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The influence of gamma irradiation on the chemical and transport properties of porous silicon

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ABSTRACT

Electrochemical cell was used to prepare Porous silicon layers from p-type silicon wafer with etching time 20 min , current 30 mA and fixed electrolyte solution HF:C_2H_5OH (1:4) . The research indicate the effect of the intensity increase of γ-ray radiation on the transport and reflectivity properties of PSi , the investigation include the FTIR spectrum that showed an increase in the number and intensity of the vibrational modes with the increase of the radiation intensity, before irradiation the Fourier Transformtion Infrared (FTIR) spectrum demonstrate numerous vibrational modes that centered at 905, 1105 , 2087 and 2116 cm^{-1} belong to different functional groups while the vibrational modes happened at 827 , 948 , 1065 , 2197 and 2248 cm^{-1} after 50Gy gamma ray irradiation and 856, 979,1056 ,1105 ,2147 and 2192 cm^{-1} after 100Gy gamma irradiation .Reflectivity spectrum over a range of wavelengths (300-1200 nm) show a reduction in the reflectivity with the increase of irradiation intensity .I-V characteristics indicate that the conductivity and identity factor of the porous silicon increases with irradiation .

Keywords: porous silicon, irradiation of PSi , FTIR spectrum of PSi, PSi reflectivity .

INTRODUCTION

Slicon can be considered as a solid material that possesses many advantages such as high stability , easily controlled and low production cost. Several factors have been used to control the electrical and optical properties such as thickness , purity , impurity type etc… [1, 2].

Different techniques (especially the vapor etching technique and the electrochemical anodization) have been adopted to prepare porous silicon layers which could be considered as a system of microstructure layers containing silicon nanostructures in the forms of columns and pores covered by amorphous silicon dioxide [3] .

Many applications of porous silicon (PSi) emerged because of the its rare properties, it has been used in optical sensing and biomedical applications such as waveguides, 1D photonic crystals, chemical sensors, biological sensors and photovoltaic devices , etc…[4,5] .

In this research , the chemical, optical and electrical properties before and after irradiation by 50Gy and 100Gy gamma ray have been studied by Fourier transformation infrared (FTIR) spectrum in the range of about (800-2400 cm^{-1}) , specimen reflectivity spectrum over a range of wavelength (300-1200 nm) and the (I-V) characteristics respectively.

MATERIALS AND METHODS

Etching process was performed on the p-type silicon wafers <111> to prepare the porous silicon using electrochemical cellthat is made out of Teflon as shown in figure 1. A current of about 30 mA and 20 min periodhave been maintained constant During the process.

Isopropanol, Methanol, Hydrofloric acid and Acetone solutions have been used to clean the surface of a small pieces of the silicon wafer(1cm x 1cm) in an ordered procedures .

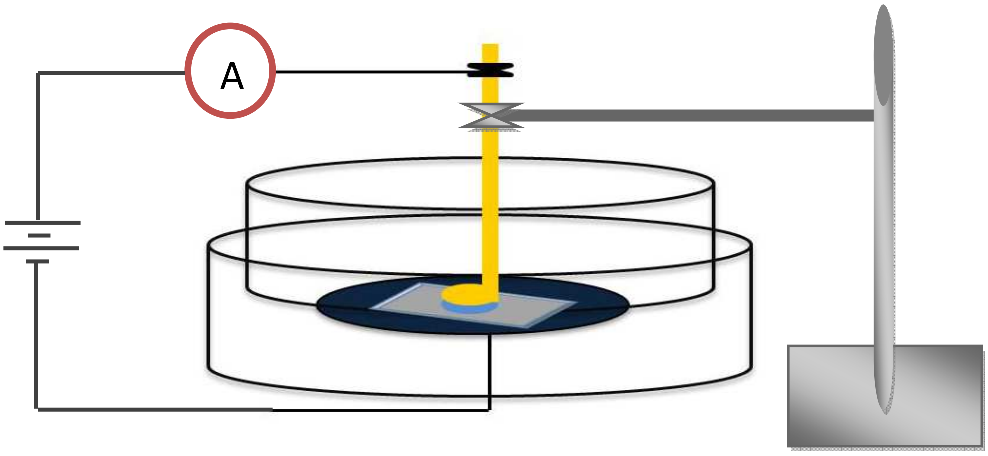

Figure1 shows a schematic diagram of the circuit used in the pursing wafer

The upper part of the cell is nearly full by the Hydrofloric acid electrolyte to supply the required fluorine ions as shown in figure 2 , and it has a circular aperture of area $1cm^2$, which exposes the silicon to Hydrofluoric acid and form the porous silicon .

The sample is located between the two parts of the cell which connected to the anode, and the circular cathode which was made of the gold submerged in the Hydrofluoric acid electrolyte .

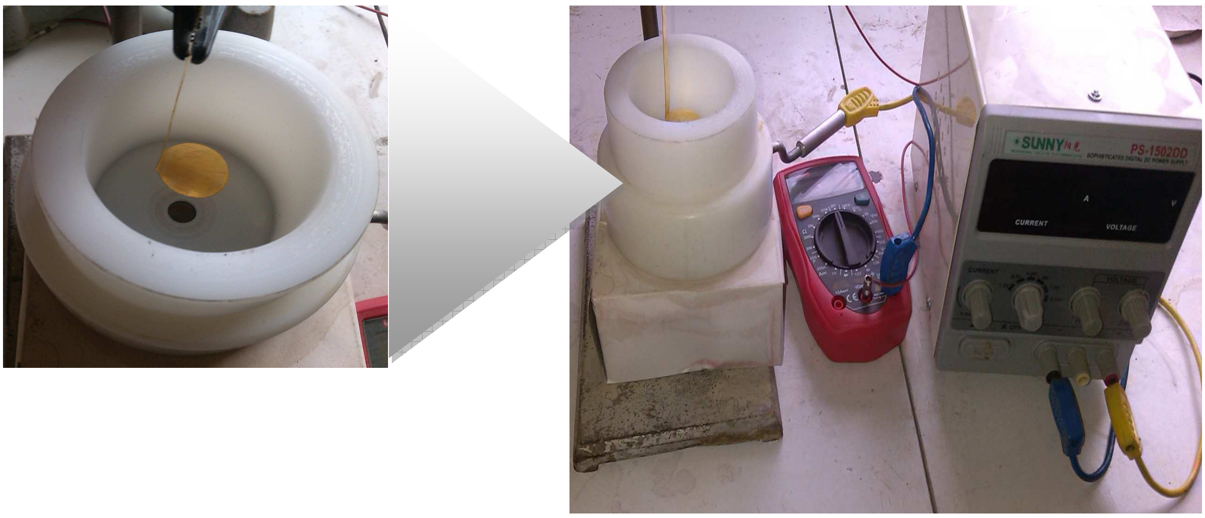

Figure 2 shows image of the electrochemical cell used in the sample preparation

The electrical resistivity of the PSi has been determine from the following equation [6] :

$$\rho = 2\pi s \frac{V}{I} \qquad \ldots \ldots \ldots \ldots \ldots . (1)$$

where s: is the distance between props = 1mm.

The identity factor of the samples were determined from the following equation [7] :

$$n = \frac{q}{kT} \frac{dV}{d \ln \left(I / I_0 \right)} \qquad \ldots \ldots \ldots \ldots \ldots . (2)$$

q:the electron charge , k:Boltzman constant, T : temperature in Kelvin.

$\frac{dV}{d \ln I/I_0}$ the slope of ln I and V curve.

Finally the barrier height was determined by using the following equation [8-9]:

$$\Phi_B = \frac{kT}{q} \ln \frac{A^{**}}{J_s} T^2 \qquad \dots \dots \dots \dots \dots . (3)$$

q : the electron charge , k :Boltzman constant , T : temperature in Kelvin , Φ_B : barrier height(eV) and A** : Richardson constant =32($A/K^2.cm^2$) for p-type silicon .

RESULTS AND DISCUSSION

Electrochemical cell was performed at a constant current 30 mA , and a period of about 20 min to preparep-type Porous silicon layers from silicon wafer . The process has been carried out of a constant current 30 mA and a period of about 20 min . Fourier transformation Infrared (FTIR) spectrum in the rang of about (800-2400 cm^{-1}) , specimen reflectivity spectrum over a range of wavelength (300-1200 nm) and (I-V) characteristics have been used to obtain the optical and electrical properties before and after gamma irradiation.

The FTIR spectrum before and after gamma irradiation shows absorption bands belong to different vibrational modes as in figure 3 . we observe a three strong absorption bands , the highest absorption band appears at the wave number (1056cm^{-1}) for SiO which represent stretching mode , absorption band at the wave number (1105cm^{-1}) for Si-O-Si which represent asymmetric stretching mode and a lower absorption band at the wave number (856cm^{-1}) for SiH_2 which represent wagging vibrational mode in addition to a several weak absorption bands [10 -11] .

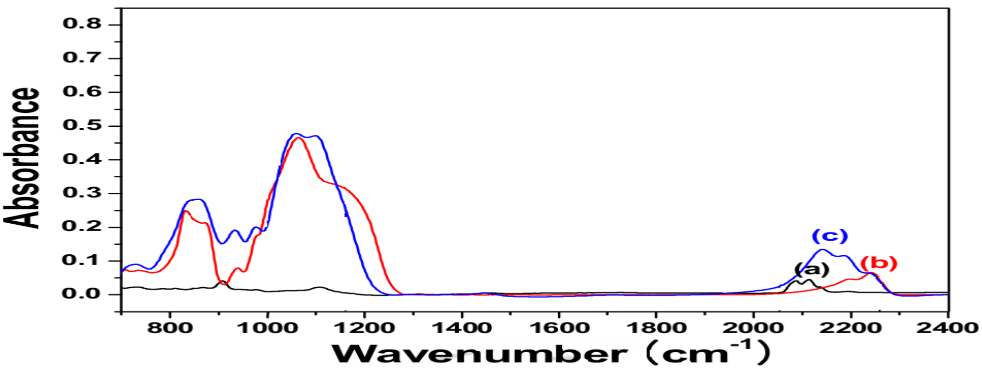

Figure3 FTIR spectrum for PSi (a)before irradiation (b)after 50Gy gamma irradiation (c) after 100Gy gamma irradiation

From figure 3 , the absorption spectra contain different chemical formulas that include silicon hydrogen ($Si-H_x$) (x=1,2,3) , silicon mono hydrogen (Si_3-SiH) and silicon trihydrogen ($Si-SiH_3$) , in addition to silicon oxides such as (SiO), (Si-O-Si) and (O_y SiH_x , x=1-3 , y=1-3) as mentioned in table 1 [12].

The functional groups silicon hydrogen (SiH) that named (Si_3-SiH , Si_2H-SiH) represent the stretching vibrational mode , it appeared at the wave numbers (2087 cm^{-1}) and (2116cm^{-1}) respectively as shown in table 1-a.After irradiation by 50Gy gamma rays , the bands at the wave numbers (2197cm^{-1}) and (2284cm^{-1}) belong to stretching vibrational mode that named (SiO_2–SiH , Si_2H-SiH) respectively , but the strong band intensity at the wave number (827cm^{-1}) represent the bending vibrational mode which belong to silicon oxide (SiO) named (O-Si-O) as shown in table 1-b [12] .

After irradiation by 100Gy gamma rays , another bands appear in the spectrum in addition to the latter bands at the wave number (1056cm^{-1}) and (1105cm^{-1}) , the band at the wave number (2147cm^{-1}) represent (Si trihydride) $SiSiH_3$[14] . The formula (O_xSiH_x) (O_2SiH_2 at the wave number 2192cm^{-1}) can be observed in the PSi layer , the appearance of the formula (O_xSiH_x) give indication about the transitions from divalent dissolution to tetravalent dissolution as in table 1-c [13-14].

specimen reflectivity spectrum over a range of wavelength (300-1200 nm) show a reduction in the reflectivity with the increase in the amount of irradiation , as shown in figure 4.

the curves (a , b , c) in figure 4 indicate that the reflectivity is decreasing at the wavelength (375-1025 nm) before and after irradiation for all specimens , the decrease in the reflectivity can be explained as a result of the variation in the porosity and surface topography [15] .

The rise in the amount of irradiation from 50Gy to 100Gy would produce a clearly reduction in the reflectivity of about (20-27 %) compared with the reflectivity before irradiation as shown in figure 4.

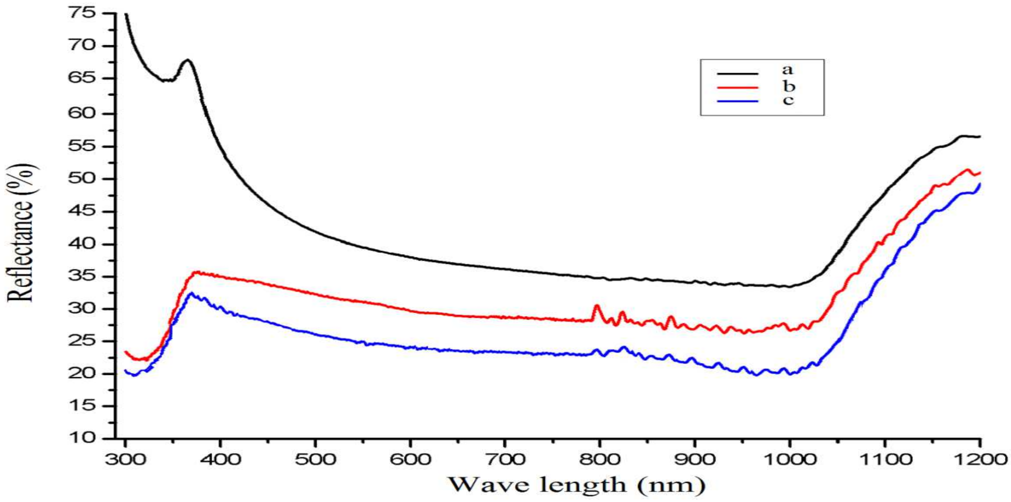

Figure4 reflectivity spectrum for PSi (a)before irradiation (b)after 50Gy gamma irradiation (c) after 100Gy gamma irradiation

Table 1 the vibretional modes for PSi before and after irradiation by 50Gy and 100 Gy gamma

Sample	Peak position (cm^{-1})	Functional group	Assignment	Vibrational modes	Reference
a	905	SiH_2	-------	scissoring	[Bisi *et al.*, 2000]
	1105	Si-O-Si	-------	asymmetric stretching	[Pong *et al* , 1996]
	2087	SiH	Si_3-SiH	stretching	[Bisi *et al.*, 2000]
	2116	SiH	Si_2H-SiH	stretching	[Bisi *et al.*, 2000]
b	827	SiO	O-Si-O	bending	[Bisi *et al.*, 2000]
	948	SiH	Si_2-H-SiH	bending	[Bisi *et al.*, 2000]
	1056	SiO	O-Si-O	stretching	[Bisi *et al.*, 2000]
	2197	SiH	SiO_2-SiH	stretching	[Bisi *et al.*, 2000]
	2248	SiH	O_3-SiH	stretching	[Bisi *et al.*, 2000]
c	856	SiH_2	-------	wagging	[Bisi *et al.*, 2000]
	979	SiH	Si_2-H-SiH	bending	[Bisi *et al.*, 2000]
	1056	SiO	O-Si-O	stretching	[Bisi *et al.*, 2000]
	1105	Si-O-Si	-------	asymmetric stretching	[Jingmei Lu *et al.*, 2010]
	2147	$SiSiH_3$	-------	-------	[ogata *et al.*, 1995]
	2192	O_2SiH_2	-------	-------	[Monk *et al.*, 1993], [Hoffmann *et al.*, 2000]

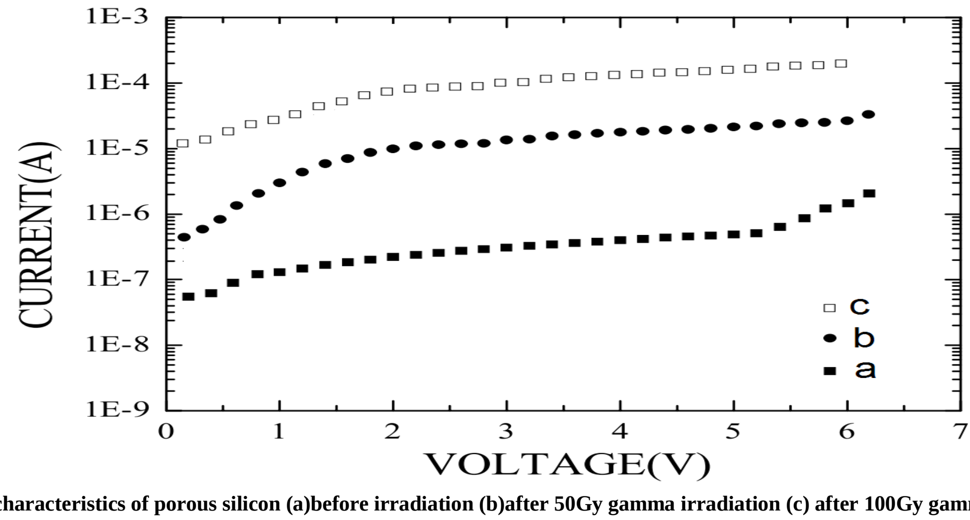

Figure5 I-V characteristics of porous silicon (a)before irradiation (b)after 50Gy gamma irradiation (c) after 100Gy gamma irradiation

From the (I-V) characteristic measurements and the equations (1) , (2) and (3) the electrical properties of the PSi such as resistivity , conductivity , identity factor and barrier height have been calculated.

Figure 5 shows the (I-V) characteristics of the p-type PSi layers before and after irradiation . Before irradiation the current increase with applied voltage at constant rate , at high voltages of about (5.5V)the current highly increases with a small increment of the applied voltage.

We note also a low current values (10^{-6} , 10^{-8} A) as a result of the high resistivity and high Schottky barrier of the pores layers as shown in figure 5-a , after irradiation by 50Gy and 100Gy gamma ray , the current clearly increase to nearly saturation values with increase of irradiation[6,16].

Table 2the electrical properties of PSi before and after irradiation by 50Gy and 100 Gy gamma

ɤ-Irradiation(Gy)	Current at 6V	Resistivity $\rho\times10^{4}(\Omega.m)$	Conductivity $\sigma\times10^{-4}(\Omega.m)^{-1}$	Ideality factor n	Barrier height Φ_B(eV)
0	1×10^{-6} A	3.766×10^{4}	0.265	4.587	0.742
50	2×10^{-5} A	0.188×10^{4}	5.319	6.457	0.664
100	1×10^{-4} A	0.037×10^{4}	27.027	8.132	0.623

From table 2 , the PSi possesses high electrical resistivity of about ($10^{4}\Omega$.cm) in comparison to the resistivity of bulk silicon of about ($10^{4}\Omega$.cm) and this is consistent with the results of published researches. After irradiation , the resistivity decrease with radiation increase ,this can be explained as the change that occurs in the structure by creation defects within the PSi layer [17-18].

Also we can note from table 2 that the identity factor increase and the barrier height decrease with the increase in the radiation , this can be explained as a result of the presence of high concentration of holes within the interface between the Porous silicon and silicon layers PSi/Si that acts as a defects influence on the interface and consequently increase in the saturated current density which lead to decrease in the barrier height of the PSi [19] .

CONCLUSION

The FTIR spectra before and after gamma irradiation show absorption bands belong to different vibrational modes. After irradiation by 100Gy gamma irradiation , another bands appears in the spectrum in addition to the latter bands at the wave number ($1056cm^{-1}$) and ($1105cm^{-1}$) .

Specimen reflectivity spectrum over a range of wavelength (300-1200 nm) show a reduction in the reflectivity with the increase in the amount of irradiation.

The PSi possesses high electrical resistivity of about ($10^{4}\Omega$.cm) which decrease with increasing radiation .

The Identity factor increase and the barrier height decrease with the increase of the radiation.

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