Extended Abstracts of the 1995 International Conference on Solid State Devices and Materials, Osaka, 1995, pp. 761-763

Electronic Raman Scattering and DX Centers in $Ga_{1-x}Al_xAs$: Te

Shiyang Lian, Bizhong Zhou, Zhanghai Chen, Jian Xu and Hetian Zhou*

Department of Physics, University of Xiamen, Xiamen 361005, CHINA

Department of Physics, University of Peking, Beijing 100871, CHINA

The first observation of the electronic Raman scattering by Te donors in $Ga_{1-x}Al_xAs(x \geqslant 0.61)$ at low temperatures is reported. These experiments revealed the existence of the electronic Raman transition associated with electrons trapped at an effective-mass-like level. At higher temperatures, this level is depopulated to the benefit of a deep state which has all the characters of the DX center. These results indicate once again a shallow-deep bistable character of donor impurities in $Ga_{1-x}Al_xAs(x>0.22)$.

KEYWORDS: electronic Raman scattering, DX centers, bistable character, $Ga_{1-x}Al_xAs$: Te

1. Introduction

Ⅲ-V alloy semiconductors are important materials for solid state devices. Because they have properties which make them attractive for fabricating heterojunction devices such as lasers, light-emitting diodes, and various types of transistors, these alloy semiconductors have been studied extensively in the last 20 years. Deep donor levels, which are often called DX centers, have been observed in many Ⅲ-V alloy semiconductors. Not only because of their peculiar and interesting properties, but also because an understanding of the physics of this deep level is necessary in order to determine the usefulness of these materials for heterojunction device structures, DX centers have also been extensively studied. Despite all this, the microscopic structure of the deep donor level in these alloy semiconductors remains controversial. [1] Under general conditions, the DX centers become more stable than the shallow donors and the shallow donors transform into DX centers. The mechanism for this transformation is not yet fully understood. [2] While a great deal of progress has been made in the understanding of the DX center, the charge state of the defect is still a main subject of controversy. [2]

On the other hand, Raman scattering at low temperatures has proved a useful tool for the observation of electronic transitions in semiconductors. In particular, it is an appropriate tool to investigate the vally-orbit splitting of donor states of given parity in indirect gap semiconductors. Since the lower conduction band of $Ga_{1-x}Al_xAs(x>0.45)$ is known to change from the Γ to the X point of the Brillouin zone, it is expected, but remains to be demonstrated, that the related shallow-deep impurity state transition will favor the appearance of electronic Raman scattering, allowing for a possible comparison between these entities and DX centers. For this reason, we have performed Raman experiments on $Ga_{1-x}Al_xAs(x \geqslant 0.61)$ samples at low temperatures.

2. Experimental

The samples used in this study were Te-doped $Ga_{0.34}Al_{0.66}As$ and $Ga_{0.39}Al_{0.61}As$ grown by liquid phase epitaxy (LPE) on n-GaAs substrates. The concentrations of Te donor impurities in these epitaxial layers were $5\times10^{16}-5\times10^{17}cm^{-3}$.

Raman scattering experiments were performed on these samples at low temperatures changed from 20K to 300K. The temperature variation, obtained with the use of a helium-flow cryostat, was monitored by a thermocouple which was composed of a chromel and a alloy of gold with iron glued to the heat sink. The 514.5nm line of an Ar^+ laser was used in these experiments, it approximated to a quasi-resonant condition giving rise to a large spectral signal. In order to improve the signal-to-noise ratio, a slowly scanning method was used in our experiments.

3. Results and Discussion

Fig. 1 and Fig. 2 represent the essential results which were the evolutions of Raman spectra with temperature change obtained from our experiments. At low temperatures (such as 20K, 40K and 80K), a new speak occurred at about 320 cm^{-1}. As soon as the sampls were heated over 100K (such as 110K and 120K), the new speak disappeared. Clearly, This new speak which appeared at low temperatures had all the characteristics of the electronic Raman scattering due to shallow donor impurities in indirect band gap semiconductors.

Temporarily, regardless of DX level being in Ⅲ - V alloy semiconductors, the shallow donor states may be introduced into $Ga_{1-x}Al_xAs$ by Te impurities substituting for As atoms. We assume that the conduction band minima of $Ga_{1-x}Al_xAs(x>0.45)$ are at the Brillouin zone boundary in the ⟨100⟩ direction, i. e. , there are three equivalent minima. The symmetries of the Te donor impurities in $Ga_{1-x}Al_xAs$ depends upon they substitute for the more electronegative As atoms. The As site donors have S-like symmetry. [3] This threefold degeneracy of the 1S donor ground state in $Ga_{1-x}Al_xAs$ $(x>0.45)$ due to multiple valleys is lifted by valley-orbit interactions, producting a lowest singlet $1S(A_1)$ and a doublet $1S(E)$. The transitions between these states gave rise to the electronic Raman scattering in our experiments.

In reality, it is well known that DX centers exist as a general call of defects inherent to $Ga_{1-x}Al_xAs$ $(x>0.22)$. The characteristics of DX centers are quite unusual. The most pronounced characteristic of this class of defects is its very large lattice relaxation. This gives rise to two striking phenomena; persistent photoconductivity and a very large Stokes shift. [1]

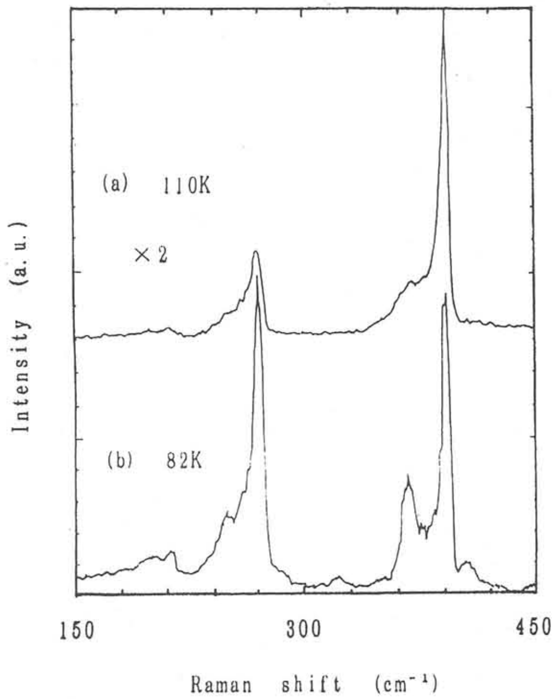

Fig. 1. Raman spectra of $Ga_{0.34}Al_{0.66}As$: Te at low temperature. Experimental condition: 514. 5nm; (a) $1cm^{-1}/3sec.$, (b) $1cm^{-1}/5sec.$

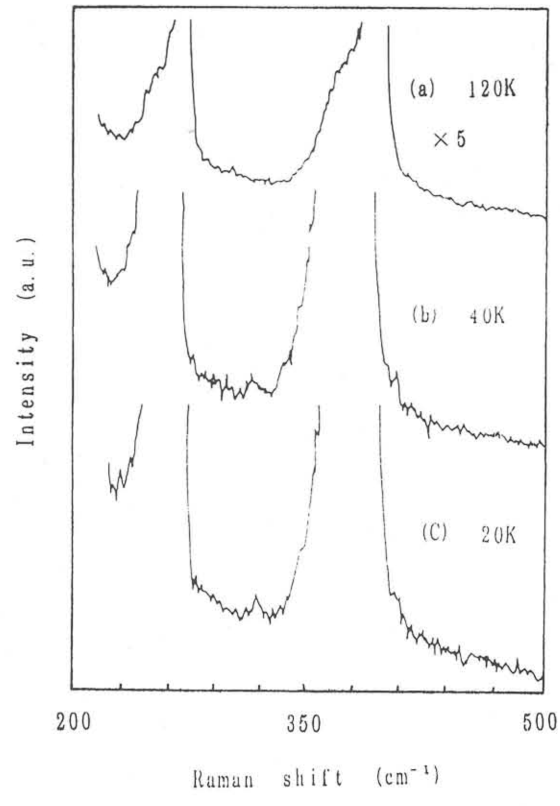

Fig. 2. Raman spectra of $Ga_{0.39}Al_{0.61}As$: Te at low temperature. experimental condition: 514. 5nm, $1cm^{-1}/0.5sec.$

However, it is observed in our experiments that at low temperatures (such as 20K, 40K and 80K), the existence of the electronic Raman scattering is associated with electrons trapped to an effective-mass-like level. Obviously, it shows that the effective-mass-like state is of photon-induced at low tempevatures. The photoinduced metastable state can last without quenching for an immeasurably long time at low temperatures. The only way of restoring a previous state of the DX center is to heat a photoconverted sample to about 100-150K.[4] Therefore at higher temperatures (such as 110K or 120K), the new speak disappeared. It is expressed that this level is depopulated to the benefit of a deep state which has all the characteristics of the DX-like level. These results indicate once again a shallow-deep bistable character of Te donor impurities in $Ga_{1-x}Al_xAs(x>.022)$.[5]

4. Conclusions

The investigations of Raman scattering experiments performed on Te-doped $Ga_{1-x}Al_xAs$ ($x\geqslant 0.61$) samples as a function of temperature show that in the given alloy compositions corresponding to the indirect-band-gap structure, the optical induced metastable state of the Te donor impurties at low temperatures is the usual effective-mass-like state giving rise to the electronic Raman scattering. This metastability disappears at higher temperatures to the benefit of a stable DX-like deep state. It shows the bistablility of donor impurities in $Ga_{1-x}Al_xAs(x>0.22)$.

Acknowledgments

We would like to thank Professor Qisheng Huang and Yuanyan Liao for their cooperation in these experiments. This work was partially supported by the National Natural Science Foundation of China and the Provicial Natural Science Foundation of Fujing, CHINA.

1) P. M. Monney, J. Appl. Phys. 67 (1990) R1.

2) J. A . Wolk, M. B. Kruger, J. N. Heyman, W. Walukiewicz, R. Jeanloz, and E. E. Haller, Phys. Rev. Lett. 66 (1991) 774.

3) Thomas N. Morgan, Phys. Rev. Lett. 21 (1968) 819.

4) Janusz E. Dmochowski, Jerzy M. Langer, Jolanta Raczynska, and Wolfgang Jantsch, Phys. Rev. B38 (1988) 3276.

5) P. Seguy, M. Zigone, and G. Martinez, Phys . Rev. Lett. 68 (1992) 518.