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Evaluation of Interfaces in Narrow InAs/AlSb Quantum Wells

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Abstract. InAs/AlSb quantum wells may be grown with two types of interfaces: InSb-like and AlAs-like. The interface type refers to the half-monolayer of the well material and half-monolayer of barrier which are in contact. The type and quality of the quantum well interface is critical to the ISBT intensity and lineshape and, to a lesser extent, position. In addition to FTIR spectroscopy of the ISBT, we have performed transmission electron microscopy (TEM) to directly evaluate the quality of the interfaces at the atomic level. In order to evaluate the effects of interface type and quality on ISBT intensity, lineshape, and linewidth, we studied the TEM of a 10 nm QW sample with InSb-InSb interfaces and a 3 nm QW sample with InSb-AlAs interfaces.

1. Introduction

Quantum structures made from the 6.1-Å family of III-V compounds – InAs, GaSb, and AlSb – provide an ideal playground for the quantum engineering of electronic energy levels and wavefunctions due to their interesting band-edge alignment. In particular, the extremely large conduction band offset between InAs and AlSb (~2 eV) is promising for highly sophisticated architecture of multi-level systems with tailored transition energies and matrix elements. We are investigating the short-wavelength limit of intersubband transitions (ISBTs) achievable in InAs/AlSb quantum wells.

We have investigated ISBTs and photoluminescence (PL) in InAs/AlSb multiple quantum wells (MQWs) of 20 periods with well widths ranging from 2.1 nm to 10.5 nm. The ISBT absorption energy increased with decreasing well width and ISBTs disappeared in wells narrower than 7 nm; the PL energy decreased with increasing well width and PL disappeared in wells wider than 6 nm. In other words, PL and ISBTs are mutually exclusive. Also, we found that the ISBT absorption linewidth of the 10 nm InSb-AlAs interfaces QW sample is much wider than the 10 nm InSb-InSb interfaces one.

Since one of our goals is to explore the short-wavelength limit of intersubband transitions, which is expected in narrow InAs wells, finding out the reason for the disappearance of ISBTs in the narrower wells is extremely important. There are three possibilities:

• The ISBT absorption intensity in narrower wells is too small to be observed. This is unlikely to be the cause because we compared the absorption intensity of 7, 8, 9 and 10 nm wells and found that the absorption intensity of the narrower wells was not significantly smaller than the wider wells.

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• The ISBT absorption is masked by another type of absorption, for example, interband absorption. This situation is possible for the 6 nm QW, in which PL and ISBTs are predicted at about the same energy. But for even narrower QWs, the intersubband transition energies should be significantly larger than the interband transition energies, therefore they should not overlap and mask each other.

• The ISBT absorption peak is so broad that the peak height is too small to be observed. It is well known that interface roughness is the major contributor to ISBT linewidth, and broadening due to interface roughness is more pronounced in narrower wells. In order to test the hypothesis that the ISBT is too broad to be observed in narrow wells due to interface roughness, we have made TEM images of wide and narrow wells.

2. Sample growth

The samples were grown by molecular beam epitaxy (MBE). Before growth, the GaAs substrates were thermally cleaned at 630 °C for 30 minutes in an As_4 atmosphere. Buffer layers consisting of 10 nm AlAs, 1000 nm AlSb and 15 periods of GaSb (6 nm) / AlSb (6 nm) superlattices were grown at 550 °C. These buffer layers are used to change from the lattice constant of GaAs (0.56 nm) to that of GaSb (0.60 nm). After the growth of buffer layers, InAs/AlSb MQWs were grown at 420 °C. Finally, GaSb was grown as a cap layer.

The InAs/AlSb MQW interface types can be controlled by the growth sequence and are expected to affect the band structure [1]. Two types of interface are possible: InSb-like and AlAs-like. Yano et al. have reported that the low temperature PL intensities of InAs/AlSb QWs with InSb-type interfaces were much stronger than those with AlAs-type [2]. For comparison, two types of interfaces were grown: InSb-like on both sides of the QW, and AlAs-like from InAs to AlSb and InSb-like from AlSb to InAs (Figure 1).

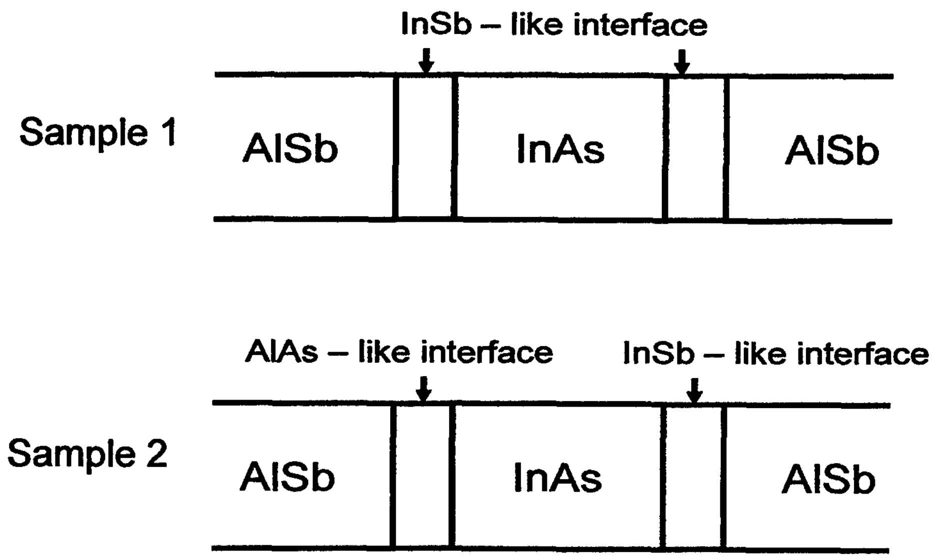

Figure 1. Two samples studied: InSb-InSb interfaces and InSb-AlAs interfaces

3. TEM sample preparation

To evaluate QW interfaces using TEM, the sample must be less than 10 nm thick (the penetration distance of electrons). The sample preparation process will be described in detail in this section.

The first step is to build a stack. Two InAs/AlSb MQW samples are glued face to face using M-bond 600/610 to increase the viewable quantum well area, and two silicon dummy pieces are attached to make the stack stronger. Then the stack is cured at 170°C for an hour. The stack is thinned to 100 µm using a hand polisher. An optical microscope is used to check the stack thickness.

The second step is to reduce the sample thickness to 10 µm using a dimple grinder. The dimple grinder has two major parts: a diamond dimpling wheel and a thickness measuring system. The effect of dimpling is to produce a thin central region on the sample stack while leaving a thick, supporting rim which protects the sample stack from damage.

The last step of sample preparation is ion-milling, which further reduces the sample thickness. The sample is glued on a copper grid and put in an ion mill. Argon ion guns, tilted at 15° to reduce sputter damage, hit the center of the sample. The rate of thickness reduction with ion-milling is much slower than with mechanical processes. Ion milling is continued until a hole appears at the QW edges and the region around the hole has a thickness of approximately 10 nm, which is good for TEM analysis.

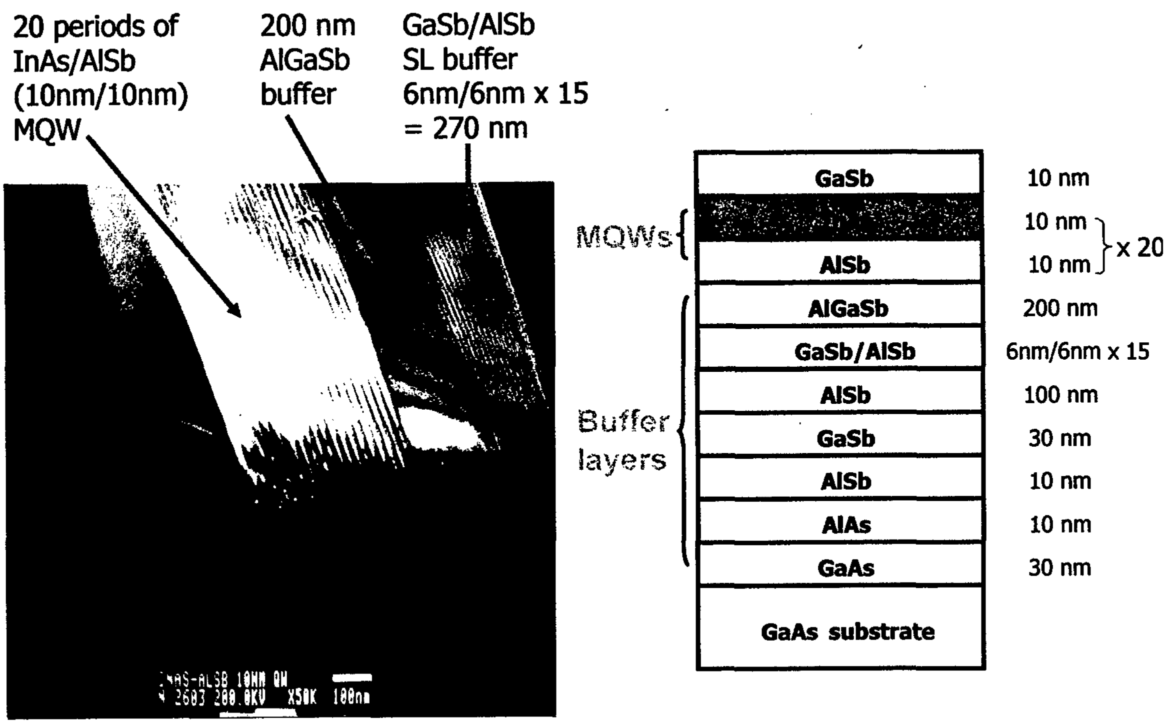

Figure 2. Left: micrograph of sample cross-section taken at 50K magnification. Right: Detailed 10 nm QW sample structure.

4. TEM analysis

We studied the TEM of a 10 nm InSb-InSb interfaces sample (Sample 1) and a 3 nm InSb-AlAs interfaces sample (Sample 2). Figure 2 shows a micrograph of the cross-section of the 10 nm InSb-InSb interfaces sample. It was taken at relatively low magnification (x 50K) to see the entire sample cross-section. The MQW region is clearly visible, along with the AlGaSb and GaSb/AlSb superlattice buffer layers. Then we looked at the QW regions using a higher magnification.

Figure 3 shows a micrograph of 10 nm InSb-InSb interfaces sample taken at 1M magnification. We can see that the interfaces are flat, parallel to each other and in good shape. The dark material is InAs and the bright material is AlAs. Figure 4 shows a micrograph of 3 nm InSb-AlAs interfaces sample taken at 1M magnification. We can tell that the interfaces are not flat and the InAs layers have different thicknesses. The InSb-InSb interfaces sample has better interface quality than InSb-AlSb interfaces sample. This finding is in agreement with our ISBT results: the ISBT absorption linewidth of InSb-AlAs interfaces sample is much wider than the absorption linewidth of InSb-InSb interfaces sample of the same well width.

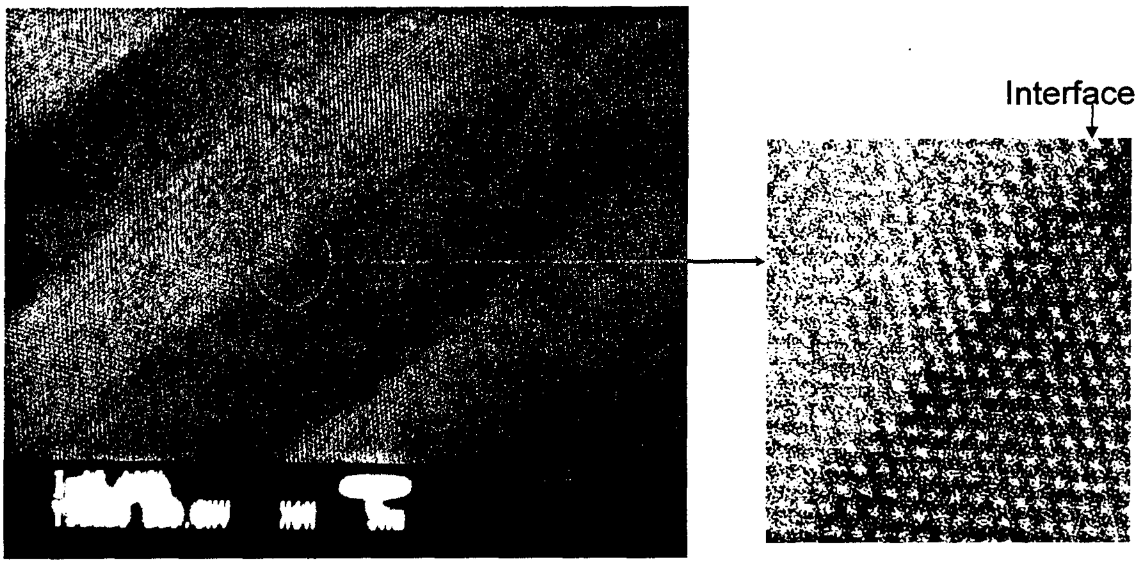

Figure 3. Left: Micrograph of 10 nm InSb-InSb interface sample taken at 1M magnification. Right: Detail of micrograph on the left at 8 times magnification.

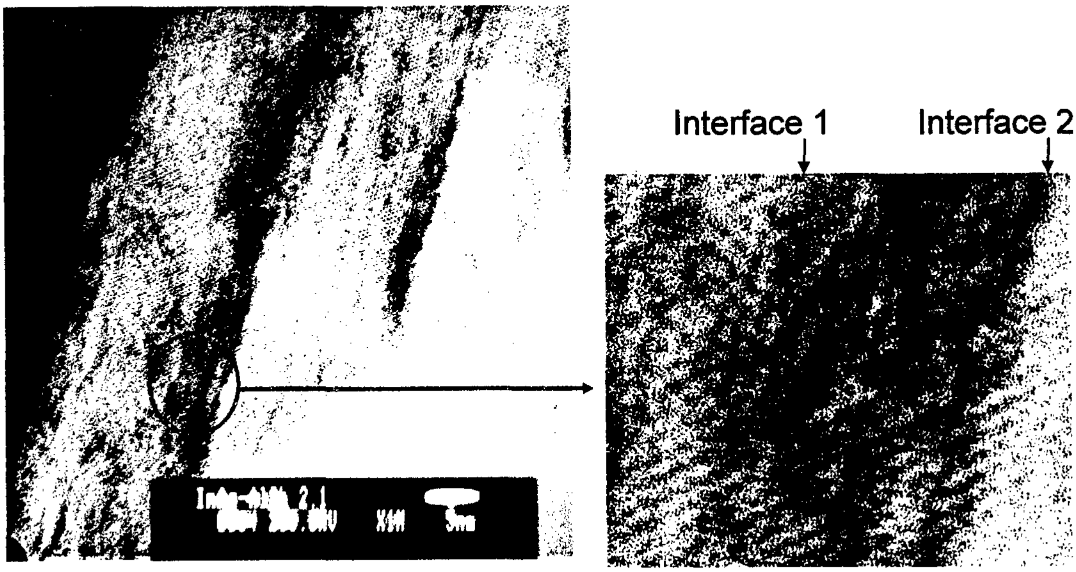

Figure 4. Left: Micrograph of 3 nm alternating interfaces sample taken at 1M magnification. Right: Deatail of the micrograph on the left at 8 times magnification.

5. Conclusion

We have taken TEM micrographs of InAs/AlSb quantum well samples with both interfaces InSb-like and with one interface InSb-like, one AlAs-like. The interface quality of the InSb-InSb sample is much better than the InSb-AlAs sample, which is in agreement with the wider ISBT absorption linewidth of InSb-AlAs samples.

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