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Porous Silicon Based Violet-UV Detector

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Abstract. A new method of fabricating porous silicon detecting (Violet-UV) spectral regions is presented. This method uses a stencil mask contained matrix of round holes, typically 0.5 mm in diameter. SEM, and PL have been used to characterize the morphological and optical properties of the porous silicon (Psi). SEM shows uniformed circular pores with 85\% porosity. The studies of the porous structure and optical properties showed that the band gap is about 3.6396 eV at 340.7 nm). Silver (Ag) fingers contact was deposited on the PSI to form MSM (full name) photo-detector. The detector shows in both wavelengths (400 nm, 365 nm) with repetitive shots have very high stability and reliability and the rise time is about 0.5 sec for a 3 volts reverse bias for UV light (365 nm) illumination and 10.41 sec for Violet light (400 nm).

Keywords: UV detector, Porous silicon, electrochemical anodic etching
PACS: 81.05.Rm
INTRODUCTION

Ultraviolet (UV) photodetectors with high responsivities for wavelengths shorter than 400 nm are very important for applications. They could open new applications in industrial products, scientific research as well as in consumer products, such as UV sterilization, UV physiotherapy, UV fluorescent analysis and investigation, UV exposure of photolithography and so on. However, devastating effects of UV radiation may be very dangerous in some cases. For example, culture relics, paintings and calligraphy works, rubber and plastics will undergo an accelerated aging process under a prolonged exposure to UV irradiation. Moreover, UV radiation may also have devastating effects on eyes, skins, plants and so on. It is very important therefore to be able to determine the intensity and the amount of UV radiation [1, 2].

Many studies have been carried out on porous silicon (PSi), and most PSi layers have been formed by anodic etching in an HF based electrolyte. The nano-crystalline porous size can lead to quantum confinement effects and the existence of a direct band gap in otherwise an indirect band gap material. Depending on the conditions, the anodic porous layers can be prepared with a wide variety of topographies from arrays of independent cylindrical pores to dense networks of nm-dimension pores that may be branched or interconnected [3]. These pores provide a large surface area for chemical partitioning or binding, and thus PSi films have generated much interest as a sensing medium. Optical detection in PSi can be performed in both the visible and ultra violet (UV) spectroscopic regimes. During the recent years there is an increasing interest in the development of UV detectors due to wide range applications of the UV light [4].

In this paper we have fabricated a new type of porous silicon - based violet - UV detector and report for the first
time a stencil mask technique for the homogeneity of the porosities areas of nano-porous silicon layer. There are different etching cavity designs in anodic etching, the experiment generally involves a Teflon cell, a hydrofluoric acid (HF) solution and two electrodes, the anode being the silicon substrate and the cathode; a platinum rod. The etching parameters include the applied voltage or current, the etching duration, the etching solution composition (HF concentration), and the illumination. These conditions can be adjusted to achieve desired porous silicon morphologies and may vary for silicon substrates of different doping type and resistivity.

POROUS AND DEVICE FABRICATION

The PSi fabrication process is illustrated in Figure 1. Samples of Si (100) of about 10 mm² and 0.5 mm thickness were cut from n-type (resistivity $\rho = 0.012 - 1.25 \, \Omega \, cm$) silicon wafers, polished on one side. The PSi layers were made by electrochemical etching of n-type wafer. Etching was performed in an electrochemical Teflon cell, brass housing with a circular window acted as a back contact, stencil mask used in contact with the silicon wafer contained matrix of round holes, typically 0.5 mm in diameter to create high porous density inside the holes. In order to create the additional charge carriers on the front surface, a standard bulb lamp (100 Watt) front side lamp was attached above the etching cell. The PSi layer was formed on substrate by anodic etching in HF: Ethanol (1:4) solution at a constant current density of 50 mA/cm² for 30 min in the light. There are different mechanisms to explain the dissolution chemistries of Si but it is generally accepted during the pore formation, two hydrogen atoms evolve for every Si atom dissolved [5,6]. The current efficiencies are about two electrons per dissolved Si atom [7-9]. The
chemical equation for the anodic reactions can be written during pore formation as

\[
\text{Si} + 6\text{HF} \rightarrow \text{H}_2\text{SiF}_6 + \text{H}_2 + 2\text{H}^+ + 2\text{e}^- \quad (1)
\]

To further increase the responsivity of our detector we have deposited on the top of the PSi two comb-shaped silver (Ag) electrodes. The contacts with thickness of 250 nm and target purity of 99.99 % has been deposited using Edwards A500 RF-sputtering system using suitable metal mask which contains five fingers with dimension of 0.38 mm, 0.32 mm and 6.6 mm for the width, finger spacing and length of each electrode, respectively as shown in Figure 2 in order to enhance the collected charge of the photogenerated carriers.
FIGURE 1. Electrochemical cell used for PSi formation.

FIGURE 2. Schematic diagram of PSi detector.
RESULTS AND DISCUSSION

Several authors have reported UV emission in PL spectra of porous silicon [10-20]. In our case we have used a new method using the stencil with matrix holes to get condense porous in small area. Figure 2 shows the top view pc-scope images of porous silicon inside the holes that were formed by electrochemical etching under anodic current density of 50 mA/cm². It seems that the circles are very uniform and have high density porous structure. From this structure we can analyze that the detector’s active area contains both silicon and porous silicon and appears as quantum dots.

![Figure 2](image1.png)

**FIGURE 2.** The top view images of porous silicon inside the holes that were formed by electrochemical etching under anodic current density of 50 mA/cm².

Figure 3 shows the morphology of the PSi formed using the new technique (stencil mask). PSi exhibited a uniformed network distribution of pores with 85 % porosity and this is analysed using MATLAB image processing software. Figure 4 shows the SEM images which reveal its

![Figure 3](image2.png)

**FIGURE 3.** The optical images of the prepared PSi with magnification of 11x, 34x, and 80x.

Figure 3 shows the morphology of the PSi formed using the new technique (stencil mask). PSi exhibited a uniformed network distribution of pores with 85 % porosity and this is analysed using MATLAB image processing software. Figure 4 shows the SEM images which reveal its
highly porous nature, and presented at higher magnifications to better reveal the details of the highly porous structure.

![SEM images at same position and different magnifications](image)

**FIGURE 4.** SEM images at same position and different magnifications

## ELECTRICAL AND OPTICAL CHARACTERIZATION

Figure 5 shows the I-V characteristics of the PSi in the dark, ambient and under UV light illumination. The measurements were carried out with an applied voltage variation from (-5 V to 5 V), the conductivity is greatly increased as a result of the UV light illumination, as evidenced by the higher current. The I-V curves for a planar configuration demonstrate the behavior of two Schottky junctions.
FIGURE 5. Current-voltage characteristic of a PSi photo-detector under dark, ambient light and UV illumination.

The leakage currents are 7.5 μA at a negative bias of 5 V and 9 μA at a positive bias of 5V. The maximum gain reached was two orders of magnitude under UV illumination. The response of M–PSi–M photodetectors increases with the bias voltage.

FIGURE 6. Photoluminescence spectra for porous silicon
In this paper, the PL measurements were performed using He-Cd laser (325 nm). The measurements were carried out at room temperature and were repeated several times to guarantee the behavior of the PL signal. UV emission peak were observed in porous silicon subjected to the nano-sized size of silicon through quantum confinement effect. This is because of the new method which creates dense porous inside the holes and this emission was enhanced by surface plasmon frequency coupling between the silver electrode and the porous net. Furthermore, the appearance of the luminescence bands in the range of 330-380 nm could be due to a quantum confinement assisted radiative recombination of electrons and holes at impurity related defects or at the vacancies of neutral oxygen.

In summary the observed photoluminescence are attributed to many reasons:

1- Quantum confinement effect in nano-size microstructures of PSi which is widening the band gap due to quantum size effect. This means the smaller the particle size, the larger the emission energy, the better the particle size homogeneity and the narrower the spectral width.

2- After the silicon surface becomes porous silicon, the energy gap undergoes a zone folding effect and changed from indirect energy gap to direct energy gap.

3- The peak appears in the UV region because of the highly porous sample and it is associated with a decrease of material skeletal dimension which causes a signal to appear in the UV region of the spectrum.

4- Plasmon is an interesting way to investigate the properties of PSi. Even though our PSi sample emits light in the UV from any above reasons the modification of the silver plasmon energy and coupling to the emitted light from active PSi could be a possibility.
Time stability of the detectors under illumination and their capacity to restore the original dark current value without radiation is a crucial parameter in evaluating the potential of these devices. We, therefore, measured current versus time and at regular intervals when we opened the light shutter. The data in Figure 7 and 9 shows clear unstable photocurrent even during simple illumination.

**FIGURE 7.** Dynamic photoresponse behavior of our porous silicon detector illuminated by UV light (365 nm) with 200 mcd luminous.
In Figure 7, we report dynamic current response versus time of the porous silicon at a bias of 3V under pulsed illumination from a 365 nm wavelength with 200 mcd luminous, the light on steps of 100 sec and off 200 sec and the complete measurement was in 10 min. The n-type based porous silicon device has a fast rise time of 0.5 sec and a very short recovery time as shown in Figure 8.

**FIGURE 8.** The rise time (10 % to 90 %) of the PSi UV detector using pulsed LED with 365 nm wavelength and 200 mcd luminous.

Figure 8 shows the time dependent data collection of dark current when a 3 V reverse bias is applied. After 100 sec, the dark current raises the constant value of 13 \( \mu A \) and the current during the illumination is 17.5 \( \mu A \). In order to evaluate the response, we have calculated the current difference between the dark current and the illumination current. The difference was around 4.5 \( \mu A \) and it was constant as a function of time. This allows using the detectors in experiments that need long illumination and repetitive shots, high stability and reliability.
FIGURE 9. Dynamic violet light (400 nm) induced current behaviour of porous silicon detector obtained under 3V bias voltage.

The violet response curve is shown in Figure 9, using 400 nm wavelength and 2000 mcd luminous. We report the dynamic current response versus time from the porous silicon at a bias of 3V under pulsed illumination from a 400 nm wavelength with 2000 mcd luminous, the light on steps of 50 sec and off 100 sec and the complete measurement was in 10 min. The n-type based porous silicon device has a rise time of 10.41 sec and a very short recovery time as shown in Figure 10. The device with repetitive shots has a very high stability and reliability.
FIGURE 10. The rise time (10% to 90%) of the PSi UV detector using pulsed LED with 400 nm wavelength and 2000 mcd luminous.

CONCLUSIONS

We have demonstrated the photoconductive Violet and UV detector using planer interdigitated electrodes. The results obtained from the PL, responsivity, dynamic photoresponse and dark current measurements prove the potential of both the porous silicon material and technological processes for Violet and UV detection. The detector shows in both wavelengths (400 nm, 365 nm) with repetitive shots have very high stability and reliability. The detector shows fast photoresponse with a rise time of 0.5 sec for UV pulse and 10.41 sec for Violet pulse. Future work will include the backside illumination and a very thin Ag layer as a semitransparent metallic contacts, as well as interdigitated structures with nanometric dimensions.
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