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Piezoresistance Effect in n-Type and p-Type $Al_{0.3}Ga_{0.7}As$/GaAs Selectively Doped Heterostructure

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Piezoresistance effect in n-type and p-type $Al_{0.3}Ga_{0.7}As$/GaAs selectively doped structures has been studied. It has been found that the maximum absolute value of the measured piezoresistance coefficient is $240\times10^{-12}cm^2/dyne$ and moreover the directional dependences of the coefficients are different compared with those of the bulk GaAs. This difference can be explained by considering the space charges induced by the piezoelectric displacement at the AlGaAs/GaAs heterointerface.

1. Introduction

GaAs can be easily made heterojunctions with AlGaAs and has wide band gap which is prefer for high temperature applications. So it is very interesting to consider the strain transducers of GaAs using piezoresistance effect as well as Si.[1] But there have been only a few studies of the piezoresistance effect in GaAs[2)3)] because of the crystallinity. Since several reliable epitaxial techniques have been developed in the last few years, it is time to study the posibility for the application of GaAs to the strain transducer.

In this paper, we measured the piezoresistance coefficients of n-type and p-type AlGaAs/GaAs selectively doped (n-SD and p-SD) heterostructures, and found the directional dependence of the piezoresistance coefficients. Its origin was also discussed.

2. Sample preparation and experimental

Selectively doped AlGaAs/GaAs heterostructures were grown on Cr,O-doped semi-insulating (100) GaAs substrates by molecular beam epitaxy (MBE). The growth conditions are shown in Table 1. The cross-sectional view of the grown layers is schematically shown in Fig. 1. The epitaxial layers consist of a 1μm thick undoped GaAs, an undoped $Al_{0.3}Ga_{0.7}As$ spacer layer with the thickness ranging from 10 to 200Å, a 500Å Si-doped (Be-doped) $Al_{0.3}Ga_{0.7}As$, a 500Å Si-doped (Be-doped) $Al_{0.3}Ga_{0.7}As$ and a 500Å Si-doped (Be-doped) GaAs. Si and Be were used as dopants for n-SD and p-SD structures, respectively. The doping density of Si was $2\times10^{18}cm^{-3}$ and Be was $1\times10^{18}cm^{-3}$. Using these wafers, the strain transducers which have the 2-dimentional electron or hole gas (2DEG or 2DHG) channels

Table 1 Growth conditions of MBE

system	V80H(VG semicon.)
V/III flux ratio	3
growth rate (GaAs)	1.0μm/hour
($Al_{0.3}Ga_{0.7}As$)	1.3μm/hour
substrate temperature	600°C

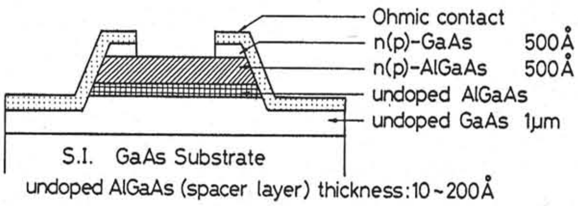


Fig.1 Cross-sectional view of the strain transducer

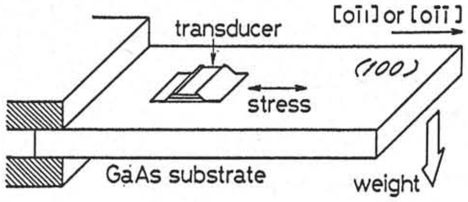


Fig.2 Illustration of the system for applying the tension (beam size is 8mm x 2mm)

were fabricated by usual photolithography method and chemical etching. The size of the transducer was 600μm in length and 50μm in width.

As shown in Fig. 2, the GaAs substrates which have the transducers on surface were cut into rectangle shapes where the longer sides were parallel to the [0$\bar{1}$1] or [0$\bar{1}\bar{1}$] direction. They were used as weighting beams for appling the tension on the transducers. One end of the beam was fixed and another was weighted.

The stress applied to the transducer by bending the beam is almost uniaxial along the beam, because the across stress is negligible.[4] The stress induced in the beam has a depth distribution from the surface. But in this configuration, only the surface tension is nescessary to be taken into account because the channel of the transducers is located on the very thin beam surface.

3. Results and discussion

We measured the relation between the tension and the relative change of the resistance of the transducer. In Fig. 3, the resistance changes as a function of tensions are shown for p-SD structure sample with the spacer layer of 100Å. The directions of tension are indicated by the crystallographic directions besides each curve and the directions of the transducers to the tension are indicated by the letter "l" or "t" (longitudinal or transversal). The resistance is increased by [0$\bar{1}$1] tension and decreased by [0$\bar{1}\bar{1}$] tension. The slope of the data is defined as a piezoresistance coefficient, π.

The resistance changes of the conventional epitaxial p-GaAs are also shown in Fig. 4. There is only a small difference of the resistance changes between [0$\bar{1}$1] and [0$\bar{1}\bar{1}$] tensions.

The resistance changes of p-SD structure are very different from those of p-GaAs. The resistance changes of p-SD structure are

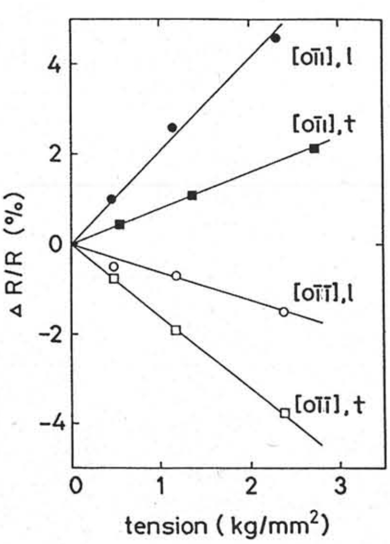


Fig.3 The relative resistance change of p-SD structure with the spacer layer of 100Å as a function of tension

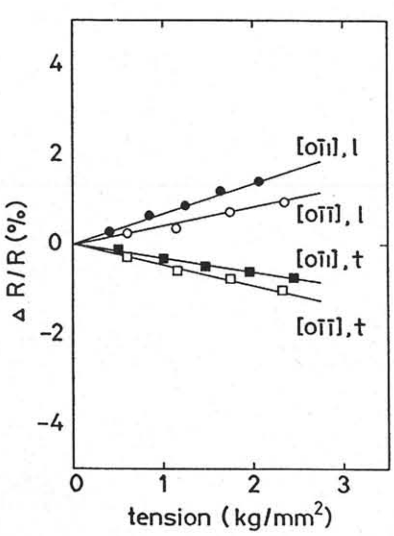


Fig.4 The relative resistance change of epitaxial p-GaAs

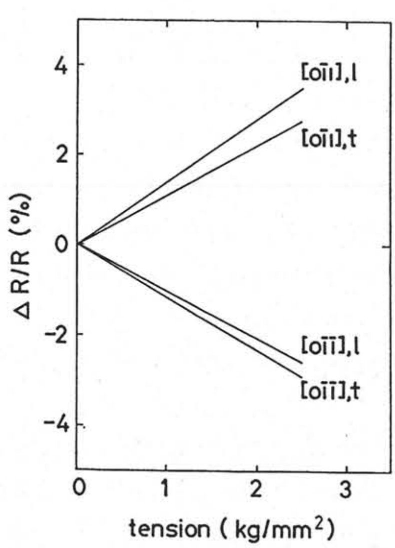


Fig.5 The result for subtracting the data in Fig.4 from the data in Fig.3

thought to be composed of the changes from the bulk GaAs effect and the changes from the heterostructure effect.

To extract the effect due to the heterostructure, the resistance changes of p-GaAs were subtracted from those of p-SD structure. The results are shown in Fig. 5. The direction of resistance changes is opposite, and depends on whether the tension is applied to the $[0\bar{1}1]$ or to the $[0\bar{1}\bar{1}]$

Here, we propose that this directional dependence can be understood from the directional dependence of piezoelectric effect. The piezoelectric effect in zincblende structure causes the [100] dielectric displacement by $[0\bar{1}1]$ tension, and the $[\bar{1}00]$ displacement by $[0\bar{1}\bar{1}]$ tension.[5] The piezoelectric coefficient of $Al_{0.3}Ga_{0.7}As$ is thought to be larger than that of GaAs.[6] As illustrated schematically in Fig. 6, the positive space charges by the piezoelectric displacement will be caused at the AlGaAs/GaAs heterointerface by $[0\bar{1}1]$ tension. These positive interface charges should decrease the 2DHG density, and the resistance will be increased. On the other hand, the negative space charges caused by $[0\bar{1}\bar{1}]$ tension will decrease the resistance. The absolute values of the resistance changes by $[0\bar{1}1]$ and $[0\bar{1}\bar{1}]$ tensions are almost the same and only the signs are opposite each other. These can be understood by the reasons of that the polarity of the piezoelectric charges is different by the direction of tension, but the density is the same. Since the direction of current flow along the transducer could not affect the piezoelectric charges, the resistance change is independent of the direction of the transducer. The charactoristics which can be explained with these speculations agree with the data in Fig. 5.

According to the discussion mentioned above, four piezoresistance coefficients, $\pi_l[0\bar{1}1]$, $\pi_t[0\bar{1}1]$, $\pi_l[0\bar{1}\bar{1}]$ and $\pi_t[0\bar{1}\bar{1}]$ which

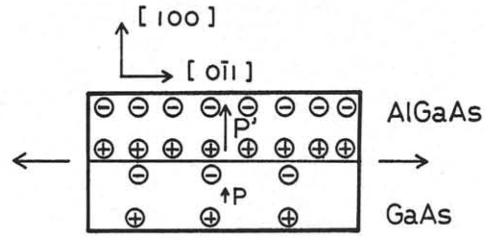


Fig.6 Illustration for the distribution of piezoelectric charges in selectively doped structure

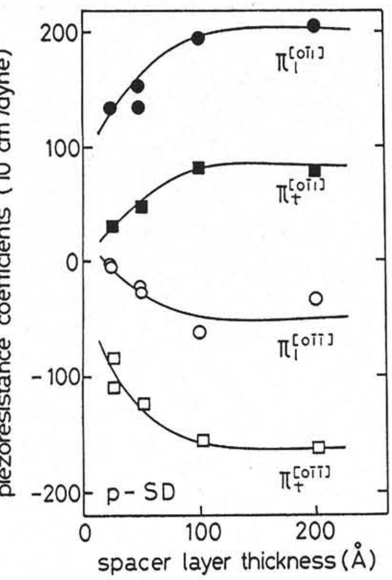
are defined as a slope of $\Delta R/R$ vs. tension curves shown in Fig. 3 and 4, can be expressed in the three variables, π_{PE}, π_1 and π_2 as eqs. 1 ~ 4.

$$\pi_l[0\bar{1}1] = \pi_{PE} + \pi_1 \quad (1)$$
$$\pi_l[0\bar{1}\bar{1}] = -\pi_{PE} + \pi_1 \quad (2)$$
$$\pi_t[0\bar{1}1] = \pi_{PE} + \pi_2 \quad (3)$$
$$\pi_t[0\bar{1}\bar{1}] = -\pi_{PE} + \pi_2 \quad (4)$$

where π_1 and π_2 are the piezoresistance coefficients corresponding to $\pi_l[0\bar{1}1]$ ($\pi_l[0\bar{1}\bar{1}]$) and $\pi_t[0\bar{1}1]$ ($\pi_t[0\bar{1}\bar{1}]$) in the bulk, respectively, and π_{PE} is that induced by the piezoelectric effect by $[0\bar{1}1]$ tension. π_{PE} can be understood to include the conversion efficiency from piezoelectric displacement to the change of the resistance.

To confirm the applicability of eqs. 1 ~ 4 to the heterostructure transducers, the piezoelectric coefficients of the several samples which have the different spacer layer thickness were measured, and π_{PE}, π_1 and π_2 values for each samples were calculated. The measured piezoresistance coefficients of p-SD and n-SD structures are shown in Fig. 7(a) and (b). These four piezoresistance coefficients can be successfuly expressed by three independent parameters π_{PE}, π_1 and π_2 shown in Table 2 with errors less than $10\times10^{-12}cm^2/dyne$.

From the data shown in Table 2, we can get the followings: (1) The signs of π_{PE} are different between p-SD and n-SD structures, and the values are changed with the spacer layer thickness. These differences are understood as the differences of the carrier

a) 

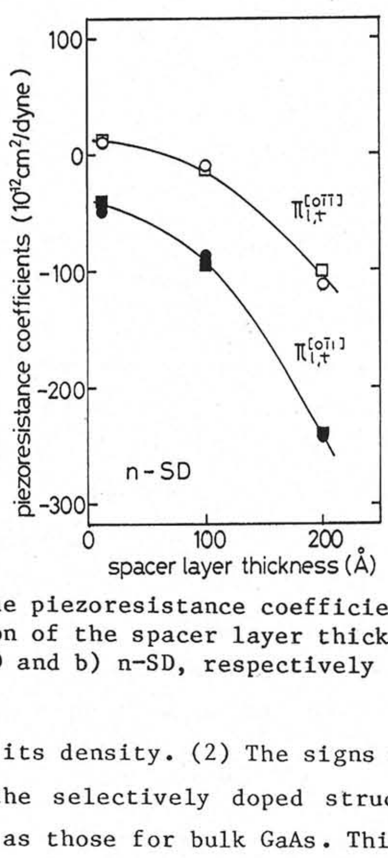
b) 

Fig.7 The piezoresistance coefficients as a function of the spacer layer thickness of a) p-SD and b) n-SD, respectively

type and its density. (2) The signs of π_1 and π_2 for the selectively doped structure are the same as those for bulk GaAs. This indicates that these coefficients are reflected mainly the balk effect. (3) The values of π_1 and π_2 are dependent on the spacer layer thickness. The more studies about the heterostructure are needed to make these dependence clear.

4. Summary

The piezoresistance coefficients in n-type and p-type $Al_{0.3}Ga_{0.7}As$/GaAs selectively doped structure were measured. The directional dependence of the coefficients in selectively doped structures was found to be different from that of bulk GaAs. This difference can be understood from the consideration of the piezoelectric charge at the heterointerface which affect the 2DEG and 2DHG densities. It was shown that the measured piezoresistance coefficient in the selectively doped structures can be separated to three factors π_{PE}, π_1 and π_2, where π_{PE} is from the piezoelectric effect, and π_1 and π_2 are mainly from the bulk effect.

Table 2 Components in the piezoresistance coefficients of several samples

sample	structure	spacer layer thickness	π_{PE}	π_1	π_2
HK203	p-SD	25Å	+68	+66	-35
HK204		50	+87	+60	-39
HK205		100	+125	+67	-39
HK206		200	+121	+85	-45
HK136	n-SD	10	-28	-20	-14
HK220		100	-40	-49	-55
HK219		200	-68	-178	-170
HK151	p-GaAs	-	+10	+52	-37
HK133	p-$Al_{0.3}Ga_{0.7}As$	-	+10	+35	-38
G-97[2]	n-GaAs	-	-	-69	-67

(π_{PE}, π_1 and π_2: $\times 10^{-12}$cm^2/dyne)

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References

1) O.N.Tufte and E.L.Stelzer, J.of Appl. Phys., 34 313 (1963)
2) R.J.Sladek, Phys.Rev., 140 A1345 (1965)
3) D.E.Aspenes and M.Cardona, Phys.Rev., B17 741 (1978)
4) K.Yamada et.al., IEEE Trans.Electron Devices, ED-29 71 (1982)
5) H.Booyens et.al., J.Appl.Phys., 48 3008 (1977)
6) K.Hübner, Phys.Stat.Sol.(b), 57 627 (1973)