Temperature-Dependent Hall Study on p-Type GaN Epilayers Grown by Metalorganic Chemical Vapor Deposition

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In this study, temperature variable Hall measurements were performed in the range of 150K –500K, on two p-type GaN epilayers grown on (0001)-plane sapphire substrates by metalorganic chemical vapor deposition.

The growth parameters are as follows: both samples were grown at 1050 ^{o}C, with the same TMGa flow rate of 226 μmol/min; the Cp2Mg flow rate is 5.7 μmol/min for sample #1 and 4.5 μmol/min for sample #2; and NH3 flow rate is 11 liters/minute for sample #1 and 18 liters/minute for sample #2.

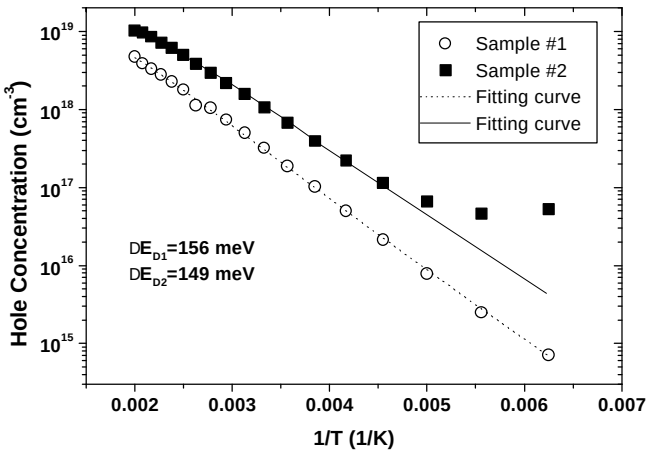

Figure 1: Temperature dependence of hole concentrations in different p-type doping GaN samples.

Figure 1 shows the temperature dependence of hole concentration of the two samples and fitting results by the charge neutrality condition. In sample #1, the hole concentration decreases monotonically with decreasing temperature, and its temperature dependence can be well explained by the charge neutrality condition with one acceptor level contributing to the carriers in valence band, throughout the whole temperature range in our experiment. The thermal activation energy was obtained to be 156 meV, which is consistent with the data reported by others[1-2]. In sample #2, one acceptor level model can only well cover the data at higher temperatures, but fails to explain the data at lower temperatures. The carriers transporting in the impurity band may account for the data at lower temperatures. The thermal activation energy from the fitting of the data at higher temperature parts is 149 meV, which is a little smaller than that of sample #1. This can be explained by interaction of the acceptor wave functions which reduces ionization energies, as has been observed for other semiconductors such as Si and Ge[3]. It is worth noting that the Mg dopant in the gas phase during growth for sample #1 is larger than that for sample #2, but the hole concentration in sample #1 is smaller that that in sample #2. This implies that Mg incorporation efficiency for sample #1 may be smaller than that for sample #2, and/or the compensation may be more severe in sample #1 than that in sample #2. This implication is confirmed by the parameters obtained from the fitting of the hole concentration with the charge neutrality condition $p+N_{comp}=N_A/[1+gp/N_V \exp(\Delta Ed/kT)]$ as seen in Table 1.

Table1: The parameters obtained by fitting the hole concentration with the charge neutrality condition.

Samples	ΔE_d (meV)	N_A (cm^{-3})	N_{comp} (cm^{-3})
#1	156	3.5x10^{20}	8.6x10^{18}
#2	149	9.0x10^{20}	7.0x10^{18}

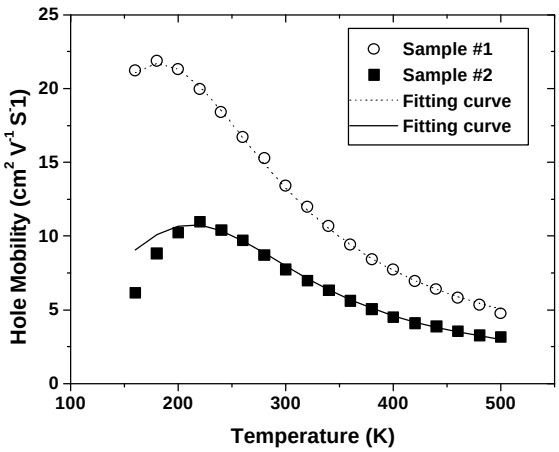

Figure 2: Variation of hole mobility as a function of temperature.

Figure 2 shows the variation of hole mobility with temperature. In both samples, the hole mobility increases at first as the temperature decreases, and then starts to saturate for sample #1, and decreases for sample #2 below a certain temperature (200K for sample #1 and 220K for sample #2). The hole mobility of sample #2 is smaller than that of sample #1. There are many scattering factors limiting the hole mobility in GaN, such as ionized acceptor scattering, acoustic phonon scattering, polar optical phonon scattering, piezoelectric scattering and so on. The temperature dependence of the hole mobility limited by these scattering factors is listed as follows,
$\mu_{io} \sim T^{1.5}$, $\mu_{ac} \sim T^{-1.5}$, $\mu_{po} \sim \exp(\Theta/T)$, $\mu_{pi} \sim T^{-0.5}$.
Obviously, any single one of these factors can not explain well the experimental data. A detailed fit was performed to interpret the experimental data by considering all these scattering factors,
$1/\mu = 1/(P1xT^{1.5})+1/(P2xT^{-1.5})+1/(P3 \text{ x } e^{\Theta/T})+1/(P4xT^{-0.5})$.
The fitting results are shown in Figure 2 and the parameters obtained are listed in Table 2. It can be seen that the data for sample #1 can be fitted very well throughout the whole temperature range while the data for sample #2 can be fitted well in a large part and the deviation only occurs at the lowest temperature part. This deviation comes from the same reason as that for hole concentration, being due to the impurity band conduction. From Table 2, it can be seen that ionized acceptor scattering plays a main part in limiting the hole mobility at low temperature, accounting for the saturation phenomenon occurring in both samples. In sample #2 the ionized acceptor scattering is even more dominant causing the mobility smaller than that of sample #1 in the whole temperature range. At high temperature, the optical phonon scattering mechanisms plays a major part in limiting the mobility. On the other hand, the acoustic phonon scattering plays a significant role throughout the whole temperature range in our experiment. Finally compared to other scattering factors, the piezoelectric scattering plays a minor role in limiting the hole mobility.

Table2: The parameters used in fitting the experimental results of hole mobility μ. $\mu = 1/(1/\mu_{io}+1/\mu_{ac}+1/\mu_{po}+1/\mu_{pi})$, where $\mu_{io}=P1 \text{ x } T^{1.5}$, $\mu_{ac}=P2 \text{ x } T^{-1.5}$, $\mu_{po}=P3 \text{ x } \exp(\Theta/T)$, and $\mu_{pi}=P4 \text{ x } T^{-0.5}$.

Samples	P1	P2	P3	P4
#1	0.015	155000	1.0	30000
#2	0.005	250000	0.43	30000

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