Fabrication of silicon 3D photonic crystal structures in 100nm scale using double directional etchings method

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Abstract: We have reported periodic pore formation with diameter in 80nm and aspect ratio above 250 on N^+(100) silicon substrate and demonstrated the fabrication of silicon 3-dimensional microstructures by applying double directional etchings method.

OCIS codes: (220.3740)Lithography; (230.4000) Microstructure fabrication

1. Introduction

Recently, a number of studies on fabricating 3-dimensional photonic crystals have been focused on downscaling and increasing the number of layers to get highest performances of their own fabrication processes. However, most of the processes suffer from the difficulties in alignment between layers when the number of layers is increased especially in the small spectral range centered around 1μm. In addition, increasing the number of layers is itself a hard task, if ordinary dry etching processes are applied to realize layer-by-layer structures. On the other hand, there are relatively simple fabricating processes called electrochemical etchings which can also be applied to realize woodpile-like structures using double directional etchings [1].

These techniques can also be applied to the fabrication of 3D photonic crystals in the visible range if the pore diameter is reduced below 200nm, which enables the realization of all silicon optical devices by incorporating silicon quantum dots into the 3D silicon photonic crystals [2].

In this paper, we report the periodic pore formation with diameter in 80nm and aspect ratio above 250 on N^+(100) silicon substrate, using magnetic field-assisted electrochemical etching method [3]. And we demonstrate the fabrication of silicon 3D microstructures by applying double directional etchings based on these deep etching properties.

2. Deep etching properties of the magnetic field assisted anodization

We have adopted controlled anodization method using magnetic field instead of photoelectrochemical etching in which only large pores in excess of 400nm in diameter has been reported [4]. The mechanism of magnetic field assisted anodization is based on the control of the motion of holes which are responsible for initiating the electrochemical dissolution of silicon. The directional etchings are realized through the cyclotron motion of the holes under a magnetic field.

The porous layers were formed on heavily doped (0.04 Ωcm) n-type (100) Si wafers. The sample was prepatterned by EB lithography and afterward ECR plasma etching was performed to the sample surface for about 7min just to make shallow etchpits. The anodization was performed in the dark condition in a solution of dilute HF (10%) at a constant current density ($12mA/cm^2$) for 10 min. The temperature of the solution was kept at 0^oC during the anodization. The samples were formed under an external magnetic field which was applied to the Si substrate in the perpendicular direction to the surface. The strength of the applied magnetic field was 1.9T.

Fig. 1(a) shows the cross-sectional view of the sample. The observed thickness of the porous layer was about 22μm. Next, the sample surface was mechanically polished at 10μm in depth. The SEM images of the revealed sample surface are shown in Fig. 1(b)(c). As can be seen from the picture, periodic pore formation with diameter in 80nm was observed. The aspect ratio of each pore can be estimated roughly above 250.

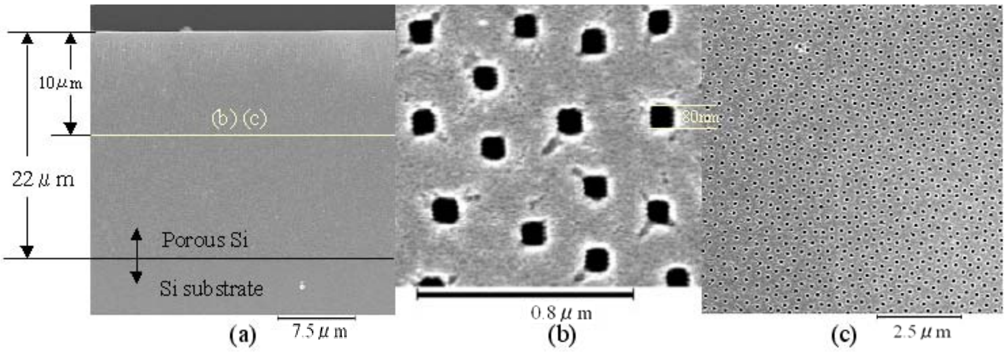

Fig.1 SEM images of the (a) cross-section and (b)(c) mechanically polished surface at 10μm in depth

3. Fabrication of silicon 3D microstructures in 100nm scale

Next, we have performed double directional etchings to the silicon substrate just as schematically shown in Fig. 2. This fabrication process is theoretically expected to generate large photonic bandgap (20%) if the patternings on the surface are precisely controlled [1]. At this time the experiment was performed without patternings on the surface just to see the etching properties of the double directional etchings structures. The type of wafer and etching conditions were all the same as in the previous section. First etching was performed from the top surface and then the sample was oxidized to fill the pores with SiO_2. Next, the slope was revealed by mechanical polishing and finally the second directional etching was performed in the direction perpendicular to the the first directional etching according to the patterings formed on the slope.

Fig. 3(a) shows the crosssectional view of the whole sample which was cleaved in the center of the etched area. Fig. 3(b) shows the evidence of the double directional etchings and Fig. 3(c) shows the partially formed 3D microstructures in 100nm scale. These results show the possibility of projecting the slope pattrenings on the side which can be applied to the fabrication of 3D photonic crystal in the visible range without additional alignment processes [1].

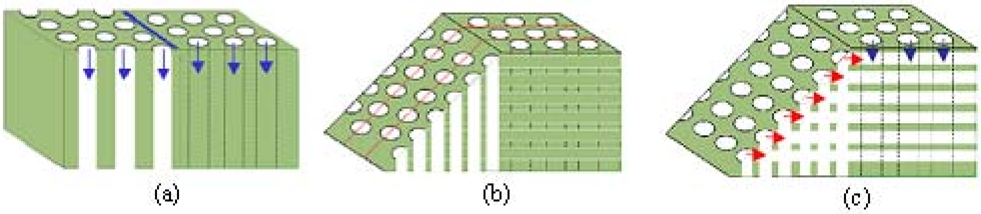

Fig.2. Fabrication process of 3D photonic crystal structures which are theoretically expected to generate large photonic bandgap [1]. (a) First directional etching, (b) mechanical polishing and (c) second directional etching.

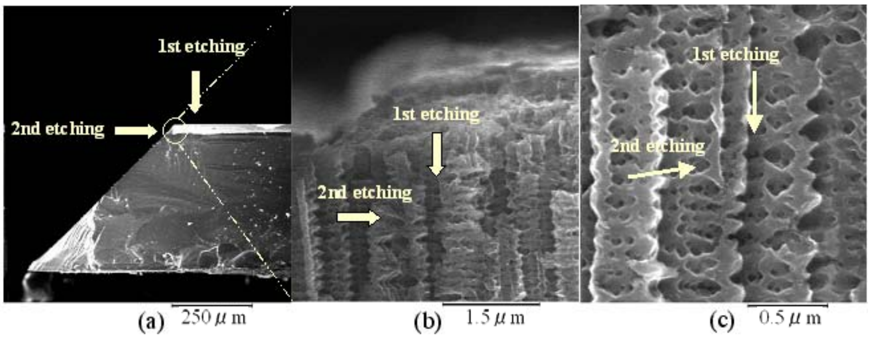

Fig.3 (a) Cross-sectional view of the whole sample.(b) Double directional etchings properties and (c) partially formed 3D microstructures

4. References

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