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Measurement of band discontinuity of ZnSe/GaAs heterojunction by a free electron laser

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The band discontinuity of ZnSe/GaAs heterojunction was investigated using the free electron laser internal photoemission(FEL-IPE) technique. This technique is based on the photocurrent spectroscopy utilizing the tunability and intense peak power of the FEL operative in the infrared range. The threshold of the photocurrent at near 110 meV photon energy which can be identified as the band discontinuity in ZnSe/GaAs heterojunction has been found.

1.INTRODUCTION

The band discontinuity of the semiconductor heterojunctions has been the subject of intense experimental and theoretical research for many years due to its significance in a variety of heterojunction devices.[1] The precise measurment of such discontinuities is indispensable for determining the behavior and performances of an entire class of semiconductor devices. In spite of the strong needs for the precise measurment of band discontinuities, there has been no effective techniques for the measurment. Recently the direct and accurate band discontinuity measurments using the free electron laser internal photoemission(FEL-IPE) technique have been proposed for the cases of AlGaAs/GaAs and GaAs/amorphous-Ge heterojunctions.[2,3] It has been suggested in these studies that direct measurments of buried conduction band discontinuities can be performed by optical pumping with a free electron laser and the accuracy can significantly contribute to the understanding of semiconductor band discontinuities which has been a basic conceptual problem in condensed matter physics.

On the other hand, the recent advances in II-VI semiconductor technology have produced the laser devices that operate in the blue/green spectral region.[4] Since these device structures are typically grown on GaAs substrates due to the small lattice mismatch, the nature of the interface between ZnSe and GaAs substrate is currently of intense because of their use in the fabrication of the blue/green laser. However, it has been difficult to measure the band discontinuity at ZnSe/GaAs interface directly by the conventional method.

In this paper we report the application of FEL-IPE technique for the band discontinuity measurment in the case of ZnSe/GaAs heterojunction.

2. RESULTS AND DISCUSSIONS

The detection, based on the principle of internal photoemission,[5-8] is obtained by amplifying and measuring the external photocurrent under optical pumping, and identifying the discontinuity-ralated threshold in the plot of current versus the photon energy. The ZnSe/GaAs heterojunction used in these experiments were prepared by molecular-beam epitaxy of a 0.54-μm-thick non-doped ZnSe layer on a Si-doped ($n=2x10^{18}/cm^{-3}$) GaAs substrate. A gold electrode with 1mm diameter and 20nm thickness was made to the ZnSe layer by vacuum evaporaton. A schematic diagram for the FEL irradiation measurment is shown in Fig.1. The free electron laser is an apparatus operated in Free Electron Research Institute, Inc.(FELI).[9] The measurments were made at 77K in an optical cryostat configurated so that the FEL beam entered the heterojunction through the ZnSe 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 average and peak powers at around 10 μm are 20mW and 1MW, respectively. The laser power was monitored by a pyroelectric joulemeter. The ZnSe layer was connected to a SRR570 low-noise current amplifier and the GaAs substrate was held at ground.

The FEL with the wavelength of λ=9.5-13 μm was used. The signal of photocurrent was recorded on a digital oscilloscope triggered by the macropulse of electron beam in the FEL appratus. Figure 2 shows a typical waveform of the photocurrent induced by FEL irradiation in the case of wavelength λ=9.5 μm and the waveform of the FEL macropulse. The signal was taken on the averaging of 50 scans. The pulse width of the induced photocurrent was about 20 μs and the sign of the current was positive to the GaAs substrate. Since the sample is measured at zero bias, this sign may be due to the electric field related to the Shottky barrier at ZnSe/Au (electrode) boundary. Estimation of the photocurrent was carried out by the time integral of the current signal, and the data was averaged for the sveral times of the measurements. The IPE spectrum shown in Fig.3 indicates that there exists the threshold of the photocurrent. As shown in the inset of Fig.3 the FEL is used to optically excite electrons over the conduction band discontinuity, thus producing an observable photocurrent. Note that the photocurent was normalized to the laser power via joulemeter. The threshold energy(ΔE_{th}) is obtained by the photon energy at this threshold. The estimtion of ΔE_{th} has been done by use of the models describing the near-threshold region that have the form $P \propto (h\nu - \Delta E_{th})^n$ where P is the photocurrent and hν is the photon energy.[5-7] The value of n has been known as 2, 2.5, 3 in the Fowler,Kane and Powell models. Here,using the standard least-square procedures we can find that the linear relation(i.e.. n=1) is the best fit. This relation is similar to the case of GaAs-amorphous Ge heterounction. [3)] Assuming the linear fit, it gives ΔE_{th}=113 meV. If we use Fowler fitting (n=2), we find that the estimate of ΔE_{th} changes by only 5 meV(i.e. ΔE_{th}=108 meV). Here, it does not seem that the value of n plays an esential role for determining the threshold ΔE_{th} of the photocurrent. We also find that no signuficant variations of ΔE_{th} occurred for the different photon densities of FEL(obtained with neutral density filters).

Band discontinuities of the heterojunction have been theoretically estimated in the emphasis on the valence band discontinuity(ΔE_v).[10)] According to this estimation, the value of ΔE_v in ZnSe/GaAs heterojunction has been in the range of 0.93 eV~1.27 eV. Then, we can obtain the conduction band discontinuity(ΔE_c) by using the

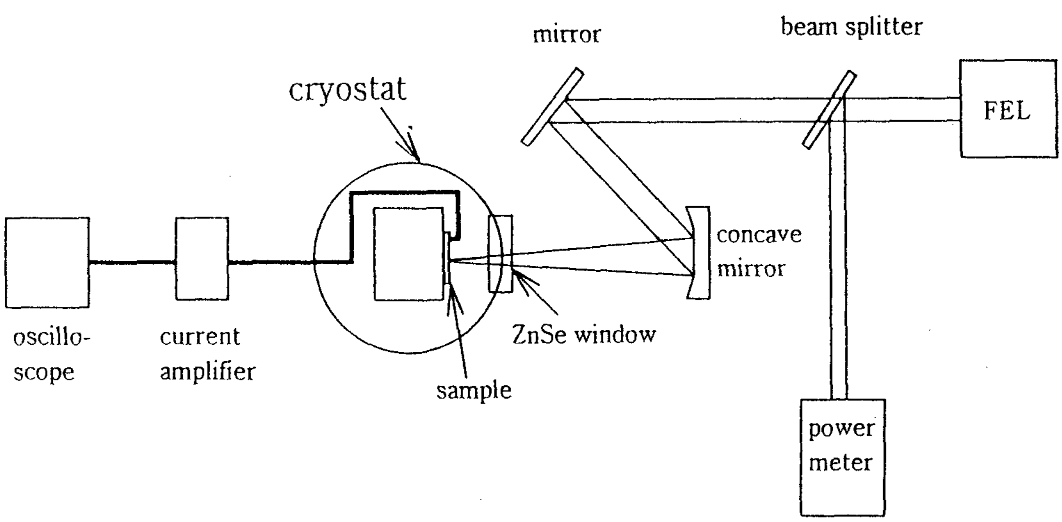

Figure 1. A schematic illustration of the experimental setup

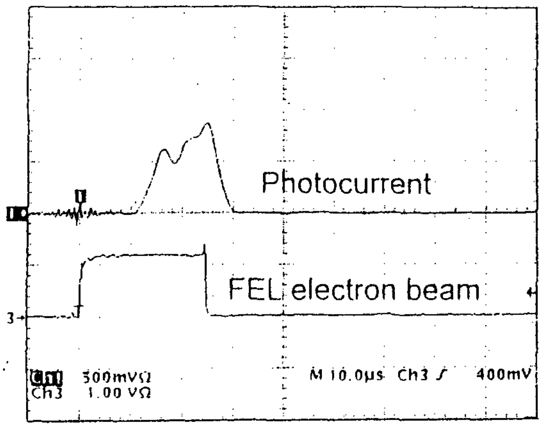

Figure 2. The wave forms of the photocurrent in the case of λ=9.5 μm and the macropulse of FEL electron beam

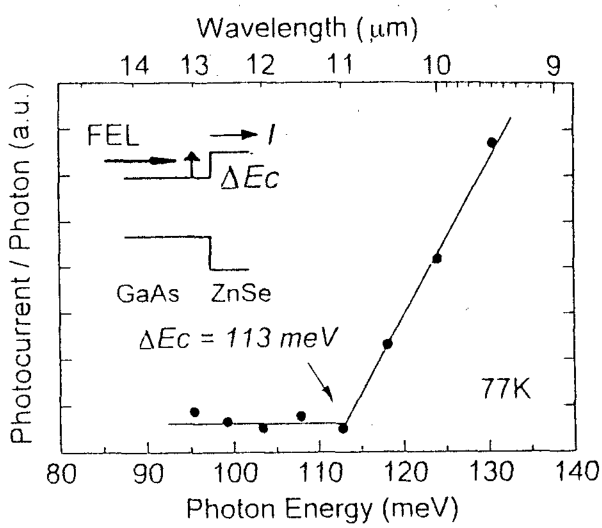

Figure 3. Spectrum of the normalized photocurrent in the heterojunction. Interface energy band diagram is shown in the inset.

relation $\Delta E_c = \Delta E_v + \Delta e_g$ where ΔE_g is the difference of the band gap energy. As the value of ΔE_g between ZnSe and GaAs is 1.27 eV at 77K, ΔE_c can be obtained in the range of 0 ~ 340 meV. Experimentally, ΔE_v of ZnSe/GaAs heterojunction has been estimated to be about 1.1 eV from x-ray photoelectron spectroscopy. [11] Similarly, this value indicates ΔE_c ~ 200 meV. However, note that there remains the uncertainty due to the indirect methods for determining ΔE_χ. We can confirm that the value of ΔE_{th} determined directly here could limit the range of the previously estimated conduction and discontinuity and could be identified as ΔE_c at ZnSe/GaAs interface.

FEL-IPE has many important advantages over other common techniques for measuring heterojunction band discontinuities. Particularly, it will be a powerful method in the case of smaller band discontinuities. Our results indicate that even the 100 meV band discontinuity can be precisely determined by FEL-IPE. Also, unlike conventional photoemission spectroscopies which require the interface to be within a few monolayers of the surface, IPE can be used on buried onterfaces deep beneath a surface, making it possible to study device-quality interfaces without the cumbersome requirement of in situ growth. We can expect that FEL-IPE will be also fruitful approach for the application to other system, such as ZnSe/ZnMgSe, GaAs/InP interfaces etc.

3. CONCLUSION

We investigated the photocurrent spectrum in ZnSe/GaAs heterojunction induced by a free electron laser. We find the threshold of the photocurrent at near 110 meV photon energy which can be identified as the band discontinuity of ZnSe/GaAs heterojunction.

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