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Stress Relaxation of GaAs on Si by Laser Pulse Irradiation

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This paper describes the stress relaxation of GaAs on Si with GaSb intermediate layer by YAG (Yttrium Aluminum Garnet) laser pulse irradiation. The effects of the intermediate layer structure, number of laser shot and the size of sample on the stress relaxation of GaAs on Si are discussed in detail. The stress of GaAs on Si is not changed when the sample size is large than the laser beam. On the other hand, the stress is relaxed when the size is smaller than the laser beam. The stress of GaAs on Si with 10 laser shots is about one-fourth of that before the laser pulse irradiation.

1.INTRODUCTION

The fabrication of lasers on Si substrate has been studied in recent years because this technology is very promising in the realization of optoelectronic integrated circuits (OEIC's). Although room-temperature continuous wave operation of AlGaAs/GaAs laser has been fabricated on Si substrate, the lifetime of laser is far from satisfaction.[1)] This is due to the stress and the high dislocation density in the GaAs layer. The stress and dislocation are caused by the differences of thermal expansion coefficients and the lattice constants between GaAs and Si.

The dislocation density has been lowered by the use of strained layer superlattice and/or thermal cycle annealing.[2)] However, there remain problems concerned with thermal stress. It has been reported that the stress in GaAs on Si is about 10^9dyn/cm^2 [3)] and that the stress in the epitaxial layer can be an origin of high dislocation density.[4)] Although low-temperature growth and selective growth have been investigated in order to reduce the stress of GaAs on Si, there remain problems for the device application. This paper describes the novel method to relax the stress of GaAs on Si by using laser pulse irradiation. The intermediate layer structure and the laser were chosen so that only the intermediate layer can be excited by the laser pulse.[5)]

2.EXPERIMENTAL

GaAs layer was grown on Si substrate using GaSb intermediate layer by molecular beam epitaxy (MBE) and metalorganic chemical vapor deposition (MOCVD). The orientation of Si substrate is (001) 4° tilted toward [110] direction. 30nm-thick GaAs nucleation layer, 0.3μm-thick GaSb intermediate layer, 0.6μm-thick GaAs layer and 1.1μm-thick GaAs layer were grown by MBE. The sources for Ga, As and Sb were pure metals. The growth temperature was 380°C, 550°C, 500°C and 550°C, respectively. The top 2.0μm-thick GaAs layer was grown by MOCVD. The source gases for Ga and As were trimethylgallium and AsH_3, respectively. The growth temperature was 750°C. The structure of samples is shown in Fig. 1. GaAs was directly grown on Si and evaluated for comparison.

The excitation of the intermediate GaSb layer was performed by the YAG (Yttrium Aluminum Garnet) laser pulse irradiation from the surface after taking out the sample from MOCVD reactor. The YAG laser is transparent to GaAs, and only the GaSb layer is excited. Since the band-gap energy

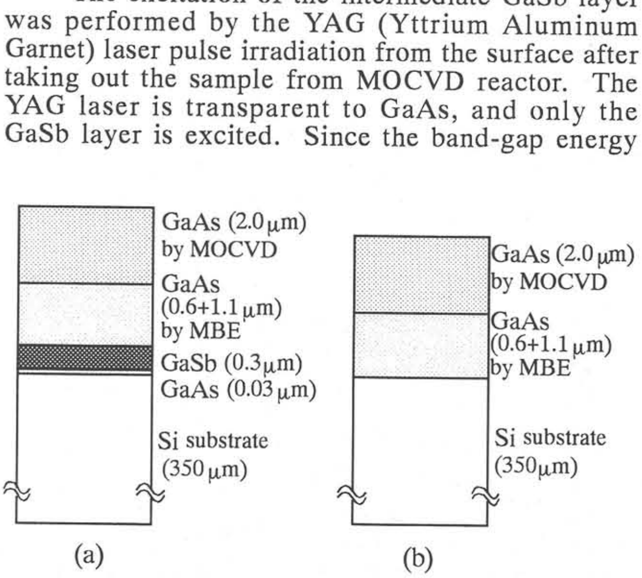

Fig. 1 Structure of GaAs on Si substrate with GaSb intermediate layer (a) and without GaSb intermediate layer (b).

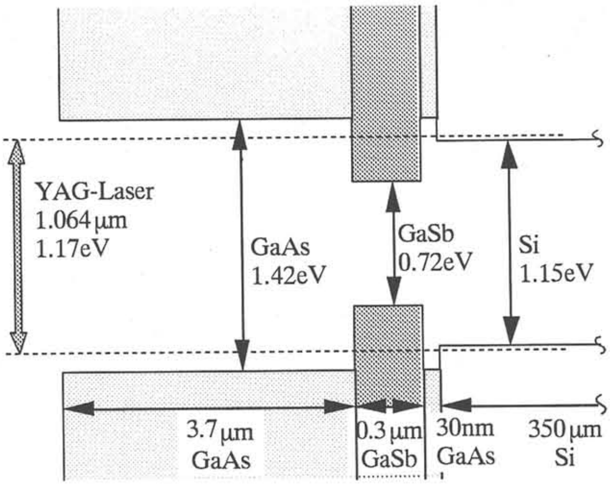

Fig. 2 Band gap energy of intermediate layer and YAG laser photon energy

values of GaAs and GaSb are 1.42eV and 0.72eV, respectively, the YAG laser with the wavelength of 1.064μm (the photon energy is 1.17eV) can satisfy these conditions. The band-gap energy values and photon energy are shown in Fig. 2. The laser pulse irradiation conditions are as follows. The laser pulse energy is about 40mJ/pulse, the repetition rate is 1pulse/second and laser pulse width is about 140ps. The area of laser beam is $14mm^2$. The number of laser shots was varied in this experiment. Two kinds of samples were examined. One is the sample whose size is small than the laser beam and the other is the sample whose size is large than the laser beam.

The stress of GaAs on Si was measured by photoluminescence (PL) at 77K using the Ar ion laser.

3.RESULTS AND DISCUSSION

The PL peak energy of GaAs on Si with and without GaSb is shifted toward the long wavelength side because of the tensile stress caused by the thermal expansion mismatch. The stress is about 1.8×10^9 dyn/cm^2. First, the samples larger than the laser beam were examined with changing the number of shot from 0 to 10. But PL peak energy was not changed. Next, small samples were examined. The PL peak energy shifted toward the short wavelength side by the 10-shot laser pulse irradiation. The PL peak wavelength of GaAs on Si with various structure before and after laser pulse irradiation (10 shots) is shown in Table I.

There are two possible reasons to explain the shift of PL peak energy by the laser pulse irradiation. One is the change of carrier concentration and the other is the change of stress. If the PL peak is varied by the carrier concentration, the PL peak shift should also be observed in the case of large samples. However, the PL peak energy does not change by the laser pulse irradiation in the case the sample size is the large than that of laser beam. Therefore, it is deduced

Table 1 PL peak wavelength at 77K

	Before irradiation	After irradiation (10shots)
GaAs/Si	837.4(nm)	833.6(nm)
GaAs/GaSb/Si (small)	837.6(nm)	827.4(nm)
GaAs/GaSb/Si (large)	837.5(nm)	837.6(nm)
GaAs/GaAs	823.2(nm)	-----

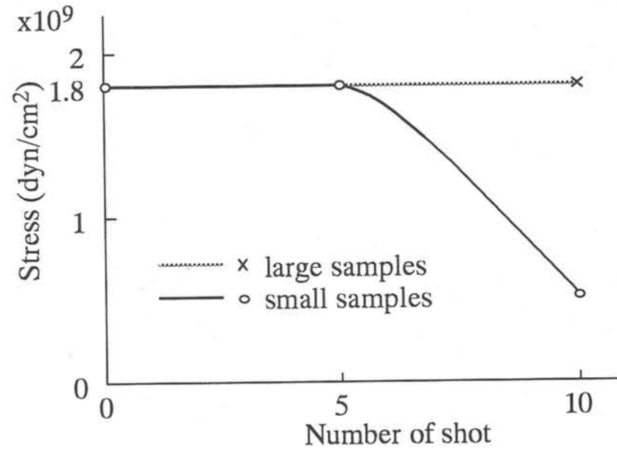

Fig. 3 Stress of GaAs on Si as a function of number of laser shots

that it is due to the reduction of stress. Figure 3 shows the stress of GaAs on Si with GaSb intermediate layer calculated by the PL peak wavelength shift as a function of number of shot. The stress is not changed at 5 shots, however, the drastic stress relaxation is observed at 10 shots when the sample size is small than the laser beam. The stress of GaAs on Si with 10 shots is about one-fourth of that before laser pulse irradiation.

Figure 4 shows the schematic illustration of the stress relaxation model. The tensile stress applied to the GaAs layer due to the thermal expansion mismatch decreases by the laser pulse irradiation when the laser beam is larger than the sample.

The reason why the stress in GaAs on Si with GaSb intermediate layer is relaxed by laser pulse irradiation is not understood well at present. But it can be said that the GaSb intermediate layer plays an important role in stress relaxation. Two reasons are considered for the stress relaxation. One is the generation of a high density of electron-hole pairs in the GaSb layer. When the density of electron-hole pairs in the GaSb layer is increased, it seems that bonds connecting GaAs and Si are cut and strength of connections becomes weak. The other reason is that only GaSb layer was melted by laser pulse irradiation. The melting points of GaAs, GaSb and Si are 1238°C, 712°C and 1415°C,

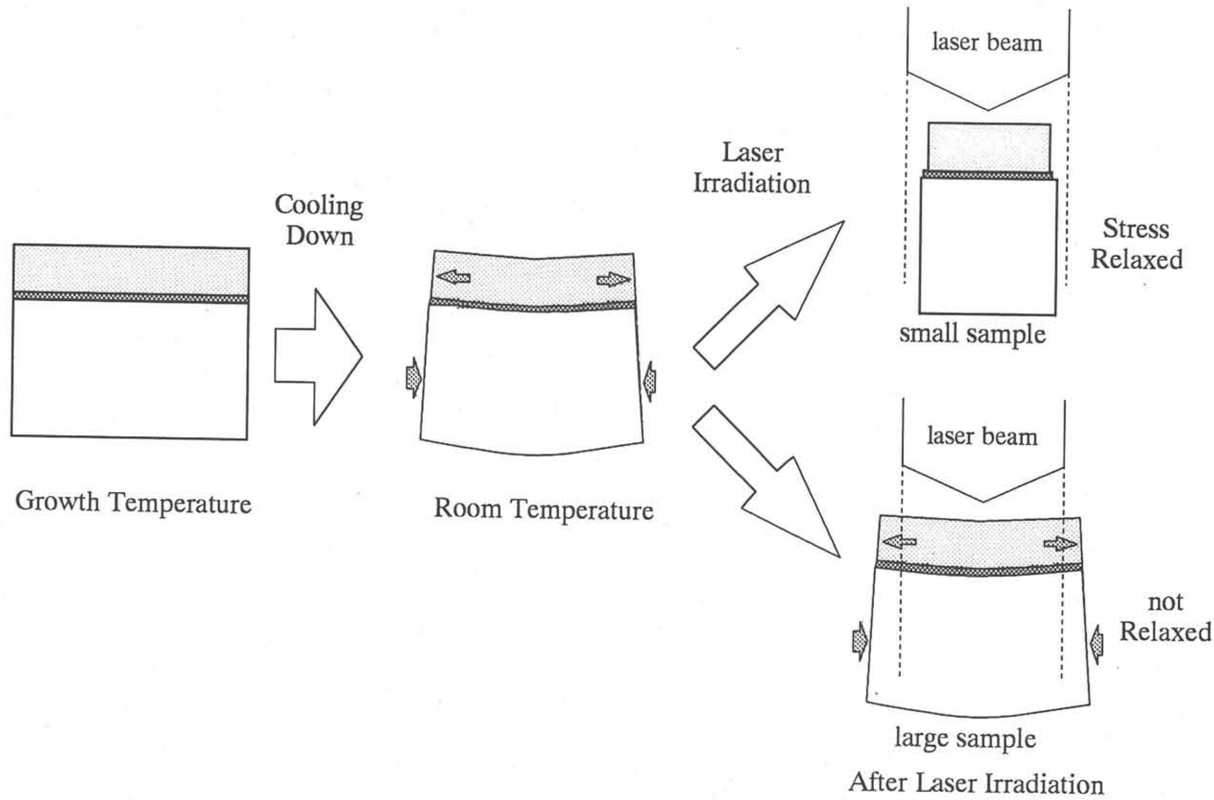

Fig. 4 Schematic illustration of mechanism for stress relaxation

respectively. The melting point of GaSb is much lower than that of GaAs or Si. Therefore it is reasonable that only the GaSb layer is melted, while the GaAs layer is not. It would be necessary to shorten the laser pulse width and increase the peak power, taking care that heat generated at GaSb layer is not transferred towards the GaAs layer.

When the laser beam is smaller than the sample, the region where the laser pulse is not irradiated is rigidly connected between GaAs and Si. Therefore, the stress cannot be relaxed. It results in the constant stress value after the laser pulse irradiation.

4.CONCLUSION

The stress relaxation was observed in GaAs on Si with GaSb intermediate layer by the YAG laser pulse irradiation when the sample size is smaller than the laser beam. On the other hand, the stress was not changed after the laser pulse irradiation when the sample size is large than the beam size. The stress of GaAs on Si with 10 shots is about one-fourth of that before laser pulse irradiation.

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