Large anomalous Hall resistance of pair δ-doped GaAs structures grown by molecular-beam epitaxy

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Beryllium/silicon pair δ-doped GaAs structures grown by molecular-beam epitaxy exhibit a Hall resistance which has a nonlinear dependence on the applied magnetic field and which is strongly correlated to the negative magnetoresistance observed under the applied magnetic field parallel to the δ-doped layers. Dependence of the occurrence of the nonlinear Hall resistance on the growth condition is investigated. A significantly large increase in both the magnitude and the nonlinearity of the Hall resistance is observed from samples whose GaAs buffer layers are grown under the condition of a low As/Ga flux ratio. Reflection high energy electron diffraction and electron microscope observations show that a faceted surface develops with the growth and postgrowth annealing of a GaAs buffer layer under the condition of a low As flux. From samples which have only Si δ-doped layers and exhibit the *n*-type conduction, such nonlinear Hall resistance is not observed. The nonlinearity of the Hall resistance of Be/Si pair δ-doped structures depends on the single parameter B/T, where B and T are the applied magnetic field and the temperature, respectively. Based on these results, it is suggested that the nonlinear Hall resistance of Be/Si pair δ-doped structures is the anomalous Hall effect caused by localized spins in δ-doped layers. [DOI: 10.1063/1.2838487]

I. INTRODUCTION

In recent years, active research aimed at incorporating the spin degree of freedom into semiconductor electronics has been carried out in the field called spintronics. Two approaches have mainly been employed in the research. One approach is the incorporation of magnetic elements into semiconductor crystals as solute atoms, resulting in the formation of diluted magnetic semiconductors. Their representative is $Ga_{1-x}Mn_xAs$.[1] The other approach is the effective manipulation of spin-orbit interactions for the generation of spin-polarized carriers. Experimental results obtained in this approach which widely attracted attention are observations of spin Hall effects.[2]

There are various methods for engineering electronic structures of semiconductors due to the past significant development of fabrication techniques of semiconductor material structures, such as the growth of low-dimensional structures. By utilizing these techniques, different approaches can be used for incorporating the spin degree of freedom into semiconductors. In a recent study,[3] we observed a Hall resistance which has a nonlinear dependence on the applied magnetic field from Be/Si pair δ-doped GaAs structures grown by molecular-beam epitaxy (MBE). In the pair δ-doped GaAs structures which exhibit *p*-type conduction, a metal-insulator transition occurs as a result of the strong localization of holes in the δ-doped layers.[4] With the applied magnetic field whose direction is parallel to the current, negative magnetoresistance was observed from these structures in the temperature range where the nonlinear Hall resistance occurs.[3,5] Because of the strong correlation of the occurrence of the negative magnetoresistance and the nonlinear Hall resistance, the observed Hall resistance was explained as an anomalous Hall effect (AHE) by assuming the existence of localized spins in the structures. The possibility of the existence of localized spins in the pair δ-doped structures was suggested from their similarity to localized spins associated with impurity states in bulk semiconductors such as P doped Si.[6] This hypothesis can be verified by using a method such as the measurement of the temperature dependence of the magnetization of a sample, but the small number of impurity atoms doped in δ-doped layers in one sample makes the use of such a method extremely difficult.

In our research, instead of using the method mentioned above, we investigated the dependence of the occurrence of the nonlinear Hall resistance on the growth condition in order to gain insights into its origin. We observed a significantly large increase in both the magnitude and the nonlinearity of the Hall resistance from samples whose buffer layers were grown under the condition of a low As/Ga flux ratio. Reflection high energy electron diffraction (RHEED) and electron microscope observations showed that a faceted surface develops with the growth and postgrowth annealing of a GaAs buffer layer under the condition of a low As flux. From samples which have only one Si δ-doped layer and which exhibit *n*-type conduction, such an increase was not observed. The nonlinearity of the Hall resistance of Be/Si pair δ-doped structures depends on the single parameter B/T, where B and T are the applied magnetic field and the temperature, respectively. On the basis of these results, the possibility of an AHE in the pair δ-doped structure is discussed.

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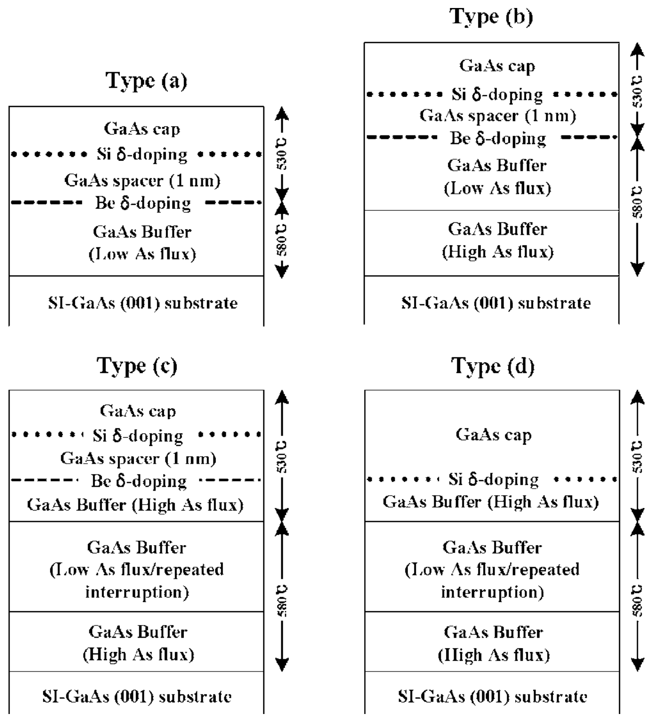

FIG. 1. Layer configurations of the Be and Si pair δ-doped structures of types (a), (b), (c), and (d).

II. EXPERIMENTAL

Figure 1 shows four types of sample structures (a), (b), (c), and (d) which were used in the present study. In the first three types of structures, a pair of Be and Si δ-doped layers with a 1 nm thick GaAs spacer were grown on a GaAs buffer layer after the buffer layer surface was annealed for 5 min under the As flux. The buffer layers were grown at 580 °C, while the pair of δ-doped layers and a cap layer were grown at 530 °C. A lower temperature for the latter was used in order to minimize Be diffusion from the δ-doped layer. The Ga flux was set at a constant value of 5.8×10^{-7} Torr for all samples. The As flux and the thickness of the buffer layer varied among the samples. Table I shows the As flux, the buffer layer thickness, the doping concentrations of Be and Si, and the Hall coefficient R_H at room temperature for 13 samples.

For the first six samples labeled 1–6, whose structures are of type (a), the As flux varied among the samples, whereas all other growth conditions were identical. Sample 7 also has a structure of type (a), but its Be and Si doping concentrations are lower than those of samples 1–6. The next three samples, 8–10, have the structure (b) whose first buffer layer was grown under a high As flux, at 2.5×10^{-5} Torr, and whose second buffer layer was grown under a low As flux, at 0.98×10^{-5} Torr, with different thicknesses ranging from 720 to 1800 nm. For sample 11, which is of type (c), after the growth of the second buffer layer under the low As flux, the As flux was increased to a high value of 2.7×10^{-5} Torr, and a 120 nm thick third buffer layer and a pair of δ-doped layers were grown. During the growth of the second buffer layer, repeated growth interruptions with a duration of 5 min were made. The reason for the growth of this structure will be explained in the next section. Samples 12 and 13 have a structure of type (d), which was grown under conditions similar to those for type (c), but have only a Si δ-doped layer. These two samples exhibit n-type conduction, while all other samples exhibit p-type conduction.

The surface morphology of these samples was analyzed by RHEED, cross-sectional transmission electron microscopy (TEM), and scanning electron microscopy (SEM). A square 5×5 mm^2 sample was cut for the van der Pauw measurements of sheet resistance and for Hall-effect measurements, and indium contacts were made at the corners of a square sample.[4] The magnetic field used for the Hall-effect measurements has a value of 0.32 T. A rectangular 3×8 mm^2 sample was cut, and four indium contacts with an equal spacing in the longitudinal direction and two indium contacts in the transverse direction were made for Hall resistance measurements.

III. RESULTS

In the initial stage of the experiment, we changed the doping concentrations of Be and Si and the growth temperatures by maintaining flux conditions at normally used values for the growth of GaAs layers. Neither the magnitude nor the nonlinearity of the Hall resistance of the samples was found to increase significantly with these changes. In the following stage, we changed the As flux and found a significant change in the Hall resistance of the samples. Figure 2(a) shows plots of the sheet resistance ρ of samples 1–7 as a function of the temperature T. For all samples, the temperature dependence of ρ exhibits a minimum. From the minimum, ρ first increases rapidly with the decrease of the temperature, and its increase becomes smaller as the temperature decreases further.

Figure 2(b) shows plots of R_H/ρ as a function of T for samples 1–7, where R_H is the Hall coefficient. If only the normal Hall effect occurs, R_H/ρ corresponds to the Hall mobility. For all samples, R_H/ρ increases with the decrease of the temperature from 300 K, reaches a maximum, and rapidly decreases with further lowering of the temperature. In the low temperature range below 30 K, R_H/ρ becomes nearly constant. There is a direct correlation of the temperature dependence of R_H/ρ with the As flux for the growth of GaAs buffer layers in these samples. As the As flux decreases from 2.61×10^{-5} Torr, the maximum value of R_H/ρ gradually increases, reaches the highest value at 0.98×10^{-5} Torr, and decreases with a further decrease of the As flux to 0.77×10^{-5} Torr. The buffer layer of sample 7 was grown with an As flux of 0.98×10^{-5} Torr, similar to that of sample 5, but its Be and Si concentrations are lower than those in sample 5, at 4.7×10^{12} and 1.8×10^{11} cm^{-2}, respectively. As seen from the results for samples 5 and 7 in Fig. 2(b), lower Be and Si concentrations led to higher values of R_H/ρ for the same growth condition for the buffer layers. The Si concentration in sample 7 was lowered significantly from that in samples 2–6, becoming nearly one quarter of the latter, in order to obtain a resistivity that is comparable to that of the latter samples; if the Be and Si concentrations were lowered by keeping the same ratio of the concentrations, the resistivity of a sample was found to increase sig-

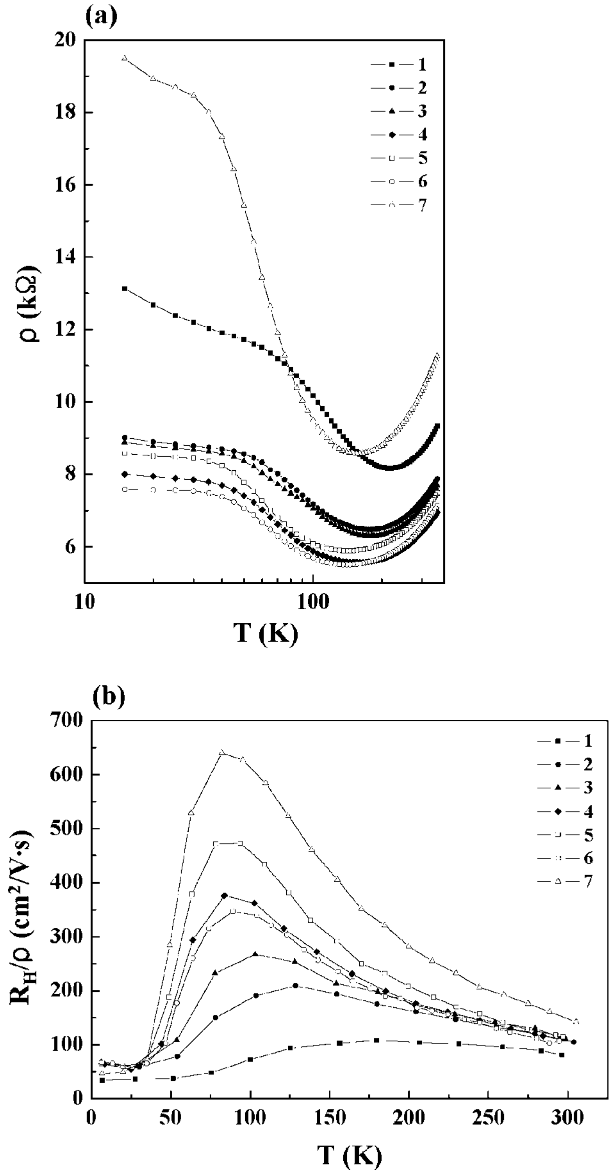

FIG. 2. (a) Temperature dependence of the resistivity ρ and (b) temperature dependence of the Hall coefficient R_H/ρ for samples 1–7.

nificantly and to exhibit an insulatorlike temperature dependence over the whole temperature range. Because higher values of R_H/ρ can be obtained, Be and Si concentrations similar to those in sample 7 were doped in the remaining pair δ-doped samples 8–11.

Figure 3(a) shows the Hall resistance R_{Hall} of sample 5 as a function of the applied magnetic field B. Hall resistance curves were obtained by calculating $[R_{\mathrm{Hall}}(B)-R_{\mathrm{Hall}}(-B)]/2$ with the measured values of $R_{\mathrm{Hall}}(B)$ and $R_{\mathrm{Hall}}(-B)$ for each value of the magnetic field B in order to remove contributions of the magnetoresistance to the Hall resistance. The figure shows a highly nonlinear dependence of R_{Hall} with respect to B. The nonlinearity increases with the lowering of the temperature, but below 30 K, R_{Hall} is completely linear with B. The nonlinearity of the Hall voltage for sample 5 is significantly greater than that for other samples grown under higher As fluxes.[3] Figure 3(b) shows the longitudinal resistance of sample 5 as a function of the applied magnetic field B. The magnetic field was applied in the direction parallel to

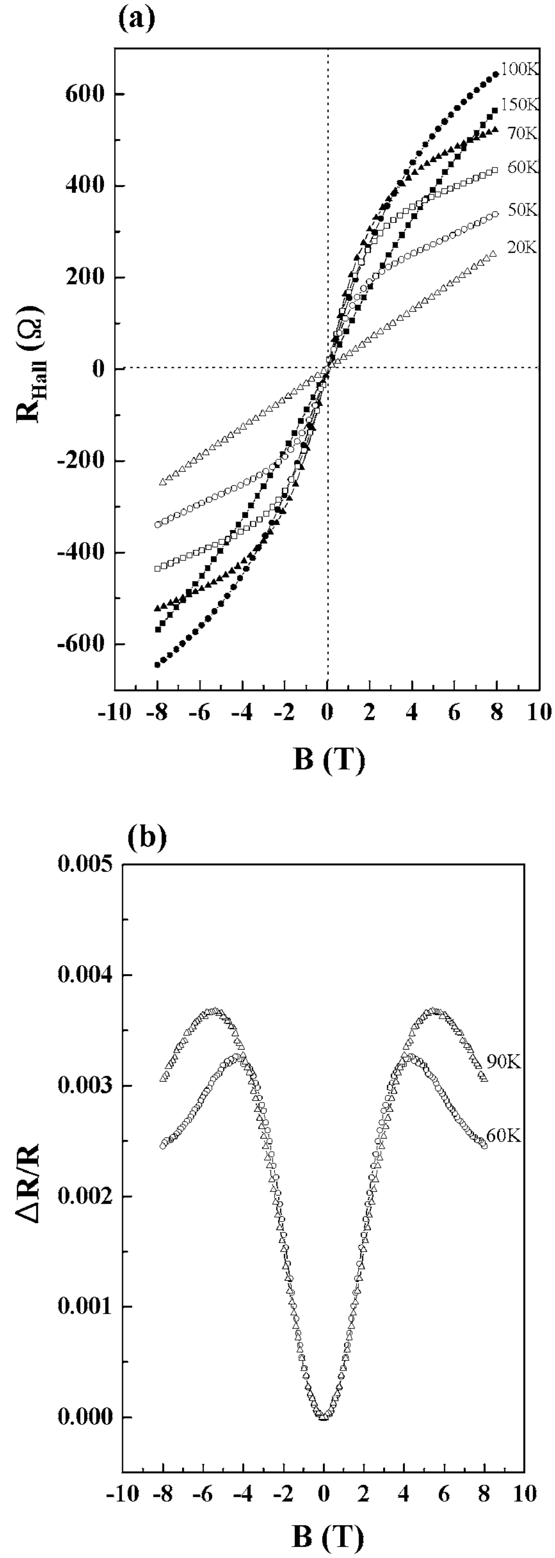

FIG. 3. (a) Hall resistance R_{Hall} of sample 5 as a function of the magnetic field B and (b) magnetoresistance of sample 5 as a function of the magnetic field B applied in the direction macroscopically parallel to the current.

the current. As seen in the figure, the longitudinal resistance initially increases with B and starts to decrease at higher values of B, corresponding to a negative magnetoresistance.

The As flux used for the growth of sample 1 is the normal value for the MBE growth of GaAs layers. A bright (2×4) RHEED pattern typical to the As-rich (001)GaAs sur-

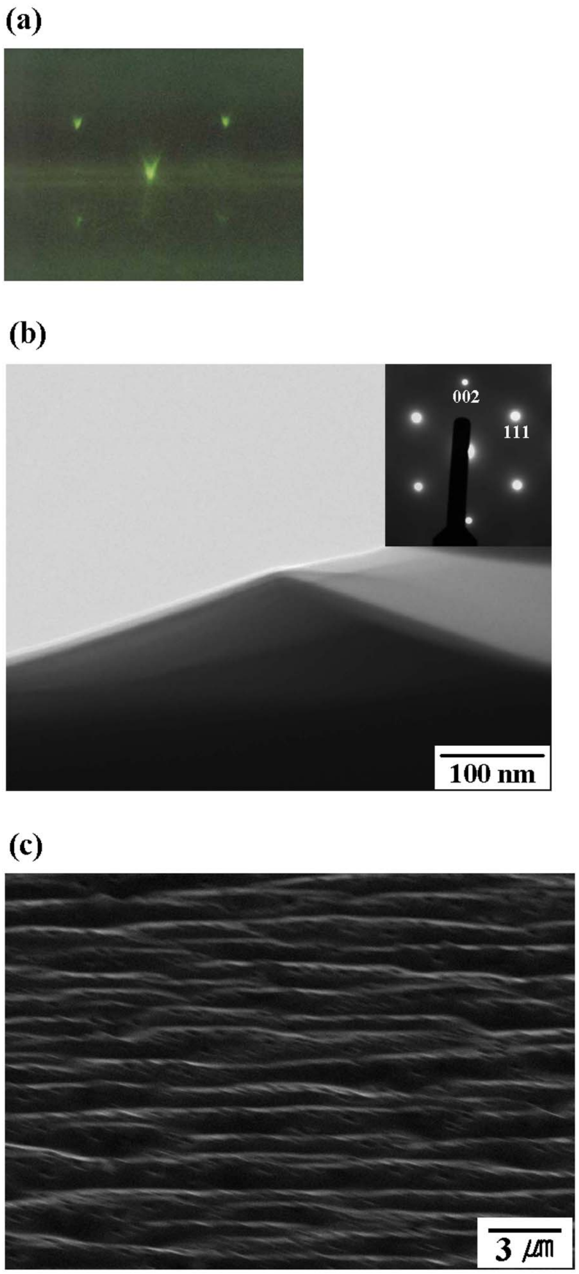

FIG. 4. (Color online) (a) $[\bar{1}10]$ RHEED pattern for a GaAs buffer layer grown under a low As flux condition at 0.98×10^{-5} Torr and annealed for 5 min. (b) Cross-sectional TEM image of a faceted surface for sample 4 with a corresponding transmission electron diffraction pattern. (c) SEM image of the surface of sample 11.

face was observed during the growth of the GaAs buffer layer in this sample. In the case of the six other samples (2–7) with lower As fluxes, RHEED patterns gradually became darker during the growth of the GaAs buffer layers, indicating a roughening of their surfaces. With the 5 min annealing following the growth of the buffer layers, RHEED patterns became brighter and exhibited V-shaped spots in the $[\bar{1}10]$ direction of the incident electron beam, as shown in Fig. 4(a). As the As flux was set to a lower value, more distinct V-shaped spots were observed. The appearance of these V-shaped spots indicates the formation of a faceted structure of the (001)GaAs surface due to the annealing process.[7] The faceted structure can be directly seen in a cross-sectional TEM image, as shown in Fig. 4(b), and was observed for sample 4. In the TEM image, the lower dark area is the cross section of the sample near its surface, and the small darker area on the right-hand side is a remaining epoxy film which was used for the preparation of a cross-sectional sample. The TEM image shows the formation of a well-defined faceted structure. Facet planes were identified as (114) and $(\bar{1}\bar{1}4)$ planes with TEM images and RHEED patterns.

The results presented above suggest a direct correlation between the formation of a faceted surface and the large increase in the magnitude and nonlinearity of the Hall resistance. We therefore next tried to grow samples which had highly developed faceted surfaces. For this purpose, we initially grew a buffer layer with an atomically flat surface by using a high As flux, and then grew a thick buffer layer with a low As flux, as shown by the type (b) structure in Fig. 1. Samples 8–10 were grown in this way. For sample 11, repeated growth interruptions were made during the growth of the second buffer layer in order to develop a faceted surface. Figure 4(c) is a SEM image of the surface of sample 11 which shows highly developed faceted surfaces. Figure 5(a) shows plots of R_H/ρ as a function of T for samples 8–11. The figure shows that R_H/ρ significantly increases as the thickness of the second buffer layer increases. At room temperature, all samples have nearly identical values of R_H/ρ, but R_H/ρ rapidly increases with a decrease in the temperature and reaches a maximum around 50 K. Below 40 K, R_H/ρ is sharply reduced to values around 50 $\text{cm}^2/\text{V s}$ for all samples. Maximum values of R_H/ρ for samples 10 and 11 are nearly identical, although a high As flux was used in the growth of δ-doped layers and of a cap layer for the latter sample. Figure 5(b) shows the Hall resistance R_{Hall} of sample 8 as a function of the magnetic field B. Hall resistance curves for this sample are highly nonlinear as compared to those for sample 5.

Figure 6(a) shows R_H/ρ and ρ for the n-type samples, samples 12 and 13, as a function of the temperature T. The growth of the buffer layers in these samples was made in the same way as for sample 11. The Si doping concentrations in these two samples were selected so as to give rise to carrier concentrations that are comparable to those of the p-type samples. The figure shows no significant enhancement of R_H/ρ values, unlike the case of the p-type samples. Values of R_H/ρ for these samples are comparable to reported values of the Hall mobility of Si δ-doped GaAs samples.[8] Figure 6(b) shows R_{Hall} as a function of the magnetic field B for sample 13. No significant nonlinearity is observed in these R_{Hall} curves at both temperatures of 50 and 80 K.

IV. DISCUSSION

The present results show that the Hall resistance of a pair δ-doped sample is significantly affected by the growth of a buffer layer grown under a low As flux condition. The most significant change is a very large increase of the value of R_H/ρ. The highest values for samples 10 and 11 reach approximately 8000 $\text{cm}^2/\text{V s}$ at around 50 K, as seen in Fig. 5(a). This value is much higher than the reported values of

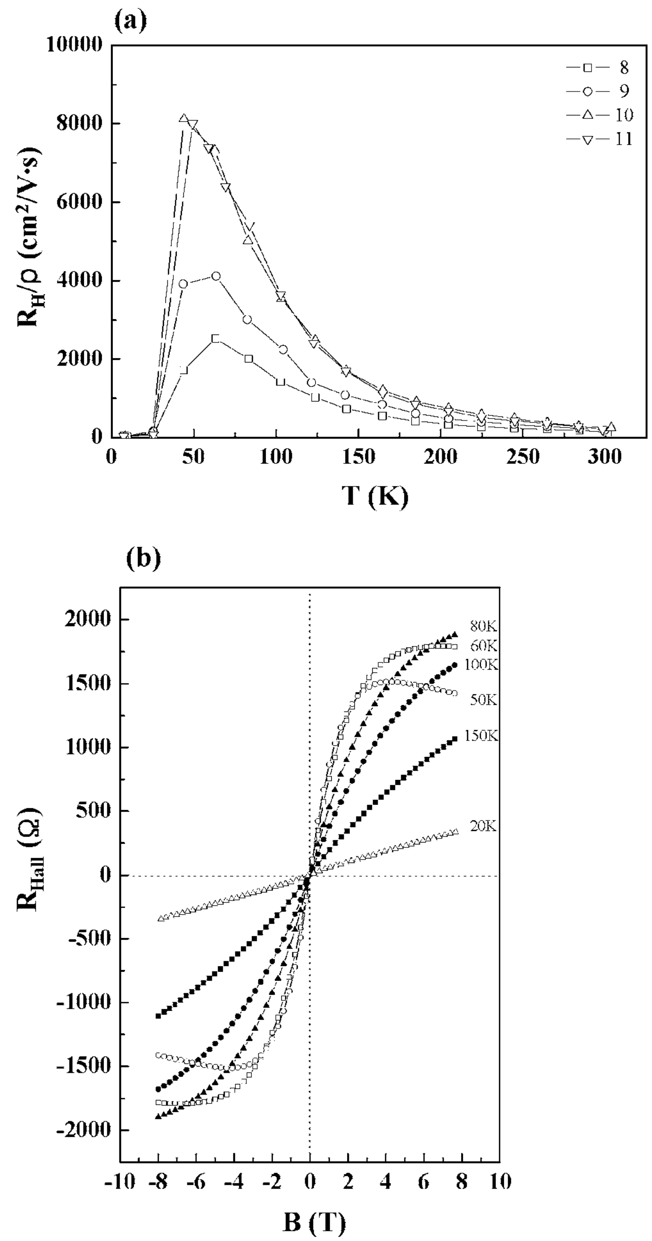

FIG. 5. (a) Plots of R_H/ρ as a function of the temperature T for samples 8–11. (b) Hall resistance R_{Hall} of sample 8 as a function of the magnetic field B.

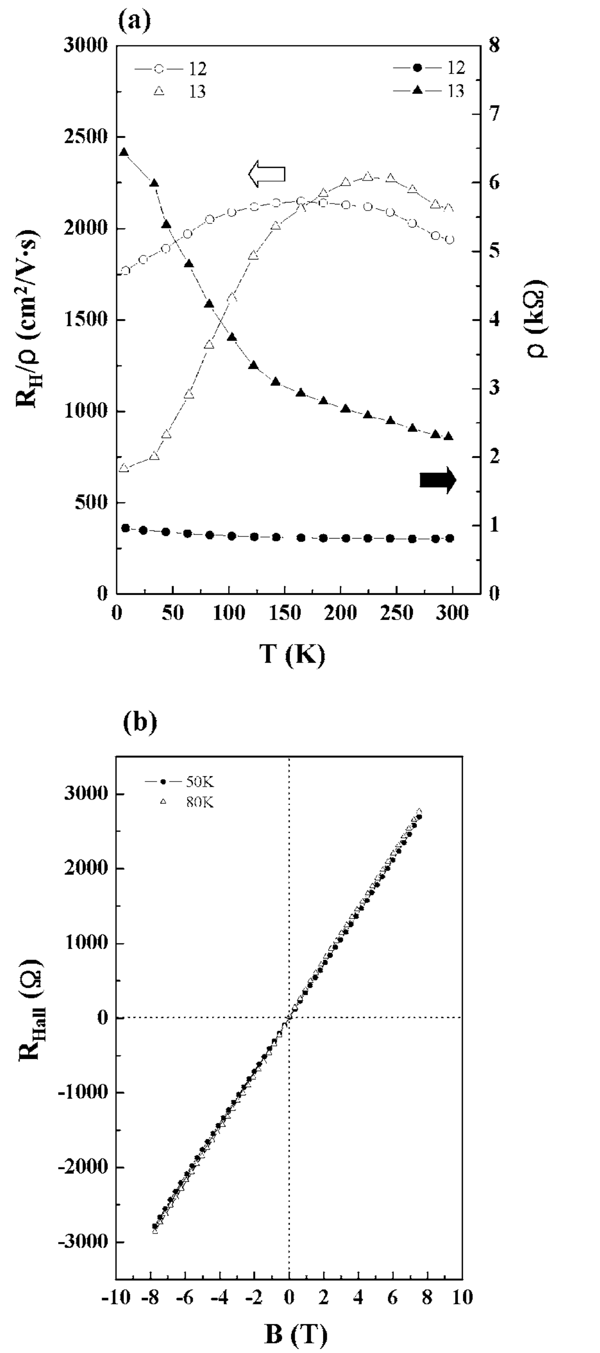

FIG. 6. (a) Temperature dependence of the resistivity ρ and of R_H/ρ for samples 12 and 13. (b) Hall resistance of sample 13 as a function of the magnetic field B.

the Hall mobility for Be δ-doped GaAs layers.[8] The highest reported value at 60 K is approximately 2000 $\mathrm{cm^2/V\,s}$, which was obtained with a Be concentration of $1 \times 10^{12}\ \mathrm{cm^{-2}}$. For Be concentrations similar to those in samples 10 and 11, the reported Hall mobility at 60 K is less than 1000 $\mathrm{cm^2/V\,s}$.[8] As explained earlier, all pair δ-doped samples from 1 to 11 exhibit p-type conduction over the whole measured temperature range. For example, the Hall coefficient R_H for sample 11 has positive values 184, 1080, and 4850 $\Omega\ \mathrm{T^{-1}}$ at 300, 100, and 50 K, respectively.

It is known that Ga droplets form in a GaAs layer grown under a low As flux condition,[9] and a semiconductor sample with such metallic inclusions exhibits an apparently high Hall mobility.[10] Such a high Hall mobility has been explained as the result of a large positive magnetoresistance caused by a geometrical effect at an interface between the semiconductor matrix and metallic inclusions;[10] to calculate the Hall mobility, the resistivity at a zero magnetic field, which is lower than that obtained for the value of the magnetic field used for the measurement of the Hall voltage, is normally used, resulting in an apparently high value of the mobility. All samples used in the present experiment exhibit positive magnetoresistance with the magnetic field direction perpendicular to the sample surface, but the increase in the resistance with the magnetic field used in the measurement of the Hall effect, $B=0.32$ T, reaches only a few percent for these samples; the increase in their nominal Hall mobility due to this effect is expected to be only a few percent. Very high values of R_H/ρ for samples 10 and 11, therefore, cannot be attributed to the existence of Ga droplets. This conclusion is also supported by the results obtained for the Si δ-doped samples 12 and 13, which do not show any significant enhancement of the Hall mobility. The R_H/ρ value for sample 13, which corresponds to the Hall mobility, becomes lower than that for sample 12, although sample 13 has a lower Si concentration than sample 12. The resistivity of sample 13 also significantly increases as the temperature is lowered. These results suggest a tendency to carrier localization at low temperatures in this sample. Such carrier localization may have been induced by carrier trapping in the surrounding matrix of the δ-doped layer.

There is a distinctive dependence of the nonlinear part of Hall resistance curves of pair δ-doped samples on the magnetic field B and the temperature T. In Figs. 7(a) and 7(b), the quantity $[R_{\mathrm{Hall}}/\rho(T)-R_{\mathrm{Hall}}/\rho(20\ \mathrm{K})]$ is plotted as a function of B/T for samples 6 and 8, respectively, where $R_{\mathrm{Hall}}/\rho(20\ \mathrm{K})$ is the linear change of R_{Hall}/ρ with B at 20 K. The division of R_{Hall} by ρ is carried out in order to remove the effect of the magnetoresistance. These figures show that the nonlinearity of R_{Hall}/ρ depends on the single parameter B/T. For both samples, whose R_{Hall}/ρ values are significantly different, the maxima and minima of the curves occur at nearly the same values of B/T. The Hall resistance curves for other samples show a similar dependence on B/T.

Very high values of R_H/ρ and the dependence of the nonlinearity of R_{Hall} curves on the single parameter B/T suggest the possibility of an AHE caused by localized spins in a paramagnetic state in these pair δ-doped structures, which we explain as follows: the anomalous Hall effect leads to the presence of an additional term in R_H/ρ, hence resulting in an apparently high Hall mobility. The thermal average of the spin polarization induced by the magnetic field which results in AHE depends on the single parameter B/T. Negative magnetoresistance observed in these pair δ-doped structures with a magnetic field parallel to the current also suggests the possibility of the existence of localized spins in a paramagnetic state.[3,5] In the case of δ-doped layers grown on a faceted surface, positive magnetoresistance due to the normal component of the magnetic field occurs along with the negative magnetoresistance, resulting in the magnetoresistance curves shown in Fig. 3(b).

By considering the possibility of the manifestation of an AHE, R_{Hall}/ρ curves are calculated in order to reproduce the experimental results. For the calculation, we assume that the electrical conduction in these structures occurs through two paths: one path is produced by holes in the valence band, and the other by holes in an impurity band of the δ-doped layers. It is assumed that both paths contribute to the conduction at high temperatures, but below 30 K, only the latter path dominates the conduction. The conductivity of these two paths are denoted as σ_1 and σ_2, respectively, with the mobility of the former, μ_1, being higher than that of the latter, μ_2. The AHE term is added to the Hall coefficient for the conduction in the valence band,

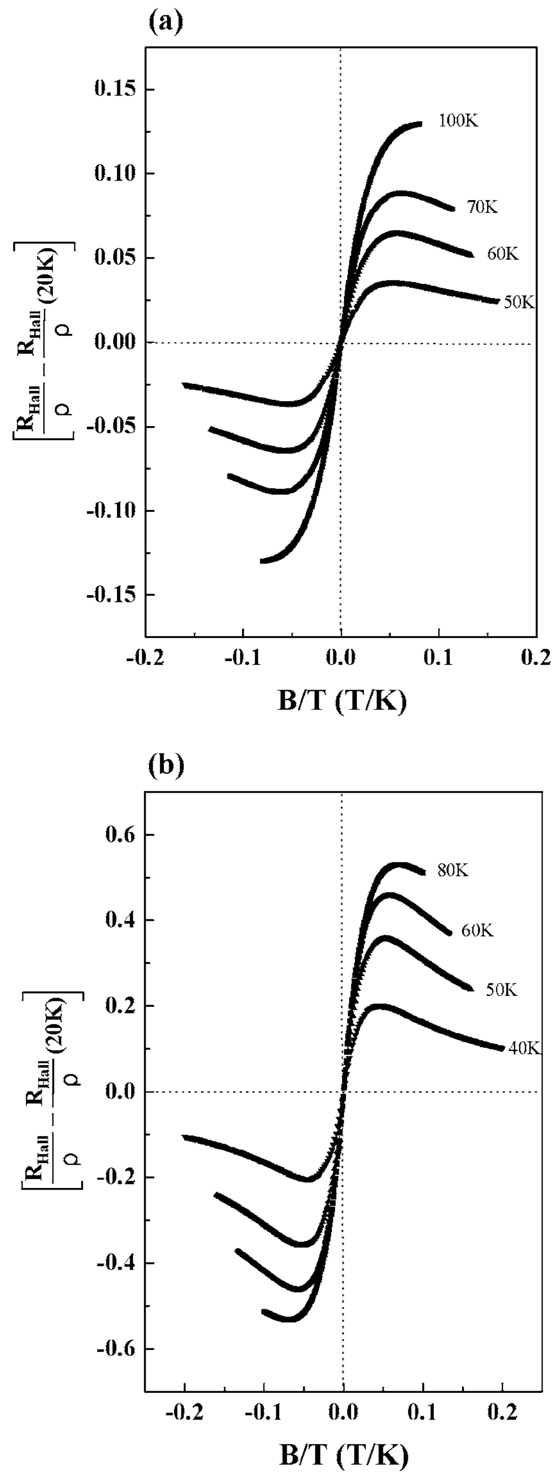

FIG. 7. Plots of $[R_{\mathrm{Hall}}/\rho(T)-R_{\mathrm{Hall}}/\rho(20\ \mathrm{K})]$ as a function of B/T for (a) sample 5 and (b) sample 8.

$$R_H{}^1 = \frac{1}{\sigma_1}\left(\mu_1 + \frac{c\langle S\rangle}{B}\right), \tag{1}$$

where c is a constant and $\langle S\rangle$ is the thermal average of the spin polarization. Here, AHE is assumed to occur through the skew scattering which is known to be significant for high mobility carriers.[11] For the conduction in the impurity band with low carrier mobility, AHE is not considered. When considering localized spins in a paramagnetic state, the average spin polarization is given by the Brillouin function $B_s(x)$,

$$\langle S\rangle = SB_s(x), \quad x = \frac{Sg\mu_B B}{k_B T}, \tag{2}$$

where S and g are the spin and the Landé g factor, respectively. The dependence of the R_{Hall}/ρ of the system on B is given by

$$R_{\mathrm{Hall}}/\rho = \frac{x_1 R_H{}^1\sigma_1(1+\mu_2{}^2B^2) + x_2\mu_2[1+(R_H{}^1\sigma_1)^2B^2]}{1+(x_1\mu_2+x_2R_H{}^1\sigma_1)^2B^2}B, \tag{3}$$

where

$$x_1 = \frac{\sigma_1}{\sigma_1+\sigma_2}, \quad x_2 = \frac{\sigma_2}{\sigma_1+\sigma_2}. \tag{4}$$

Without the AHE term, Eq. (2) becomes a standard formula of R_{Hall}/ρ for the system with two conduction paths.[12]

If the AHE term, that is, $c\langle S\rangle/B$, is significantly larger than μ_1 and μ_2, Eq. (3) gives rise to Hall resistance curves, similar to the experimental curves, as shown in Fig. 8(a). Figure 8(b) shows that the nonlinearity of the calculated curves depends on the single parameters B/T. For the calculation, it was assumed that $\mu_1=300\ \mathrm{cm^2/V\,s}$, $\mu_2=50\ \mathrm{cm^2/V\,s}$, $x_1=0.2$, and $x_2=0.8$. For the calculation of the Brillouin function, S and g were assumed to be equal to $\frac{1}{2}$ and 2, respectively. The value of the constant c was chosen by assuming that $c\langle S\rangle/B=4000\ \mathrm{cm^2/V\,s}$ at $T=60$ K for small values of B. A linear term which corresponds to μ_2B is not subtracted from R_{Hall}/ρ in Fig. 8(b) because its contribution is very small in this case. Besides $\langle S\rangle$, the other parameters μ_1, μ_2, x_1, and x_2 also change with the temperature, unlike the assumption made for the above calculation. Even with the inclusion of the temperature dependence of these parameters, R_{Hall}/ρ curves were found to depend approximately on the single parameter B/T under the condition that the AHE term $c\langle S\rangle/B$ is far larger than μ_1 and that x_2 does not change appreciably with the temperature. By fine tuning the temperature dependence of other parameters appropriately, calculated profiles of R_{Hall}/ρ which better reproduce experimental profiles can be obtained. The results of the calculation hence show that the large nonlinearity of the Hall resistance curves and the dependence on the single parameter B/T result from two conduction paths with different values of the hole mobility, where the contribution of the anomalous Hall term dominates the R_H of the higher-mobility path.

Finally, we consider the question as to why the value of R_H/ρ significantly increases through the growth of a Be/Si pair δ-doped structure on a faceted surface. Experimental results relevant to this question are summarized as follows. The R_H/ρ value increases primarily through the development of a large-scale faceted surface structure. Such a faceted surface structure develops through the growth of a thick GaAs buffer layer under a low As flux condition and through the postgrowth annealing of the surface. The growth of a pair of δ-doped layers and of a cap layer under a low As flux condition is not responsible for the significant increase in the value of R_H/ρ since sample 11, which has a structure of type (c), exhibits large values of R_H/ρ similar to those for sample

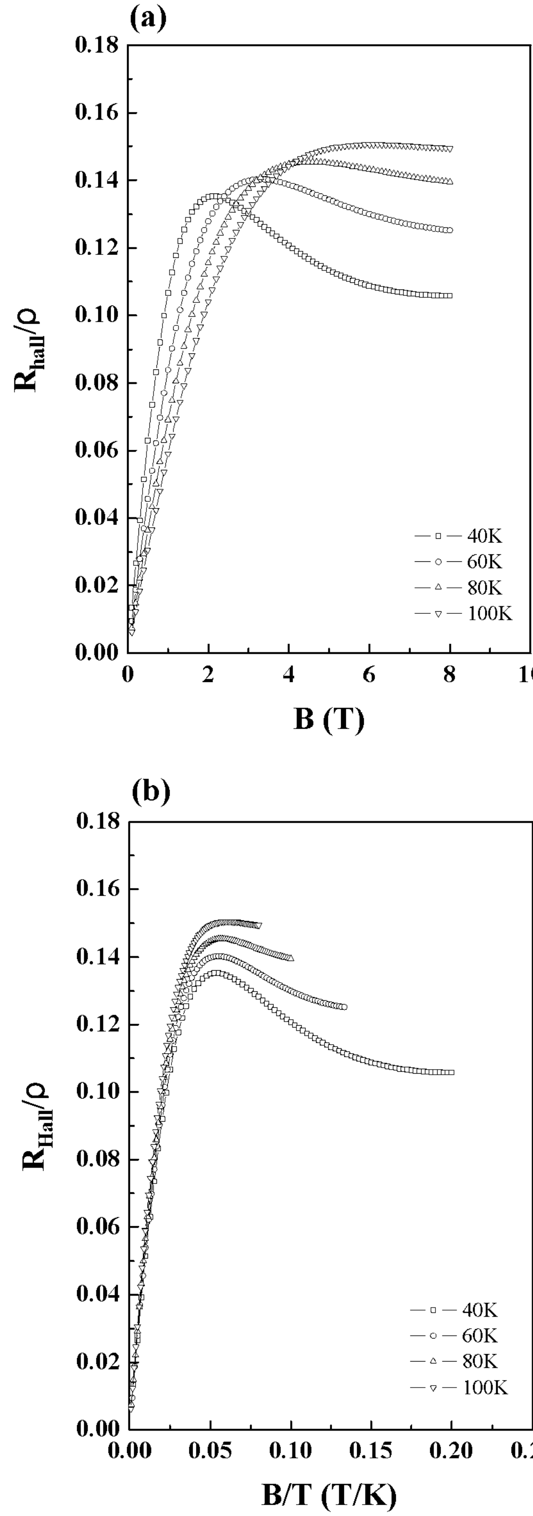

FIG. 8. Calculated profiles of (a) R_{Hall}/ρ as a function of B and (b) R_{Hall}/ρ as a function of B/T.

10. Lower concentrations of Be and Si for a pair of δ-doped layers also give rise to higher value of R_H/ρ, as seen from the results for samples 5 and 7 in Fig. 2(b), although their effect is not as significant as that of the development of a large-scale faceted surface structure. Another experimental result which may be relevant to the above-mentioned question is that, in spite of large variations of values of R_H/ρ among pair δ-doped samples, values of R_H/ρ for all samples

become lower than $100\ \mathrm{cm^2/V\,s}$ at temperatures below 40 K. This result suggests that the occurrence of the high value of R_H/ρ is attributable to holes thermally excited to high energy states.

The AHE results from the spin polarization of carriers which is induced by their interaction with localized spins.[13] Therefore, in order to clarify the origin of the significant increase in the value of R_H/ρ, it is essential to understand how the carrier transport process in the pair δ-doped structure grown on a faceted surface changes from that in the pair δ-doped structure grown on a (001) singular surface. Carrier transport properties of δ-doped semiconductors are known to be different from those of homogeneously doped semiconductors.[8] The main difference results from the spreading of wave functions of high energy states from the δ-doped layer into the surrounding matrix. The experimental results described above suggest that these high energy states and, hence, the carrier transport process through these states change significantly through the growth on a faceted surface. For example, the distribution of carrier trap sites in the surrounding matrix may have changed through the growth on a faceted surface. It is, however, difficult to clarify such changes with the present experimental results alone. In order to answer the question above, we need further analyses of the carrier transport process in δ-doped structures grown on a faceted surface, including an analysis of Si δ-doped samples similar to samples 12 and 13.

To summarize, this paper presents the results of magnetotransport measurements of Be/Si pair δ-doped GaAs structures whose buffer layers were grown under low As flux conditions. Two main results, significantly higher values of R_H/ρ than the reported values of the Hall mobility of Be δ-doped GaAs layers, and the dependence of the nonlinearity of the Hall resistance curves on the single parameter B/T, are reasonably explained by assuming the occurrence of an AHE caused by localized spins in the δ-doped structures. Other results such as the negative magnetoresistance observed with the magnetic field parallel to the current and the lack of enhancement of the value of R_H/ρ for Si δ-doped samples are consistent with this assumption. These results do not necessarily constitute direct evidence for the occurrence of an AHE or for the existence of localized spins in the pair δ-doped structures, but they point the way to further researches aimed at investigating such possibilities.

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