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Characterization of epitaxial semimetallic ErAs particles in an $In_{0.53}Ga_{0.47}As$ matrix by high-angle annular dark-field imaging

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Epitaxial metal/semiconductor composites have attracted attention due to their optical, magnetic and electronic properties. Composite properties can be engineered through controlling the density, size and arrangement of the metal particles. Composites can be conductive or insulating [1], show ultrafast photoconduction [2], interesting magnetotransport properties [3] and strong electron plasmon resonances [4].

ErAs is a semimetal that can be grown epitaxially on zinc blende III-V semiconductors such as $In_{0.53}Ga_{0.47}As$. Bulk ErAs has the rock salt structure, but the crystal structure of small epitaxial (< 2 nm) embedded particles is not known. For example, it is conceivable that they adopt the crystal structure of the zinc blende host. Furthermore, the interfacial atomic structure plays an important role in determining the electrical properties of the composite, such as the Schottky barrier properties. Two distinctly different models have been suggested in the literature for the rock salt/zinc blende interface. They differ in the termination of the zinc blende semiconductor (Fig 1). Conventional high-resolution electron microscopy is not capable of distinguishing between these two models. In this work, we report the structural characterization of ErAs particles embedded in a $In_{0.53}Ga_{0.47}As$ matrix using high angle annular dark-field imaging in scanning transmission electron microscopy (HAADF-STEM). We show that even for the particles of less than 2 nm in size, the ErAs adopts the rock salt structure (Fig 2). The interface atomic structure of the particles cannot be resolved due to the overlap with the matrix, thus layered structures of the ErAs on $In_{0.53}Ga_{0.47}As$ and ErAs on GaAs were used to determine the atomic arrangement at the interface. HAADF-STEM images (Fig. 3) show that the As sublattice is continuous across the interface. Imaging the interface in two perpendicular <110> directions, the interfacial atomic arrangement was unambiguously established. For both $In_{0.53}Ga_{0.47}As$ and GaAs substrates, the interface shows Ga(In) terminations which corresponds to so-called the chain model proposed in the literature (Fig 1 a-c). Using these images, we will also discuss image intensity and formation in HAADF.

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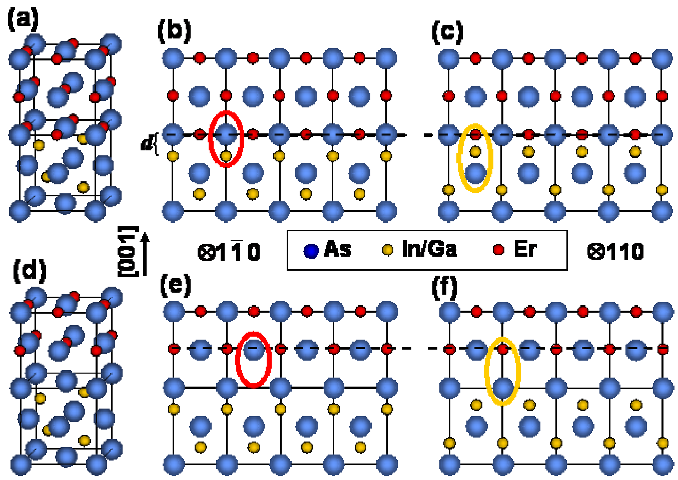

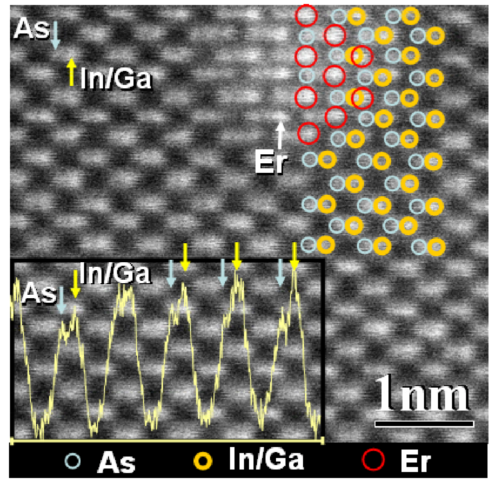

Fig. 1. Schematic representation of the two possible ErAs/$In_{0.53}Ga_{0.47}As$ (GaAs) interfaces: (a-c) chain model and (d-f) shadow model, viewed along $[1\bar{1}0]$ (b, e) and [110] (c, f), respectively.

Fig. 2. HAADF-STEM micrograph of an ErAs particle. The dumbbells in the matrix (spacing ~ 0.15 nm) are clearly resolved. The intensity profile (left bottom corner) across the dumbbells shows different intensities in the As and In/Ga atomic columns due to the atomic number sensitivity of the image. The overlay shows the atomic positions obtained directly from the image.

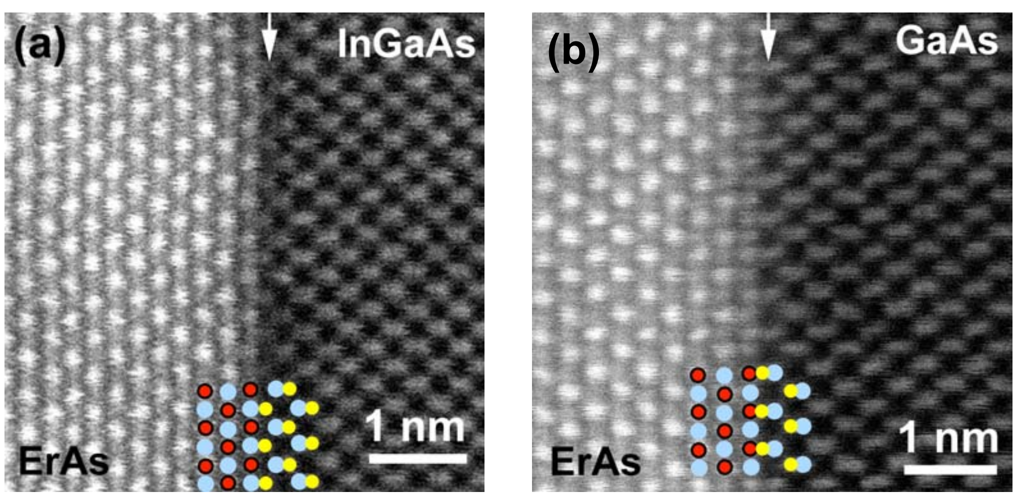

Fig. 3. HAADF-STEM images of the ErAs/GaAs and ErAs/$In_{0.53}Ga_{0.47}As$ interfaces viewed along [110] and $[1\bar{1}0]$, respectively. The overlay represents the atomic column positions, determined from the image. Large blue disks represent As and small red and yellow disks represent Er and Ga, respectively.

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