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Application of Plasma-Assisted Epitaxial GaSb to Photoelectronic Divices

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As the first application of plasma-assisted epitaxial GaSb to photoelectronic devices, p-GaSb/n-GaAs heterojunction photodiodes were fabricated by growing epitaxial $GaSb_2$ directly on (100)GaAs. The backward current densities were 5.7×10^{-6} and 8.7×10^{-4} A/cm^2 at 4V, for GaAs with electron density of 4.2×10^{15} and 2.8×10^{17} cm^{-3}, respectively, which are drastically reduced compared with those of GaSb Schottky diodes. Photoresponse in the wavelength region between 0.85 and 1.7μm was obtained for the light incident from the GaAs substrate.

§1. Introduction

One of the important aspects in epitaxial growth of semiconductor crystals is a low temperature growth process for the fabrication of controlled device structures. Plasma-assisted epitaxy(PAE) has been intended for epitaxial growth at low substrate temperatures by giving high chemical reactivity and enhanced atomic migration on the growing surface of a crystal with the help of plasma.[1] This low-temperature epitaxial-growth process has been successfully applied to grow GaSb epitaxial layers on (100)GaAs as well as on (100)GaSb at relatively low substrate temperatures between 340 and 440°C.[2),3)]

GaSb is one of the promising materials for the application to optoelectronic devices which operate in the infrared wavelength region near 1.5μm because of its suitable band gap width of 0.7eV and its direct band gap structure. GaSb p-n homojunction photodetectors, however, show large backward dark current, which is likely to flow through the p-inverted surface of n-GaSb.[4)] Therefore a new diode structure is required to cut off this leakage current path along the surface.

The purpose of this paper is describe firstly the electrical and optical properties of PAE GaSb grown on semi-insulating (100)GaAs in hydrogen plasma, and secondly the electrical characteristics and photoresponses of p-GaSb/n-GaAs heterojunction photodiodes which can cut off the surface leakage path due to the near-intrinsic nature of n-GaAs surface. The PAE GaSb grown directly on (100)GaAs at low temperatures is considered to be useful for the optoelectronic IC in 1.5μm wavelength region, monolithically combined with high speed GaAs FET's on the same GaAs substrate.

§2. Properties of PAE-GaSb

An experimental PAE apparatus and epitaxial growth processes have already been described in ref. 2 with several favourable effects of hydrogen plasma. Undoped GaSb layers deposited in hydrogen plasma showed p-type conduction. Hole concentrations and Hall mobilities of undoped GaSb layers deposited at a substrate temperature of 410°C are about $6\times10^{16}cm^{-3}$ and $750cm^2/Vsec$, respectively which are comparable to those obtained by other methods like MBE, MOCVD, etc, in spite of a lower substrate temperature in PAE, as shown in Fig. 1.[2)]

It was found that the applied plasma power should be optimized to obtain the highest mobility at each substrate temperature and that it shifts to higher values as the growth temperature is decreased.[2)] Photoluminescence measurement also indicated that it should be optimized to remarkably enhance the luminesent intensity near edge emission, as shown in Fig.2.

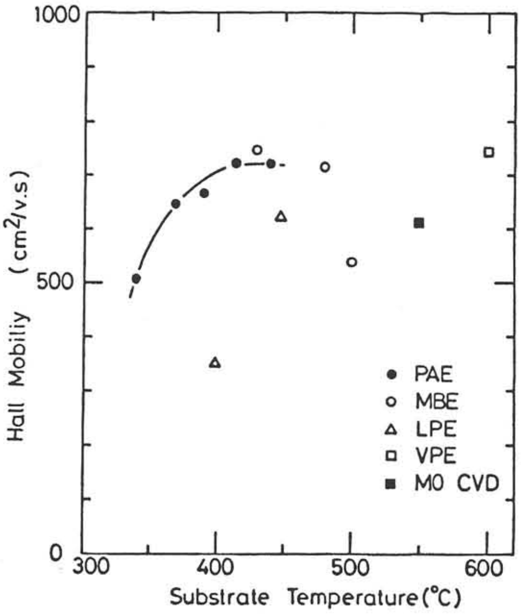
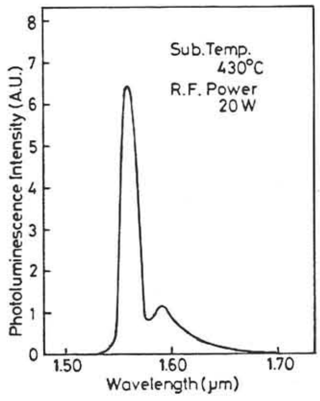
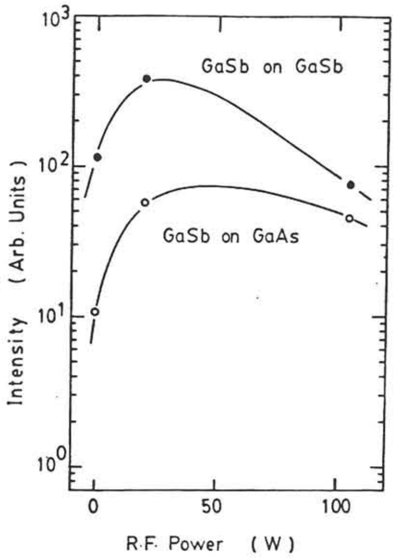


Fig. 1. Hall mobilities of undoped p-GaSb films deposited by PAE in comparison with those by other methods as a function of substrate temperatures.



(a)



(b)

Fig. 2. (a) Photoluminescence spectrum of a GaSb films deposited by PAE
(b) Maximum luminescent intensity in GaSb layers deposited on (100)GaSb and (100) GaAs as a function of plasma power.

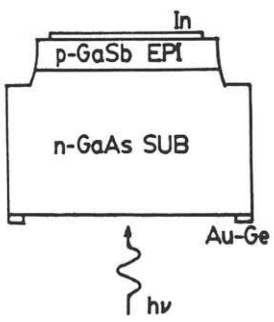


Fig. 3. Device structure of p-GaSb/n-GaAs heterojunction photodiodes.

§3. p-GaSb/n-GaAs heterojunction photodetector

p-GaSb/n-GaAs heterojunction photodiodes were fabricated by growing undoped PAE GaSb directly on n-type (100)GaAs, the device structure of which is shown in Fig. 3. The PAE GaSb on n-GaAs was mesa-etched and metalized using In metal. A ring-shaped ohmic contact was provided to n-GaAs substrate with Au-Ge by using usual photolithographic technique. No anti-reflection coating was prepared.

Table 1. Thicknesses and carrier concentrations of p-GaSb layers and n-GaAs substrate.

Sample No.	n-GaAs Substrate		p-GaSb Epi.Layer	
	Thickness (μm)	Carrier Conc. (cm^{-3})	Thickness (μm)	Carrier Conc. (cm^{-3})
A-15	352	$4.2x10^{15}$	1.06	$4.1x10^{16}$
A-17	345	$2.8x10^{17}$	1.06	$4.1x10^{16}$
B-17	345	$2.8x10^{17}$	1.30	$5.73x10^{16}$
H-18	(n-GaSb)	$1.7x10^{18}$	(LPE)	$7.0x10^{16}$

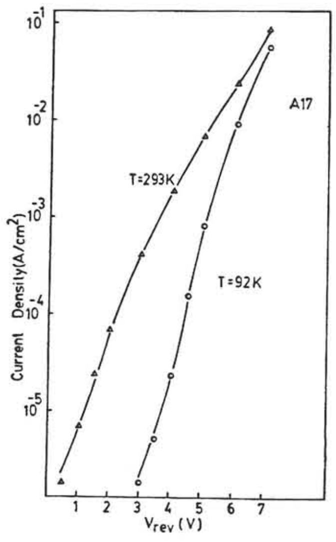


Fig. 4. Forward current-voltage characteristics of samples A-15 and A-17 .

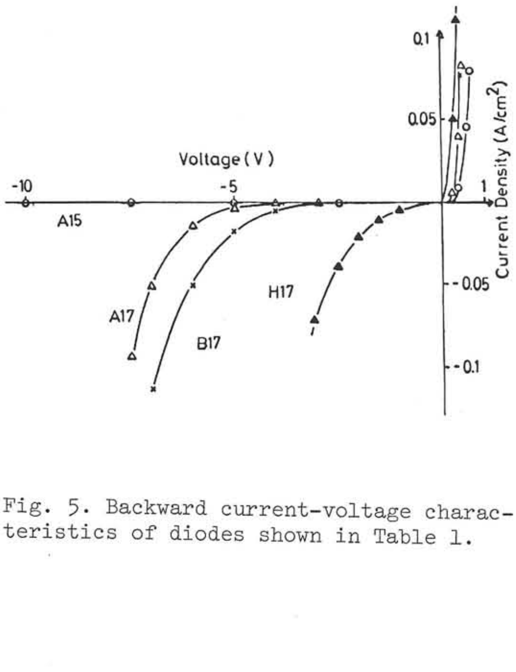


Fig. 5. Backward current-voltage characteristics of diodes shown in Table 1.

Table 1 shows thicknesses and carrier concentrations of p-GaSb layers and n-GaAs substrates in these heterojunction photodiodes. A-15 and A-17 used the p-GaSb layer deposited at the same time. A-17 and B-17 used the same n-GaAs substrate. H-18 is a typical example of GaSb p-n homojunction photodiode fabricated using LPE p-GaSb on n-GaSb substrate.

Fig. 4 shows the forward current-voltage characteristics of samples A-15 and A-17. The n-values in the forward current-voltage characteristics are 1.08 and 1.18 on GaAs with carrier concentration of $4.2x10^{15}$ and $2.8x10^{17}cm^{-3}$, respectively, in spite of the relatively large lattice-mismatch of about 8% between GaSb and GaAs.

Fig. 5 compares the backward current-voltage characteristics of diodes shown in Table 1 at room temperature. The backward current densities were $8.7x10^{-4}$ and $5.7x10^{-6}A/cm^2$ at 4V, respectively for n-GaAs with electron density of $2.8x10^{17}$ and $4.2x10^{15}cm^{-3}$, which are drastically reduced comparing with $2.6x10^{-1}A/cm^2$ of a GaSb homojunction fabricated by LPE, as shown in Table 2. In these p-GaSb/n-GaAs heterodiodes a guard-ring structure is automatically attained owing to the p^+-surface layer of p-GaSb and the near-intrinsic nature of n-GaAs surface.

Fig. 6 shows the external quantum efficiency of sample A-17 at various bias voltages. Photoresponce in the wavelength region between 0.85 and 1.7μm was obtained for the light incident from the GaAs substrate.

Table 2. Comparison with backward current densities of sample A-15, A-17 and H-18.

Sample	Reverse Current Density (at V_{rev}=4V)
n-GaSb/p-GaSb Homo Junction	2.6×10^{-1} (A/cm^2)
n-GaAs/p-GaSb Hetero Junction (A17)	8.7×10^{-4} (A/cm^2)
n-GaAs/p-GaSb Hetero Junction (A15)	5.7×10^{-6} (A/cm^2)

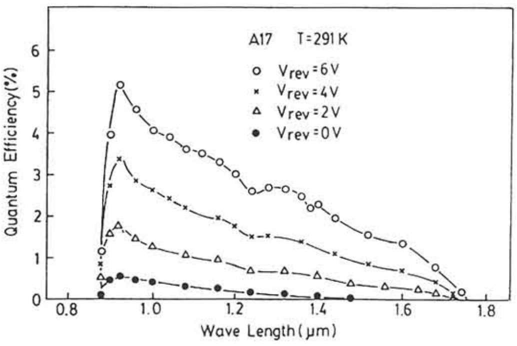


Fig. 6. External quantum efficiency of sample A-17 at various bias voltages.

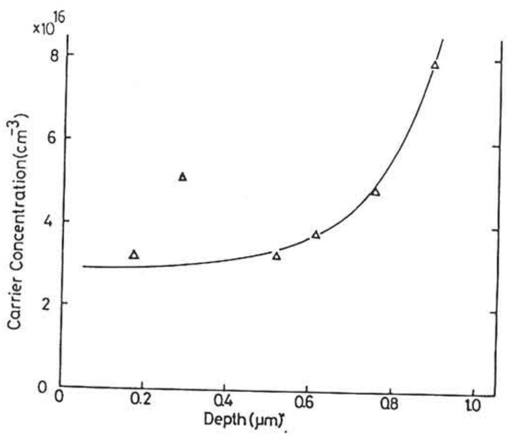


Fig. 7. Bias dependency of quantum efficiency of sample A-17.

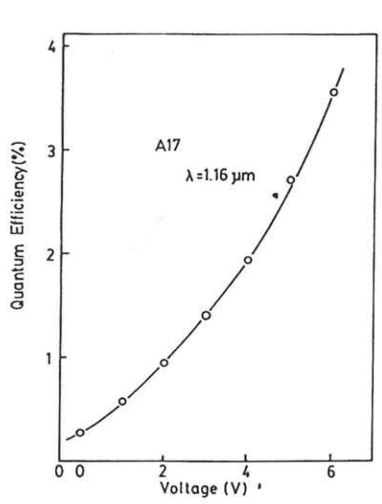


Fig. 8. Depth profile of carrier concentration of sample A-15 and A-17.

The bias dependency of quantum efficiency is shown in Fig.7. This seems to show that the depletion region width was not broad enough to collect sufficient number of photo-carriers.

In order to estimate the width of depletion region differential van der Pauw method was used. The depth profile of carrier concentration of sample A-15 and A-17 is shown in Fig.8, which shows that the carrier concentration increases toward the interface of GaSb and GaAs. This tendency is probably due to the large lattice-mismatch of about 8% between GaSb and GaAs. It will, however, be possible to increase quantum efficiency by using a buffer layer between GaAs and GaSb, such as a graded composition layer.

§4. Conclusion

Low temperature epitaxial growth of GaSb with carrier density of $4x10^{16}cm^{-3}$ and hole mobility of $750cm^2/Vsec$ has been achieved by plasma-assisted epitaxy in hydrogen plasma at substrate temperatures around 400°C. As the first application of PAE GaSb tc photoelectronic devices p-GaSb/n-GaAs photodiodes were fabricated by growing epitaxial GaSb directly on (100)GaAs. It is found that the backward dark current can be drastically reduced, compared with that of a GaSb homojunctions and can make excessive compensation for rather low quantum efficiency obtained so far..
The present PAE technology and the heterodiode structure is considered to be useful for the opto-electronic IC in 1.5μm wavelength region, monolithically combined with high-speed GaAs FET's on the same GaAs substrate.

Reference

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2) Y. Sato, K. Matsushita, T. Hariu and Y. Shibata Appl. Phys. Lett. 44, 592 (1984).
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4) Y. Nagao, T. Hariu and Y. Shibata, IEEE Trans. Electron Devices ED-28, 407 (1981).