Capture Barrier of Sn-Related DX Centers in AlGaAs Epilayers

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ABSTRACT

Thermal capture and emission processes of Sn-related DX centers in $Al_xGa_{1-x}As$ ($x = 0.26$) were measured by a constant capacitance (CC) voltage transient in various temperatures. By employing a Laplace defect spectroscopic (LDS) method, the non-exponential transients were decomposed into several discrete exponential components. The results shown that more exponential components appeared in the small emission rate region as capture period increased. This indicates that electrons preferentially fill shallow energy levels due to their lower capture barriers. Discrete exponential components of the capture process were identified and four of their barriers were preliminarily measured to be about 0.14, 0.15, 0.16, and 0.17 eV, respectively.

Keywords: capture barrier, DX centers, AlGaAs epilayers

1. INTRODUCTION

DX centers, one of deep centers related to donors, have been found to be the universal deep states in most of III-V alloy semiconductors. They have been attracting much interest for their unusual properties. People have adopted kinds of methods to study them. One of most widely used techniques for deep level measurements is the junction capacitance and current transients caused by the carrier transitions from deep levels.[1] To decompose non-exponential transients with high resolution, a Laplace DLTS was proposed to undertake numerical inverse Laplace transformation.[2] Recently, we developed a relatively simple program, a Laplace defect spectroscopy (LDS), to carry out the numerical inverse Laplace transformation in real time, employing the conjugate gradient method.[3] In the previous work, the emission rates of holes and electrons from deep centers have been studied in several III-V alloy semiconductors.[3, 4, 5] The results were consistent with the DLTS measurements. However, the thermal capture process has not been systematically investigated. Most scholars usually adopted fitting routines to decompose non-exponential transients, which can not reflect the realistic fine structures of capture barriers. Therefore, it is worthwhile to analyze capture behavior of DX centers in detail.

In this work, thermal capture and emission processes of Sn-related DX centers in $Al_xGa_{1-x}As$ ($x = 0.26$) were measured by a CC voltage transient. The non-exponential transients were decomposed into discrete exponential components by employing LDS method. The order of the capture process was investigated by measuring the variation of exponential components of emission as capture period increased. The discrete exponential components of the capture process were identified and their barriers were finally obtained.

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2. EXPERIMENTAL

The samples used in this study were n-type Sn-doped $Al_xGa_{1-x}As$ (x = 0.26). Sn-doped AlGaAs layers were grown on n^+-type GaAs substrates by liquid-phase epitaxy. The Sn donor impurity was introduced during the growth with net electron concentration of $(3\text{-}10) \times 10^{16}$ cm^{-3} at room temperature. P^+-type layers were formed by Zn diffusion. Temperature of the sample was varied in the region of 77-400 K. The temperature dependence of free electron concentration was measured by capacitance-voltage characterization. Capacitance variation was detected by a capacitance meter of Booton 72BD with modified response time shorter than 0.1 ms. Voltage transient was carried out by a bias controller to keep the junction capacitance constant. The voltage transient was recorded and analyzed by a personal computer with an Intel Pentium II /400 CPU, a 128 MB RAM, and a hard disk of about 10 GB storage space.

3. RESULTS AND DISCUSSION

Since there are several emission peaks for Sn-related DX centers in AlGaAs,[3, 6] it is necessary to determine the corresponding relation between the capture and emission rates. The corresponding relation was investigated by measuring the voltage transients of electron emission from the DX centers filled up with different capture periods of 100 us, 380 ms, and sufficient long, respectively. Only four distinguishable peaks are visible in the spectrum obtained with capture period of 100 us. A new peak appears in the low emission region of the spectrum as the capture period being increased to 380 ms. As the capture period increased to sufficient long, six well-resolved peaks are visible in the spectrum. Since the electrons preferentially fill the energy levels with larger capture coefficients, the facts indicate that the energy levels with larger capture rates correspond to those with higher emission rates.

Thermal capture process was further investigated by measuring the CC voltage transient due to the electron capture of the Sn-related DX centers. To exhaust electrons from the DX centers, the sample was cooled down to measuring temperatures in a reverse bias of -3 V. Then the bias was changed to zero and the capacitance of the sample was kept on constant by varying the bias. The bias transients were non-exponential. Similar to the emission process, the CC voltage transients of thermal capture process were analyzed by the numerical inverse Laplace transformation through employing LDS method. The spectra were displayed with the reciprocal of time constant of capture transient as abscissa and the signal amplitude as ordinate, as shown in Fig. 1. A peak in the spectra represents a single exponential component of the voltage transient of the capture

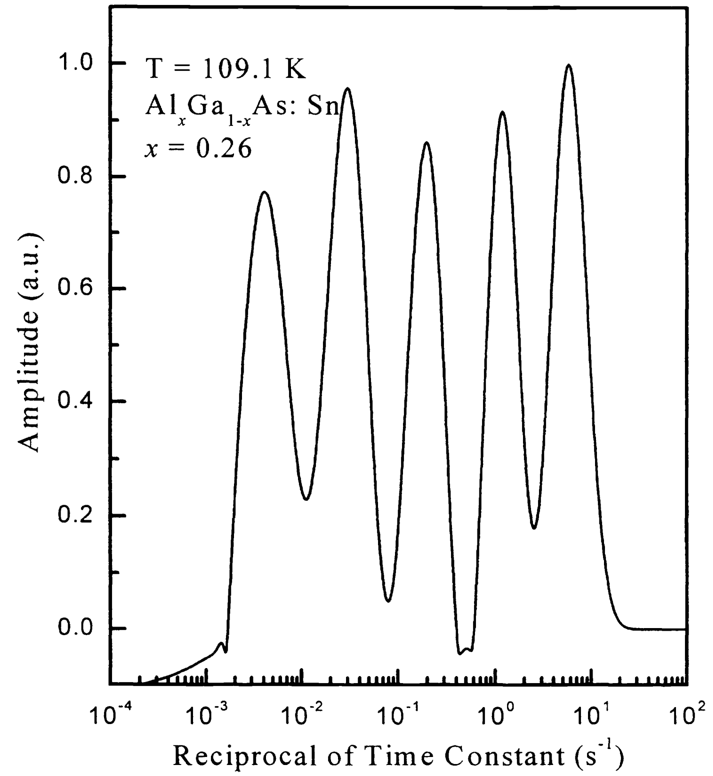

Fig. 1. Typical LDS spectrum of time constants of Sn-related DX centers in $Al_xGa_{1-x}As$ (x = 0.26).

process, and its position corresponds to a time constant. In the capture process, the time constant τ_c can be expressed as:

$$\frac{1}{\tau_c} = c_n \cdot n(T) + e_n, \qquad (1)$$

where c_n is capture coefficient, e_n is the relevant emission rate, $n(T)$ is the temperature dependent concentration of free electrons in the conduction band. The number of peaks decreases as the measuring temperature increases. Since the voltage transient of capture process in higher temperature is faster than that in lower temperature and the response times of the capacitance meter and of the bias controller are fixed in the order of millisecond, the faster exponential components must be lost. For this reason, we believe that the peaks from left to right of the capture spectra correspond to those of emission spectra measured with sufficient long capture period. By subtracting the relevant emission rate from the reciprocal of time constant of capture process, capture rates were obtained.

The free electron concentrations were measured by capacitance-voltage characteristics of the sample in relevant temperature, as shown in table 1. The capture coefficients were thus obtained according to Eq. (1). The capture coefficient is the function of the capture barrier E_c and can be expressed as:

$$c_n = BT^{1/2}\exp(-\frac{E_c}{kT}), \qquad (2)$$

where B is temperature independent constant. The temperature-dependent capture coefficients were plotted and the capture barriers were determined by line fitting of the slope of the Arrhenius plots of $\log(c_n/T^{1/2})$ versus $1000/T$, as shown in Fig. 2.

Table 1. Free electron concentration in various temperatures

Temperature (K)	Free electron concentration $n(T)$ (10^{16} cm^{-3})
104.1	5.44
106.6	5.05
109.1	4.94
114.0	4.81
118.7	4.94
127.8	4.97
136.4	5.08
144.7	5.10
152.7	5.14
160.3	5.24

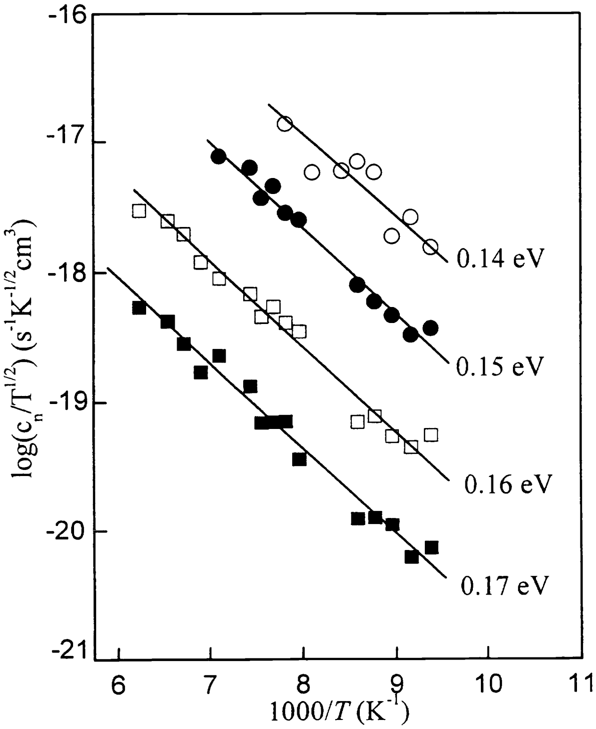

Fig. 2. Arrhenius plots of the capture coefficients of Sn-related DX centers in $Al_xGa_{1-x}As$ ($x = 0.26$)

Since the peaks in right of the LDS spectra of the capture process disappear in higher temperature, only the four peaks in left of the spectra are shown in the plots and their capture barriers are determined to be about 0.14, 0.15, 0.16, and 0.17 eV, respectively. These values are believed to be the fine structures of the capture barriers.

4. CONCLUSION

Thermal capture and emission processes of Sn-related DX centers were measured by the CC voltage transient in various temperatures. By employing the Laplace defect spectroscopic method, the non-exponential transients were decomposed into several discrete exponential components. The results shown that more exponential components appeared in the small emission rate region as capture period increased. This indicates that electrons preferentially fill shallow energy levels due to their lower capture barriers. The discrete exponential components of the capture process were also identified and four of their barriers were preliminarily measured to be about 0.14, 0.15, 0.16, and 0.17 eV, respectively.

5. ACKNOWLEDGEMENTS

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