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Changes of thermal Conductivity, Optical Conductivity, and Electric Conductivity of Porous Silicon With Porosity

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Abstract

Porous silicon (PS) was prepared by electrochemical etching method. Mirage effect in transverse photothermal deflection PTD (skimming configuration) was used to determine thermal conductivity the experimental results of PS thermal conductivity was compared with theoretical results they were almost the same. Optical extinction coefficient and absorption coefficient were calculated from transmittance T and reflectance R curve which measured with UV-Vis-NIR Spectrophotometer, and they were used to calculate the optical conductivity and electric conductivity from the Shankar and Joseph equations, and optical conductivity and electric conductivity were studied with porosity in porous silicon.

Key words: *thermal conductivity, optical conductivity, electric conductivity, porous silicon, electrochemical etching, porosity, optical extinction coefficient , absorption coefficient , film.*

1. Introduction

Porous silicon has attracted considerable research interest after their discovery in 1956 [1]. Low-dimensional materials are finding ever-widening application in many areas of science and Engineering [2]. Nanostructured porous silicon shows a variety of other interesting properties, including tunable refractive index, tunable energy gap, low light absorption in the visible, high internal surface, variable surface chemistry, or high chemical reactivity. Properties, along with its ease of fabrication and the possibility of producing precisely controlled layered structures make this material adequate for its use in a wide range of fields, such as optics, micro- and optoelectronics, chemical sensing or biomedical applications [3].

2. Experimental Methods

Porous silicon samples were prepared by electrochemical etching method of p-type cubic silicon wafers (c-Si), (100) orientation with resistivity of 0.01-40 Ω·cm, electrochemical dissolution of Si wafers is used: HF-ethanol (measured by volume) aquas with concentration from 20% . The current density was always kept Constant for each sample during etching of PS (10,..,50 mA/cm2).Fabricating process done in a normal etching Teflon cell fig(1). After anodization, PS samples are carefully removed from the bath and cleaned in deionized water . Few examples of AFM measurement is presented to show differences between samples according to preparing current (fig.2).

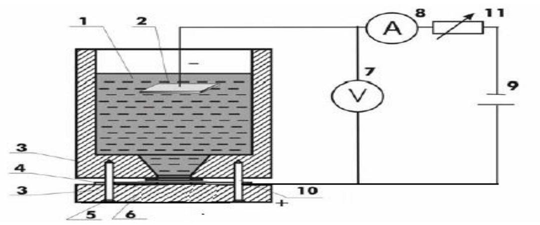

Figure 1. Iiustration of the experimental setup:
a) schematical view,
b) crossection of the electrochemical etching cell:
1 – electrolyte, 2 – copper cathod, 3 – electrochemical etching tank (teflon), 4 – platinum anode , 5 – seal,
6 – Si wafer, 7 – voltmeter, 8 – amperemeter,
9 – DC source, 10 – grips, 11 – rheostat [4].

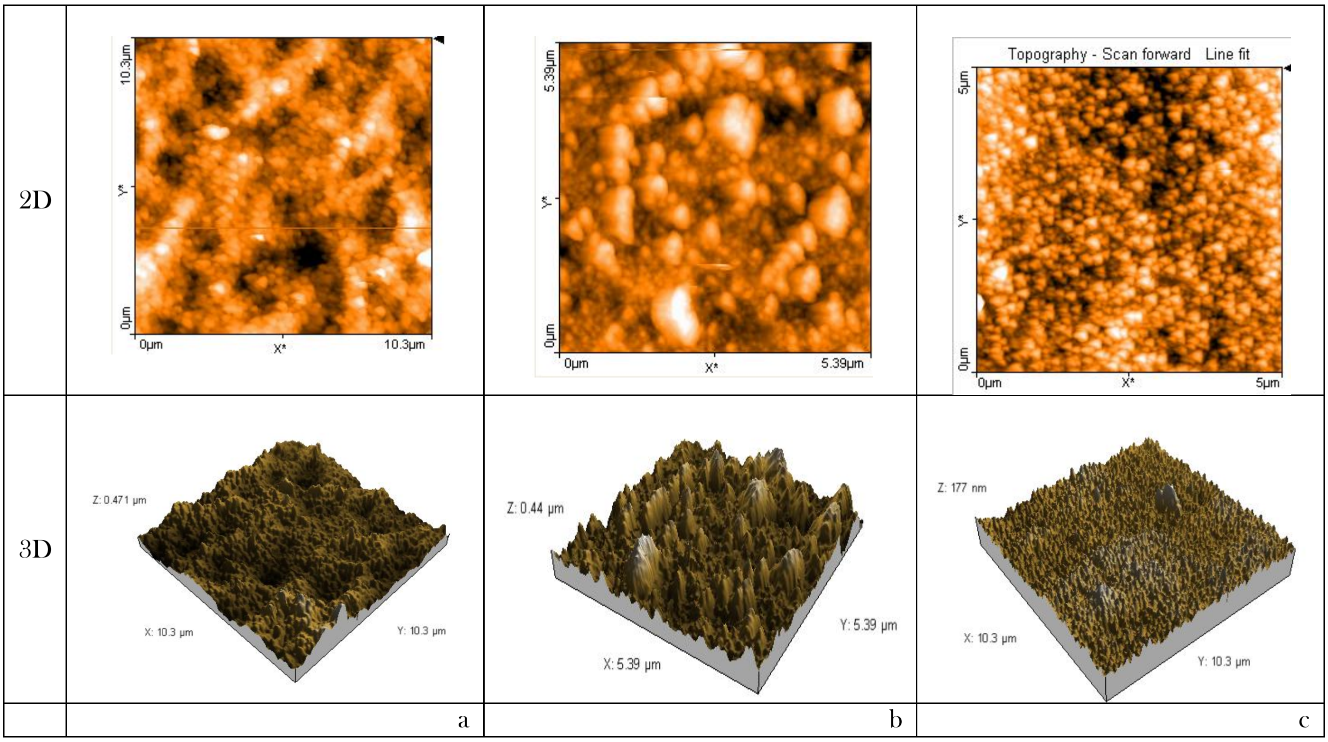

Figure 2. 2D and 3D AFM image of porous silicon samples prepared with etching time of 5 min and current density of (a-20,b-30,c-45) mA·cm^{-2}, at HF concentration 20%.

3. Theory

3.1 The porosity of porous silicon P

Porosity is defined as the fraction of void within the porous silicon PS layer and can be determined easily by weight measurements. The virgin wafer is first weighed before anodisation (m1), then just after anodisation (m2) and finally after dissolution of the whole porous layer in a molar KOH aqueous solution (m3).

$$P(\%) = \frac{m_1 - m_2}{m_1 - m_3} \qquad (1)$$

the removal is made through a dip for some minutes in an aqueous solution of KOH (3% in volume), that leads to a selective removal of the PS layer without reacting with the bulk crystalline silicon.

Different techniques are employed to determine the porous layer thickness d. From the gravimetric measurements,

$$d = \frac{m_1 - m_3}{\rho S} \qquad (2)$$

where ρ is the silicon density and S the etched surface [5].

3.2. Thermal conductivity

We've used transverse photothermal deflection PTD to determine thermal properties of PS, in skimming probe beam configuration [6, 7, 8, 9] fig.3

We've measured κ_{eff} of the two layers Si-PS from PTD then by using two layers model, thermal conductivity of porous silicon film is calculated from eqs. (3, 4) [10]:

$$\kappa_{eff} = \frac{L\kappa_1\kappa_2}{\kappa_1 L_2 + \kappa_2 L_1} \qquad (3)$$

$$\kappa_1 = \kappa_{eff} \frac{\kappa_2 L_1}{\kappa_2 L - \kappa_{eff} L_2} \qquad (4)$$

Where κ_1 is thermal conductivity of porous silicon, κ_2 thermal conductivity of silicon (150w/mk) , κ_{eff} the effective thermal conductivity(for porous silicon and silicon layer), L_1 the porous silicon film thickness, L_2 the silicon substrate thickness, L thickness of porous silicon film and silicon substrate together(0.4 mm).

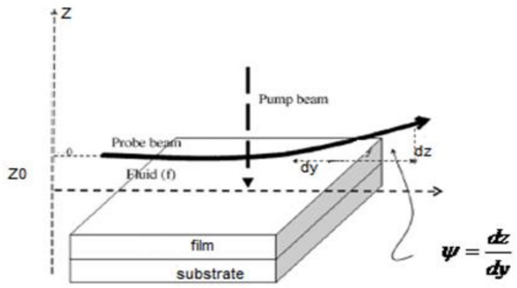

Figure3. schematic representation of the probe beam deflection in Skimming probe beam configuration

3.3. Optical conductivity measurement

As incident photon energy is given by : $E = h\nu$
Where h is blank's constant, ν is the light frequency. The optical conductivity is directly proportional to optical extinction coefficient [11]:

$$k = \frac{\alpha\lambda}{4\pi} \quad (5)$$

λ is the wavelength of light, α absorption coefficient which is calculated from transmittance T and reflectance R curve measured with UV-Vis-NIR Spectrophotometer[11]:

$$\alpha = (1/d)\ln((1-R)/T) \quad (6)$$

d film thickness.
and results were used to calculate the optical conductivity from the Shankar and Joseph equation [12]:

$$\sigma_{op} = \frac{k\,n\,c}{\lambda} \quad (7)$$

k is the optical extinction coefficient, n is the optical refractive index, c is the velocity of light and l is the wavelength of light.

3.4. Electrical conductivity measurement

The electrical conductivity measurement using the Shankar and Joseph equation [12]:

$$\sigma_{ec} = \frac{2k\,c\,n}{\alpha} \quad (8)$$

4. Results and discussion

It was found that the Thermal conductivity of PS films decreases with increasing porosity. The measured thermal conductivities, of our samples was close to theoretical results predicted by Eq. (9) [13, 14].

$$\kappa_{1th} = \kappa_{si}(1-p)^3 \quad (9)$$

The decreasing in Thermal conductivity is attributed to that: The solid contribution is normally significantly higher than that of the gas contained in the pores, and thus, the gaseous conduction contribution is considered to be negligible. The radiative contribution, k_{rad}, is derived from heat radiated throughout the pores, and is highly dependent on the porosity, pore size, and temperature [15]. For all that reasons thermal conductivity in bulk silicon is higher than that of PS samples. fig(4) shows the measured and theoretical calculated thermal conductivity of PS sample they are almost the same.

α absorption coefficient which is calculated from transmittance T and reflectance R curve measured with UV-Vis-NIR Spectrophotometer fig.(5), using eq.(6). Then from α absorption coefficient the extinction coefficient k is calculated from eq.(5), using α , k optical conductivity is calculated then from eq.(7). Fig.(8), and electric conductivity is calculated from eq.(8),fig(9) ,our work shows that absorption coefficient and the extinction coefficient decreases with porosity increases.

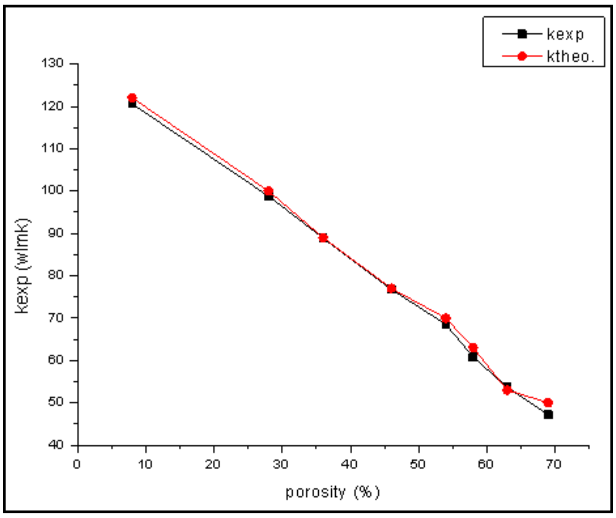

Figure4. the thermal conductivity of PS changes vs porosity

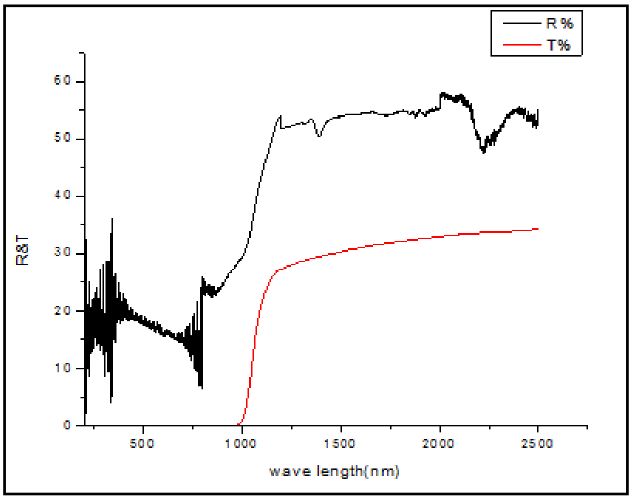

Fig.5 reflectance and transmittance as function of wave length for sample S01

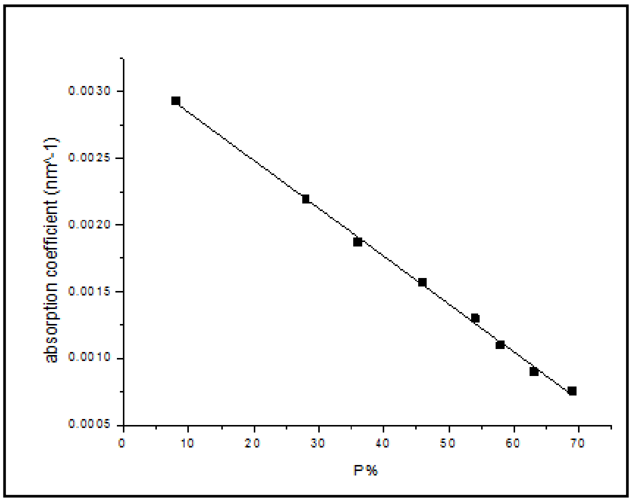

Figure 6. absorption coefficient vs. porosity

One can see that optical conductivity doesn't changes in our rang of porosity that means this is suitable material for optoelectric device . and that agrees with others results [11] where the variation of conductivity remains at zero up to photon energy of 5.35eV, while the electrical conductivity drops down because optical extinction coefficient decreases with porosity.

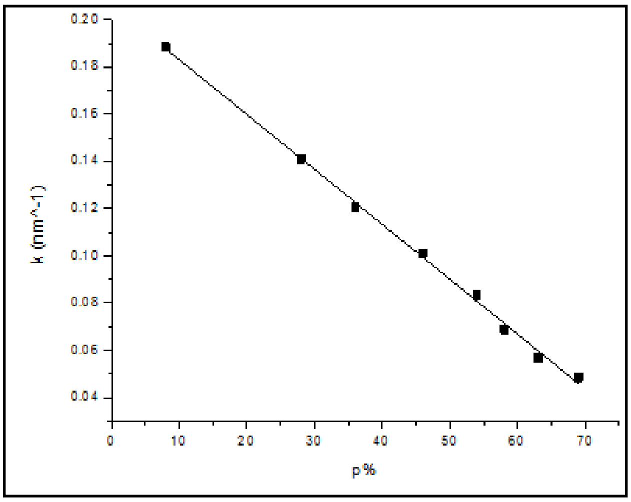

Figure7. Optical extinction coefficient vs. porosity

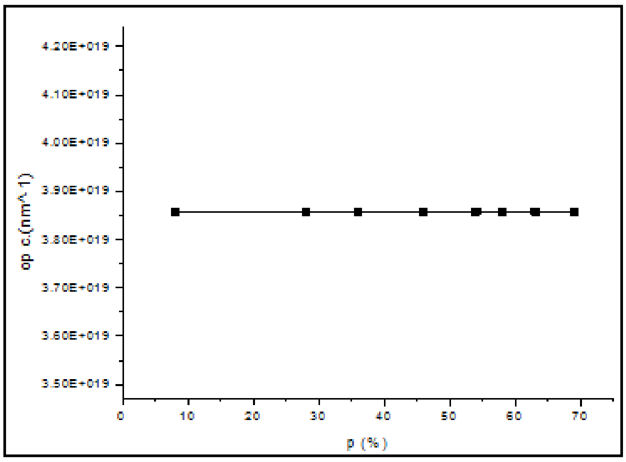

Figure 8. optical conductivity VS Porosity%

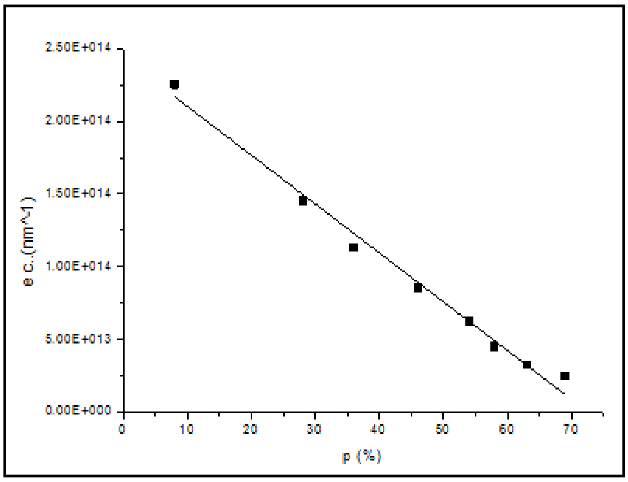

Figure 9. electric conductivity VS Porosity%

5. Conclusion

Porous silicon samples were prepared by electrochemical etching method , HF-ethanol concentration from 20% ,The current density was (10,..,50 mA/cm^2).Fabricating process done in a normal etching Teflon cell, Mirage effect in transverse photothermal deflection PTD (skimming configuration) is used to determine effective thermal conductivity . It changed from120W/Mk for 8% porosity to 47.2 W/Mk for 69 % porosity. Experimental results of PS thermal conductivity with porosity was compared with theoretical results and it was almost the same . Absorption coefficient was calculated from transmittance T and reflectance R curve measured with UV-Vis-NIR Spectrophotometer was used to calculated extinction coefficient then to calculate electric conductivity and optical conductivity, our work shows that absorption coefficient and the extinction coefficient decreases with porosity increases. So is electric conductivity, while optical conductivity remains constant in rang of our porosity.

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