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Photovoltaic Investigations of Interband Transitions in SiGe/Si Multiple Quantum Wells

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Abstract

The photovoltaic measurements have been carried out for the strained $Si_{1-x}Ge_x/Si$ multiple quantum well samples. The structures related to the interband transitions could be seen in the photovoltaic spectrum of good quality sample.

Due to the indirect band gaps of Si and SiGe, the optical interband transitions in SiGe/Si quantum wells are relatively difficult to observe in experiments as compared with that in the direct band gap III-V materials. Until recently, the photoluminescence (PL) induced by the near band edge exciton recombinations in SiGe/Si single quantum wells (SQWs) and multiple quantum wells (MQWs) were revealed by a number of groups. To study the optical transitions between hole subbands and electron subbands, one requires the absorption type measurements. The photovoltaic (PV) measurement is a simple version of optical absorption which has been successfully used in III-V quantum well systems. In this work, we report for the first time the PV measurements on SiGe/Si MQWs.

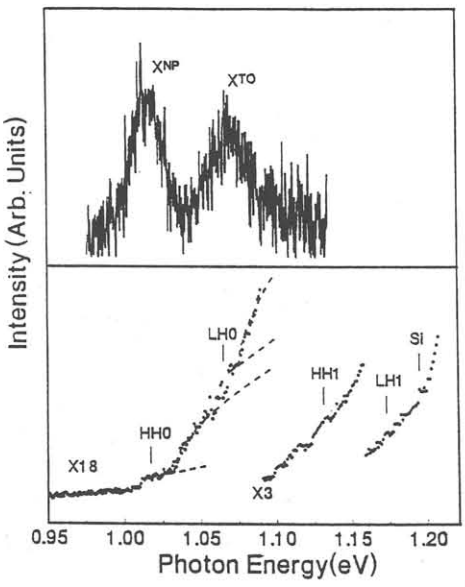

Fig 1. The PV spectrum of sample A at T=18K, the upper part is the PL spctrum of sample A at T=10K. The PL spectrum has been transformed by a mirror reflection with respect to the NP peak.

Samples were grown by the molecular beam epitaxy on Si (100) substrates. A Si buffer layer with the thickness of 500~600 nm and a Si cap layer with the thickness of 50 nm were deposited before and after growing the multiple quantum well structure. Two samples (A and B) with different Ge contents (0.25 and 0.5) and different numbers of periods were prepared for comparison. The unintentional doped layers

were found to be p-type, and thus are good for providing sufficient concentration of confined holes in measurements. Fig. 1 shows the PV spectrum of sample A, which has the structure of Si(50nm)/15[$Si_{0.75}Ge_{0.25}$(4nm)/Si(15nm)]/Si(600nm)/Si(100). The band alignment of sample A is type I with both the valence band quantum well and the unconfined conduction band quantum well in the alloy layer. Two plateau structures in the PV spectrum at 15K could be identified between the photon energies of 1.00 and 1.10eV, which equal approximately to the energy gaps of $Si_{0.75}Ge_{0.25}$ and Si, respectively. The first plateau at 1.010-1.035eV could be assigned to the transition from the heavy hole ground state (HH0) to the unconfined conduction states, and the second plateau at 1.060-1.070eV is related with the transition between the light hole ground state (LH0) and the conduction band. By using a Kronig-Penney model, the subband energy levels with respect to the conduction band in $Si_{0.75}Ge_{0.25}$ quantum well are calculated. The good coincidence between theoretical estimation (indicated by the four vertical bars in Fig.1) and experimental observation illustrates that the two dimensional densities of states in the hole subbands are revealed in the PV spectrum. The above argument could be further confirmed by the PL spectrum, where the non-phonon (NP) peak coincides fairly well with the steep rise of PV signal at 1.01eV, and the TA and TO phonon replica are agreed with the slope structures at 1.035 and 1.070eV in PV spectrum, respectively. The theoretical predicted transitions from HH1 and LH1 to the conduction band locate at 1.106eV and 1.169eV. In PV spectrum we do see these two structures. However, due to the rapid rise of absorption intensity above 1.10eV, the confirmative identification of HH1 and LH1 seems not easy.

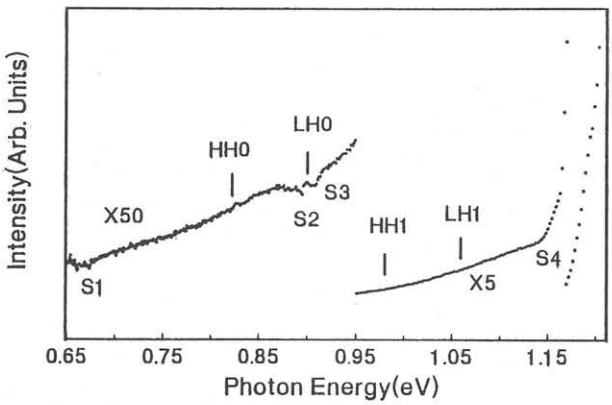

Fig 2. The PV spectrum of sample B at T=18K. The four vertical bars from left to right indicate the theoretical predicted HH0,LH0,HH1, and LH1 respectively.

Fig. 2 shows the PV spectrum of sample B with the structure as Si(50 nm) / 10 [$Si_{0.5}Ge_{0.5}$(4nm) / Si (15 nm)] / Si(500 nm) / Si(100). In addition to structures related from HH0 and LH0, some new structures related with defects appear. These defect structures not only smear out the signals from HH1 and LH1, but also make the HH0 and LH0 plateau structures not very clear. In PL measurement, the near band edge exciton PL peak can not be found, it might be quenched by these defects. The interfacial defects in sample B have been revealed by the deep level transient spectroscopy (DLTS) measurement, whereas no defect related DLTS signal was detected in sample A. Hence the defects might originated from the partial relaxation of large misfit strain between $Si_{0.5}Ge_{0.5}$ and Si layers. Although the details about these structures of defects are not known by now, it is safe to say that in order to study the intrinsic PV spectra of $Si_{1-x}Ge_x$/Si quantum wells, good quality sample with the defect density below the detection limit of DLTS is required.

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