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Deep Levels in SnTe-Doped GaSb Grown on GaAs by Molecular Beam Epitaxy

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A dominant deep level with an activation energy of 0.23–0.26 eV was observed by admittance spectroscopy in SnTe-doped GaSb layers grown directly on GaAs substrates by molecular beam epitaxy (MBE). The Sb_4/Ga flux ratio was found to affect the Hall mobility and the concentration of the deep level in a similar way, with an optimal beam equivalent pressure ratio of around 7 obtained for GaSb grown at 550°C, which should correspond to the lowest ratio at which a Sb-stabilized surface reconstruction can be maintained. This electron level is commonly detected in n-type (SnTe-, S- and Te-doped) GaSb, but not in undoped p-type GaSb, suggesting that the level is not a simple native defect, but may be connected with the impurity used for n-type doping of GaSb.

KEYWORDS: GaSb, SnTe dopants, deep levels, admittance spectroscopy

The GaSb Schottky barrier is attractive for such device applications as metal-semiconductor field-effect transistors (MESFETs), and metal-semiconductor photodetectors due to its comparatively high mobility and hole-to-electron impact ionization ratio.[1,2] Its hole-to-electron mobility ratio is also high, which is promising for circuit applications. Recently, a compound SnTe source was demonstrated to be an effective n-type dopant in GaSb grown on GaAs by molecular beam epitaxy (MBE).[3] However, the deep-level properties of SnTe-doped GaSb Schottky diodes have not been characterized. The characterization of deep levels in GaSb may be better accomplished by admittance spectroscopy than by deep-level transient spectroscopy (DLTS) because admittance spectroscopy is performed under quasiequilibrium conditions using small signal modulation. The variation of the leakage current resulting from this small signal change is smaller than that resulting from the large voltage modulation in DLTS. In this work, admittance spectroscopy was used to study the deep-level properties of SnTe-doped GaSb Schottky diodes and the effect of the Sb_4/Ga beam equivalent pressure (BEP) ratio on their properties.

The GaSb samples employed here for the fabrication of Schottky diodes were SnTe-doped GaSb films directly grown on (001) semi-insulating GaAs substrates by MBE. The growth temperature was about 550°C with a growth rate of 0.5 μm/h and various Sb_4/Ga BEP ratios from 2 to 9 obtained by varying the Sb_4 flux, which was measured using an ionization gauge. The SnTe source temperature was fixed at 260°C to give a Hall concentration of about 6×10^{16} cm^{-3}. Details of the growth conditions were reported previously.[3] The epilayers investigated here were about 2 μm thick. For electrical characterization, Schottky contacts were fabricated by evaporating Au through a metal mask with apertures 0.5 mm in diameter.

An HP4194 impedance analyzer was used to measure the frequency-dependent capacitance and conductance of all samples at temperatures from 77 to 400 K. The small signal oscillation level was kept at 100 mV and the diode was reverse biased at a voltage of −0.5 V. Serial resistance effects were observed to occur at frequencies much higher than those of interest. The results for conductance versus temperature showed a dominant peak associated with the trapping effect in deep levels for all samples. Figures 1(a) and 1(b) show the frequency dependence of capacitance and conductance, respectively, with temperature as a parameter, for the sample grown with a

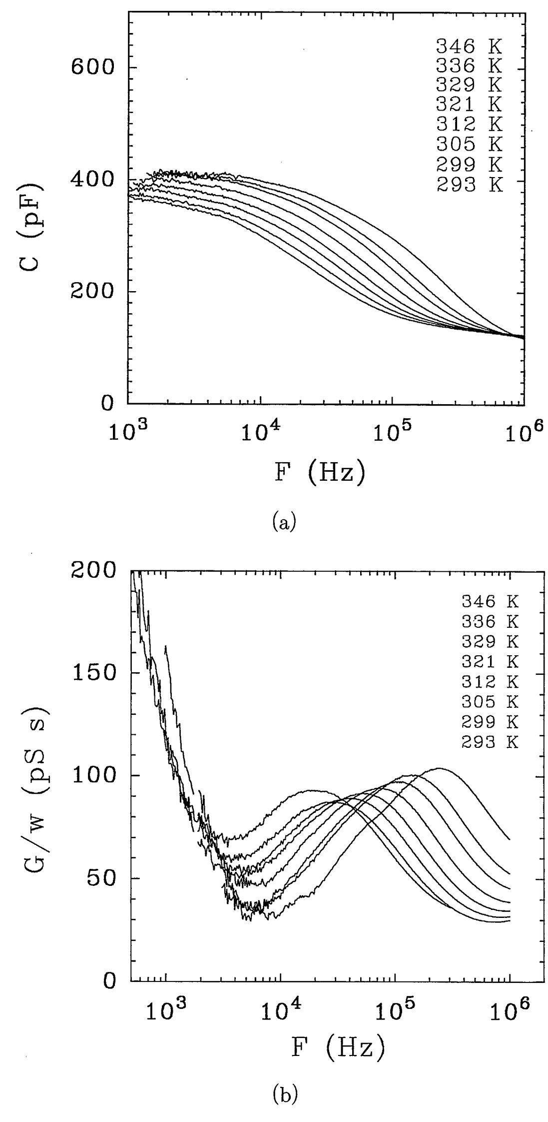

Fig. 1. The frequency dependence of (a) capacitance and (b) conductance at various temperatures for a SnTe-doped GaSb sample grown by MBE at 550°C with a Sb_4/Ga beam equivalent pressure ratio of 2.

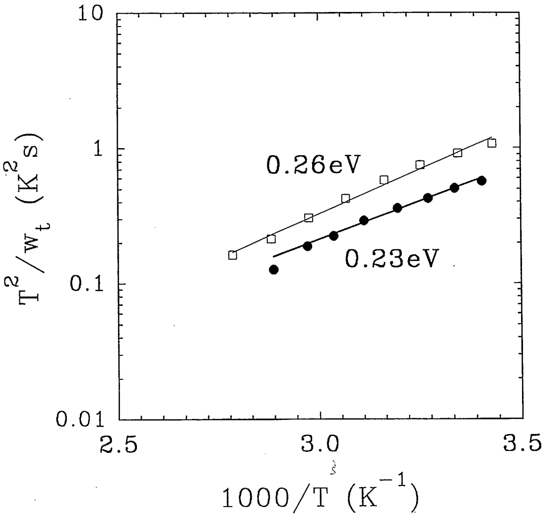

Fig. 2. The temperature-corrected emission rate as a function of the inverse temperature for SnTe-doped GaSb Schottky diodes grown with Sb_4/Ga BEP ratios of 2 (solid circles) and 9 (open rectangles).

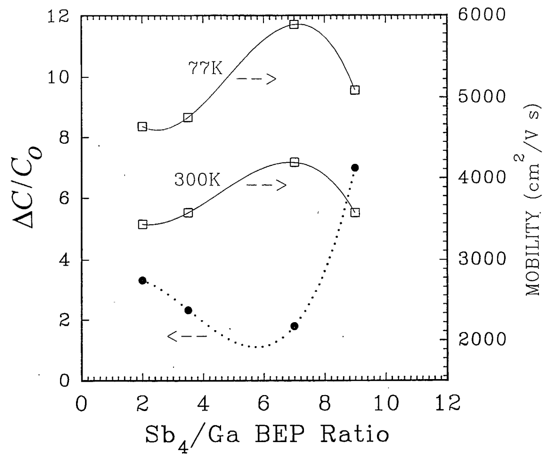

Fig. 3. The measured $\Delta C/C_0$ and Hall mobility as a function of the Sb_4/Ga BEP ratio for SnTe-doped GaSb samples.

Sb_4/Ga BEP ratio of 2. The thermal emission rate of this deep level was taken to be the frequency at the inflexion point of the capacitance curve and was consistent with the peak position of the conductance G/ω curve. The inflexion point of the capacitance curve and the peak in the conductance G/ω curve shifted towards higher frequencies with increasing temperature as expected from the increase of the emission rate with temperature. The activation energy of the deep level was obtained by plotting the temperature-corrected emission rate versus the inverse temperature, as shown in Fig. 2, for samples with Sb_4/Ga BEP ratios of 2 and 9. The activation energies and the corresponding capture cross sections were determined as 0.23 and 0.26 eV and 7.46×10^{-17} and 1.73×10^{-16} cm^2 for these two samples, respectively. Although there are slight differences in the activation energies and capture cross sections for each sample, they should correspond to the same deep level according to the activation plots in Fig. 2.

The activation energy and capture cross section of the deep level that we observed are similar to those of the DX-like center detected recently in n-GaSb grown by MBE. Poole *et al.*[4] observed a deep level with an activation energy of 0.28 eV in S-doped GaSb and a coordinate model for a large lattice relaxation was used to account for the S donor. Polyakov *et al.*[5] also reported a deep level at 0.25 eV ($\sigma_n = 1.3 \times 10^{-15}$ cm^2) in Te-doped GaSb Schottky diodes. On the other hand, Kuramochi *et al.*[6] reported that only hole traps were observed in undoped GaSb. Therefore, if we accept that the trap observed by us is the same as that observed by Poole *et al.* and Polyakov *et al.*, this electron trap is commonly detected in n-type (SnTe-, S- and Te-doped) GaSb, but not in undoped p-type GaSb. This observation indicates that the trap is not a simple native defect, but is connected with the impurity used for n-type doping of GaSb. The small difference between the activation energies of the trap observed by us and that observed by Poole *et al.* and Polyakov *et al.* indicates that the changes in activation energy of this trap with impurity may be small compared to that for the DX-center in the AlGaAs material system.

The effects of the Sb_4/Ga ratio on the deep-level properties and the Hall data are investigated. For the range of Sb_4/Ga ratio studied, the V-III ratio has a negligible effect on the Hall concentration, which is confirmed by the similar high-frequency capacitances of all samples. However, the low-frequency capacitances were significantly different, indicating that the deep-level concentration is affected by the Sb_4/Ga ratio. Since the doping concentrations of all samples are almost the same, $\Delta C/C_0$, the difference between the low-frequency and high-frequency capacitances, can be used to compare the deep-level concentrations of different samples. The measured $\Delta C/C_0$ values and the Hall mobilities at 77 and 300 K versus the Sb_4/Ga ratio are shown in Fig. 3. It is interesting that the effects of the Sb_4/Ga ratio on the mobility and concentration of the deep level are similar. GaSb samples with a high mobility have a low deep-level concentration. The highest mobility and the lowest deep-level concentration were obtained for GaSb with a BEP ratio of around 7.

The result in Fig. 3 shows that there exists an optimal V-III ratio at which the mobility is highest and the deep-level concentration is lowest. This Sb_4/Ga BEP ratio, which corresponds to the lowest ratio at which a Sb-stabilized surface reconstruction can be maintained,[7] has been found to give rise to the highest crystal quality at each growth temperature. If the Sb flux is lower than the optimal flux, the grown layer may have a high Sb vacancy concentration. On the other hand, if the Sb flux is higher than the optimal value the grown layer may have a high Ga vacancy concentration or Sb may start to precipitate at the growth surface. From the data in Fig. 3, since $\Delta C/C_0$ increases with increasing V-III ratio up to 9, this deep level is not a simple Sb vacancy. The observation that the optimum V-III BEP ratio is about 7 at a growth temperature of 550°C is consistent with the observation by Ivanove *et al.*[8] who reported that reduction of the Sb_4/Ga ratio from 14–16 to 4–10 for undoped

GaSb growth at 530°C increases the photoluminescence intensity and mobility.

In summary, a dominant deep level with activation energies ranging from 0.23 to 0.26 was observed for SnTe-doped GaSb layers grown on GaAs substrates by molecular beam epitaxy. The Sb_4/Ga V-III BEP ratio was found to affect the concentration of this deep level. The highest mobility together with the lowest deep-level concentration was obtained for GaSb grown at 550°C with a Sb_4/Ga BEP ratio of around 7, which should correspond to the lowest ratio at which a Sb-stabilized surface reconstruction can be maintained. This electron level is commonly detected in n-type (SnTe-, S- and Te-doped) GaSb, but not in undoped p-type GaSb, which indicates that the level is not a simple native defect, but may be connected with the impurity used for n-type doping of GaSb. However, the exact origin of this level is not yet clear and is the subject of further investigation.

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1) O. Hildebrand, W. Kuebart, K. W. Benz and M. H. Pilkuhn: IEEE. J. Quantum Electron. QE-**17** (1981) 284.
2) S. J. Eglash, H. K. Choi and G. W. Turner: J. Cryst. Growth **111** (1991) 669.
3) J. F. Chen and A. Y. Cho: J. Cryst. Growth **111** (1991) 619.
4) I. Poole, M. E. Lee, I. R. Cleverley, A. R. Peaker and K. E. Singer: Appl. Phys. Lett. **57** (1990) 1645.
5) A. Y. Polyakov, M. Stam, A. G. Milnes and T. E. Schlesinger: Mater. Sci. Eng. B **12** (1992) 337.
6) E. Kuramochi, N. Kondo, Y. Takanashi and M. Fujimoto: Appl. Phys. Lett. **63** (1993) 2664.
7) M. Lee, D. J. Nicholas, K. E. Singer and B. Hamilton: J. Appl. Phys. **59** (1986) 2895.
8) S. V. Ivanove, P. D. Altukhov, T. S. Argunova, A. A. Bakun, A. A. Budza, V. V. Chaldyshe, Y. A. Kovalenko, P. S. Kop'ev, R. N. Kutt, B. Ya. Meltser, S. S. Ruvimov, S. V. Shaposhnikov, L. M. Sorokin and V. M. Ustinov: Semicond. Sci. Technol. **8** (1993) 347.