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The approach to dislocation-free Ge mesa on Si fabricated by dry etching

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1. Introduction

The human skin is transparent to the light whose wavelength range is from 1 μm to 1.5 μm. The photodetector in this range can be applied to medical fields, for example, image sensing devices for brain of human. Arrayed Ge photodetectors on Si are useful because they can detect this range of light. Low threading dislocation Ge epilayers are necessary to increase the sensitivity of the photodetectors. However, it is difficult to grow a high-quality Ge epilayer due to the large lattice mismatch of 4% between Si and Ge.

Cyclic thermal annealing is effective in reducing the threading-dislocation density. In fact, selectively-grown mesas free from threading dislocations can be achieved [1]. This behavior is induced by the thermal stress generated in the Ge epilayer on Si. The thermal stress can glide the threading dislocations and they disappear when arriving at the edge of mesa.

In fabricating arrayed photodetectors, the shape of selectively-grown mesas is not appropriate due to the large sidewall areas of (311) facets. This can be resolved by Ge mesa with vertical sidewall fabricated using dry etching processes. However, there is a challenge. Dry etching may induce new types of defects and also may increase threading dislocation density.

To understand if such side effects should really appear, we have conducted annealing experiments of mesas fabricated using dry etching and selective growth. The present paper shows that the difference between dry etching mesa and growth mesa, and discusses the origin.

2. Experiments

For fabricating dry etching Ge mesa, Ge was grown by a UHV-CVD reactor. The thickness of blanket Ge epilayer is 1 μm. Square-shaped resist pattern was fabricated by photolithography. Ge epilayer was etched by dry ething. After dry etching, the sidewall of some samples is slightly etched by H_2O_2 to remove defects that might have been generated by dry etching. The substrate with a 500 nm SiO_2 layer was used for fabricating selective growth Ge masa. The area for the selective Ge growth was defined by the wet etching of SiO_2 by BHF (buffered HF). The Ge growth area is square-shaped, whose side length of 10 μm.

For reducing threading-dislocation density, we carried out a rapid anneal in N_2 atmosphere. The furnace is schematically shown in Fig. 1. The temperature at the center of the furnace is 900°C, while the temperature at the edge is about 100°C. The chip was moved from the edge to the center with about 10 seconds to raise the chip temperature rapidly, and similar quick motion was used to cool down the sample rapidly. The maximum raising rate of temperature in this rapid annealing is about 80°C/sec.

The evaluating method of dislocation density is etch pit counting by AFM. The etchant is a mixture of CH_3COOH(67ml), HNO_3(20ml), HF(10ml), and I_2(30mg). The etching time is 4 seconds.

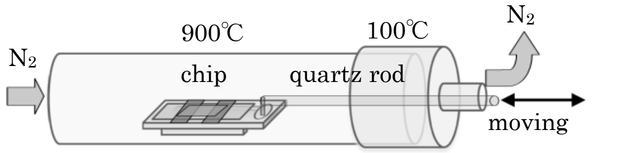


Fig.1. The furnace for rapid anneal and slow one.

3. Results

The as-grown sample showed an etch pit density (EPD) of $5.6\pm0.2\times10^{8}$ cm^{-2}. After the annealing at 900℃, the EPD for the annealed samples is more than one order of magnitude lower. This result confirms the previous report that the threading dislocation in Ge mesa can glide at 900℃ [1]. However, the EPD values are deviated in the range of 10^{6} - 10^{7} cm^{-2}, depending on the fabrication process.

Although the EPD for the samples by the dry etching showed almost a constant value, independent of the wet etching of sidewalls ($4.2\pm0.3\times10^{7}$ cm^{-2} and $3.6\pm0.4\times10^{7}$ cm^{-2} for the samples with and without the wet etching). The EPD for the selectively-grown mesa revealed a smaller value of $9.0\pm1.0\times10^{6}$ cm^{-2}. This is one quarter of that for the dry etched one.

The EPD for the dry-etched mesa was also found to be almost the same as that for the blanket area. This result indicates that there is a difference in the dislocation reduction mechanism between the selectively-grown mesa and the dry-etched mesas.

4. Discussions

As shown above, dislocation-free Ge mesas cannot be obtained. Particularly, the EPD for the dry-etched sample is four times larger than that for the selectively-grown mesa. This behavior can be explained in terms of the strain relaxation. For the dry-etched mesa, the strain is relaxed at the top edges of Ge mesa due to the change in shape. There should be weak thermal stresses at the edges, leading to the result that the threading dislocations cannot slide beyond the edges of mesa. On the other hand, the selectively-grown Ge mesa is trapezoidal with the (311) sidewall facets, which should be more rigid against the change in shape. Thus, there should be still a strong thermal stress at the edges, i.e., the threading dislocation can slide beyond the edge.

5. Conclusion

Threading dislocation density in Ge mesas fabricated by the dry etching was investigated for the application of near-infrared arrayed photodetector. Dislocation-free Ge mesas could not be achieved, and the obtained density was four times larger than that for the selectively-grown mesas. This difference reflects that the thermal stress can be relaxed by changing the shape of Ge mesa, leading to the threading dislocation cannot slide beyond the edge.

Reference

[1] Hsin-Chiao Luan and and Lionel C. Kimerling, Appl. Phys. Lett. 75, 2909 (1999)

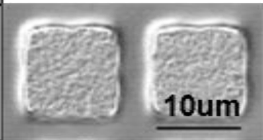
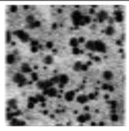
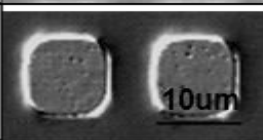
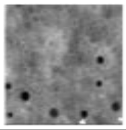
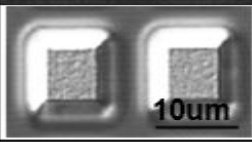
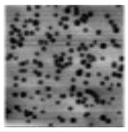
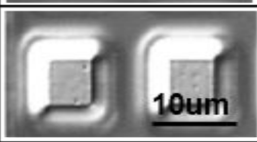
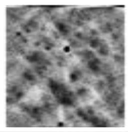
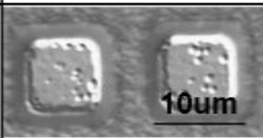
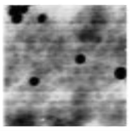
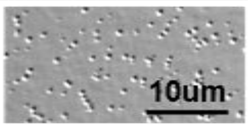
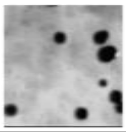
Sample	Anneal recipe Rate of temperature raise	EPD(/cm^2)	Nomarski image	AFM image
dryetching	No anneal	$5.6\pm0.2\times10^8$		
	(900℃,10min)×2 max 80℃/min	$3.6\pm0.4\times10^7$		
Selective growth	No anneal	$6.8\pm0.2\times10^8$		
	(900℃,10min)×2 max 80℃/min	$9.0\pm1.0\times10^6$		
dryetching Sidewall etching	(900℃,10min)×2 max 80℃/min	$4.2\pm0.3\times10^7$		
blanket	(900℃,10min)×2 max 80℃/min	$3.1\pm0.4\times10^7$		

Fig.2. sample, anneal recipe, EPD result, nomarski images and images of etch pit on Ge mesa. AFM picture is 5um×5um.