Photonic crystal for optoelectronic integrated circuits (OEICs)
-Technology and application of photonic crystal-

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1. Introduction

Photonic crystals are new optical materials having periodically changed refractive index and considered to act as a base medium for future ultra-small large-scale photonic integrated circuits (PICs).[1] In order to realize high performance PICs, a three-dimensional photonic crystal with a perfect photonic bandgap is necessary.[2] The functional devices such as nano-ampere laser arrays and optical waveguides with sharp bends can be integrated using the three-dimensional photonic crystals in the PICs. Therefore, we need the fabrication technique for three-dimensional photonic crystal to control the structure easily.

At the Research Center for Nanodevices and Systems (RCNS), Hiroshima University, we are studying the technology of three-dimensional photonic crystals not only for the Si-based large-scale PICs but also for optoelectronic integrated circuits (OEICs). The research topics developed so far are demonstrated.

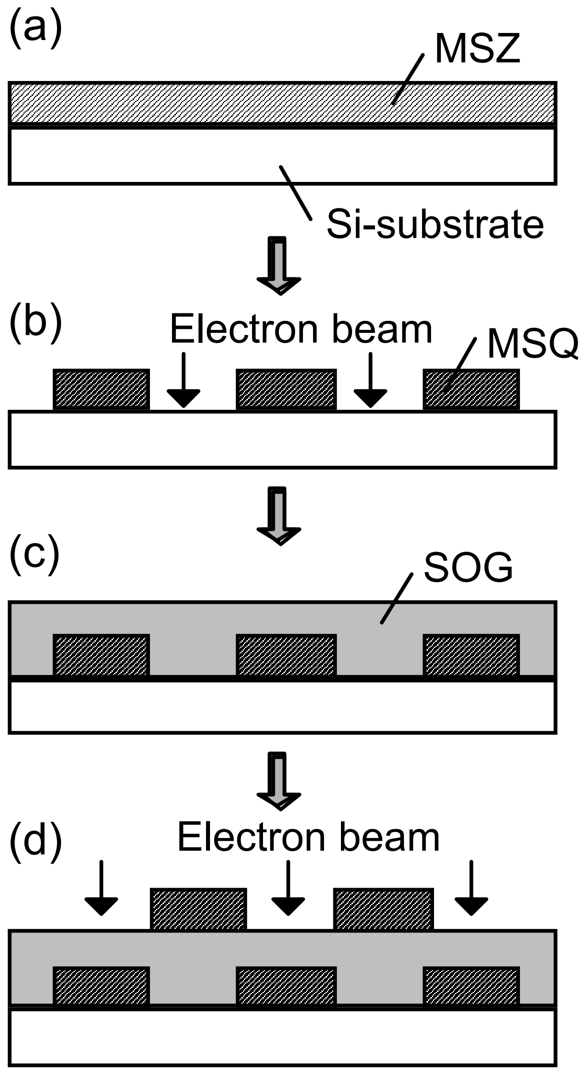

Figure 1 The proposed realization method for three-dimensional photonic crystals.

2. Research Results

There have been a few reports of such a fabrication technique of three-dimensional photonic crystal. However, the reported methods for fabricating three-dimensional photonic crystals are fairly complicated[3,4] or have less flexibility of structure designing.[5] Also, realization of optoelectronic integrated circuits (OEICs) with low cost is difficult when Si-based materials[4,5] are not used for the fabrication. Recently, we have developed a direct patterning technique of interlayer dielectric films using the photosensitive methylsilazane (MSZ) film for multilevel interconnetions in ultra-large scale integrated circuits (ULSIs).[6-8] The photosensitive MSZ film can be directly patterned (without using the resist) by the use of electron-beam (EB) or ultraviolet lithography. In this process, EB-resist or photo-resist coating and dry etching is not necessary for the patterning. We applied this direct patterning technique to the formation of three-dimensional photonic crystals. Owing to this technique, the number of process steps can be reduced by about half for the fabrication of three-deminsional photonic crystals.

Figure 1 shows the proposed method. A photosensitive MSZ precursor (refractive index of 1.55) is spin coated on a Si wafer to form a 150-nm-thick film [Fig. 1(a)]. After prebaking, to form a basic two-dimensional structure, EB lithography is carried out [Fig. 1(b)]. After the development and curing, the photosensitive MSZ film is changed to methylsilsesquioxane (MSQ) film (refractive index of 1.45).[6] In these processes, both EB-resist and dry-etching processes are eliminated for the pattern formation and the desired pattern of MSQ film is formed. Then, spin-on-glass (SOG, refractive index of 1.38) film is spin coated on the

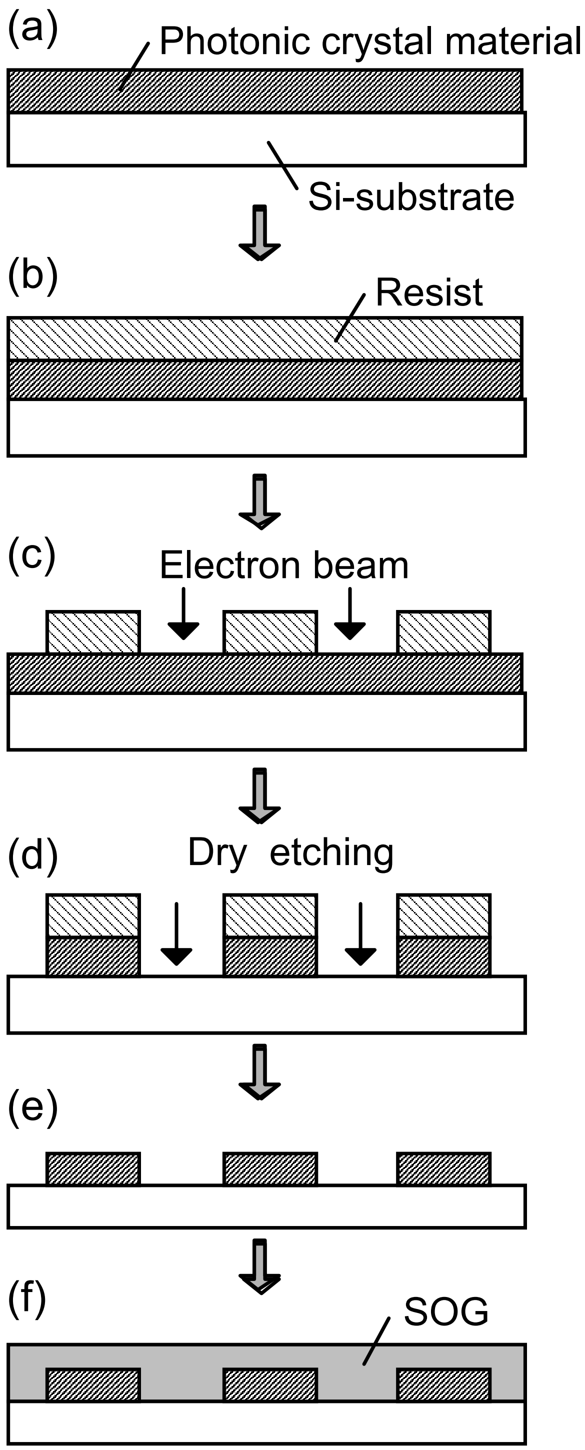

Figure 2 A conventional method for the fabrication of three-dimensional photonic crystals.

patterned film (200-nm-thick film is formed for a plane film) [Fig. 1(c)]. After baking, SOG film with flat top surface is formed. Repeating above processes, we can easily fabricate a three-dimensional photonic crystal having the periodically changed refractive index [Fig. 1(d)].

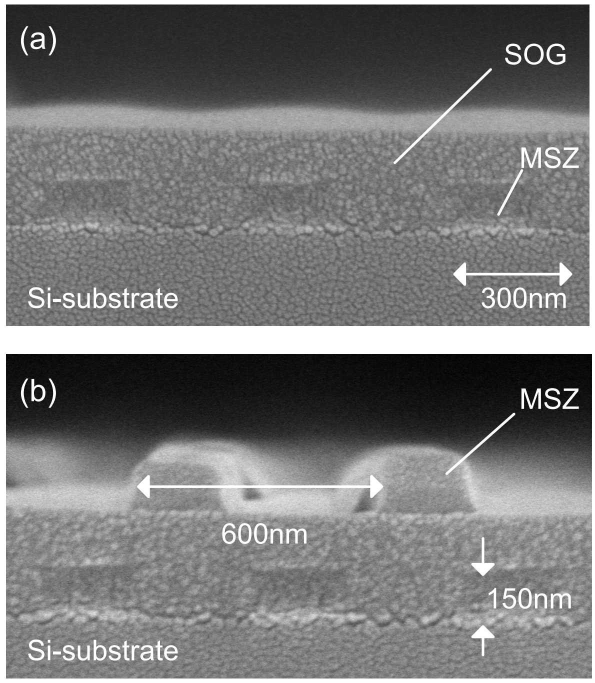

Figure 3 Cross sectional SEM image of the fabricated structure having MSZ stripe patterns.

On the other hand, in the conventional fabrication method, resist coating [Fig. 2(b)] after the film formation of the photonic crystal material having the refractive index different from that of SOG [Fig. 2(a)], dry etching of the material with the resist mask [Fig. 2(d)], and the resist mask stripping [Fig. 2(e)] are added compared with the proposed processes (Fig. 1). Therefore, the number of process steps in the proposed method is reduced by about half.

Figure 3 shows a SEM image of the fabricated structure. As seen in Fig. 3(a), a basic two-dimensional structure of the MSZ film with the stripe pattern is indeed formed and covered by the SOG film having the flat top surface. The line and space of the stripe pattern is 300 nm, which is suitable to the photonic crystal in the optical wavelength region (500 ~ 1600 nm). Owing to the flatness of the top SOG surface, the periodic two-dimensional structure of the MSZ can be stacked repeatedly [Fig. 3(b)].

Figure 4 shows the bird's-eye view SEM image of the woodpile structure fabricated using the proposed process. The stripe patterns of the stacked MSZ layer crosses over the underlying one.

Figure 5 shows a SEM image of a two-dimensional structure with a Y-branch wave guide fabricated using the proposed technique. Thus, we can easily incorporate such basic two-dimensional structures into three-dimensional photonic crystals for functional devices.

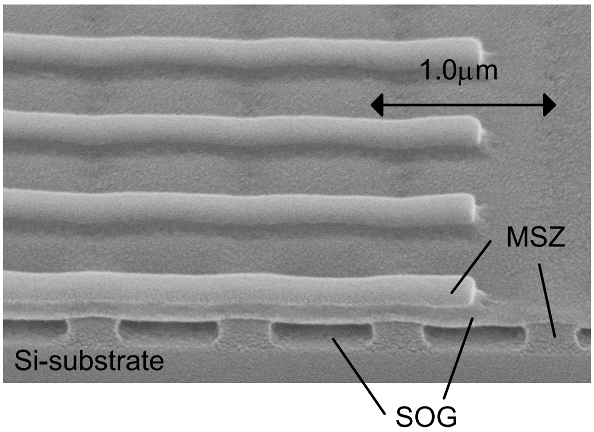

Figure 4 Bird's-eye view SEM image of the fabricated woodpile structure.

Our process proposed in this study is compatible with those of ULSIs because the direct patterning technique has been primarily developed for the dielectrics for interconnections in ULSIs. The compatibility leads to the capability of utilizing state-of-the-art nanostructure-fabrication technologies in ULSIs. Moreover, we can combine the fabricated photonic crystals with ULSIs easily. This is advantageous to the realization of OEICs with low cost.

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3. Summary

In summary, we have successfully applied the direct patterning technique to the formation of three-dimensional photonic crystals. The basic structures with stacked striipe pattern, woodpile structure, and two-dimensional Y shape waveguide have been realized. Utilizing this process, the number of process steps can be reduced by about half. The proposed process is promising for realizing low cost OEICs.

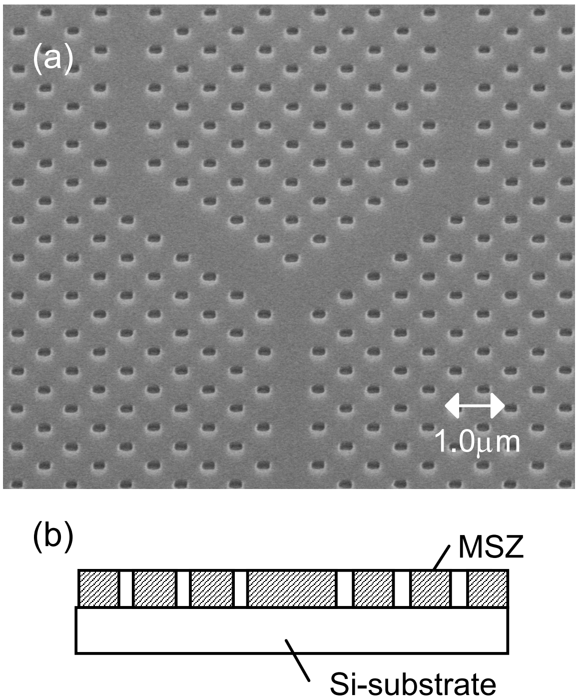

Figure 5 Top view SEM mage of the fabricated two-dimensional Y-branch waveguide structure (a) and the schematic of the cross section (b).

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Achievements

Photonic Crystal

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