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A Novel Lithographic Method for Fabricating Three Dimensional Periodic Stacks

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1. Introduction

Three dimensional periodic structures(Fig. 1) are currently interested by many researchers because of their application potential to photonic crystals[1-5]. However, the reported fabrication methods contain complicated, difficult, slow, and/or less-controllable processes, which seriously reduce application potential to the integrated systems. In the present paper, a novel method for fabricating three dimensional periodic stacks with full use of a micro-lithography technique is proposed, a prototype structure is fabricated, and potential merits of the method are discussed

2. Fabrication Process

The essence of the proposed method for fabricating three dimensional periodic stacks by lithography is that multiple layers of resist are coated on the wafer with each layer being exposed with a different pattern and the resist is developed finally after all the resist layers are exposed. A typical process flow for multiple layers of the periodic photo-resist stack is shown in Table I.

The first photo-resist layer is coated on the wafer pre-patterned with an alignment pattern, pre-baked for drying, and exposed to the light with the first layer pattern. The resist is not developed at this time, which is different from the case of the conventional method. Instead, aluminum is vacuum-evaporated on the exposed resist, before the second photo-resist layer is coated over it. This aluminum layer suppresses mixing of the first layer resist with the second one during coating as well as the penetration of the light to the first layer during exposing the second layer with a different pattern. The ~20nm thick aluminum layer was found to be enough for these purposes, which scarcely affects the process, because such the thin aluminum layer was easily removed by diluted HF. The aluminum evaporation, resist coating, pre-baking, and the light exposure are repeated for desired times. After post-exposure-bake for chemical amplification of the resist sensitivity, the resist is developed layer-by-layer with the aid of aluminum interlayer removal with diluted HF. Then, the wafer can be post-baked or forwarded to the subsequent process.

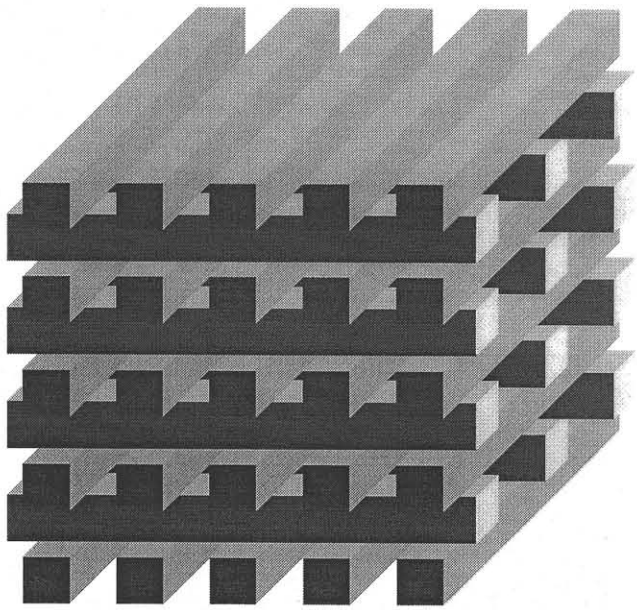

Fig. 1 Typical structure of a three dimensional periodic stack.

Table I Process Flow for Fabricating Three Dimensional Periodic Stacks with the Lithographic Method.

Process Step	Typical Condition
1. Alignment pattern fabrication	Patterned oxide on Si(100)
2. Surface treatment	HMDS
3. Resist coating	Conventional spinner
4. Pre-baking for drying	90℃
5. Light exposure for patterning	g-line stepper
6. Vacuum-evaporation of Al	Room temperature, ~20nm
(Repeating the 2-6 steps for desired times without the final 6 step)	
7. Post-exposure bake	110℃
8. development	Conventional NMD-W developer
9. Al etching	Diluted HF
(repeating the 8 and 9 steps for development and Al etching)	
10. Post-baking or forwarding process	130℃

3. Fabricated Structure and Potential Merits

By applying the proposed process method, four layers of the periodic stack of photo-resist rods have been fabricated, as shown in Fig. 2. A remarkable difference of the structure from the conventional one is that a space is present at some parts below the resist. This feature comes from that the lower-resist-layer is developed after the over-layer film is coated on the lower-resist, whereas the conventional coating is done only after the lower-layer-resist is developed or the lower-layer film is etched. This under-layer space makes it possible to introduce low-dielectric-constant regions three-dimensionally between the materials.

The minimum feature size of the present prototype was 0.7-1 μ m, which is due to the not-optimized use of our available g-line stepper, but it will be improved easily by using a most-advanced excimer laser stepper. Increasing the number of the layers is also easy by repeating coating and exposure processes with careful attention to the resist baking/chemical process. The vacuum evaporated aluminum can be substituted by another material as far as it suppresses the resist mixing and the exposing light penetration.

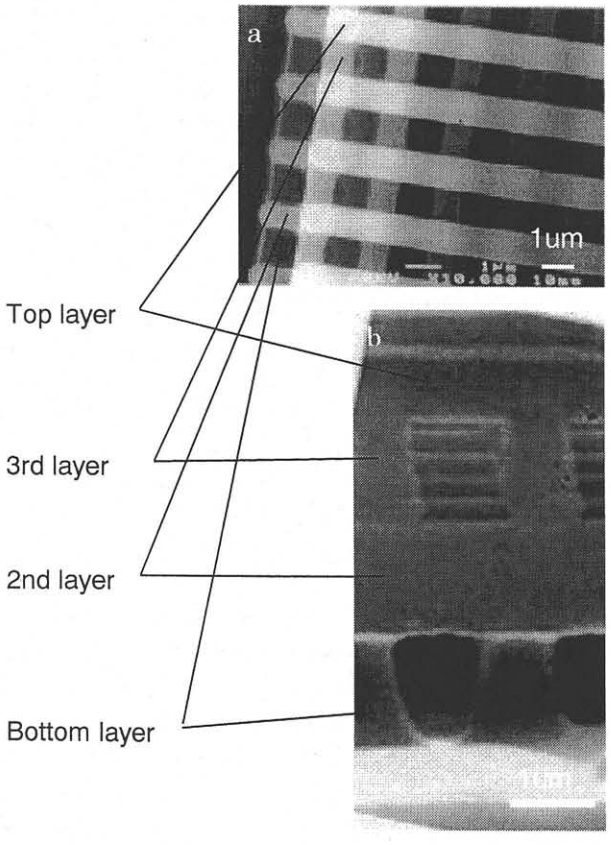

Fig. 2 Scanning electron micrographs of the fabricated three-dimensional periodic stack of the resist. (a) top view and (b) cross-sectional view.

Potential merits of the present method are that: (1) the method is so fully compatible with the microlithography as to be favored with day-by-day improvement of the minimum feature size and cheapness for the mass-production, (2) the intentional defects are easily introduced to the pattern, which makes it possible to fabricate functional components such as light wave guides and resonators, and (3) the space can be filled, for further application, with subsequent low-temperature deposition of materials such as wet-chemical selectively-deposited SiO_2[6].

4. Conclusions

A novel lithographic method for fabricating three dimensional periodic stacks has been proposed and the stack with four layers of the photo-resist is fabricated. The potential merits of the method discussed are fruitful for future application to the integrated systems.

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