Efficient Fabrication Method of Micro-Pyramid Structures for High-Speed Imaging

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1. Introduction

High-speed imaging is demanded in the consumer market as well as in the experimentally observation in various research fields. Theoretical limitation of 11.1 ps was suggested for Si photodiode[1]. Toward the goal, some charge collection structures were proposed such as p-well that was already realized and used for recording light-flight[1] and guide-pipe that is reported to be the highest speed of 49.0 ps in the simulation[2]. However, pyramid structure is a good candidate that can accomplish a temporal resolution and light-collection ratio at the same time. Additionally, germanium (Ge) is suitable material for achieving higher temporal resolution, for example 10.1 ps for NIR light[3].

In this paper, we propose fabrication method of the Si concave pyramid structures with SiO_2 film on the sidewalls without SiO_2 patterning process.

2. Ge in Si concave pyramid structure

Charge collection structure we use is concave pyramid as shown in Figure 1. The pyramid charge collector is the most promising method to effectively suppress the horizontal motion of generated electrons, which achieves the temporal resolution of 100 ps with the 100% aperture ratio. The penetration depth of light to Ge is 1/50 to 1/90 of that to Si and the saturation drift velocity in Ge is about 2/3 of that in Si. Therefore, it is expected that the temporal resolution limit of the Ge PD is less than 1/30 of the theoretical limit of the Si PD. Therefore, our target is Ge-filled concave-pyramid structure as a charge collection layer.

3. Fabrication method and results

To fabricate the concave pyramid structure, an oxide film mask with a square shape of 10 μm was formed on a silicon wafer and etched with a 20 wt% TMAH solution. The etching temperature was 80 °C, and etching was performed from 100 sec to 113 sec to etch 0.5 μm depth.

Then we developed a new method to form the oxide film on the sidewalls without a second lithography step, which requires precise alignment. The oxide film is thermally oxidized followed by RIE etching to achieve the sidewall oxide film without a second photolithography.

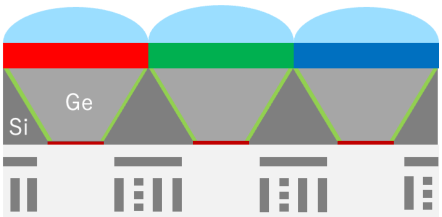

Fig.1 Concave-pyramid Ge-photodiode structure

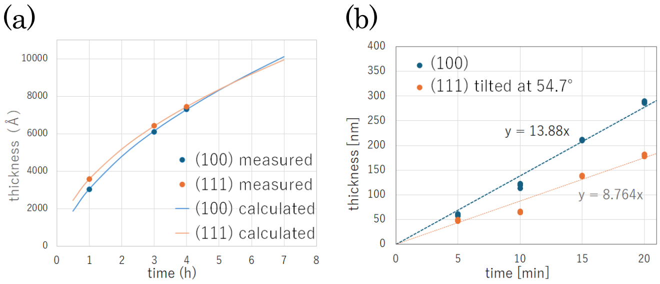

Fig.2 Comparison of fabrication velocity between (100) and (111) plane; (a) Oxidation, (b) SiO2 etching

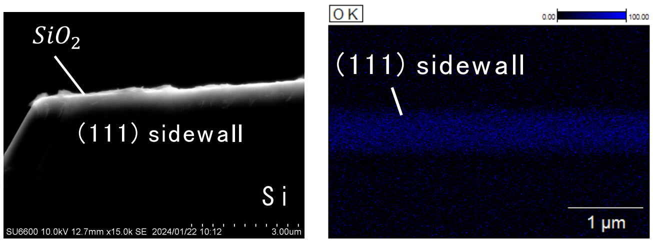

Fig.3 SEM image of concave pyramid structure with SiO_2 film on inclined (111) wall.

Using the difference in oxide film thickness between (100) and (111) due to thermal oxidation as shown Fig. 2(a), SiO_2 on (111) plane is thick at appropriate oxidation times. In addition, etching depth depends on the angle between the etching source flux and the substrate. Figure 2(b) shows the etching depth of (100) and (111), which has lower etching rate due to the crystallographic angle of 54.7°.

Figure 3 shows a cross-sectional SEM image and EDS of the fabricated structure. EDS mapping shows the distribution of oxygen on the sidewall It was confirmed that SiO_2 film was left on the inclined wall.

5. Conclusions

We successfully fabricated pyramid structure with SiO_2 sidewalls with efficient fabrication method. The next step will be to epitaxially growth Ge inside the structure.

Acknowledgements

This work was supported by JSPS KAKENHI Grant Number JP22K18797.

References

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