Self-assembly of Single Crystal Rare-earth Monopnictide Nanostructures in III-V Epilayers

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Epitaxial rare earth monopnictide (RE-V) nanostructures embedded within a III-V semiconductor matrix are of great interest due to a number of exciting electrical and magnetic properties, including phonon scattering for high ZT thermoelectrics and sub-picosecond carrier lifetimes for terahertz devices. Most work on this nanocomposite system has focused on embedded RE-V nanoparticles, e.g. ErAs or ErSb nanoparticles embedded in GaAs (001) and GaSb (001).

This presentation will focus on the growth of highly anisotropic Er-group-V (Sb and As) nanostructures embedded in a III-V semiconductor matrix by self-assembly during molecular beam epitaxial growth of Er_xIII_{1-x}-V by codeposition. In-situ scanning tunneling microscopy in combination with molecular beam epitaxy allows for atomic scale characterization during different stages of growth. For growth of GaSb(001) with increasing Er concentration, ErSb embedded nanostructures change from nanoparticles to vertical nanorods, nanotrees, horizontal nanorods and nanosheets[1]. The resulting $Er_xGa_{1-x}Sb$ nanocomposites are single crystalline with a continuous Sb-sublattice. The vertical nanorods are continuous throughout the $Er_xGa_{1-x}Sb$ layer, their axes are parallel to the [001] growth direction, and they self-assemble into ordered arrays aligned along the [-110] direction. The horizontal nanorods grow in the [-110] direction.

In the case of GaAs, ErAs nanorods can also form by self-assembly during molecular beam epitaxial growth of $Er_xGa_{1-x}As$ by codeposition. In this case the nanorod formation with the rods growing in the <211> direction was found for growth on GaAs (h11)A surfaces. In contrast, ErAs nanorods do not form on GaAs (h11)B or GaAs (001) surfaces.

Scanning tunneling spectroscopy and angle resolved photoemission spectroscopy were used to measure the electronic bandstructure of embedded RE-V nanostructures of varying dimensions, namely 0D nanoparticles, 1D nanorods, and 2D thin films.

The growth mechanisms for $Er_xGa_{1-x}Sb$ and $Er_xGa_{1-x}As$ that result in embedded vertical and horizontal nanorod formation will be discussed. The atomic scale growth mechanisms are a result of surface diffusion and wetting characteristics which are used to explain the differences for the self-assembly of nanostructures for $Er_xGa_{1-x}Sb$ and $Er_xGa_{1-x}As$.

[1] J. K. Kawasaki, B. D. Schultz, H. Lu, A. C. Gossard, and C. J. Palmstrøm, *Nano Letters* **13**, 2895 (2013)