Interface properties of (Al)GaAs/GaAsBi quantum wells grown by MBE

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Dilute bismide alloys, such as Ga(As,Bi), represent a novel class of materials that have garnered significant attention due to their unique properties and potential applications in various fields, such as in infrared optoelectronic devices and high-efficiency solar cells. Despite their immense potential, the precise understanding of Bi incorporation into the lattice has remained challenging yet essential for optimizing material quality and harnessing their full functionality.

In this work, we focus on the investigation using (Scanning) Transmission Electron Microscopy (S)TEM of the interface properties and segregation effects in (Al,Ga)As/Ga(As,Bi) quantum well (QW) structures grown by molecular beam epitaxy (MBE).

We find that the interfaces of GaAs/Ga(As,Bi) QWs are dramatically broadened by Bi segregation, as clearly observed in elemental composition profiles directly obtained from the analysis of chemically-sensitive $\mathbf{g}_{002}$ dark-field TEM (DFTEM) micrographs. Evaluation of segregation effects is possible via quantification of the interface width using a combination of Muraki´s phenomenological segregation model with a sigmoidal function defining the intrinsic interfacial width. We discuss how the use of innovative growth procedures/strategies at the interfaces of GaAs/Ga(As,Bi) QWs is very successful in reducing Bi segregation. In particular, the use of a two-temperature growth procedure [1] or the most recent strategy of replacing GaAs barriers with (Al,Ga)As [2,3] significantly reduce Bi segregation.

On the other hand, our detailed TEM investigations of (Al,Ga)As/Ga(As,Bi) QWs disclose the presence of Bi_{Ga} hetero-antisites, a highly anticipated defect yet challenging to detect in dilute bismides, at the interfaces of (Al,Ga)As/Ga(As,Bi) QWs [4]. Detection is made by employing the above mentioned diffraction-based $\mathbf{g}_{002}$ DFTEM technique. The spatial resolution associated with TEM enables the precise determination of the location of the defects, in this case at the interfaces of the (Al,Ga)As/Ga(As,Bi) QWs. This discovery significantly advances the ability to identify point defects in novel materials based on III-V semiconductors with zincblende structure, a crucial step in enhancing material quality and facilitating practical applications. The formation of Bi_{Ga} hetero-antisites is discussed in the context of some specific procedures during MBE growth. This highlights the relevance of combined TEM and MBE investigations in advancing materials science.

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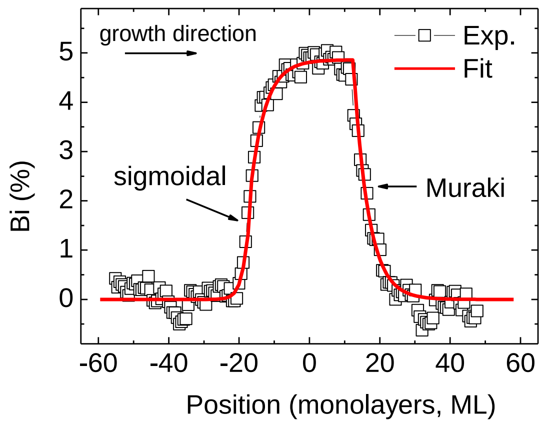

Fig 1. Experimental Bi composition profile obtained from the analysis of $\mathbf{g}_{002}$ DFTEM images of GaAs/Ga(As,Bi) QWs grown using a two-temperature growth procedure [1], a successful strategy to reduce Bi segregation.

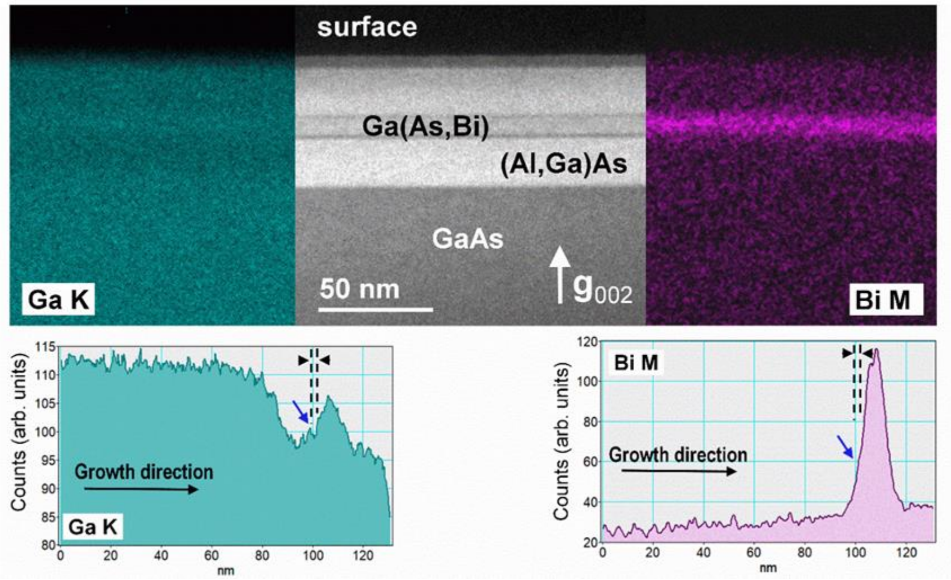

Fig 2. Energy-dispersive x-ray spectrometry (EDS) elemental maps reveal Bi-rich and Ga-depleted features at the location of the dark-line at the Ga(As,Bi)-on-(Al,Ga)As interface in $\mathbf{g}_{002}$ DFTEM micrographs. The "dark-lines" are explained by the presence of Bi_{Ga} hetero-antisites at this location. [4].

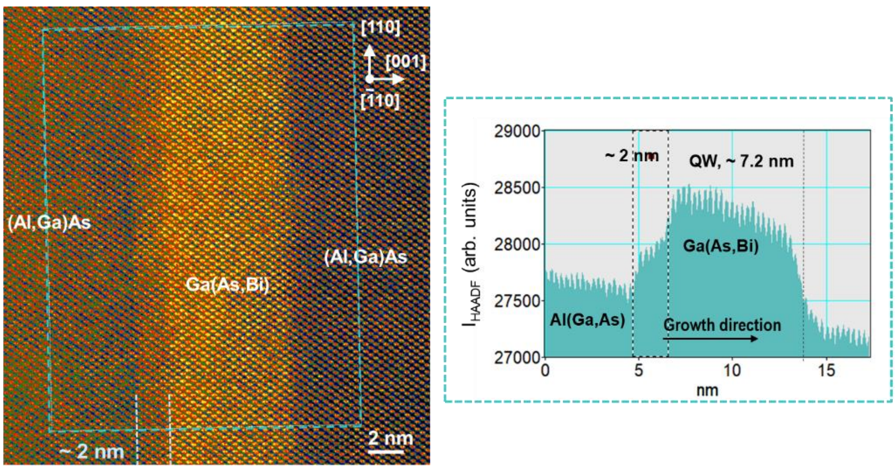

Fig 3. Features in aberration-corrected STEM image at the Ga(As,Bi)-on-(Al,Ga)As interface which match the position and width of the dark-line in $\mathbf{g}_{002}$ DFTEM micrographs associated to Bi_{Ga} hetero-antisites at this location.