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Second harmonic generation in porous silicon multilayer periodic structures

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Abstract. In the paper second harmonic (SH) generation in a photonic bandgap structure was investigated. The intensity of SH from a multilayer structure exceeds the intensity of SH from both homogeneous layer of porous silicon and a single crystal silicon (100) substrate. The SH generation efficiency was found to be sensitive to parameters of photonic bandgap structures. The dependence of the SH signal on the azimuthal rotation angle is isotropic. SH radiation is polarized in the plane of incidence. The SH intensity is a nonmonotonic function of the angle of incidence, reaching its maximal value at the angle of incidence corresponding to the minimal phase mismatch in the multilayer periodic structure.

Introduction

In last decade porous silicon (PS) became a material attracting great attention. Due to its well-developed surface, possibility of nanocluster formation and simplicity of production PS is a very perspective material for various technological applications [1]. One of them is a fabrication of multilayer periodic structures of PS alternate layers of different porosity. Such structures have a photonic bandgap and may be used as Bragg reflectors, microcavities, control of short laser pulse parameters and so on [2, 3, 4]. That is why it is important to elicit the ability to apply PS photonic bandgap structures for nonlinear optical process controlling. For this purpose dispersion properties of a periodic structure may be used [5].

Second harmonic (SH) generation in homogeneous porous silicon layer was found to be very inefficient [6]. This fact is due to an optical isotropy of PS on a wavelength scale. The way to increase SH efficiency proposed in the paper is a fabrication of multilayer periodic structure with appropriate parameters.

1 Experimental

The multilayer structure was made by an electrochemical etching of a crystalline silicon wafer in HF ethanol solution (1:1). To fabricate the structure alternate pulses of current density 5 and 105 mA/cm^2 were used. Varying the duration of the current pulses, we were able to control the layer depths. Single crystal silicon wafer with (100) surface orientation was used as a substrate. Three structures were produced (samples A, B and C), each of them consisted of 12 pairs of layers alternating refractive indices. Porosities of layers are 70% (refractive index $n_1 = 1.4$) and 80% (refractive index $n_2 = 1.2$). The obtained samples are Bragg reflectors, their reflection spectra are shown in Fig. 1.

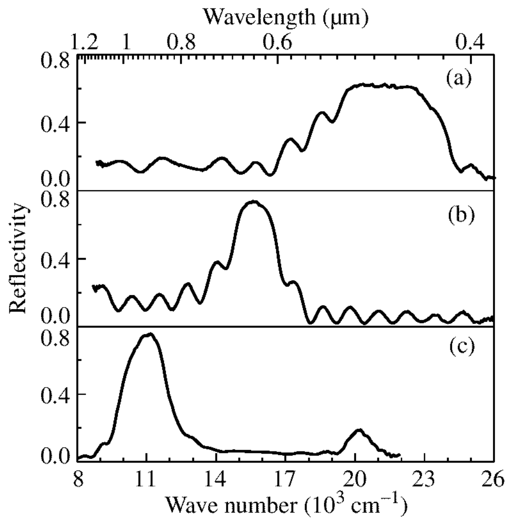

Fig. 1. Reflection spectra of structures A (*a*), B (*b*) and C (*c*) at normal light incidence.

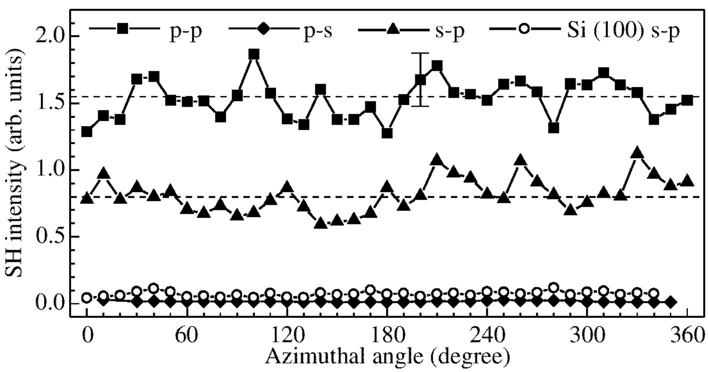

Fig. 2. The dependences of the SH signal of the sample A on the azimuthal angle at different polarizations of fundamental and SH intensities. For comparison the dependence for a single crystal silicon surface (100) is shown.

2 Results and discussion

The dependence of the SH intensity on the azimuthal rotation angle for the sample A is shown in Fig. 2. One can see that the dependence is isotropic. Another important result is a polarization of the SH radiation in the plane of incidence. Besides, the SH generation is more efficient when the pumping radiation is polarized in the plane of incidence. These effects may be explained by properties of PS layers: optical isotropy in directions perpendicular to the normal to the surface and formation of silicon nanoclusters along the normal to (100) surface. It is worth noting that the SH intensity from PS structure exceeded the SH intensities both from a crystalline silicon surface (100) (see Fig. 2) and homogenous PS layer.

The SH generation efficiency was found to be sensitive to parameters of the photonic bandgap structures. The dependences of the SH intensities on the angle of incidence θ for structures A, B and C are shown in Fig. 3. The dependence is nonmonotonic, for the sample

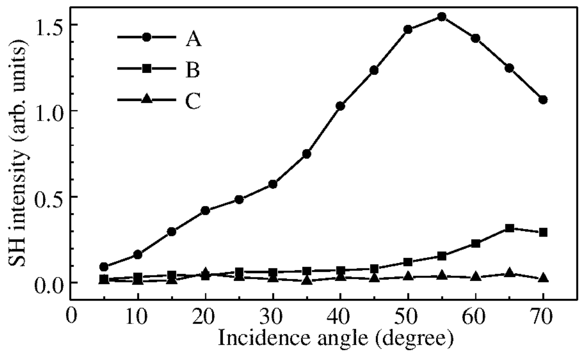

Fig. 3. The dependence of the SH intensity on the angle of pumping radiation incidence for samples A, B, and C.

A maximal signal is reached at the angle of incidence about $\theta = 55^\circ$. For the samples B and C the SH signals are much weaker and their maxima are reached at greater angles of incidence.

The analysis of phase mismatch of fundamental and SH radiation in such structures was carried out. The dispersion in a periodic structure was taken into consideration. According to our calculation the angle of minimal phase mismatch in structure A is 50° what is close to the experimental results.

Thus, it was found in experiment that in porous silicon multilayer periodic structure SH generation takes place, its efficiency exceeds those of crystalline silicon substrate and homogenous porous silicon layer. The SH generation efficiency depends on parameters of multilayer periodic structures. The isotropic azimuthal dependence of the SH signal is obtained. The SH intensity is a nonmonotonic function of the angle of incidence. Carried out modeling shows that SH intensity reached its maximal value at the angle of incidence corresponding to the minimal phase mismatch in the multilayer periodic structure.

Acknowledgements

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