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Fabrication of one-dimensional photonic crystals using porous silicon layers

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Presently, one-dimensional photonic crystal by using porous silicon layers has been preferred because of its easy fabrication method by electrochemical etching. In this paper, the electrochemical etching of boron doped silicon wafer of <100> orientation has been done in ethanolic solution containing aqueous hydrofluoric acid. The porous silicon layered structures have been studied by using FTIR, XRD and SEM. The XRD spectras reveals that the porous silicon has the same orientation that of the bulk silicon as the etching process does not change its orientation. The silicon and oxygen bonding produces prominent absorbance band as shown in IR spectras, it is analyzed that the antisymmetric stretching peak of Si-O-Si bond is present in the porous silicon structures. The surface morphology analysis by SEM, demonstrates the first and second layer thicknesses are 1.36 μm and 0.56 μm of sample PSL1 and 1.84 μm and 0.72 μm of sample PSL2.

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1. Introduction

A single interface between two dielectric materials has very less reflection therefore a structure composed of many such interfaces can be developed which provides very high reflection to a certain range of wavelengths. Such structures are known as the photonic crystals, which are the primary need of advanced communication system. It ensures high reflectivity within broad spectral range and allows for the control of the parameters of short light pulses as passive optical components. Photonic crystals are the periodic dielectric structures which posses a photonic band gap and allows the control of the light propagation similar to electrons in a semiconductor crystal. These structures are classified in three categories such as one, two and three-dimensional photonic crystals however, fabrication of one-dimensional photonic crystal is easy and has emerged as a solution of many problems of optical communication systems [1-5].

The photonic bandgap increases as the ratio of the refractive indices of two constituent layers increased for a fixed number of periods. While for a fixed ratio of refractive indices, the photonic bandgap increases as the number of periods increased. Therefore in order to obtain complete bandgap, the optimization of physical and optical parameters such as refractive index contrast, lattice constant, number of stacks, angle of incidence etc. are needed [6]. One interesting property of a photonic crystal is that it can reduce the magnitude of the group velocity of propagating electromagnetic waves. The group velocity approaches to zero in photonic structures, which allows its applications as optical delay lines or as data storage compounds. In addition, not only small group velocities have been observed in photonic crystals but also a superluminal group velocity is also predicted which indicates the delocalization of photons in the bandgap [7-11]. Such types of structures are the need of modern optical technologies where its remarkable properties are widely employed and has found potential applications in photonics, communication, chemical sensors and biosensors.

Silicon has been the choice for microelectronics technology because of various reasons such as its cost, compatible with mass production and availability. Silicon based photonic devices are very significant from commercial point of view and are much compatible with established technology for microelectronic processing [12]. Porous silicon has received a great attraction since the discovery of efficient photoluminescence [13]. It is a material, which offers major potential for integrated photonics technology and accepts new challenges to fabricate silicon based nano photonic devices.

Presently, the porous silicon has become a very thrust area of research due to its potential applications for silicon based optical integrated circuits for faster process and high speed communications. Hence, it is an ideal candidate for the fabrication of one-dimensional photonic crystals (1DPCs), which can be economically fabricated using porous silicon layers (PSLs) with controlled process parameters [13-15]. The value of the refractive index of each layer depends on its porosity, which can be obtained by changing the etching currents for specific HF concentration and anodization time during electrochemical etching process. The choice of modulating two different current densities has been a convenient procedure to fabricate the 1D porous silicon photonic crystals. The change of the current density does not affect the previously formed porous silicon layer because silicon dissolution occurs at the silicon–electrolyte interface.

In this paper, we have presented the analysis of two porous silicon layered structures PSL1 and PSL2 by electrochemical etching of silicon and compared its

surface morphologies. In section two, the experimental procedure for making the 1D porous silicon photonic crystals has been discussed. Results and discussions are summarized in section third. Finally, section fourth concludes the paper.

2. Experimental

Porous silicon layers (PSLs) were formed by electrochemical anodization on p-type silicon wafer of <100> orientation in 48% (w/o) HF solution at current densities of 30 mA/cm^2 and 50 mA/cm^2 during etching time 2 and 1 minutes. The electrochemical cell used has two electrode configurations with a platinum electrode and a silicon wafer as anode. The electrolyte used was $HF:H_2O:C_2H_5OH$ in a volume ratio of 1:1:2. The anodization starts when a constant current is applied between the silicon wafer and the electrolyte by means of an electronic circuit controlling the anodization process. We have prepared two structures of porous silicon layers (PSLs) where one period consists of one low and one high refractive index layer. The samples were prepared under dark condition to avoid the adverse chemical effect due to light.

The samples were characterized by XRD (Rigaku Miniflex, Japan) in the range of 20-80^o 2θ. The infrared absorption spectras of the porous silicon layered structure were recorded by a FTIR spectrometer (Nicolet 380, USA) in the range of 400 - 4000 cm^{-1} wavenumbers. The surface morphologies of as-grown porous silicon layered structures were studied with scanning electron microscopy (Leica Cambridge 440 Microscope, UK).

3. Results and discussion

The electrochemical etching method provides control over the porosity and thickness of the porous silicon layer as a function of etching parameters. Modulating the current density does not affect the previously formed porous silicon layers as silicon dissolution occurs at the silicon electrolyte interface. Two samples of porous silicon have been fabricated which are named as sample PSL1 and PSL2, under two and one minutes etching time respectively. The obtained refractive indices of first and second layers are 2.14 and 1.88 respectively of PSL1. However, it is 2.65 and 1.42 for PSL2 of the first and second layer respectively.

The samples of the layered porous silicon show the different structural morphology, due to different etching time. Therefore, study of IR spectra has importance to identify the different modes of bondings and chemical information present in the prepared samples. Different absorption peaks are identified in Fig. 1 and 2 which shows the infrared absorption spectras of prepared samples PSL1 and PSL2 in the range of 400 cm^{-1} to 4000 cm^{-1} of wavenumbers. As shown in the Fig. 1 for PSL1, there is a peak of Si-H_x wagging at 635 cm^{-1} at which silicon is back bonded to hydrogen atoms. A peak of Si-H_2 scissor at 905 cm^{-1}, Si-O-Si stretching mode at 1052 cm^{-1} and Si-H_x stretching at 2100 cm^{-1} are presented. However, for PSL2 there is a peak of Si-H_x wagging at 630 cm^{-1} at which silicon is back bonded to hydrogen atoms and the another peaks of Si-H_2 scissors at 901, Si-O-Si stretching at 1037 and Si-H_x stretching at 2096 are shown in the Fig. 2. The important surface bondings and vibrational modes obtained by FTIR spectra of sample PSL1 and PSL2 has been demonstrated in Table 1 which shows agreement with reported works [16-18].

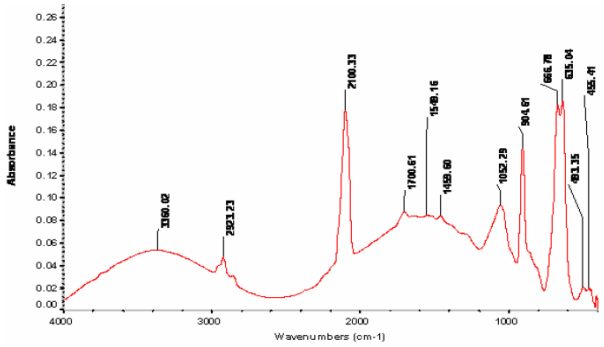

Fig. 1. FTIR spectra of sample PSL1.

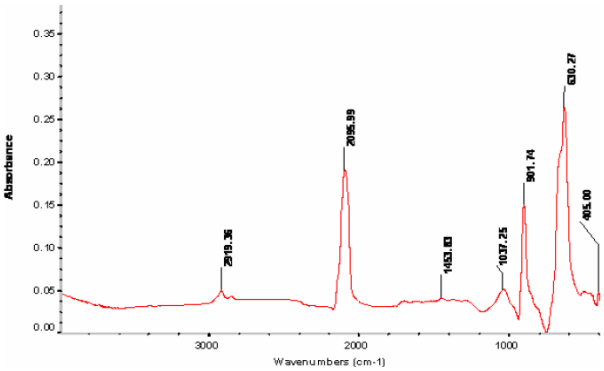

Fig. 2. FTIR spectra of sample PSL2.

Table 1.

Frequency (cm^{-1}) (Sample PSL1)	Frequency (cm^{-1}) (Sample PSL2)	Bonds	Vibrational Modes
635	630	Si-H_x	waging
904	901	Si-H_2	scissors
1052	1037	Si-O-Si	stretching
2100	2096	Si-H_x	stretching

Fig. 3 and 4 shows the x-ray diffraction (XRD) graph of sample PSL1 and PSL2 prepared by electrochemical etching, in the range from 20-80^o 2θ. The XRD graph of sample PSL1 and PSL2 shows are almost similar which reveals that the etching process duration has not changed the orientation as compared with the bulk silicon. There is a very sharp peak in a XRD spectras at 2θ=68.00 as depicted in Fig. 3 and Fig. 4, which indicates the single crystal nature of silicon. This strong peak is due to the reflection of the silicon crystal and first allowed peak in the silicon of <100> orientation.

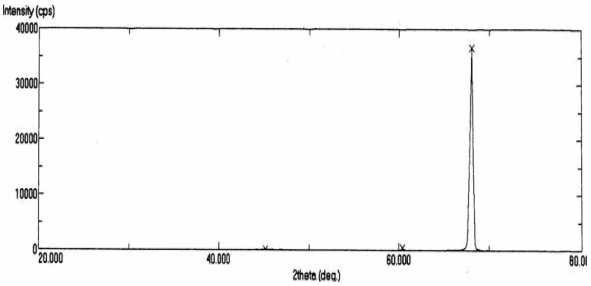

Fig. 3. XRD spectra of sample PSL1.

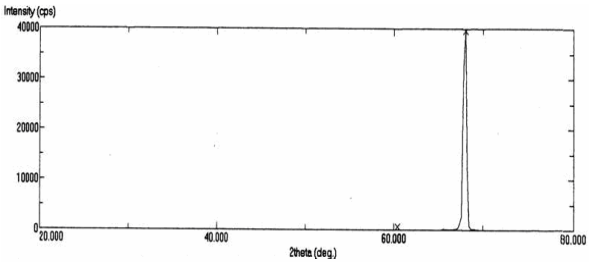

Fig. 4. XRD spectra of sample PSL2.

Fig. 5 and 6 shows the SEM micrographs of PSL1 and PSL2 fabricated using the conditions discussed in section 2. For PSL1, we have found the first and second layer thicknesses are 1.36 μm and 0.56 μm for current density of 50mA/cm^2 and 30mA/cm^2 under two minute etching time. However, for PSL2 we have found that for current density of 50mA/cm^2 and 30mA/cm^2 the obtained thicknesses are 1.84 μm and 0.72 μm corresponding to the first and second under one minute etching time. Fig. 5 and 6, show the layered structures of porous silicon by white and black strips of n_1=2.14 and n_2=1.88 of sample PSL1 and n_1=1.42 and n_2=2.65 of sample PSL2 respectively. The SEM micrograph of PSL1 show the non-uniform layers under 2 minutes etching time but, as the etching time reduces to the 1 minute the structure of PSL2 becomes more uniform with good homogeneity as depicted in SEM micrograph. The refractive index contrast of PSL2 is large as compared to the PSL1 hence. A large photonic bandgap can be obtained by tuning the etching time. The thicknesses of porous layers were measured by scanning electron microscopy.

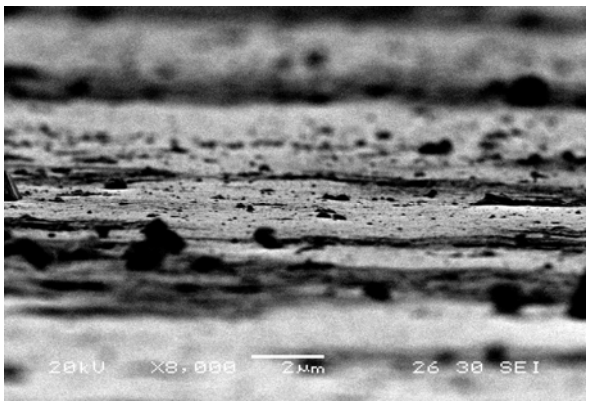

Fig. 5. SEM micrograph of sample PSL1.

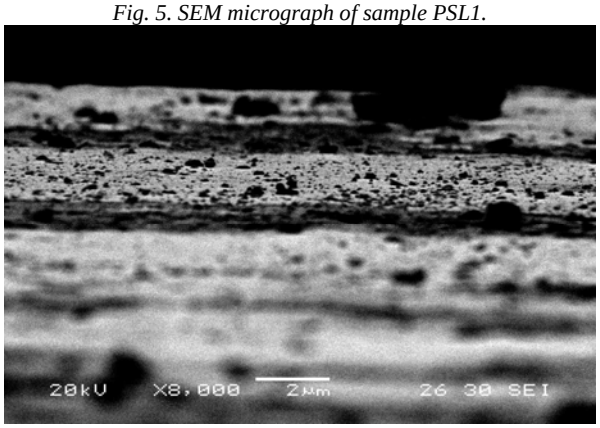

Fig. 6. SEM micrograph of sample PSL2.

4. Conclusions

In conclusion, we have fabricated two one-dimensional photonic crystals by electrochemical etching method. The prepared samples exhibits different structural features as evidenced from the local bonding environment of oxygen and hydrogen atoms. A sharp peak in the XRD spectras shows that the porous silicon has the same orientation as that of the bulk silicon and the etching process does not change the orientation. The surface morphology evidenced using SEM, demonstrates that when the etching time is varied the layered structure of porous silicon becomes more uniform with good homogeneity. The pore morphology and thickness of layers depend on the applied current and processing time.

References

[1] J. D. Joannopoulos, Pierre R., Villeneuve, Shanhui Fan, Photonic Crystals, Solid State Communication **102**(2-3), 165-173 (1997).

[2] J. D. Joannopoulos, Pierre R., Villeneuve, Shanhui Fan, Photonic Crystals: putting a new twist on light, Nature **386** (13), 143-149 (1997).

[3] J. D. Joannopoulos, R. D. Meade, J. N. Winn, Photonic Crystals: Molding the Flow of Light (Princeton U. Press, Princeton, N.J., 1995).

[4] K. Sakoda, Optical Properties of Photonic Crystals, Springer Series in Optical Sciences, (2001).

[5] C. M. Soukoulis, 13**,** 420-423 (2002).

[6] R. S. Dubey, D. K. Gautam, Photonic Bandgap Analysis in One-Dimensional Porous Silicon Photonic Crystal by Transfer Matrix Method, Optoelectron. and Adv. Mater.–Rap. Commun. **1**(9), 436-441 (2007).

[7] Jonathan P. Dowling, Michael Scalora, Mark J. Bloemer and Charles. M. Bowden, The Photonic Band Edge Laser: A New Approach to Gain Enhancement, J. Appl. Phys. **75**(4), 1896-1899 (1994).

[8] Li-Gang Wang, Nian-Hua Liu, Qiang Lin, Shi-Yao Zhu, Superluminal Propagation of Light Pulses:

A Result of Interference, J. Phys. Rev. E **68,** 066606-1-066606-9 (2003).
[9] Nian-Hua Liu, Shi-Yao Zhu, Hong Chen, Xiang Wu, J. Phys. Rev. E **65,** 046607-1-046607-8 (2002).
[10] R. S. Dubey, D. K. Gautam, J. Opto. & Advan. Mate.–Rap. Commun. **1**(11), 563-567 (2007).
[11] L. Pavesi, J. Phys.: Codens. Matter **15**, R1169-R1196 (2003).
[12] R. T. Collins, P. M. Fauchet, M. A. Tischler, Porous Silicon: From Luminescence to LEDs, Physics Today **50**(1), 22-31 (1997).
[13] V. Agarwal, J. A. del Rio, Appl. Phys. Lett. **82**(10), 1512-15414(2003).
[14] J. E. Lugo, H. A. Lopez, S. Chan, P. M. Fauchet, J. Appl. Phys. **91**(8), 4966-4972 (2002).
[15] P. Ferrand, D. Loi, R. Romestain, Appl. Phys. Lett. **79**(19), 3017-3019(2001).
[16] T. Ya Gorbach, G. Yu Rudko, P. S. Smertenko, S. V. Svechnikov, M. Ya Valakh, V. P. Bondarenko, A. M. Dorofeev, Semicond. Sci. Technol. **11**, 601-606 (1996).
[17] Structural Characterization of Photoluminescence Porous Silicon with FTIR Spectroscopy, Brazillian J. Phys. **27**(4), 158-161 (1997).
[18] Y. H. Ogata, T. Tsuboi, T. Sakka, S. Naito, J. Pour. Mater. **7**, 63-66 (2000).

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