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Improvement of life time of minority carriers in GaAs epi-layer grown on Ge substrate

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Abstract

A buffer layer structure on Ge substrate was studied for MOCVD growth of a high-quality GaAs layer. The buffer layer structure was designed taking into consideration both lattice constants and thermal expansion coefficients of GaAs and Ge. It consisted of a preliminarily grown thin layer of $Al_xGa_{1-x}As$ and a GaAs layer. Photoluminescence (PL) decay of a GaAs layer in an $Al_{0.2}Ga_{0.8}As$-GaAs-$Al_{0.2}Ga_{0.8}As$ double-hetero (DH) structure, which was grown on the buffer layer structure, was observed by time-resolved PL method to estimate the quality of epilayers in the DH structure. The PL decay time strongly depended on Al content (x) of the $Al_xGa_{1-x}As$ preliminary layer, and the highest value was obtained when the x was 0.25. A PL decay time above 20 ns was successfully obtained for the DH structure grown on the buffer layer structure, which consisted of a 0.05 μm thick $Al_{0.25}Ga_{0.75}As$ layer and a 1 μm thick GaAs layer. Although this value was half of that for the DH structure grown on GaAs substrate, it was much longer than the value of 3 ns for the DH structure grown on Ge substrate with a conventional GaAs buffer layer 1 μm thick.

Keywords: Life time; Minority carriers; GaAs epi-layer; Ge substrate

1. Introduction

Because of the potential cost reduction of Ge substrate compared with GaAs substrate, high efficiency solar cells based on GaAs/Ge technology are attractive

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devices for terrestrial photovoltaic (PV) power systems where cost is one of the most important items. Whereas a positive cost of energy result has been calculated for concentrator PV power plants using cells based on GaAs/Ge technology, a very thick (~ 5.5 μm) buffer layer of GaAs whose growth time is more than half of that for GaAs cell structure, is still assumed in the solar cell design [1]. Growth of a high-quality GaAs layer on Ge substrate with a thin buffer layer is one of the most important aspects in further cost reduction of the cells. In the latest study, a good photoluminescence (PL) decay time above 50 ns was obtained for an $Al_{0.2}Ga_{0.8}As$-GaAs-$Al_{0.2}Ga_{0.8}As$ double-hetero (DH) structure with 0.5 μm thick GaAs buffer layer grown on GaAs substrate, while only 1 ns was obtained for that grown on Ge substrate. Minority carrier lifetime, which is recognized by PL decay time, is strongly influenced by crystal defects, therefore the result indicated that there were more crystal defects in the epilayers grown on Ge substrate than in those grown on GaAs substrate. Although both lattice constant and thermal expansion coefficient of GaAs are very close to those of Ge, crystal defects in the epilayers on Ge substrate are believed to arise from mismatches of those parameters between the heterocrystals. A buffer layer structure on Ge substrate for growth of a high quality GaAs layer should be designed taking into consideration these mismatches of the crystal parameters.

In this paper, the new design of a buffer layer structure on Ge substrate and results on measurement of PL decay time for a DH structure grown on the buffer layer structure are described.

2. Basic design of structure for buffer layer on Ge substrate

The basic concept of the design of a buffer layer structure on Ge substrate is to reduce mismatches in lattice constant and thermal expansion coefficient at the interface between heterocrystals. For this purpose, these parameters of buffer layers in the buffer layer structure should be changed gradually or incrementally from those of Ge to those of GaAs. In this study, the simplest structure was selected and the parameters were changed in a single step. For this structure, an epilayer was preliminarily grown on Ge substrate before growth of the GaAs layer.

The key to the structure is selection of a material for the preliminary layer. The material should be easily grown by the metalorganic chemical vapor deposition (MOCVD) method as well as fitting the design concept. The authors noticed a relation of the parameters among AlAs, GaAs, and Ge. Fig. 1 shows lattice constants of these materials at temperatures ranging from 300 to 1300 K. Values above 300 K were estimated using the lattice constants at 300 K and the thermal expansion coefficients [2, 3]. The lattice constants of Ge were estimated to be almost intermediate between those of AlAs and GaAs in the temperature region used. Assuming that both lattice constant and thermal expansion coefficient of $Al_xGa_{1-x}As$ shift from those of GaAs to those of AlAs proportionally to Al content (x) as Adachi [2] reported, these parameters of $Al_{0.5}Ga_{0.5}As$ are almost equal to those of Ge, thus indicating that

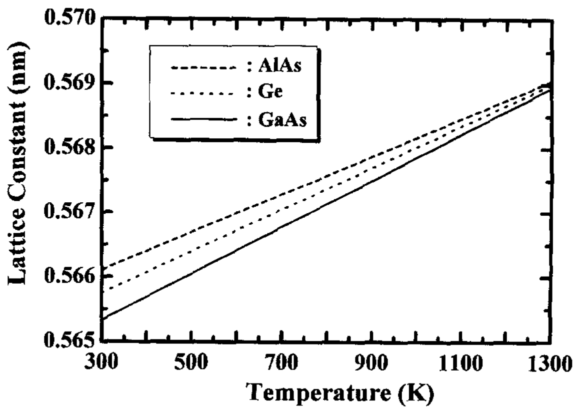

Fig. 1. Estimated lattice constants of AlAs, GaAs and Ge at temperatures ranging from 300 to 1300 K.

$Al_xGa_{1-x}As$ ($0 < x < 0.5$) is appropriate for the material for the preliminary layer of the new buffer layer structure.

Total thickness of the buffer layer structure should be thin to reduce growth time, which influences the cost of cell fabrication. Thickness of the $Al_xGa_{1-x}As$ ($0 < x < 0.5$) preliminary layer was fixed at 0.05 μm in this study, while that of the GaAs layer was varied from 0 to 4 μm.

3. Experimental

3.1. Sample preparation

All samples were grown by MOCVD method in a horizontal quartz tube reactor under a reactor pressure of 1×10^4 Pa. Trimethylgallium (TMG) and trimethylaluminum (TMA) were used as group III source gases, whereas a 10% mixture of arsine (AsH_3) in hydrogen was used as group V source gas. A 5 ppm mixture of disilane (Si_2H_6) in hydrogen was used as n-type dopant source.

The schematic structure of samples which were used in measurement of PL decay time is shown in Fig. 2. Substrates used were Sb-doped n-type Ge oriented 2° off toward [0 1 1] from (1 0 0) with resistivity ranging from 0.2 to 0.6 Ω cm. A 0.05 μm thick undoped $Al_xGa_{1-x}As$ layer was grown first at 560°C as the preliminary layer, and an n-type GaAs layer grown next with a carrier concentration of 5×10^{17} cm^{-3}. These were component layers of the newly designed buffer layer structure. Thickness of the GaAs layer was varied from 0 to 4 μm. The DH structure, which includes 0.1 μm thick n-type $Al_{0.2}Ga_{0.8}As$ (cladding) layers with carrier concentration of 5×10^{17} cm^{-3} and a 2 μm thick n-type GaAs (absorption) layer with carrier concentration of 6×10^{16} cm^{-3}, was grown on the buffer layer structure. All layers except for the preliminary layer were grown at 650°C. A similar layer structure was also grown on GaAs substrate at 650°C for reference.

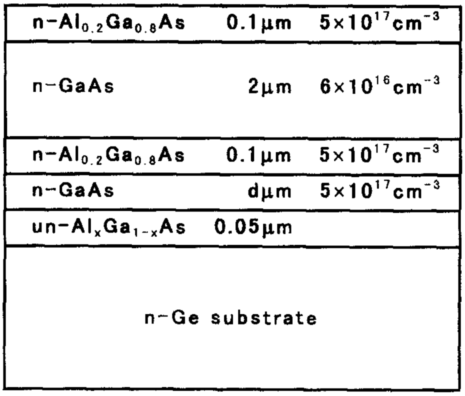

Fig. 2. Schematic structure of the samples for PL decay time measurement.

3.2. Pl decay measurement system

The measurement of PL decay time was performed by time-resolved photoluminescence technique at room temperature, details of this technique are described in the literature [4]. The measurement system used was a commercially available one from Hamamatsu Photonics. The system includes photoexcitation source, spectroscope, streak scope and computer. The photoexcitation source used was a pulsed AlGaAs laser diode with excitation wavelength of 820 nm. The streak scope, the main component in this system, consists of a photoelectric surface (PS), an acceleration electrode (AE), a couple of deflection electrodes (DE), a micro-channel plate (MCP), a fluorescent plate (FP) and a CCD camera. Time resolution of the system is about 15 ps at full-width at half-maximum (FWHM).

4. Results and discussion

4.1. Influence of AlGaAs preliminary layer

Based on the structure shown in Fig. 2, several samples were grown on Ge substrates by changing the Al content (x) of the $Al_xGa_{1-x}As$ preliminary layer from 0 to 0.8. The thickness of the GaAs layer in the buffer layer structure was fixed at 0.5 μm. The PL decay of the GaAs absorption layer in the DH structure was then measured on these samples. Fig. 3 shows examples of the PL decay data from $x = 0$, $x = 0.16$ and $x = 0.25$ samples. The PL decay time of each sample was determined from those PL decay data and plotted versus the Al content (x). Fig. 4 shows the relation between PL decay time and Al content (x). The former strongly depended on the later. The highest value was obtained when the Al content of the preliminary layer was 0.25. In cases where the Al content was higher or lower than 0.25, the PL decay time showed a large deterioration. The value of 14.4 ns at $x = 0.25$ was about 15 times

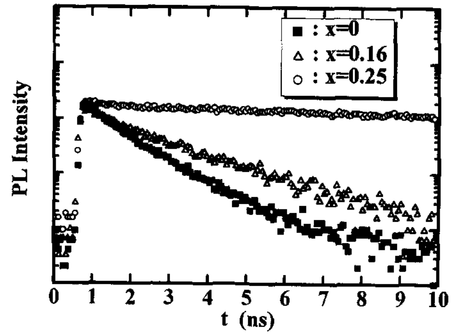

Fig. 3. Examples of the PL decay data from $x = 0$, $x = 0.16$ and $x = 0.25$ samples.

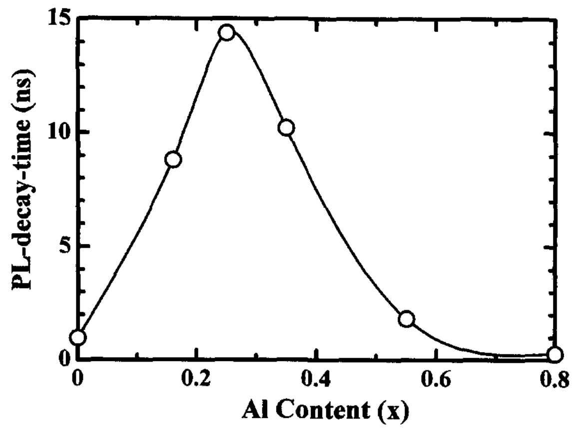

Fig. 4. Relation between the PL decay time and Al content (x) of the $Al_xGa_{1-x}As$ preliminary layer for samples grown on Ge substrates.

that for the sample with a conventional GaAs buffer layer ($x = 0$). Considering that both lattice constant and thermal expansion coefficient of $Al_xGa_{1-x}As$ ($0 < x < 0.5$) shift from those of GaAs to those of Ge in proportion to Al content (x), these parameters of $Al_{0.25}Ga_{0.75}As$ are almost intermediate between the two. Therefore, PL decay time of the DH structure becomes maximum when mismatches of the parameters at the two interfaces of $Al_xGa_{1-x}As$/Ge substrate and GaAs/$Al_xGa_{1-x}As$ in the buffer layer structure are minimum. Fig. 5 shows the PL decay time of samples grown on GaAs substrates. The highest value of 50.6 ns was seen at $x = 0$, and it then deteriorated with increase of the Al content of the $Al_xGa_{1-x}As$ preliminary layer. This result was quite similar to that of the samples grown on Ge substrates, because mismatches of the parameters at $Al_xGa_{1-x}As$/GaAs interface grow large with increase of the Al content.

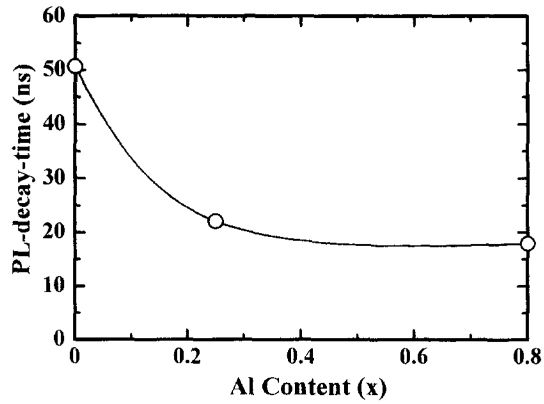

Fig. 5. Relation between the PL decay time and Al content (x) of the $Al_xGa_{1-x}As$ preliminary layer for samples grown on GaAs substrates.

The experimental results shown in Figs. 4 and 5 indicate that the PL decay time is strongly influenced by mismatches of lattice constant and thermal expansion coefficient at both interfaces between the preliminary layer/substrate and the GaAs layer/the preliminary layer in the buffer layer structure. It is also deduced that the deterioration of the PL decay time is caused by increase of crystal defects in the GaAs absorption layer and/or at the interface between $Al_{0.2}Ga_{0.8}As$ cladding layer and the GaAs absorption layer. Although these two factors are not considered separately in this study, the result is quite useful for a design of solar cells fabricated on Ge substrates. In the case of the GaAs cell structure [5], an n-type $Al_{0.2}Ga_{0.8}As$ layer is grown on the buffer layer structure as the back-surface field before growth of an n-type GaAs as the base layer. The structural parameters of these two layers are closely similar to those of the cladding layer and the absorption layer in the DH structure.

4.2. *Influence of thickness of buffer layer structure*

The samples, whose schematic structure is shown in Fig. 2, were grown on Ge substrates to investigate the influence of thickness of the GaAs layer in the buffer layer structure on PL decay time of the DH structure. Samples were divided into three groups according to their Al content (x) of the preliminary layer: the $x = 0$ group, the $x = 0.16$ and the $x = 0.25$. Thickness of the GaAs layer in the buffer layer structure was varied from 0 to 4 μm for the samples in each group.

Fig. 6 shows the relation between PL decay time and thickness of the GaAs layer for the three groups of samples. In each group, the decay time was improved with increase in GaAs thickness. That of the samples in the $x = 0.16$ and the $x = 0.25$ groups was remarkably improved in the GaAs thickness region from 0 to 1 μm, while it was saturated in the region of > 1 μm. At a GaAs thickness of 1 μm, high values of 13 and 21 ns were obtained for the samples in the $x = 0.16$ and the $x = 0.25$ groups, respectively. In the $x = 0$ group where a conventional GaAs buffer layer was used, the

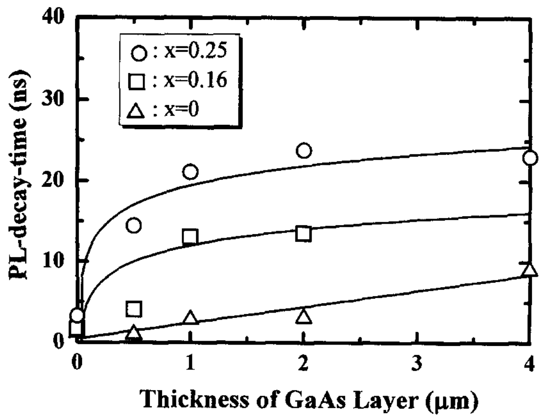

Fig. 6. Relation between the PL decay time and thickness of the GaAs layer in the buffer layer structure.

PL decay time, which was 2.8 ns at 1 μm, was considerably lower than that in the other two groups. The factor result in improvement of the PL decay time is not clear, but an effect of reduced dislocation density with increased epilayer thickness [6] may be involved.

5. Conclusion

A new buffer layer structure was designed for MOCVD growth of a high quality GaAs layer on Ge substrate. PL decay time of an AlGaAs-GaAs DH structure grown on the structure was remarkably improved compared with that grown on a conventional GaAs buffer layer. The result is viewed as being useful not only for high efficiency solar cell design but also for cost reduction of the cells based on GaAs/Ge technology.

Acknowledgements

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