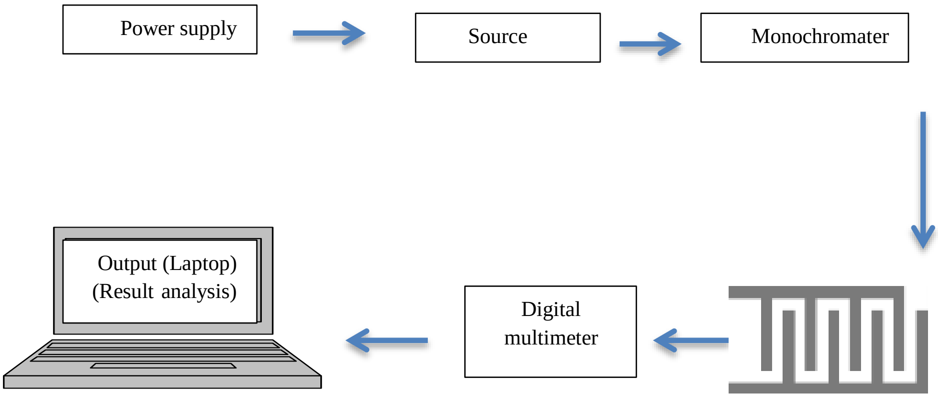

Figure (1): Experimental arrangement of detector device parts.

Results and discussion:

Figure(2)shows SEM image of the etched surface prepared under current density of 25 mA /cm^2 and etching time of (40) minutes. The pore diameter ranges from (0.5-1) μ m, the bright regions in the figure are the Si structures and the dark regions the pores.

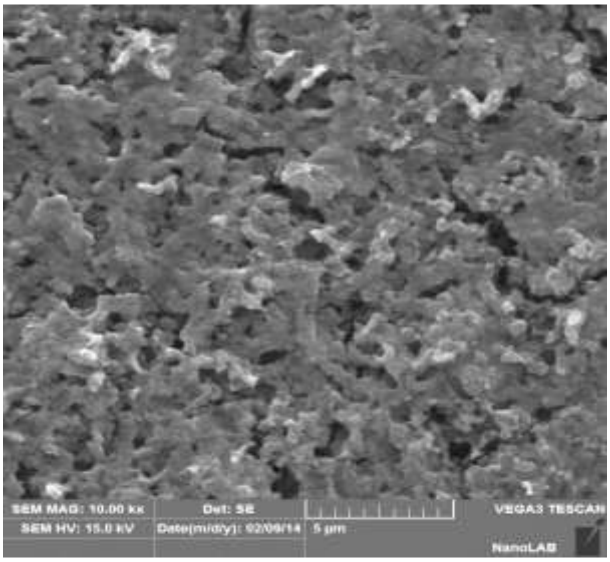

Figure: (2): The SEM image of the PS front side (polish side).

Figure (3) shows the nanostructure of IZO film deposited on porous silicon substrates. There are significantly change in the morphology of porous silicon after deposition of the IZO film. It is found that the IZO has a significant influence on porous silicon front surface.

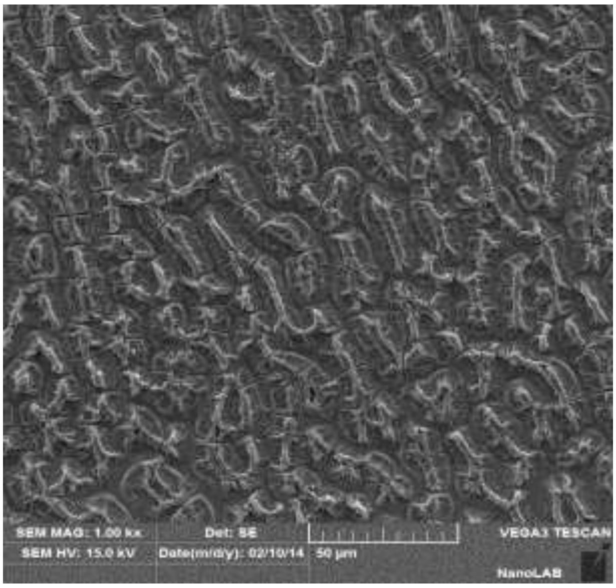

Figure (3): SEM topography of IZO deposited on porous silicon substrates.

Figure (4) shows AFM images (2D and 3D) of porous silicon substrate for front side. The average roughness is (34.12 nm) and the root mean square is approximately (41.88 nm).

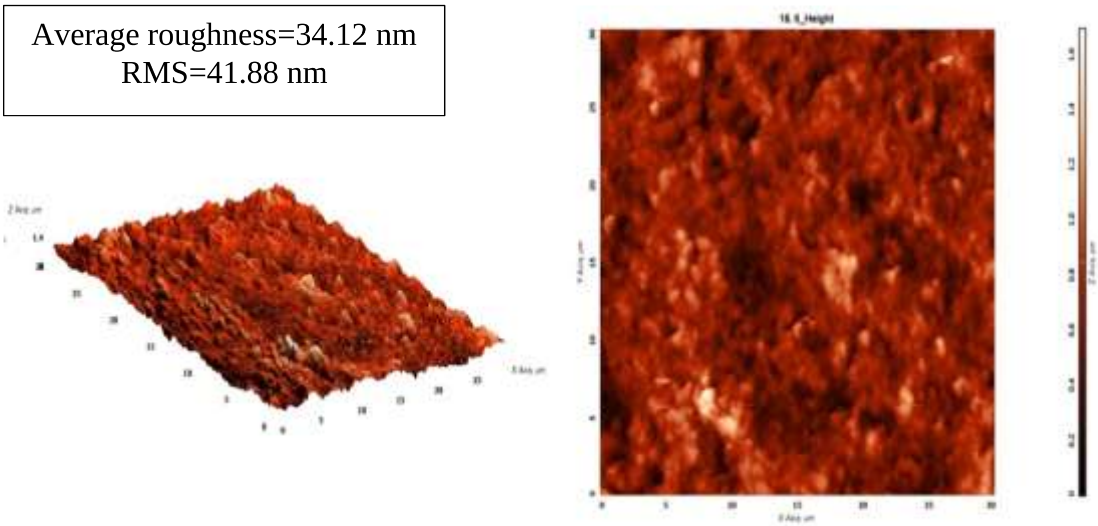

Figure (4): AFM images (2D and 3D) of porous silicon substrate.

Figure (5) shows the AFM images in 2-D and 3-D of IZO on porous silicon substrate. It shows randomly distributed nanocrystalline pillars and voids through surface, In 2-D average roughness was measured and found to be around (23.4 nm) and RMS is around (28 nm) for IZO.

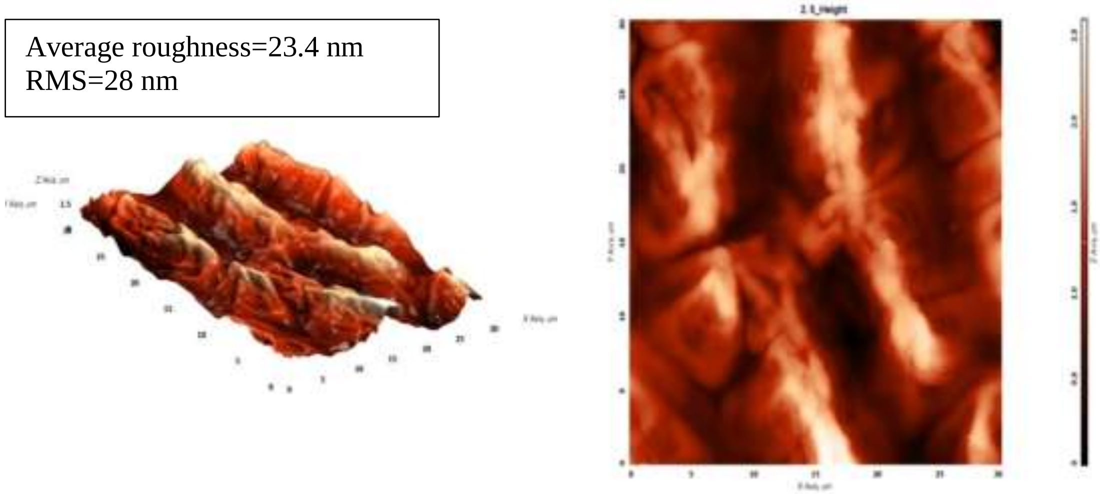

Figure (5): AFM images (2D and 3D) IZO deposited on porous substrates.

Figure (6) illustrates the spectral responsivity as a function of various incident wavelengths of porous silicon. The spectral responsivity increases with increasing the wavelength that because increase the absorption that lead to increase the free electron. At wavelength about (490 nm) best spectral responsivity of (0.69 A / Watt) is observed, then curve of spectral responsivity decreases because the incident photon do not have enough energy. The response time of porous silicon detector is about (8) seconds and the recovery time is about (6) seconds.

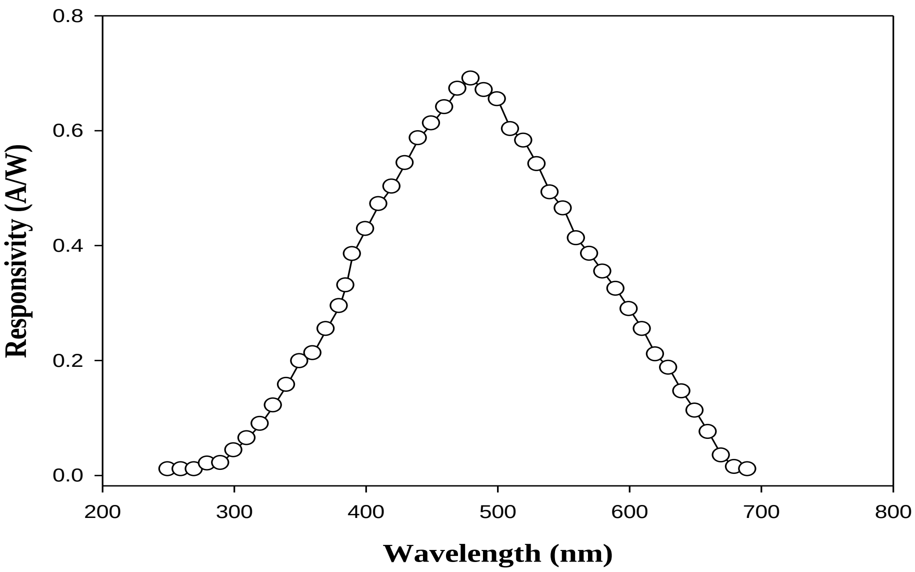

Figure (6): Spectral responsivity as a function of incident wavelength of porous silicon.

Figure (7) illustrates the spectral responsivity for IZO (0.84) A /W at (400) nm. In this figure it can be seen the increased in spectral responsivity with increasing the wavelength, until it reaches the maximum responsivity corresponding to its energy band gap. The ratio of surface to the size increases with IZO depositing on porous silicon that leads to increase the trapping of incident photon on sample that leads to increase the absorption then responsivity. In case of IZO deposited on porous silicon substrate the response time decreases to reach (4) seconds and recovery time is about (2) seconds.

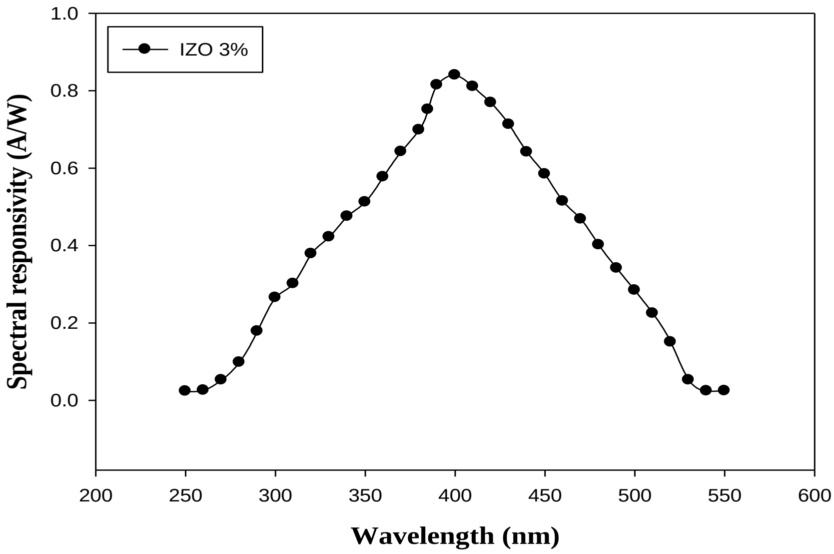

Figure (7): Spectral responsivity as a function of incident wavelength of IZO on porous silicon.

Conclusion:

Porous silicon substrates were prepared by electrochemical etching method, thin films of IZO deposited on Porous silicon substrates by chemical spry pyrolysis**.** The AFM was used to study the surface roughness and the RMS of porous silicon is about (41.88 nm), (28 nm) for IZO film deposited on porous silicon. The spectral responsivity of porous silicon was about (0.69 A / Watt) whereas in IZO film deposited on porous silicon substrate it becomes (0.84 A / Watt). Response time and recovery time of porous silicon is about (8) seconds and (6) seconds respectively and decreased by depositing IZO film on porous silicon and becomes (4) seconds and recovery time is about (2) seconds.

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