Fabrication of 3-D Photonic Bandgap Structures

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Photonic BandGap (PBG) structures offer opportunities for miniaturizing a variety of conventional optical devices. 3-D PBG structures have advantage over 2-D structures in that they eliminate the loss of light through substrates or air.

Last year we reported an improvement in the 3-D structure design. The process developed in previous years using e-beam lithography has been carried over to the new structure. A two-layer structure fabricated by that process is shown in Figure 1. In order to fabricate 4 layers, the process needs to be more robust and also simplified. We improved the robustness of the process by regenerating the e-beam alignment marks at each new layer of Si deposition. A new planarization process with Hydrogen SilsesQuioxane(HSQ), a type of Spin-On-Dielectrics(SOD) is applied to fill in the holes and planarize the surface. This new planarization step simplifies the overall process and makes batch processing possible. With these improvements, four deposition layers, which is equivalent to seven optical layers, have been fabricated.

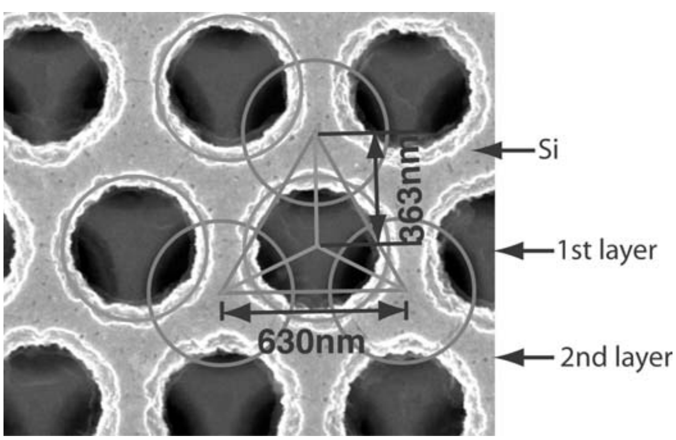

Fig. 1: A top view of a two-layer 3-D PBG structure. The SiO_2 is etched away with HF. The lower array of shifted holes is barely visible through the top layer, and indicated by the drawn circles.

Due to the periodic nature of the PBG structure, the pattern shift in two consecutive PBG layers will not be more than 363nm in x-y translations. This leads to a novel scheme for the alignment in proximity X-ray lithography. The finite gap between mask and substrate, and the highly directional nature of the short wavelength radiation, enables one to shift the entire mask image by tilting the mask-substrate assembly relative to the axis of illumination, as illustrated in Figure 2. The amount of such image shift depends on the mask-substrate gap, and the tilt angle, and can be calculated by simple geometry. An overlay registration scheme can be devised from the tilt scheme. Using Moiré patterns, translational misalignment can be measured and subsequently corrected by tilting the mask-wafer assembly. Rotational misalignment can not be compensated by tilting but can be shown to be decoupled from x-y translations and aligned accurately before tilting the stage.

Preliminary experimental results show that the shifts are consistent with calculations and are uniform across the whole X-ray exposure area. We believe that this alignment scheme is simple, robust and easy to control.

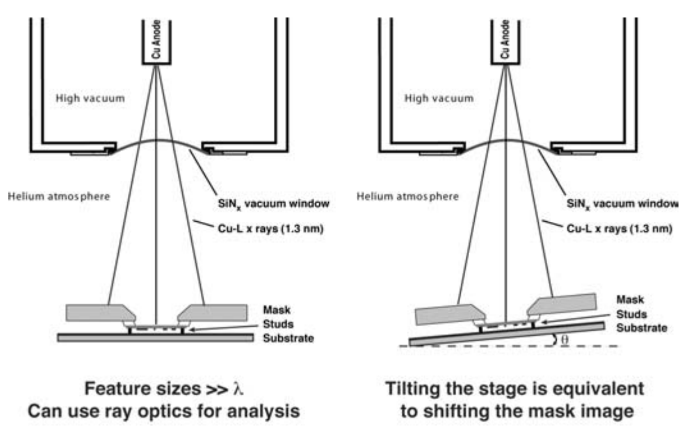

Fig. 2: A schematic of tilted X-ray exposure.

The periodic hexagonal pattern of holes in each PBG layer can be fabricated with a combination of interferometric lithography and the tilted X-ray exposure. As shown in Figure 3, the hexagonal pattern of holes can be decomposed into two identical grids of rectangular form, with one shifted from the other a half period in both x and y directions. The rectangular grids can be easily patterned with a double exposure in interferometric lithography, and the shift can be easily achieved with the tilt exposure.

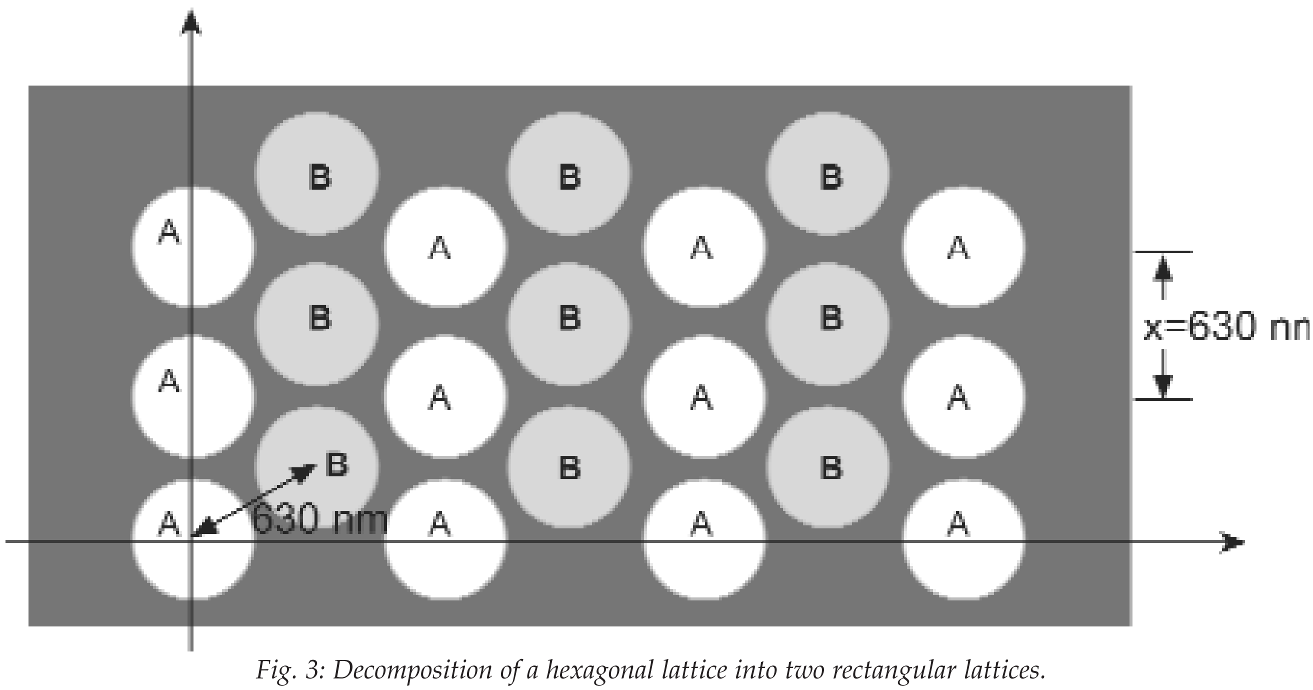

Fig. 3: Decomposition of a hexagonal lattice into two rectangular lattices.