The influence of size engineering for aligned-well vertical Si/Ge nanosheet array using SWIR photodetector

°WANG Guanghui[1,2], Wipakorn Jevasuwan[1], Naoki Fukata[1,2]
Research Center for Materials Nanoarchitectonics (MANA), National Institute for Materials Science (NIMS)[1], Univ. of Tsukuba[2]
E-mail: WANG.Guanghui@nims.go.jp, FUKATA.Naoki@nims.go.jp

Semiconductor nanostructures, especially optoelectronic detection devices represented by silicon/germanium (Si/Ge) core-shell vertical nanostructures, have received widespread attention in recent years. The Si/Ge core-shell vertical nanostructure exhibits great potential in improving carrier mobility, enhancing photogenerated carrier separation efficiency, and improving device stability due to its excellent heterojunction interface quality and unique band structure[1]-[4]. Although Si/Ge core-shell vertical nanosheets have shown promising prospects in the field of optoelectronic detection, there are still several urgent issues that need to be addressed in current research. For example, in the preparation process of nanosheet arrays, how to accurately control the orientation of nanosheets and maintain the uniformity of the array is one of the important challenges to achieve maximum performance. In addition, the specific effects of array density and aspect ratio of nanosheets on optoelectronic performance are not yet clear, and existing research mostly focuses on a single or few parameters, lacking systematic and comprehensive exploration. In this report, we achieved a significant improvement in the performance of the photodetector by changing the aspect ratio and density of the nanosheet, allowing its absorption to reach 100% and enabling selective absorption within a specific wavelength range. The purpose of this work is to reveal the physical mechanism between parameter regulation and optoelectronic performance improvement of Si/Ge nanosheet arrays, providing important experimental basis and theoretical guidance for the design of future high-performance nanostructure photodetectors.

Preparation of Si/Ge nanosheet array:

Si/Ge nanosheet arrays were formed as follows Si substrates were coated with a resist layer via spin coating, followed by the formation of patterns with varying diameters through elctron beam lithography (EBL).

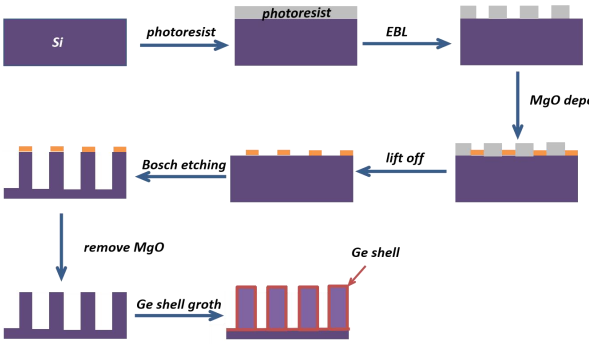

Fig. 1. Fabrication processes of Si/Ge nanosheet array.

Next, MgO layers were deposited onto the resist to serve as a mask. The mask was then lifted off, and the Bosch Etching process was employed to etch away the regions not protected by MgO, resulting in the creation of NSs. Finally, these NSs were reintroduced into the CVD chamber to form n-Ge shell, as illustrated in Fig. 1.

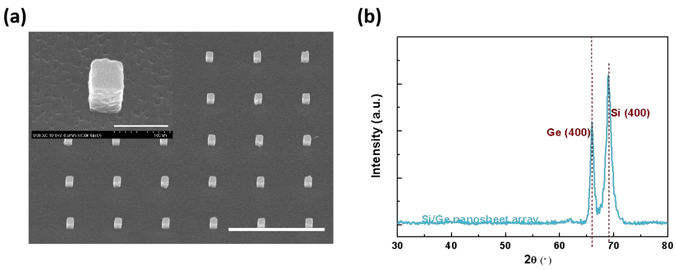

Fig. 2. (a) SEM images and (b) XRD data of Si/Ge nanosheet array.

The SEM image from Fig. 2(a) reveals that the Si/Ge NS arrays exhibit well-aligned structures and can be easily controlled using EBL. Fig. 2(b) XRD reveals the assurance of good crystal quality for the next step of optoelectronic performance analysis.

Optoelectronic performance evaluation:

Figure 3 (a) shows the PL spectrum of NSs, from which it can be seen that the peak intensity of Si/Ge core-shell is lower than that of Si, indicating the formation of type II energy bands and an increase in carrier separation efficiency. Figure 3 (b) shows the photodetector diagram, revealing a significant improvement in photoelectric performance.

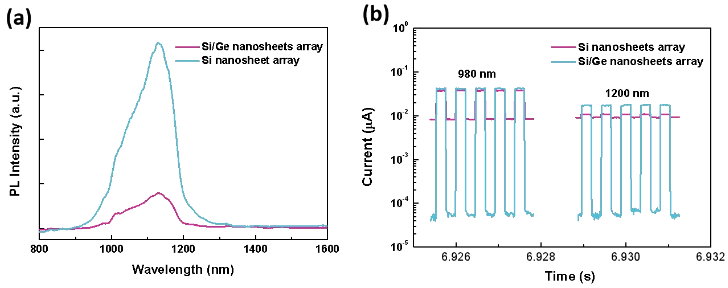

Fig. 3. (a) PL spectrum of Si/Ge NSs compared with Si NSs, (b) Photodetector performance under the laser illustrated by 980nm and 1200 nm of 0.5V bias and 2mW/cm^2

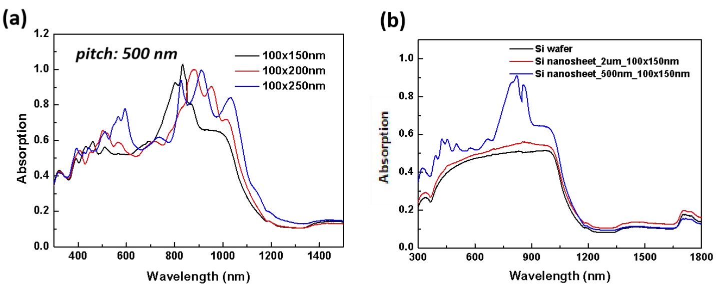

Fig. 4. (a) Absorption of Si/Ge NSs with different Si NSs planar size, (b) Comparison of Si wafer and various density Si NSs with 2-um and 500-nm pitches.

Afterward, we planned to achieve selective control of light absorption by photodetectors by adjusting the aspect ratio and density of NSs. Figure 4 shows the results of the first attempt on Si NSs. It was found that with the increase of aspect ratio and density, the absorption peak gradually redshifts, and the absorption efficiency significantly improves, which may be due to the influence of Mie resonance. This result lays an important foundation for the subsequent research on core-shell photodetectors.

Conclusion:

We significantly improved the performance of the photodetector by changing the aspect ratio and density of the nanosheets to achieve an absorption rate upto 100% and achieving selective absorption within a specific wavelength range.

References:

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