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Abstract. We present a fast, novel method for building porous silicon-based silicon-on-insulator photonic crystals in which a periodic modulation of the refractive index is built by alternating different electrochemical etching currents. The morphology and reflectance spectra of the photonic crystals, prepared by the proposed method, are investigated. The scanning electron micrograph and atomic force microscopy images show a very uniform structure and the porous silicon demonstrates an 829 nm wide photonic band gap. © *2012 Society of Photo-Optical Instrumentation Engineers (SPIE).* [DOI: 10.1117/1.OE.51.4.040502]

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1 Introduction

Photonic crystals (PhCs) which can control the propagation of light very efficiently, have beenattracting great interest in a wide range of optoelectronics fields. One of the most important and useful properties of PhCs is the existence of a photonic band gap (PBG).[1] This structure is very suitable for designing various functional photonic devices such as sensors and waveguides.[2,3] Due to the versatile nature of porous silicon (PSi), high surface-area-to-volume ratio and biocompatibility, PSi PBG structures have already found many applications such as dielectric mirrors, waveguides, sensors and many other devices.[4–8]

On the other hand, silicon-on-insulator (SOI) has demonstrated great potential in both photoelectric devices and has improved a number of desirable features, such as lower power consumption, higher package density and other parameters.[9–11] For these reasons, porous silicon PhCs on SOI wafer can be a very interesting aspect of PSi research which can combine the advantages of porous silicon PhCs and SOI technology. M. Balarin et al. reported that PSi was successfully prepared by electrochemical etching of SOI wafers consisting of 45 μm thick *p*-type silicon epitaxial layer grown on a thin 100 nm SiO_2 layer on silicon substrates.[12] However, despite many attempts, our work team could not reproduce their results. We believe the most likely reason is that their buried layer contained impurities. Furthermore, in their most recent work,[13] they used another substrate which had no insulator layer. The *n*-type silicon wafers consisted only of upper and lower layers with different resistivity. This shows that the conventional electrochemical etching method for preparing PSi on SOI wafers has many restrictions. Non-electrochemical etching methods can be easily used to prepare PSi on SOI wafers, but it is difficult to prepare multilayer PSi. Moreover, the electrochemical etching method yields reproducible porosity and thickness at the same key parameters.

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In this paper, a novel method for preparing multi-layer PSi is presented. In addition, we have designed an unusual double tank electrochemical etching cell, which is shown in Fig. 1, and have successfully prepared PSi-based PhCs on SOI substrate. The optical and physical properties were studied by cross-sectional scanning electron microscope, SEM, micrographs, atomic force microscopy (AFM) and reflectivity spectra.

2 Experimental Details

PSi photonic crystals were prepared using boron doped *p*-type SOI silicon wafer consisting of 50 μm thick *p*-type silicon epitaxial layer with a resistivity of $0.02\ \Omega \cdot \mathrm{cm}$ which were grown on a thin 12 μm SiO_2 layer on silicon substrates. The resulting PSi was prepared at an applied current density of 10 $\mathrm{mA/cm^2}$ and 50 $\mathrm{mA/cm^2}$ under 15 five minute periods, respectively. The electrolyte solution was a 1:1 mixture of 49 percent hydrofluoric acid (HF) and 95 percent ethanol.

A specially designed double tank electrochemical etching cell, illustrated in Fig. 1, was used for preparation of PSi samples. In this method, the outside of etching area was immersed in conducting liquid. A cushion was used to separate HF electrolyte solution and conducting liquid. Thus, the accumulation of positive charge carriers, which is necessary for the chemical reaction, was provided through the bottom of the top layer.

3 Results and Discussion

Figure 2 displays cross sections SEM and AFM images of the freshly prepared multilayer PSi. This multilayer structure is simply nothing but a one dimension PSi photonic crystal prepared on SOI wafer which is composed of 15 periods of high and low refractive index, respectively. From the Fig. 2(a), we can found that the PSi layer shows a good uniformity and homogeneity. Figure 2(b) represents the cross-section of the sample. From this image, it is possible to see the parallel multi-layer structures. The measured thickness of the sample is approximately 9 μm. This shows the modified electrochemical etching method can be used to prepare multilayer PSi. A. Splinter et al.reported[14] that thick PSi had been successfully prepared by the stain etching method, but the PSi was a single layer. It is important to mention, that using this etching method yields a one-dimensional PSi-based PhCs prepared on SOI wafer.

The optical reflectivity spectrum of the sample, presented in Fig. 3, where solid line is the reflectivity spectrum at the centre of PSi layer and dotted line is the reflectivity spectrum

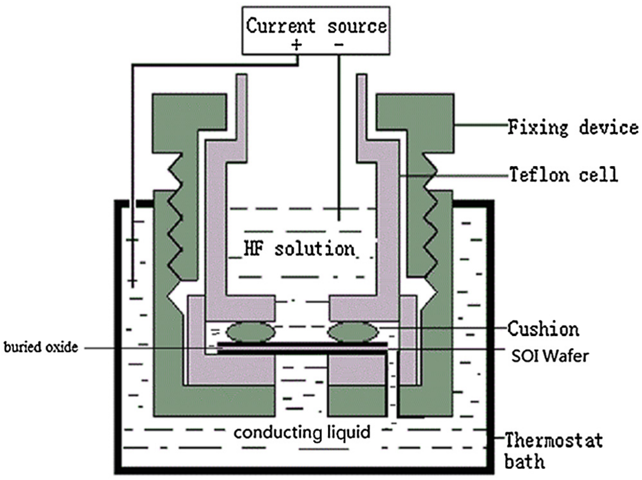

Fig. 1 Schematic of experimental setup.

of the edge. At the angle of incidence of 5 degrees, the width of the PBG of the two positions, corresponding to reflectivity higher than 80 percent, is approximately 829 nm, ranging from 3792 to 4621 nm at the center and 3832 to 4661 nm at the edge. The value of R_{max} has been determined by standard reflectivity. The center wavelength of the PBG centers has a little shift to the red side. According to D.R. Huanca's research,[15] the different PBG centers, shown by the samples, can be explained only by the difference between layer thicknesses and porosity of samples. Accordingly, we can expect that the edge of the PSi has greater layer thickness and porosity. If a transverse current exists in the etching process, the etching rate near the edge will be higher than that of the center and the optical thickness increase. If suitable etching process parameters are selected, the PBG can be tuned almost anywhere within the near infrared range.

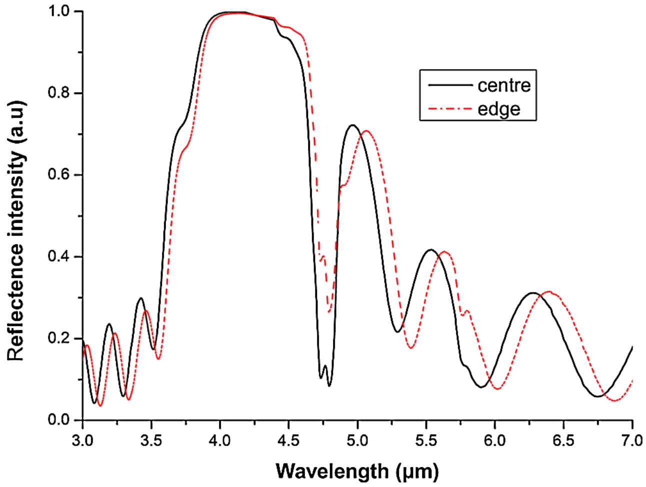

Fig. 3 Reflection spectra of 1D porous silicon PhCs at two different positions.

The theoretically estimated PBG of this PhCs is shown in Fig. 4. The refractive indexes of each layer were estimated by the single layer of etched by constant current of 50 and 10 mA, respectively. The width of the stop band, corresponding to reflectivity higher than 80 percent, is around 730 nm, ranging from 3860 to 4590 nm. The measured PBG of the PhCs is broader than that of simulated reflectance spectra. It is known to all, that in the electrochemical etching process, reaction products and bubbles are produced and HF concentration reduces at the bottom of PSi holes which leads to the slower etching rate of PSi and decrease the porosity. Thus, even in the same etching parameters, the refractive index of PSi increases from upper to the bottom. For this reason, the refractive index of the PhCs increased from the upper to the bottom layers which caused the broader PBG.[16]

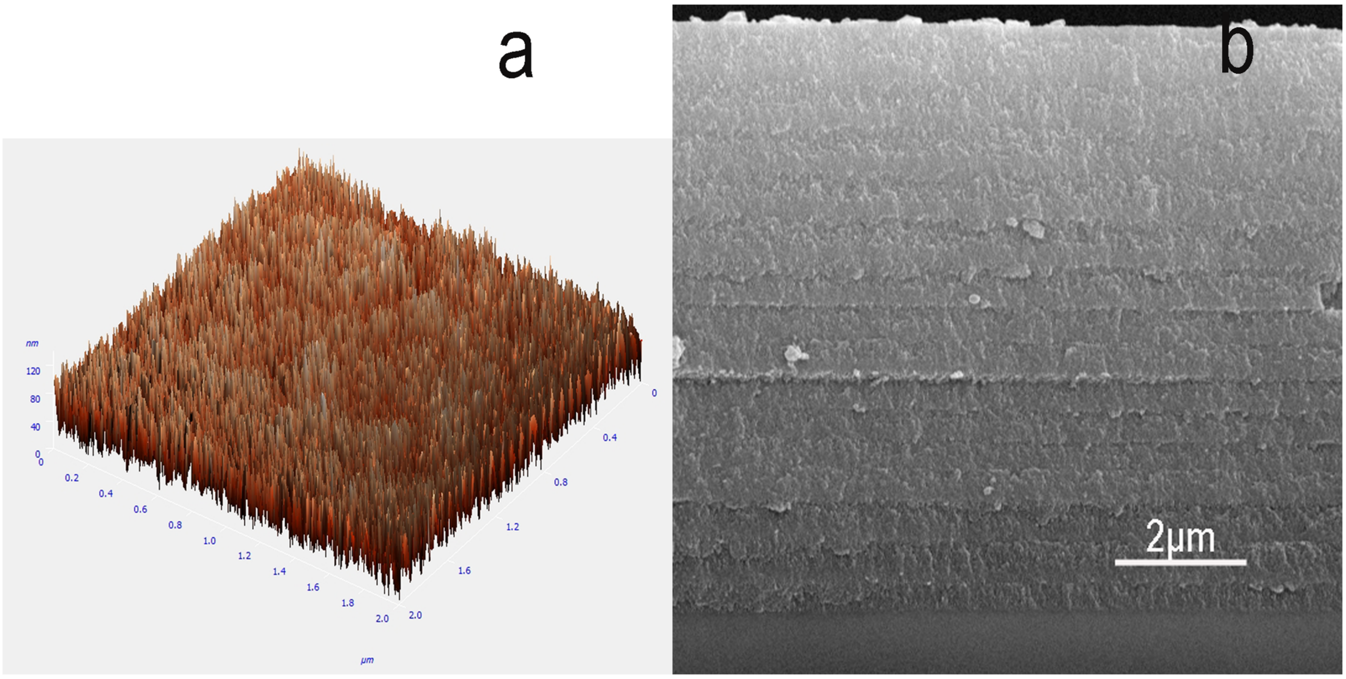

Fig. 2 Atomic force microscopy and cross-section SEM of 15 periods' porous silicon layers.

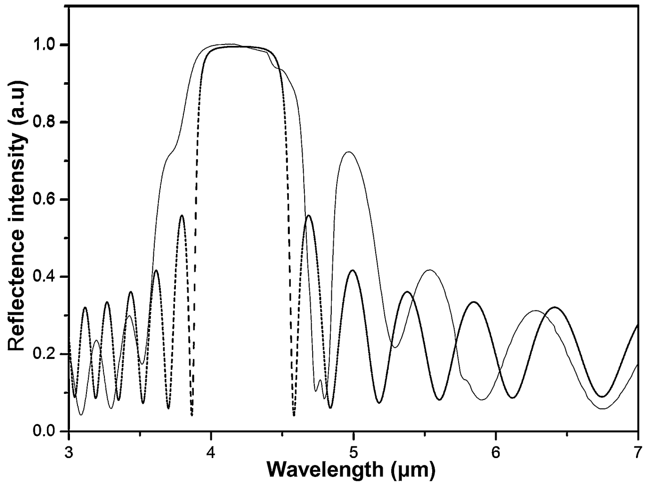

Fig. 4 Measured (solid line) and simulated (dashed line) reflectance spectra of PhCs.

4 Conclusion

It has been demonstrated, that the modified double-tank electrochemical etching method allows formation of PSi on SOI silicon which was very difficult using the conventional electrochemical etching method. Bragg structure PSi, with 829 nm bandwidth, was successfully fabricated on SOI wafer.

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