Extended Abstracts of the 2005 International Conference on Solid State Devices and Materials, Kobe, 2005, pp.330-331

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Investigation of β-$FeSi_2$/Si Heterostructures by Photoluminescence with Different Optical Configurations

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1. Introduction

Semiconducting β–$FeSi_2$ shows photoluminescence (PL) and photoresponse near 1.54 μm, which is a wavelength for fiber optics communications. This material has been regarded as a candidate for application to monolithic integrated circuits of optoelectronics devices because of the compatibility with the Si-process technology [1]. Epitaxy of β–$FeSi_2$ on Si contains a large lattice mismatch, however, it is a crucial technology for device applications. Defective layers at the β–$FeSi_2$/Si interface act as nonradiative centers and induce poor optical properties [2]. The β–$FeSi_2$/Si interface has mainly been examined by TEM observations. In this study, we demonstrate nondestructive characterization of β–$FeSi_2$/Si heterostructures by photoluminescence (PL) measurements with different optical configurations.

2. Experiments

β–$FeSi_2$/Si samples were prepared by an ion beam synthesis (IBS) methods. After the implantation of $^{56}Fe^+$ ions into Si(100), the substrates were annealed at 800ºC for 2-16 h by a rapid thermal anneal (RTA) in order to form β–$FeSi_2$ and to remove implantation damages. In Al-doped β–$FeSi_2$/Si samples, $^{17}Al^+$ ions were implanted after the implantation of $^{56}Fe^+$. Details of the sample preparation were described elsewhere [2,3]. The cross-section images of scanning electron microscope (SEM) show the formation of β–$FeSi_2$ precipitates near the surface with an average size of 60 nm. PL was investigated at 10-300 K with an Ar^+ ion laser of the 514.5 nm line, a 32 cm focal length single monochromator and a liquid nitrogen-cooled Ge pin photodiode. PL spectra were measured with various optical configurations of FEFP and BEFP, where FE, BE, and FP denote PL excitation from the β–$FeSi_2$ surface (front excitation: FE), PL excitation from the Si substrate (back excitation: BE), PL observation from the β–$FeSi_2$ surface (front PL: FP), respectively.

3. Results and Discussion

Figure 1 shows the optical configurations of FEFP and BEFP. β–$FeSi_2$/Si samples were excited from the β–$FeSi_2$ side (FE) and the Si side (BE), respectively. And PL was observed from the β–$FeSi_2$ surface (FP). The FEFP originates direct optical excitation of β–$FeSi_2$ (a). It is a common PL mode. The BEFP is caused by an injection process (c) of electrons and holes from the Si substrate into β–$FeSi_2$ through the interface with defective layers. Some of the injected electrons and holes (*e-h*) may be captured at the defective layer and consumed in a nonradiative recombination process (b). Assuming that the β–$FeSi_2$ thickness is thinner than the diffusion length of injected *e-h*, a uniform profile of the *e-h* injected at a steady state should be realized. Therefore, we can know the injection efficiency (γ) at the β–$FeSi_2$/Si interface. It can be calculated by γ= I(BEFP)/I(FEFP), where I(BEFP) and I(FEFP) are PL intensities measured for the respective excitation cases.

Figure 2 shows FEFP (a, b) and BEFP (c, d) spectra measured at 10 K for an Al-doped β–$FeSi_2$/Si sample and non-doped one. We observed FEFP and BEFP spectra near 0.8 eV and obtained γ = 0.41 for the Al-doped sample and γ = 0.19 for the non-doped one. This shows that the injection efficiency can be improved by Al-doping. Figure 3 shows the temperature dependence of BEFP spectra in (a) the Al-doped β–$FeSi_2$/Si and (b) the non-doped one. As temperature increases, the intensity of BEFP spectra decreases more rapidly in the non-doped one. From the analysis of the temperature dependence of the BEFP intensity, we examined an activation energy (E_a) for non-radiative recombination processes, and obtained E_a = 51 meV for the Al-doped sample and E_a = 16 meV for the non-doped one. This shows that non-radiative processes in the BEFP configuration are suppressed by Al-doping.

From these PL measurements, we can conclude that the high injection efficiency and the large activation energy observed in the Al-doped sample are due to decrease in nonradiative recombination centers at the β–$FeSi_2$/Si epitaxial interface.

4. Conclusions

We demonstrated that PL measurements employed in this study are promising and nondestructive characterization of the heterostructure. And, it was confirmed that Al-doping is effective on the improvement of defective layers at the β–$FeSi_2$/Si interface.

References

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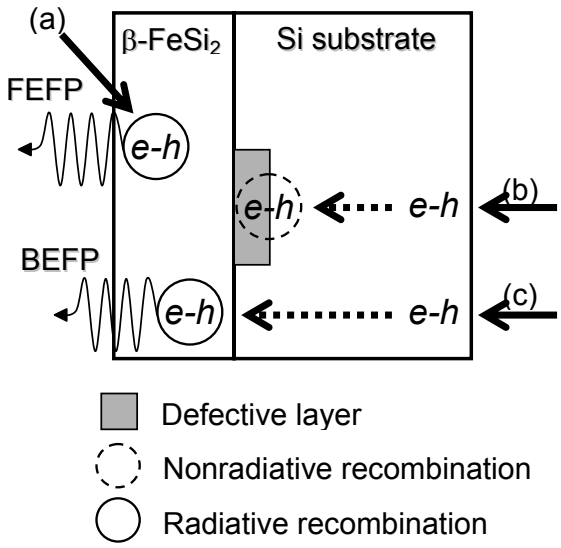

Fig. 1 Optical configurations of FEFP and BEFP measurements. Sample was excited from (a) the β-$FeSi_2$ side :FE and (b,c) the Si side :BE, respectively. In both cases, PLs were observed from the β-$FeSi_2$ side : FP.

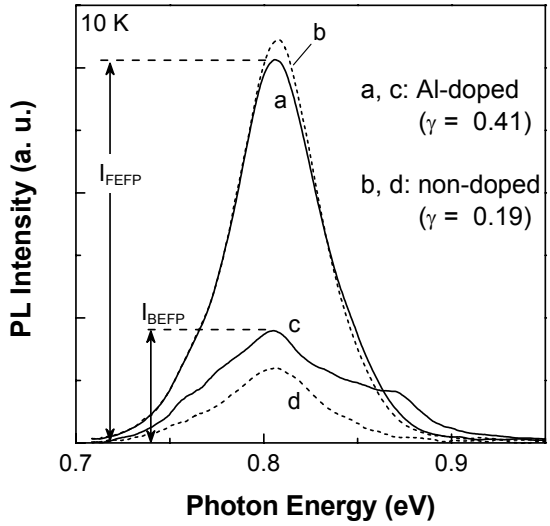

Fig. 2 PL spectra of FEFP (a, b) and BEFP (c, d) from Al-doped β-$FeSi_2$/Si (a, c) and non-doped one (b, d).

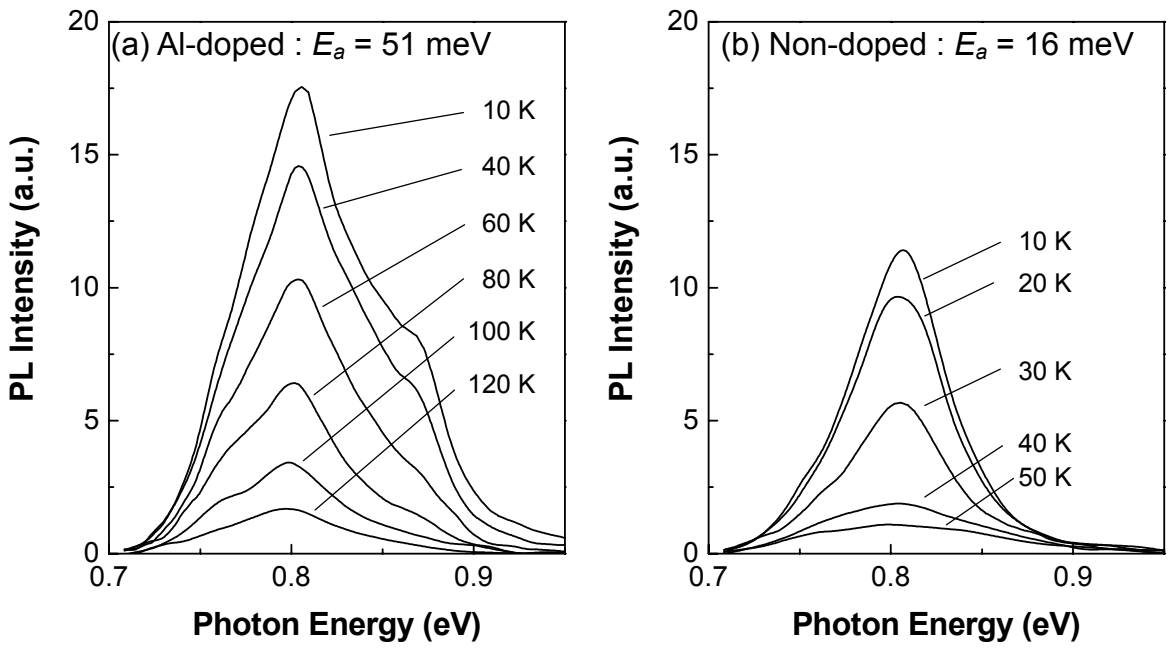

Fig. 3 Temperature dependence of the PL spectra of BEFP for (a) Al-doped β-$FeSi_2$/Si and (b) non-doped sample. E_a is an activation energy for non-radiative recombination processes obtained from the temperature dependence of the PL intensity.