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Fluoride Buffer Layer Relaxing the Stress of GaAs on Si and Its Effects

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Stress in GaAs layers in GaAs/CaF_2/Si heterostructures was investigated by photoluminescence measurements, so that it was found that CaF_2 layer was effective as a buffer layer to relax thermal stress in GaAs on Si. Dependence of CaF_2 thickness revealed that the stress relaxation was occurred by plastic deformation of the CaF_2 layers. And this effect is obvious in growth on not (100) but (111) oriented substrates.

1. INTRODUCTION

The structure of GaAs grown on Si substrate is attracting large interests in device applications. However, this structure has the problem of the stress caused by the mismatch of thermal expansion coefficient between GaAs and Si. Buffer layers of fluoride materials such as CaF_2 and SrF_2 between GaAs layer and the Si substrate are expected to be effective in solving this problem. It has been reported that good photoluminescence (PL) characteristics was observed from GaAs/CaF_2/Si structure grown by using surface modification technique by electron beam exposure[1], so called EBE-epitaxy method[2]. In this paper, stress relaxation in GaAs layer by the CaF_2 buffer layer is investigated and it is shown that this structure has potential to obtain stress-relaxed high-quality GaAs layers grown on Si substrates.

2. EXPERIMENTAL

The GaAs/CaF_2/Si structures were grown by using a MBE system composed of two growth chambers. Si(111) and Si(100) wafers were used for substrates. CaF_2 layers were grown at about 600°C on the substrate in the fluoride growth chamber, varying its thickness ranging from 0 to 700nm. For growths on (111) oriented substrates, EBE-epitaxy method[2] was employed. In this method, the surface of the CaF_2 was exposed to an electron beam under impingement by As_4 flux at about 550°C in the GaAs growth chamber, so as to improve wettability of GaAs on the CaF_2. This process was skipped in the case of growth on (100) oriented substrates because it is not effective on (100) surface. After that, GaAs layers were grown at 575°C for (111) growth, or at 450°C + 575°C two step growth for (100) growth[3]. The thickness of the GaAs layers was 1.5μm, and it was dope with Si($2\times10^{17}cm^{-3}$) in the top surface 0.5μm-thick region. A homoepitaxial GaAs(111)B sample with the same growth thickness and doping condition as those of the heteroepitaxial ones was also grown as a reference sample.

PL measurements were carried out at the temperatures ranging from 10K to 300K using a He refrigerator. The excitation source for PL was a 488nm Ar^+ laser with power of 200mW.

3. RESULTS AND DISCUSSION

3.1 Stress relaxation by CaF_2 layer.

Figure 1 shows a typical PL spectrum at 10K from the GaAs/CaF_2/Si(111) structure whose thickness of the CaF_2 layer is 300nm, compared with that from a reference homoepitaxial sample. The peak-a in this spectrum can be

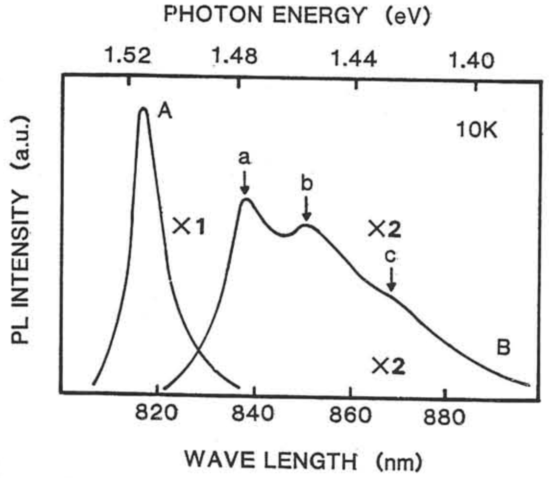

Fig. 1 PL spectra from GaAs layers at 10K.
A) Homoepitaxial layer grown on GaAs(111)B.
B) GaAs layer grown on CaF_2/Si(111) structure.

considered to be free to bound transition related to Si donors same as that observed on the homoepitaxial sample. The energy shift of the peak-a from the peak of the homoepitaxial sample shows that the GaAs layer on the CaF_2/Si has tensile stress which was also verified by another X-ray diffraction measurements. Thus, value of the energy shift is considered to be proportional to the tensile stress.

Figure 2 shows relation between the energy shift and thickness of the CaF_2 layer in the case of (111) oriented growth. It can be seen that the stress in the GaAs layer is reduced as the CaF_2 layer becomes thicker. The stress was reduced to about 60% of that in the direct growth (without CaF_2 layer) case. This result shows that the CaF_2 layer can relaxes the stress in the GaAs layer.

Dotted line in Fig. 2 shows calculated value under assumption that the thermal stress due to temperature difference between growth temperature and RT is decided only by elastic deformation of the 3-layer structure. It is apparent that the calculated result is far from the experimental result. The result that effect of elastic deformation is negligibly small can be understood because thickness of GaAs and CaF_2 layer are much thinner than that of Si substrate, in spite of large thermal expansion coefficient of CaF_2 (18×10^{6}deg.$^{-1}$). Thus, it can be said that dominant factor of the stress relaxation in the GaAs layers is not elastic but plastic deformation, and that the plastic deformation appeared in Fig. 2 occurs in the CaF_2 layer.

3.2 Stress relaxation effect depending on substrate orientation.

It was found that the stress relaxation effect was strongly depend on the substrate orientation. Figure 3 shows a comparison between (111) and (100) orientations. Energy shift is independent on the thickness of CaF_2 layer in the case of growths on (100) substrates. It can be said from the result that insertion of a CaF_2 layer is not effective on the (100) oriented growth. It must be noticed that the absolute value of stress cannot compare between (111) and (100) since pressure coefficients are different between these orientations.

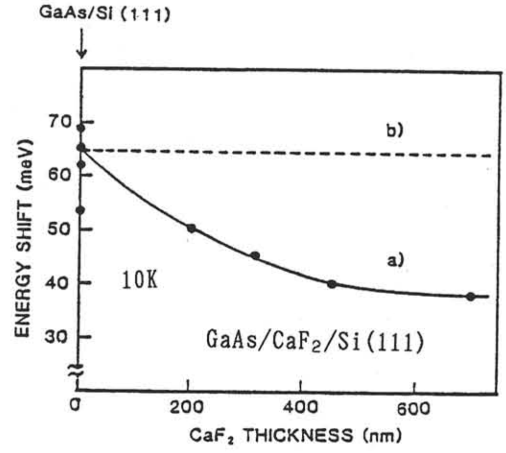

Fig. 2 Relation between peak energy shift of $GaAs/CaF_2$/Si(111) structure and thickness of the CaF_2 layer. Curve a) shows the measured value and curve b) shows calculated value considering only elastic deformation of the structure.

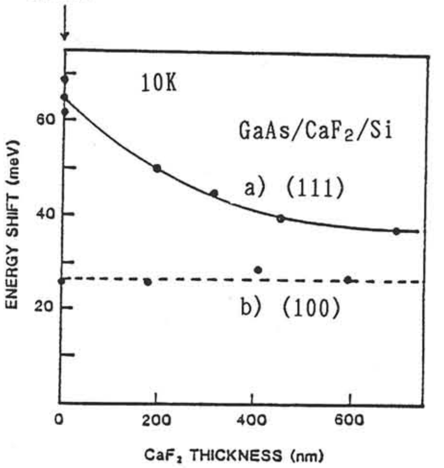

Fig. 3 Relation between peak energy shift of $GaAs/CaF_2$/Si(111) structure and thickness of the CaF_2 layer. Curve a) shows measured value for the growth on (111) orientation and curve b) shows that for the growth on (100) orientation.

3.3 Temperature dependence of the stress in GaAs.

Relation between the value of energy shift and measurement temperature are shown in Fig.4(a) for the sample of $GaAs/CaF_2/Si$ and that of GaAs/Si whose substrates were (111) oriented. The energy shifts are decrease as temperature becomes higher. From these plots, the characteristic temperatures, T_1 for the sample having CaF_2 layer and T_2 for that without CaF_2 layer, at which the energy shift becomes zero can be estimated by extraporation of these plots. It can be considered that the stress in GaAs layer becomes zero at these temperature for each sample.

Both T_1 and T_2 are much lower than the growth temperature, T_G. It can be reasonably assumed that the stress in GaAs layer is also negligibly small at T_G since lattice mismatch between GaAs and CaF_2 would be almost fully relaxed by dislocations during the growth. Thus, the stress in GaAs layer is considered to be changed depending on temperature regions as follows: As the temperature falls from T_G to T_1 or T_2, the tensile stress which would be caused by the thermal expansion difference is relaxed by plastic deformation. When the temperature falls below these temperatures, this type relaxation is practically frozen so that the tensile stress due to elastic deformation begins to be caused in GaAs layer. The fact that T_1 is lower than T_2 results in the stress relaxation effect by CaF_2 layer in (111) orientation.

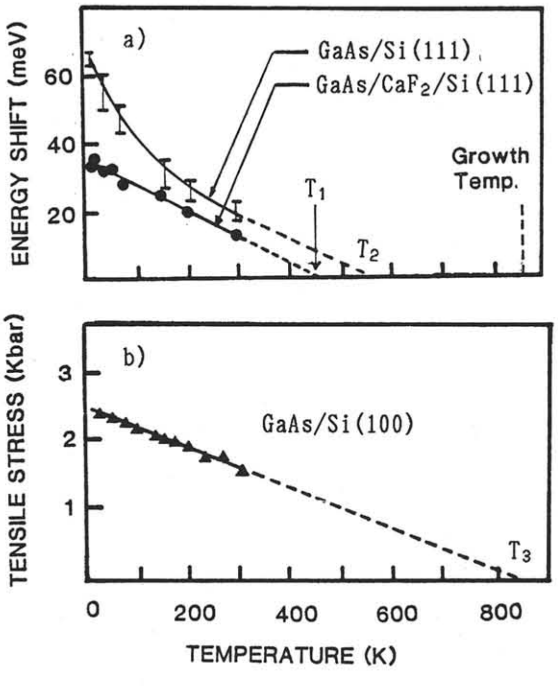

Fig.4 a) Temperature dependence of the peak energy shift of the $GaAs/CaF_2/Si(111)$ structure and GaAs/Si(111) structure.
b) Reported result of relation between temperature and stress in GaAs/Si(100) structure[4].

A similar result reported for the case of GaAs/Si grown on not (111) but (100) substrate[4] is shown in Fig.4(b). The characteristic temperature, T_3, can be evaluated in the same manner as shown in Fig.4(a) though the vertical axis indicates stress in Fig.4(b). The fact that T_2 is lower than T_3 indicates that dominant plastic deformation occurs easily for growth on (111) face rather than that on (100) face.

4. CONCLUSION

CaF_2 buffer layer was found to be effective to relax the thermal stress in GaAs layer grown on Si substrate. This effect was apparently observed in the case of growth on (111) rather than that on (100) substrate. Thus GaAs/fluoride/Si(111) structures is a candidate of stress-free GaAs on Si, and it will be possible to obtain high quality GaAs on Si provided that growth condition and structure, such as use of $Ca_xSr_{1-x}F_2$ in order to lattce-match, are optimized.

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