Band Alignment of InAsSb/InAsPSb Multiple Quantum Well

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Band alignment of $InAs_{1-x}Sb_x/InAs_{0.67}P_{0.23}Sb_{0.10}$ quantum wells (QWs) with 0.05<x<0.13 has been determined by fitting the photoluminescence emission energy of the QWs measured from 10 to 280K. The results show the energy gap bowing of the InAsSb is totally from valence band, and the conduction band varies linearly as Sb fraction increases. The band lineup behavior can be well explained by a valence band anticrossing model. The model is also used to calculate the splitting-off energy of InAsSb, which is in good agreement with the reported data determined from photo-reflectance spectroscopy.

InAsSb/InAsPSb multiple quantum well

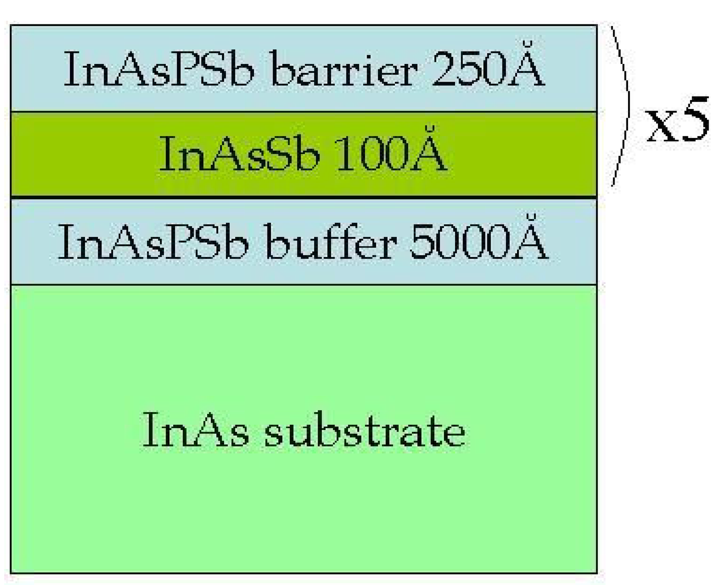

Fig 1. Layer structure of MQW.

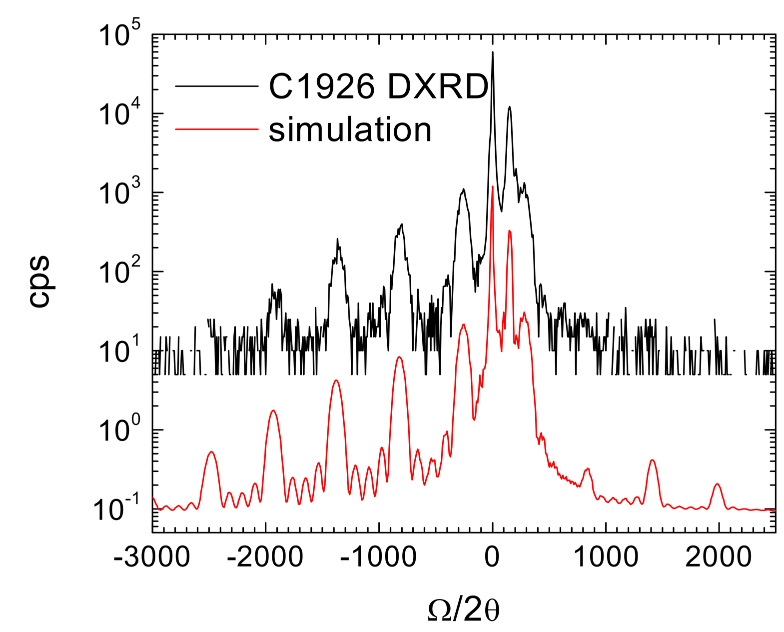

Fig 2. Experimental and simulated DXRD spectra of MQW.

The MQWs are composed of 100-Å-thick strained $InAs_{1-x}Sb_x$ wells (0.05<x<0.13) and 250-Å-thick $InAs_{0.67}P_{0.23}Sb_{0.10}$ barriers. Samples with 5-period QW were grown on (100) oriented n-type InAs substrates at 420 ~ 470ºC by a VG-V80H gas-source MBE system. HXRD measurements were used to analyze the layer structures. The black line is the experimental data, and the red one shows the simulation result from Bede RADS software. The parameters of the MQW structure were obtained from the simulation.

Temperature dependent PL

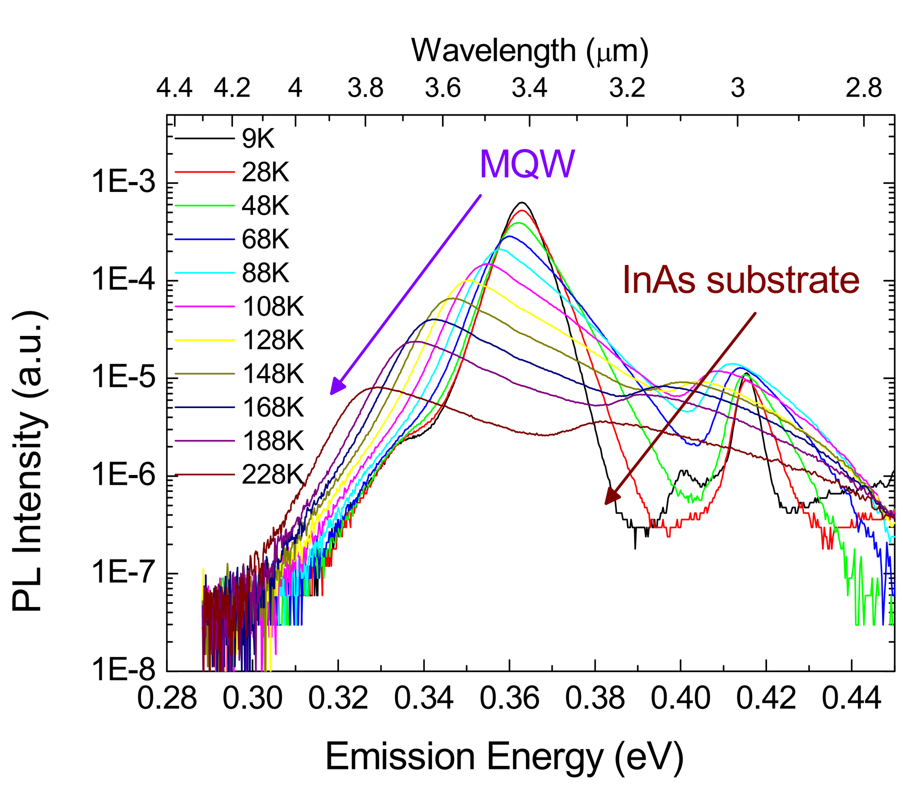

Fig 3. PL spectra measured from10 to 230K.

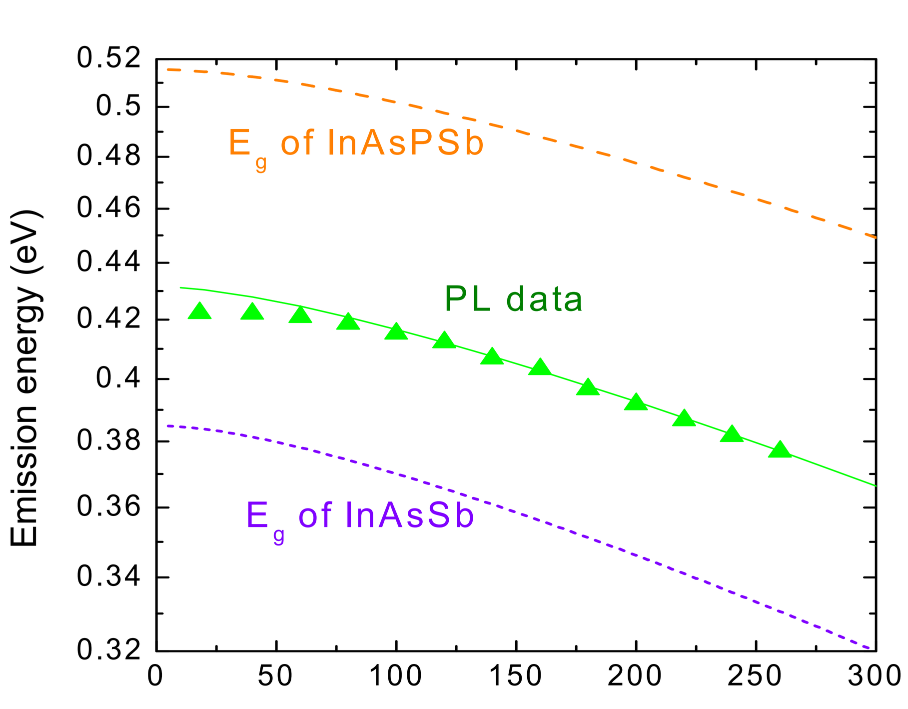

Fig 4. PL emission energy and energy gaps of barrier and well as functions of temperature.

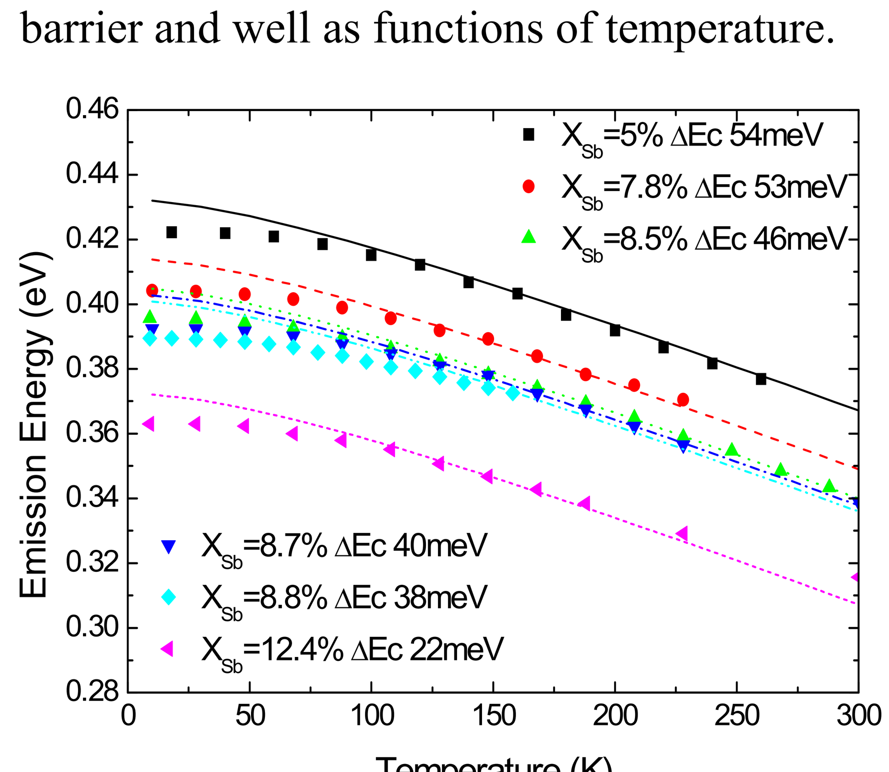

Fig 5. PL emission energy as a function of temperature.

Typical PL spectra are shown in Fig. 3. The spectra have two emission bands. The higher energy band is from InAs substrate, while the lower energy band is from the MQWs. As can be seen in Fig. 4, in the whole temperature range, the PL emission energy of the MQW is between the energy gaps of InAsSb well and InAsPSb barrier, indicating that the alignment of the MQW is type-I.

We use conduction band offset as a fitting parameter to fit the ground state energies of the electron and the heavy hole in the MQWs in the temperature range from 100 to 280K. From the emission energy fitting, the band offsets of each MQW sample are determined.

The experimental result deviates from the fitting curve only when the temperature is lower than 100K. At 10K, the PL emission energy is lower than the calculated transition energy by ~10 meV. We attribute the low temperature emission to the exciton recombination in the tail states of the MQW. When the temperature is higher than 100K, the carriers obtain thermal energy (~9 meV) and delocalize from the tail states.

Valence band anticrossing model

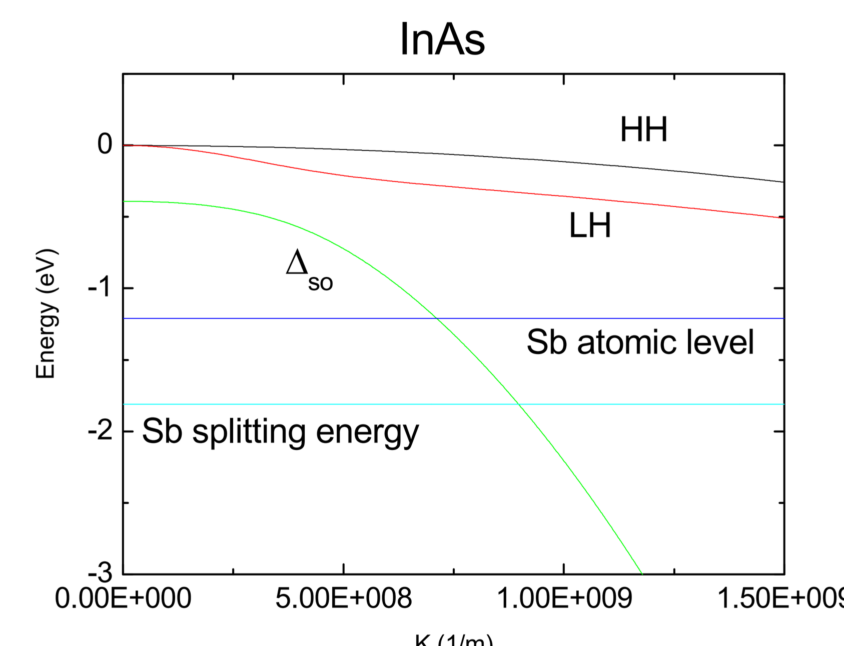

Fig 6. E-K diagram of InAs host bands and atomic levels of Sb.

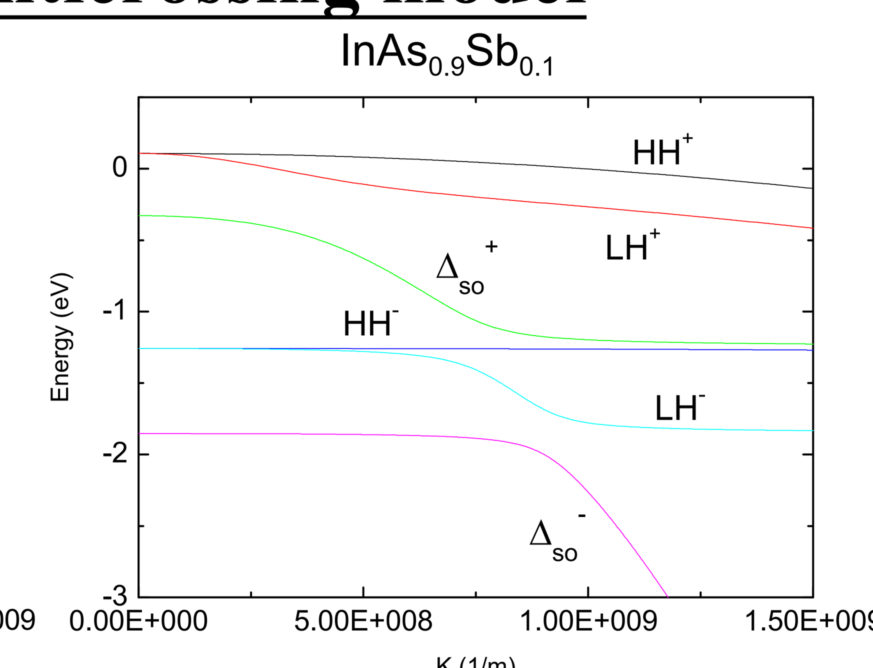

Fig 7. E-K diagram of $InAs_{0.9}Sb_{0.1}$ calculated by VBAC model.

A valence band anticrossing (VBAC) model [1] has been used to analyze the band structure of diliute-Sb InAsSb. The VBAC model considers a 6x6 standard Luttinger Hamiltonian by the addition of the six localized p-like states of the minority Sb. Fig. 6 shows the valence bands of the host InAs, the p-like atomic Sb level, and the atomic spin-orbit splitting energy of Sb. Fig. 7 shows the calculated band structure of InAsSb.

Ref [1]: K. Alberi, J. Wu, W. Walukiewicz, K. M. Yu, O. D. Dubon, S. P. Watkins, C. X. Wang, X. Liu, Y.-J. Cho, and J. Furdyna, Phys. Rev. B 75, 045203 (2007).

Band alignment and splitting-off energy

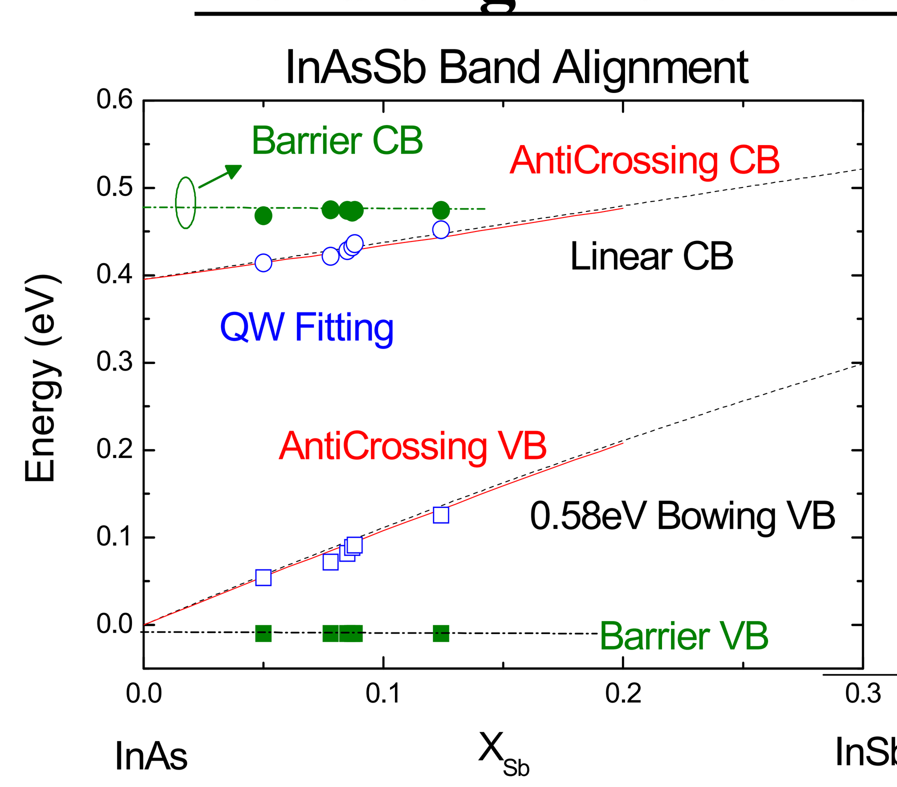

Fig 8. Band alignment of InAsSb /InAsPSb MQW.

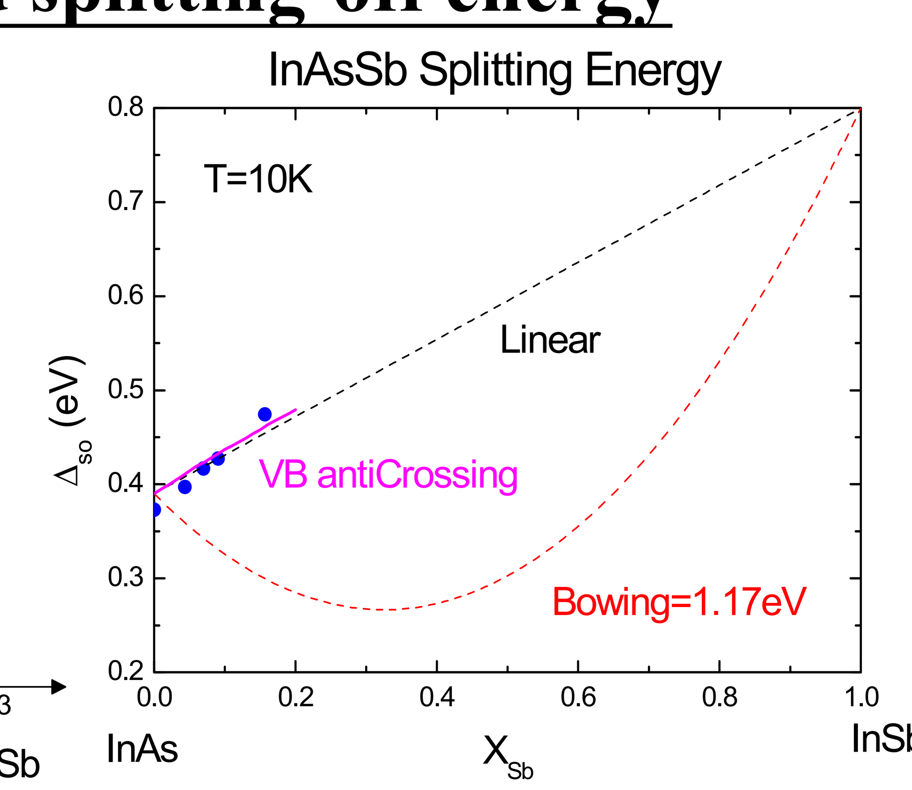

Fig 9. Spin-orbit splitting off energy of InAsSb.

The conduction band and valence band energies of $InAs_{1-x}Sb_x$ (0.05 < x < 0.13) and $InAs_{0.67}P_{0.23}Sb_{0.10}$ are shown in Fig. 8. After comparing the bowing parameters of the individual bands and the energy gap, we found that the energy gap bowing of InAsSb is nearly 100% from the valence band. Furthermore, VBAC model with the coupling parameter C_{Sb} as a fitting parameter was used to fit the conduction and valence band energies of InAsSb. The experimental data matches the calculation very well, as can be seen in Fig. 8. We also used the model to calculate the splitting off energy of InAsSb. The results as well as the reported experimental data, determined from photo-reflectance spectroscopy [2], are shown in Fig. 9. The calculated results are in good agreement with the experimental data, showing that the splitting off energy does not follow the curve with a bowing parameter of 1.17-eV [3].

Ref [2]:S. A. Cripps, T. J. C. Hosea, A. Krier et al., Appl. Phys. Lett. 90, 172106 (2007).

Ref [3]:O. Berolo, J. C. Woolley, and J. A. Van Vechten, Phys. Rev. B 8, 3794 (1973).

Conclusion

The band alignment of the InAsSb/InAsPSb MQWs have been determined by fitting the PL emission energy in the temperature range of 10~280K. The energy gap bowing is completely from the valence band, and therefore the conduction band change linearly with the Sb mole fraction. A modified valence band anticorssing model has been successfully used to calculate the energies of conduction band, valence band and spin-orbit band in InAsSb. The results are in good agreement with the experimental data.