

Synthesis and analysis of porous silicon for applications in fabricating 1-D photonic crystals

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ABSTRACT

Porous silicon has a great potential in photonics applications due to its tunability of refractive index by controlling the porosity of its layer during formation. Hence, the bandwidth of 'Photonic Bandgap' can be tuned by refractive index contrast of two constituent layers of porous silicon. In the present work, we have prepared porous silicon of boron doped silicon wafer with <100> orientation by vapor phase chemical etching and electrochemical etching. The ellipsometry characterization divulges the variation in refractive index of bulk silicon after pore formation of the two samples obtained to be 1.83 and 2.1. The XRD spectra reveal the shifting of intensity peak to its higher values, which confirms the existence of porous silicon. A broad peak in the spectra shows that the porous silicon has the same orientation as that of the bulk silicon and the etching process does not change its orientation. The FTIR shows the existence of strong hydrogen incorporation in porous silicon which can be minimized by annealing. The characterization of surface morphology using AFM, demonstrates the pore diameters are 70nm and 85nm of sample S1 and S2 respectively.

Keywords: Porous Silicon, Photonic Crystals, Porosity, Nano-Structures.

INTRODUCTION

The progress in semiconductor materials for optoelectronic applications have raised the hope of silicon based optical interconnects for faster response and high-speed communications. 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 processing¹.

Porous silicon (PS) is a material that offers major potential for integrated photonics technology and can accept new challenges to fabricate silicon based nano photonic devices. This technology is able to face Moore's law and has been used to fabricate photonic crystals, waveguides, sensors, nanocavities, photodetectors, channel drop filters etc. Porous silicon was discovered by Uhlir during the experiment of electropolishing of silicon wafer

in HF based electrolyte². After this invention many efforts have been taken towards the fabrication of porous silicon layers. Porous silicon is considered as a suitable material for the fabrication of photonic crystals with electrochemical anodization of silicon wafer, which provides a structure of arbitrary refractive index profile³⁻⁵. The one-dimensional (1D) photonic crystals are periodic dielectric structure in one direction, which possess a gap known as 'Photonic Bandgap' in which a range of specified frequency is forbidden⁶⁻⁷. The concept of photonic crystal has been developed and explained by Yablonovitch and John^{8,9}. Porous silicon provides a wide tunability of refractive indices of layers by controlling the porosity during synthesis hence it has found enormous applications for the fabrication of 1D photonic crystals and devices.

In this paper, porous silicon samples have been prepared by vapor phase chemical etching and electrochemical etching. These samples have been characterized using AFM, XRD and FTIR measurements to realize the confirmation of the

porosity, surface morphology and refractive index. The characterization study has shown that the porous silicon prepared by electrochemical etching is suitable to obtained photonic crystal based devices.

EXPERIMENTAL

We have prepared two samples of porous silicon by vapor phase chemical etching and electrochemical etching of p-type boron doped silicon wafer of <100> orientation. In case of electrochemical anodization/etching the silicon wafer exposed to electrolyte with constant current source under dark conditions to avoid the adverse chemical effect due to light. The electrochemical cell has two electrode configurations with a platinum electrode and a silicon wafer anode. The electrolyte used was HF(48%):H₂O:C₂H₅OH in a ratio of 1:1:2. The anodization was carried out at current density of 20mA/cm² for 10 minutes. In case of vapor phase chemical etching, the silicon wafer was exposed by vapor enchanths which was produced from the mixtures of HF(48%):HNO₃:H₂O in a volume ratio of 1:1:2. After preparation of the samples, the FTIR, XRD and AFM measurements have been done.

RESULTS AND DISCUSSIONS

Porous silicon is an attractive material due to the possibility of fabricating high quality optical structures, either as single layers, like Fabry–Perot interferometers, or multilayers, such as photonic crystals or rugate filters. In this study, the porous silicon samples S1 and S2 were prepared by vapor phase chemical and etching electrochemical etching in a HF-based solution at room temperature and characterized. We have found that the refractive index of sample S1 and S2 are 2.1 and 1.83 respectively.

Depending upon various electrochemical parameters such as silicon doping and resistivity, HF concentration porous silicon can be in different structural forms. Hence, the study of IR spectra has importance to identify the different modes of bondings and chemical information present in the porous silicon. The infrared spectra of porous silicon (sample S1) were measured in absorbance mode by Nicolet 380 FTIR Spectrometer. Fig.1 shows the infrared absorption spectra of porous silicon sample

in the range of 400 cm⁻¹ to 4000 cm⁻¹ of wave numbers. Different absorption peaks are identified, at 673 there is a peak of Si-H₂ wagging or rolling at which silicon is back bonded to one or more oxygen. The peaks which is related with the oxygen complexes and hydrogen absorbed on the surface of the porous silicon are Si-O-Si bending at 467 which depends on the oxidation degree of porous silicon, Si-OH/SiO-H stretching/bending at 802, O₂-Si-H(OH) stretching at 876 and 2360 and Si-OH/O-H stretching at 3740. The analysis of FTIR spectra of sample S1 with its surface bondings and vibrational modes has been demonstrated in Table 1.

Table 1:

Frequency (cm ⁻¹)	Bonds	Vibrational Modes
467	Si-O-Si	bending
673	Si-H ₂	wagging or rolling
802	Si-OH/SiO-H	stretching/bending
876	O ₂ -Si-H(OH)	stretching
2360	O ₂ -Si-H(OH)	stretching
3740	Si-OH/O-H	stretching

Fig. 2 shows the x-ray diffraction (XRD) graph of sample S1 prepared by vapor phase chemical etching in the range from 20-100° 2θ. The XRD graph shows the distinct variation between the silicon and porous silicon surfaces before and after etching. Similarly, Fig. 3 shows another XRD graph of sample S2 prepared by electrochemical anodization of silicon wafer at 20mA/cm² current density in the range from 20-80° 2θ. From these XRD spectras, it is revealed that at 2θ=69.4 there is a very sharp peak, 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.

The surface morphology of porous silicon was investigated using atomic force microscopy (AFM) as shown in Fig. 4 and 5 of sample S1 and S2. The AFM studies focus on the nanoscale characterization of porous which shows the important surface roughness in both figures. The surface of S1 sample is flat with interconnected

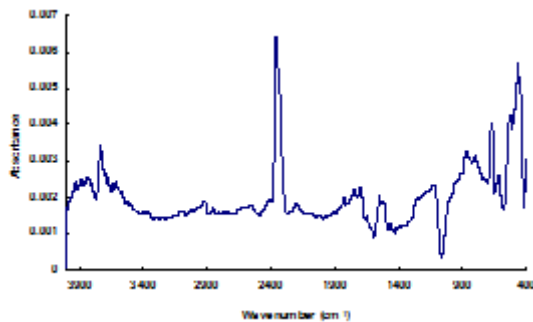


Fig. 1. FTIR Spectra of Porous Silicon sample (S1) Prepared by Vapor Phase Etching.

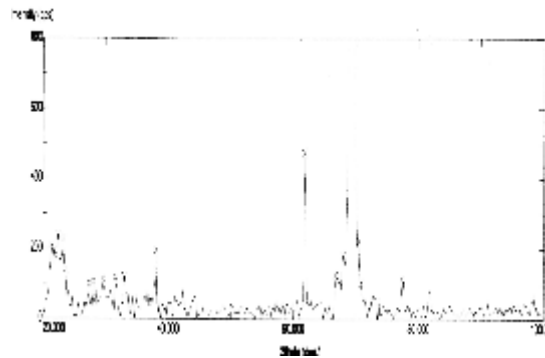


Fig. 2. XRD of Porous Silicon Sample (S1) Prepared by Vapor Phase Etching.

pores as compare to S2 but the pores are in random direction and irregular in both samples. Somewhat uniform distributed and high density pores were observed on the surface of porous silicon. However, on the surface of sample S2 the pores only appear on the location of surface defects hence, the density of pores are low and the distribution of pores are

more irregular comparatively. The average size of pore is 70nm for S1 and 85nm for S2 have been estimated, however it is also observed that the overall uniformity of porous silicon layer for the sample prepared by vapor phase chemical etching could not be maintained.

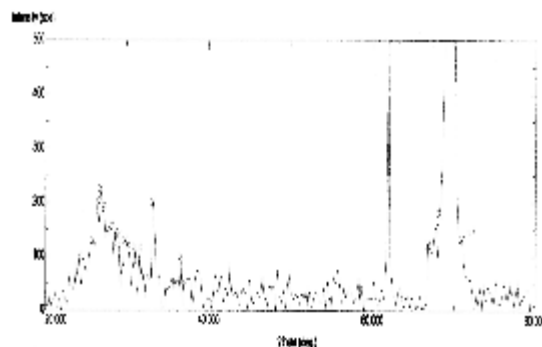


Fig 3. XRD of Porous Silicon Sample (S2) Prepared by Electrochemical Etching.

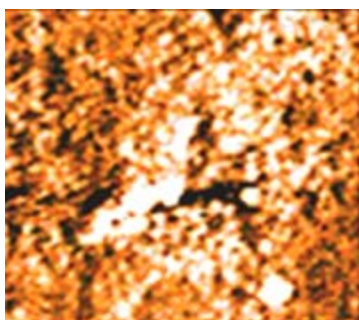


Fig. 4. AFM Picture of Porous Silicon sample (S1) Prepared Vapor Phase Etching.

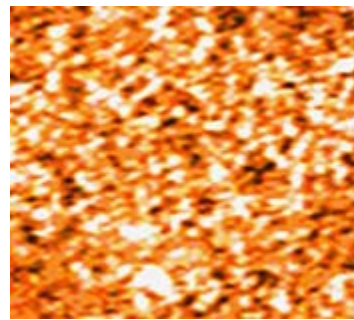


Fig. 5. AFM Picture of Porous Silicon sample (S2) Prepared by Electrochemical Etching.

Conclusions

The two porous silicon samples prepared by using vapor phase chemical etching and electrochemical etching to study affect of different chemical etching on the silicon wafer. It is observed that in case of electrochemical etching, it is possible to fabricate a structure of porous silicon layers with good uniformity and homogeneity. This technique is suitable to achieve a wide range of refractive indices of porous silicon layers as one-dimensional photonic crystals in nanometer size. By this technique, the optical properties of porous silicon layers can be control with proper tuning of thicknesses of individual layers. The vapor phase chemical etching method provides nonuniform layers, which degrades the performance of photonic crystals. The porous silicon

layer formed by vapor phase chemical etching has low reflectivity, which is having very high demand in photovoltaic applications. The XRD spectra shows distinct variation between the silicon and porous silicon surfaces before and after etching. A broad peak in the XRD spectra shows that the porous silicon has the same orientation as that of the bulk silicon and the etching process does not change its orientation. The characterization of surface morphology of porous silicon sample using AFM, demonstrates the roughness structure of porous silicon. Finally, for the fabrication of nano-structured photonic crystals and photonic devices, the electrochemical anodization technique is more suitable in comparison to vapor phase chemical etching technique.

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