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Degradation Mechanism and Dislocation Dynamics in GaAs Light Emitters Grown on Si Substrate

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Dislocation dynamics is observed by photoluminescence image, and those that are seen in UCGAS (undercut GaAs on Si), planar GaAs on Si, and in homoepitaxial GaAs are compared. Dislocation's motion is much reduced in the UCGAS, since stress and dislocation density are relaxed. The relation between dislocation's motion and LED lifetime is discused.

1. INTRODUCTION

GaAs on Si technology is attractive for an advanced opto-electronic integrated circuit. However, GaAs light emitters that were fabricated on Si so far degraded rapidly due to large residual stress and high dislocation density. We have proposed UCGAS (undercut GaAs on Si) structure to reduce stress and dislocation density down to less than 2×10^8 dyn/cm^2 and to less than 5×10^5 cm^{-2}, respectively.[1,2] In this paper, dynamic motion of dislocations in planar GaAs on Si with large stress, stress-released-UCGAS and in the homoepitaxial GaAs are compared for the first time. LED performances are also discussed in conjunction with the dislocation dynamics.

2. EXPERIMENTAL

UCGAS structure was fabricated as follows. 2-μm-thick-GaAs and 1-μm-thick-$Al_{0.65}Ga_{0.35}As$ were grown on (100) 4° off Si and on (100) GaAs substrates by MOCVD (metalorganic chemical vapor deposition). GaAs and AlGaAs layers were vertically etched to the substrate, and then AlGaAs was selectively etched in lateral direction by 80 μm. In some samples, 1-μm-thick-GaAs and SLS (strained layer superlattice) with proper number and thickness were grown on the fabricated UCGAS to control dislocation density. The surface GaAs layers were doped with Si to 10^{17}-10^{18} cm^{-3} to obtain clear PL (photoluminescence) image at room temperature. The same structures were fabricated both on Si (UCGAS) and on GaAs (UC on GaAs) substrates, but no SLS was grown in the latter. The fabricated structure and the thickness are shown in Fig.1. The residual stress in the UCGAS and in the planar GaAs on Si are less than 2×10^8 dyn/cm^2 and 2×10^9 dyn/cm^2, respectively[3].

An Ar-ion laser beam was focused to an ellipsoidal shape of 30×60 μm^2 on the sample surface to measure PLI (PL image) at room temperature. The image was observed by a 2400 times microscope and an infrared TV camera using shorter-wavelength-cut (720 nm) optical filter. The power density of an Ar-ion laser on the sample surface was changed from 2 to 10 kW/cm^2. The temperature on the sample surface during PLI measurement is estimated by measuring PL intensity as a function of laser power and comparing it with the calibrated PL intensity versus temperature curve. The temperature is functions of irradiation power and thermal resistance of the sample. The ratio of the thermal resistance measured by other experiment is approximately (planar GaAs on Si) :

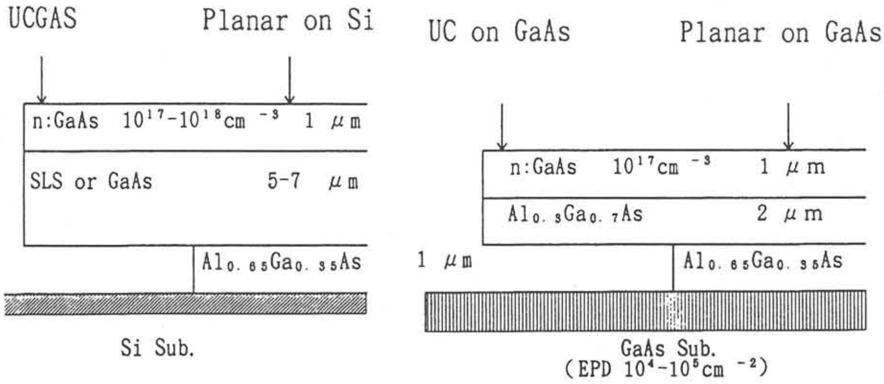

Fig.1 Sample structure used in the PLI measurement.

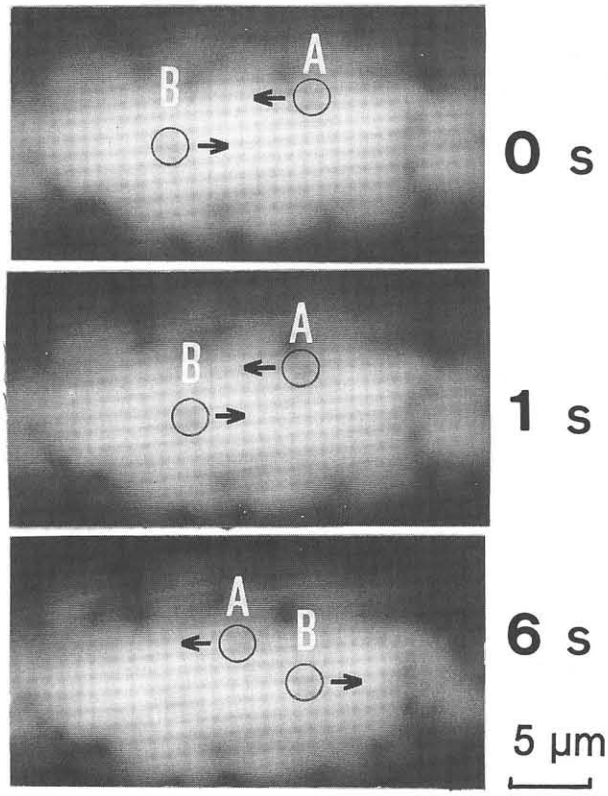

Fig.2 Dark spots in planar GaAs on Si measured by PLI. The spots marked A and B are moving parallel in the opposite directions.

(UCGAS) : (planar GaAs on GaAs) : (UC on GaAs)= 1 : 2 : 2 : 10.

3. RESULTS AND DISCUSSION

Some of the dark spots (DS) in the PLI was found to move under laser irradiation as shown in Fig.2 for planar GaAs on Si. The DSs marked A and B are moving parallel in the opposite directions. Some of them were merged in the fixed DS and stopped to move,

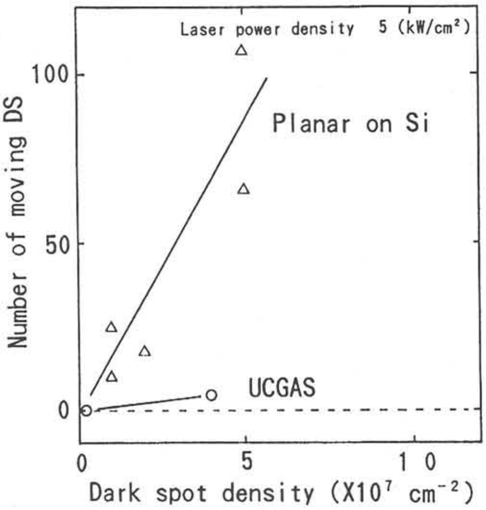

Fig.3 Number of moving DS as a function of DS density.

and the others went out from the sample edge. Two DSs moving perpendicular with each other crossed without any interaction. The DS started to move just after the irradiation, and the number and the speed of moving DS were large and high, respectively, in the first 2 s. They then decreased with time, and no DS moved any more after 30 s. The number of moving DS in the first 2 s increased with increasing laser power, however, the total number of DS that moved was independent on the laser power.

All DSs move parallel either to $[0\bar{1}1]$ or $[0\bar{1}\bar{1}]$. 70-80 % of them are parallel to $[0\bar{1}\bar{1}]$ direction which is perpendicular to the substrate off direction. GaAs on Si has its own special wave-like surface morphology. DS motion also seems to be influenced by the wavy pattern.

The total number of moving DS is shown in Fig.3 as a function of the DS density in the UCGAS and in the planar GaAs on Si. The number of moving DS in the planar GaAs on Si increases much faster than that in the UCGAS with increasing DS density. Velocity of moving DS increases with increasing laser power as shown in Fig.4. The velocity in the UCGAS is slower than that in the planar GaAs on Si.

The observation on dynamic motion of DSs are summarized in Table I. The residual stress is measured by the PL spectrum at 55 K, and is high only in the planar GaAs on Si. In addition to this residual stress, Ar-laser-induced stress is also applied on the sample surface during PLI measurement due to ununiform heating of the sample. This stress must be high when sample heating is high. The estimated temperature when laser power density is 10 kW/cm^2 is shown in Table I.

The estimated temperature of UC on GaAs is as high as 500 °C which is also verified by the fact that the sample surface is deteriorated after laser beam irradiation. Although no DS is observed on the virgin sample, DSs or DLs (dark lines) are nucleated by the laser irradiation. On the other hand, neither DS nor DL is found on the planar GaAs on GaAs substrate even after irradiation.

DS movement is observed both in the UCGAS and in the planar GaAs on Si, although the number is much less in the former and the residual stress in the former is low. According to the previous experiment on dislocation motion, temperature higher than 400 °C and the stress higher than 1 x 10^8 dyn/cm^2 are necessary to obtain the dislocation velocity faster than 1 $\mu m/s$.[4] However, the estimated temperature during laser irradiation is around 100 °C, and the stress in the UCGAS is low. This implies that the energy released through non-radiative recombination is directly transferred to the crystal lattice to cut their bond. Therefore, the total energy released to the lattice increases with increasing DS density. Although macroscopic stress measured by the PL spectrum is low in the UCGAS, the stress near or in the DS must be large, since the lattice is deformed in DS. In addition to this local deformation in DS, planar GaAs on Si contains fairly high macroscopic stress which increases the dislocation motion.

These observations are consistent with operation lifetime of the LED (light-emitting diode). The UCGAS LED lasts more than 3000 h, while the planar LED degrades quickly in a first few tens of hour. LED degradation rate is also functions of stress and original dislocation density. The reduction of both of them suppresses DS motion and improves LED lifetime.

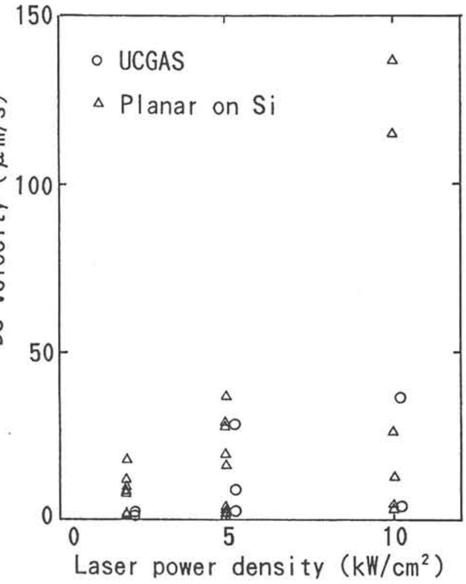

Fig.4 DS velocity as a function of excitation laser power.

Table 1 Summary of PLI observations.

	ON GaAs		ON Si	
	UC on GaAs	Planar	UCGAS	Planar
Residual stress (dyn/cm^2)	≅ 0	≅ 0	< 2 x 10^8	≅ 3 x 10^9
Temperature at 10 KW $/cm^2$ (°C)	> 500	≅100	135	81
Comments on DS motion	nucleation of DS & DL	No DS,DL	Few DS	Many DS

4. CONCLUSION

Dynamics of dislocation is observed by PLI, and it is related to the residual stress and the dislocation density. The residual stress and the energy released at the DS play key role both in enhancing DS motion and the LED degradation. Residual stress and the dislocation density have to be reduced to improve LED lifetime.

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