Fabrication of 20-nm half-pitch dense lines using block copolymer lithography and the hard-mask etching process

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Block copolymer lithography (BCL) is one of the promising methods for nanopatterning toward 16-nm-technology nodes and beyond. We have already devised a novel method for the graphoepitaxy of the lamellar domains of symmetric diblock copolymers using resist patterns as alignment guides. The use of a resist pattern as alignment guides is a very effective method because the surface modification of the substrate and the formation of guide patterns with a different affinity can be carried out separately. Therefore, this method enables the lateral alignment of lamellar domains with a period lower than the pitch of the guide pattern. For introducing BCL into a semiconductor process, it is essential to confirm that these aligned domains can be transferred to substrates. In this paper, we report the fabrication of 20-nm half-pitch dense lines of amorphous silicon (a-Si) by combining this alignment method of lamellar domains and the hard-mask etching process.

Figure 1 shows the schematic diagram of the fabrication process. First, stacking layers composed of SiO_2 (hard mask)/a-Si/SiO_2 on a Si substrate are fabricated. Second, the neutralization layer of cross-linked poly(α-methylstyrene-*alt*-methylmethacrylate) is formed on the substrate and then a guide pattern made of a hydrophilic resist for alignment is formed on the neutral surface by using hydrogen silsesquioxane (HSQ). Third, a block copolymer film of symmetric poly(styrene-*b*-methylmethacrylate) (Mn: 74,800 g/mole) is formed over the resist guide pattern, and the film is baked to induce a lateral alignment of the lamellar domains as well as a microphase separation. Fourth, the film is exposed to oxygen plasma in order to remove the poly(methylmethacryalate) (PMMA) domain. Finally, the hard mask is etched by using $CF_4/CHF_3/Ar$ chemistry and then a-Si layer is etched by using $Cl_2/O_2/SF_6$ chemistry.

Top-down SEM images of the microphase-separated domains in confined spaces between guides with various pitches are shown in Fig. 2. It is evident that two dark lines corresponding to the PMMA domain are formed parallel to the guide with a pitch of 130 nm (Fig. 2(a)). This indicates that the lateral alignment of the lamellar domains with a width of $3L_o$ (L_o: lamellar period) can be achieved. Unfortunately, in the confined spaces between the guides with a pitch of 170 nm ($\cong 4L_0$) and 210 nm ($\cong 5L_0$), the alignment is no longer perfect because the PS domains partially cover the surface owing to the fact that they have a lower surface tension than the PMMA domains. However, it becomes evident that a perfect alignment throughout the film is not necessarily important for the pattern transfer. Figure 3 shows the SEM images of the guide pattern regions with a pitch of 210 nm after etching. From the top-down view (Fig. 3(a)), it is apparent that five lines of the hard mask with a pitch of approximately 40 nm are formed, although the alignment was not confirmed at least from the surface observations (Fig. 2(c)). Moreover, it is observed that a-Si dense lines with a width of approximately 16 nm are clearly observed in the cross-sectional view (Fig. 3(b)).

The most important observation is that the lateral lamellar domains are perfectly aligned inside the film, regardless of the surface morphology of the self-assembled domains; further, these buried domains also function as an etching template. This means that this approach could provide a wider process margin for the initial film thickness and the annealing condition than was previously expected.

This work was partly supported by JSPS KAKENHI (16206003).

[1] T. Yamaguchi and H. Yamaguchi, J. Photopolym. Sci. Technol., **19**, 385 (2006).

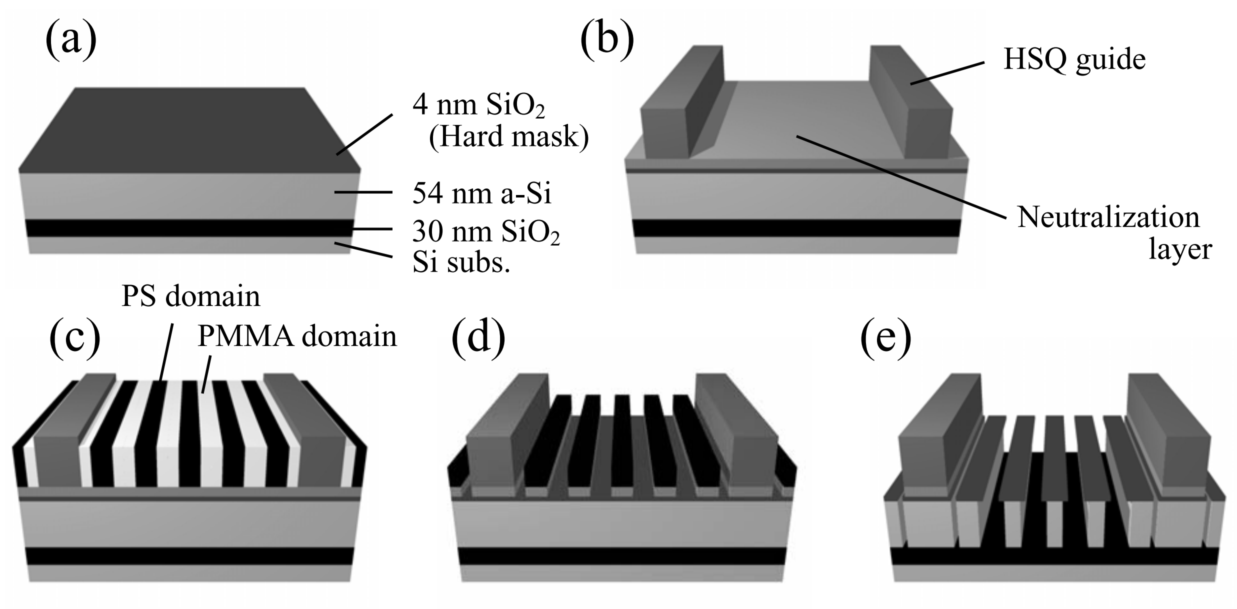

Fig. 1. Schematic representation of the fabrication process.

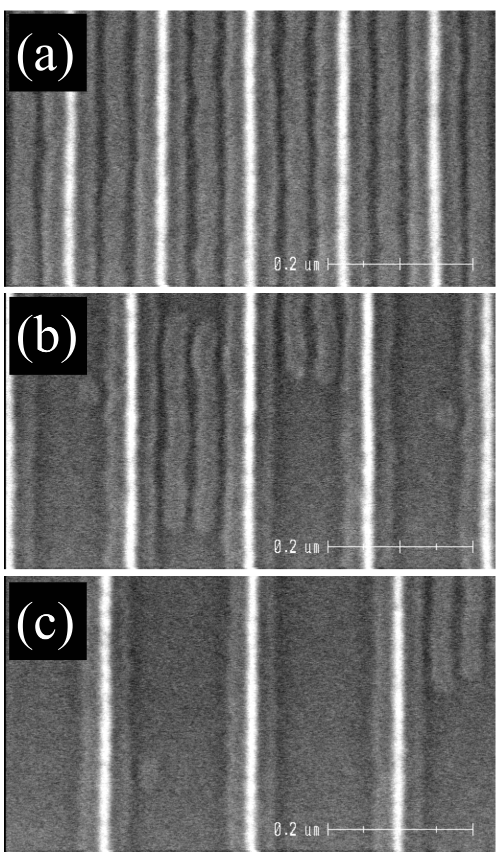

Fig. 2. Top-down SEM images of the microphase-separated domains in confined spaces between guides with various pitches: (a) 130 nm, (b) 170 nm, and (c) 210 nm (Scale bar: 200 nm).

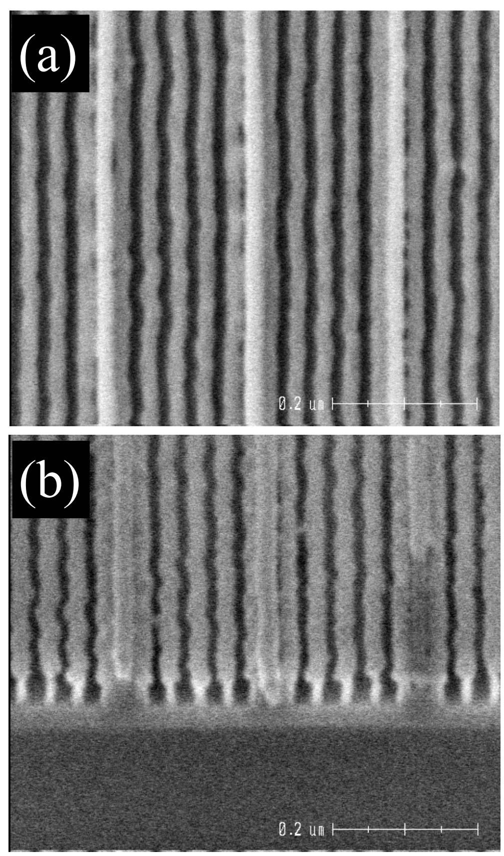

Fig. 3. SEM images of the guide pattern regions with a pitch of 210 nm ($\cong 5L_0$) after etching: (a) top-down view and (b) 60° angled view of the cross section of the patterns (scale bar: 200 nm).