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Evaluation of the Semiconductor Heterojunctions Interface Using a Free Electron Laser

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1. Introduction

It is well known that the nature of the interface in semiconductor heterojunctions plays an important role for determining the behavior and performances of an entire class of semiconductor devices. Among the parameters which characterize the interface in semiconductor heterojunctions, the band discontinuity has been the subject of intense experimental and theoretical research due to its significance in a variety of heterojunction devices [1]. Various experimental methods to measure band discontinuities can be divided into three categories: optical spectroscopy such as optical absorption, electron spectroscopy such as x-ray photoelectron spectroscopy, electrical techniques such as *C-V* or *I-V* characteristics and photocurrent measurement such as internal photoemission technique. Of these methods, internal photoemission (IPE) is a simple and direct method for determining the band discontinuities. IPE, however, have suffered from the need of the highly bright and tunable light which is suitable for studying the band discontinuities of heterojunctions interested in optoelectronics such as GaAlAs/GaAs. Recently the free electron laser [FEL] has been of much interest in utilizing its tunability and intense peak power operative in the infrared range [2]. Here we investigate the band discontinuity of the GaAlAs/GaAs heterojunctions using a free electron laser internal photoemission technique [FEL-IPE] and discuss the results in comparing the previous studies.

2. Results and Discussions

The $Ga_{1-x}Al_xAs/GaAs$ heterojunction system is currently the most important technologically, and has therefore been the subject of by far the most extensive experimental investigation. Despite these efforts, there existed for some time considerable controversy regarding the actual value of the $Ga_{1-x}Al_xAs/GaAs$ band discontinuity [3].

Figure 1 shows an experimental setup of measuring the conduction band discontinuity in semiconductor heterojunctions. The detection, based on the principle of internal photoemission, is achieved by amplifying and measuring the external photocurrent under optical pumping, and identifying the discontinuity-related threshold in the plot of current versus the photon energy. The GaAlAs/GaAs heterojunctions were obtained by MBE growth of 1 μm of a Si-doped ($n=1x10^{16}/cm^3$) GaAs followed by MBE growth of 100 nm of nominally undoped GaAlAs, with 15 or 20 at.% Al. The structure was capped by 30 nm of highly doped GaAlAs with the same Al content and the electrical contacts were made of deposited gold. The measurement were made at 77 K in an optical cryostat configured so that the FEL beam entered the heterojunction through the GaAlAs layer. The FEL beam consists of trains of 10 ps pulses (micropulses) with 45 ns separation. The train continues for about 20 μs (macropulses) being repeated at 10 Hz. The FEL with a wavelength of λ = 7-12 μm was used. The photocurrent signal was recorded on a digital oscilloscope triggered by the macropulse of the electron beam in the FEL apparatus. The band discontinuity was estimated by use of the square-root plot. Figure 2 represents the square-root plot of the photocurrent spectrum in the cases of x = 0.15 and =0.2. We obtain ΔE_c = 118±1 meV (x = 0.15) and ΔE_c = 130±1 meV (x = 0.2). Assuming that ΔE_c is proportional to x, the relation ΔE_c = 0.73 x was derived.

For the $Ga_{1-x}Al_xAs/GaAs$ heterojunctions, it has

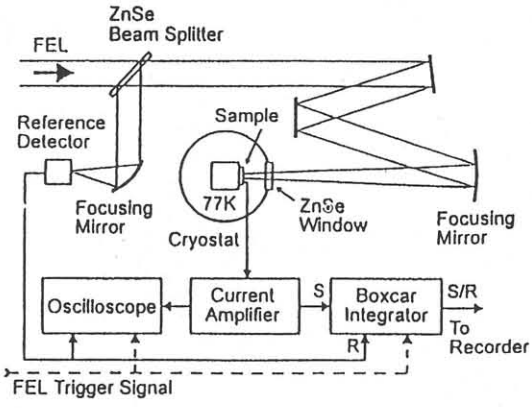

Fig.1. Setup for heterojunction band discontinuity measurement.

been widely accepted that the difference between the energy gaps (ΔE_g) is distributed with a conduction band discontinuity $E_c \sim 1.1$ x (x; Al content). However, recent experimental results based on photoluminescence from parabolic wells, capacitance-voltage (C-V) profiling through barriers, thermionic emission above barriers and the carrier concentrations in selectively doped heterojunctions suggest that $E_c \sim 0.75$ x, for $x < 0.4$. The previous results are shown in Fig.3 including the results obtained here. Our results indicate strongly that the relation of $E_c \sim 0.75$ x is most probable.

3. Summary

We investigated the interface of GaAlAs/GaAs heterojunctions using a free electron laser. The relation of ΔE_c (conduction band discontinuity) = 0.73 x (Al content) was derived. However, in order to confirm that FEL-IPE is a powerful method for measuring the band discontinuities more precisely, it will be indispensable to estimate in detail the properties such as temperature dependency or to compare them with the electrical measurements such as *I-V* characteristics. The study considering these problems is now in progress.

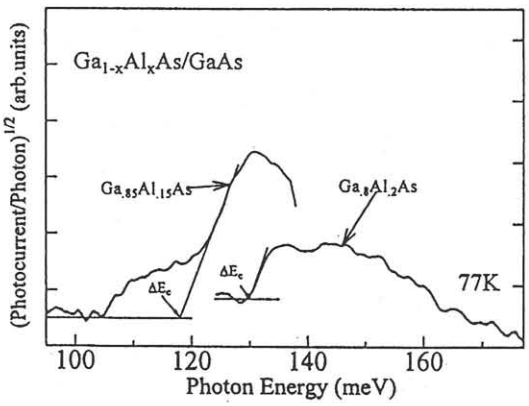

Fig. 2. Square-root plot of the normalized photocurrent spectrum in the $Ga_{1-x}Al_xAs/GaAs$.

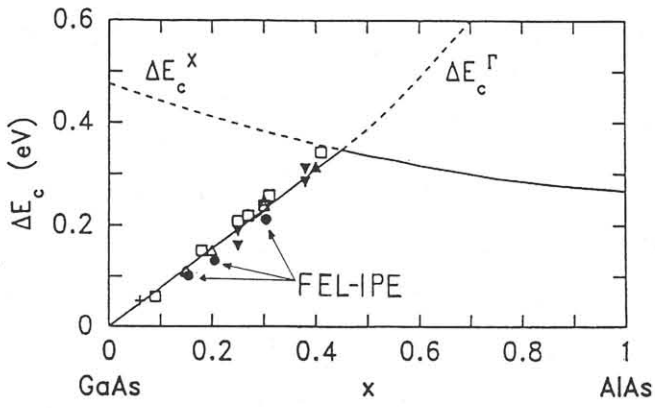

Fig. 3. Summary of experimental conduction band discontinuities data for the $Ga_{1-x}Al_xAs/GaAs$. The results by FEL-IPE method are also shown.

References

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