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Characterization of Ge photodetectors fabricated on vicinal Si substrate

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1. Introduction

Recently, on-chip optical interconnection has attracted much attention to improve the performance of LSI [1]. Ge is attractive for photodetector because it can detect the light with wavelength of 1.55μm used for long distance optical communications especially under stress application [2]. Although many studies have been reported concerning Ge heteroepitaxial growth on Si substrate [2], there are few reports on the influence of misorientation azimuth to the behavior of the Ge photodetectors grown on them.

In this study, we have studied influence of Si substrate with different off azimuths on dark and photocurrents of Ge p-i-n (pin) photodetectors fabricated on these substrate.

2. Experimental

Three kinds of substrates are used for Ge heteroepitaxial growth, (a) Si just (100) ($\pm$ 1°) substrate, (b) Si(100) substrate 4°off toward <001> azimuth, (c) Si(100) substrate 4°off toward <011> azimuth. The ideal atomic structures of these samples are shown in the insets of Fig. 5 [3]. The Ge film has been epitaxially grown by two-step chemical vapor deposition (CVD) to reduce dislocation density [2]. The schematic of the CVD system is shown in Fig. 1 and the deposition condition is listed in Table I. The structure of the Ge-pin photodetector is shown in Fig. 2, which was fabricated as follows. The Ge film is grown on respective Si substrate, and n^+-Ge is formed by phosphorus ion implantation. Next, the activation annealing was carried out at 600°C for 1 min, followed by mesa etching in H_2O_2+HF+H_2O mixture. Finally, electrodes (InGa or Al) are formed. The measurement system is shown in Fig. 3.

3. Results and Discussion

3.1 Dark- and Photocurrent versus off azimuth

The typical currents of photodetector with InGa electrode at dark and under illumination of light with wavelength of 1.5 μm and intensity of 1.75 mW/cm^2, are shown in Fig. 4 for the Si(100) substrate 4°off toward <011> azimuth. The dark current and photosensitivity for three kinds of substrates with InGa substrate at applied reverse bias of 3 V are summarized in Fig. 5. Here, InGa metal (liquid at room temperature) was employed to save the sample preparation time. From Fig. 5 it is found that the dark current is the lowest and photosensitivity is the highest for the substrate 4°off toward <011> azimuth, which has the atomic step similar to the staircase. Next, the influence of the electrode is investigated because the photosensitivity is not so good (0.32A/W) compared with other report [4] and InGa/Ge contact resistance may be relatively high.

The Al electrode was employed instead of InGa. The results are shown in Fig. 6, where the dark current is increased but the photocurrent is also enhanced. Figure 7 summarizes the dark current and photosensitivity at applied reverse bias of 3 V. Here, again it is confirmed that the dark current is the lowest and the photosensitivity is the highest for the substrate 4°off toward <011> azimuth. The best photosensitivity for this substrate is calculated to be 0.50 A/W which is smaller than that (0.75 A/W) of the other report [4]. A relatively small photosensitivity of our work may be due to the thinner Ge film (1.4 μm) compared with the other work (2.35 μm) [4]. The photosensitivity of our sample is calculated to be 0.7 A/W for the same Ge thickness (2.35 μm) using the light absorption coefficient of the bulk Ge, which is almost comparable.

3.2 Discussion

The reverse current of n^+p junction J_R is given by [5],

$$J_R = q\sqrt{\frac{D_e}{\tau_e}}\frac{n_i^{\,2}}{N_A} + \frac{qn_iW}{\tau_p}, \qquad (1)$$

where the first term is diffusion current, and the second term is generation current. Here, q is electron charge, D_e and τ_e are, respectively, diffusion constant and lifetime of electron, n_i is the intrinsic carrier density, N_A is the impurity concentration in p layer, W is the thickness of depletion layer, and τ_p is lifetime of hole. Generally, for Ge the first term is dominant. The higher dislocation density Ge layer has, the smaller life time of electron, τ_e, is, therefore the reverse current increases. The Ge film grown on Si(100) 4°off toward <011> may have the lowest dislocation density in three kinds of substrates. Moreover, the lower dislocation density reduces the recombination current, therefore the photocurrent may be enhanced.

In the heteroepitaxial growth of GaAs [6] and Al [3] on Si(100) substrate, the vicinal substrate misoriented toward <011> azimuth is reported to be suitable. The atomic steps arranged in one direction in this substrate may cause the small dislocation density. The similar mechanism may also operate in the heteroepitaxial growth of Ge on Si.

4. Conclusions

Influence of Si substrate with different off azimuths on dark current and photosensitivity of Ge pin photodetectors fabricated on it has been investigated. It is found that the dark current is the lowest and photosensitivity is the highest for the sample fabricated on Si(100) 4°off toward <011>.

Further improvement of the photosensitivity of Ge photodetectors is expected by optimizing the structure and also by applying the suitable stress in the Ge film [2].

Acknowledgments

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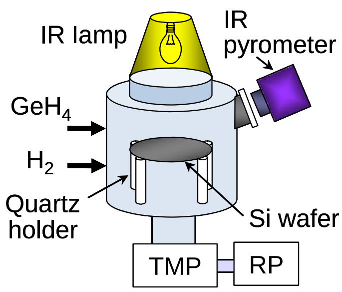

Fig. 1. Schematic of Ge CVD system.

Table I. Deposition condition.

Background pressure	2.0x10^{-8} Torr
Gas	GeH_4 (GeH_4 10%, He 90%):H_2 =100:200 sccm
Pressure	0.36 Torr
1st step growth	300ºC, 10 min
2nd step growth	580ºC, 40 min

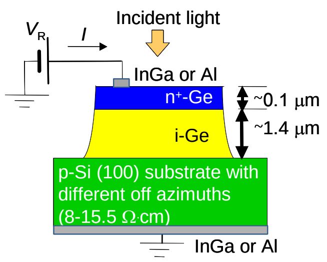

Fig. 2. Structure of Ge pin photodetector.

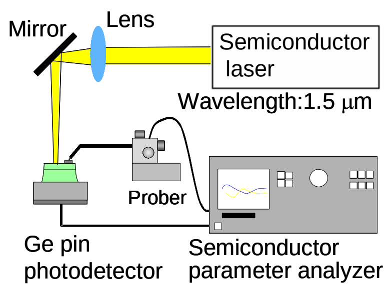

Fig. 3. Measurement system of photocurrent.

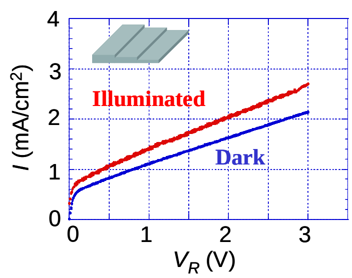

Fig. 4. Current at dark and under illumination (λ=1.5 μm) for sample grown on Si(100) 4° off toward <011> azimuth with InGa electrode.

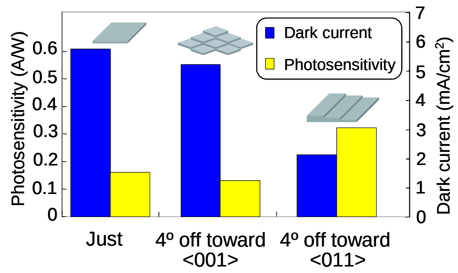

Fig. 5. Dark current and photosensitivity at applied voltage of 3 V for three kinds of samples in case of InGa electrode.

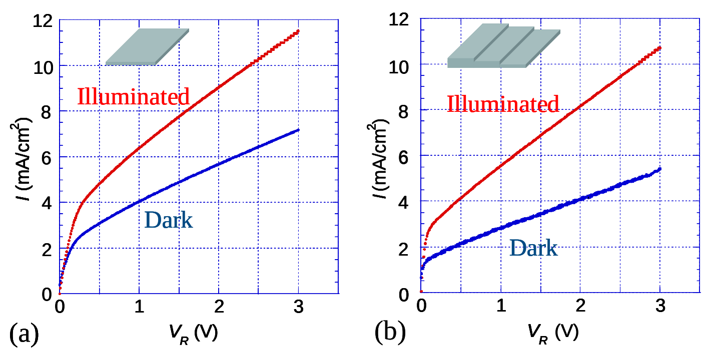

Fig. 6. Current-voltage characteristics at dark and under illumination (λ=1.5 μm) for samples grown on (a) Si just (100) substrate and (b) Si (100) substrate 4° off toward <011> azimuth in case of Al electrode.

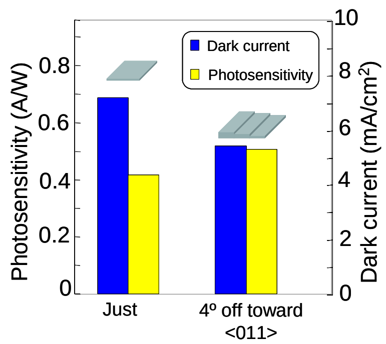

Fig. 7. Dark current and photo-sensitivity at applied voltage of 3 V for two kinds of samples in case of Al electrode.

Table II. Comparison of photosensitivity with other research group.

	Photosensitivity at 1.5 μm (A/W)
J. Liu *et al*. [4]	0.75
This study	0.50