Overgrowth of Growth of Epitaxially-Embedded ErAs Films in GaAs

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Epitaxial metal films could be useful as embedded current spreading layers, Ohmic contacts, metallic-base transistors, as well as the fundamental building block to epitaxial integrated plasmonic devices. Finding a suitable material system for epitaxially embedding metallic films into III-V semiconductors has proven to be a formidable challenge.[1] We recently reported suppression of defects in the overgrowth of ErAs films on GaAs,[2] where reflection high-energy electron diffraction and cross-sectional transmission electron microscopy characterization displayed defect-free GaAs overgrowth of the ErAs films. However, neither technique is sufficiently sensitive to assess the true optical quality of the overgrown III-V materials. Here we present an investigation of both the optical quality of the overgrowth of such films and methods to overcome parasitic erbium doping of layers grown after an ErAs film. We find that the with proper treatment, InGaAs quantum wells grown above an ErAs layer possessed 60% of the luminescence efficiency as that from the ErAs-free control. This ability to grow high quality III-V materials in close proximity to complete ErAs films is of paramount importance for future all-epitaxial plasmonic devices.

Samples were grown by solid-source molecular beam epitaxy in a Varian Gen II system. The ErAs film growth method consisted of: growth of an ErAs nanoparticle layer, which was overgrown with a GaAs spacer. The substrate was heated to 600˚C and an erbium flux was initiated; the erbium diffused through the GaAs spacer layer to the underlying ErAs nanoparticles, displacing gallium and growing the ErAs into a full film. The ErAs film continued to grow vertically through the GaAs spacer layer, which was used to seed the subsequent growth of III-V layers, mitigating antiphase domain formation. After the ErAs film, growth of subsequent III-V layers without parasitic erbium doping required cooling of the erbium cell and management of surface erbium that accumulates during the source idle time. In separate samples, this was accomplished by utilizing either the ErAs film to sink the surface erbium or a separate nanoparticle layer. These two methods allow us to isolate the effect of prolonged annealing of the GaAs spacer layer which acts as a template for III-V overgrowth of ErAs films grown with the nanoparticle-seeded film growth method.

Photoluminescence structures consisting of an InGaAs quantum well embedded in a GaAs absorbing region surrounded by AlAs diffusion blocking layers were used to quantify the optical quality of the III-V overgrowth of the embedded ErAs films. The sample utilizing the GaAs spacer to sink surface erbium displayed <10% of the peak PL intensity of the erbium free control sample. However, the sample with a separate ErAs nanoparticle layer to sink the surface erbium displayed ~60% of the peak PL intensity of the erbium free control. This result implies the degradation in optical quality of the overgrowth of nanoparticle-seeded ErAs films is manageable, providing strong evidence to the suppression of defects associated with the overgrowth of the ErAs films. However, it also elucidates the problem with prolonged high temperature exposure of the GaAs spacer layer, as is required for thick ErAs film growth. Further advances in the growth method will be required for ErAs/GaAs plasmonic heterostructure devices.

[1]C. J. Palmstrøm, *Ann. Rev. Mat. Sci.* **25**, 389-415 (1995)
[2]A. M. Crook, H. P. Nair, D. A. Ferrer, and S. R. Bank, *Appl. Phys. Lett.* **99**, 072120 (2011)

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Figures

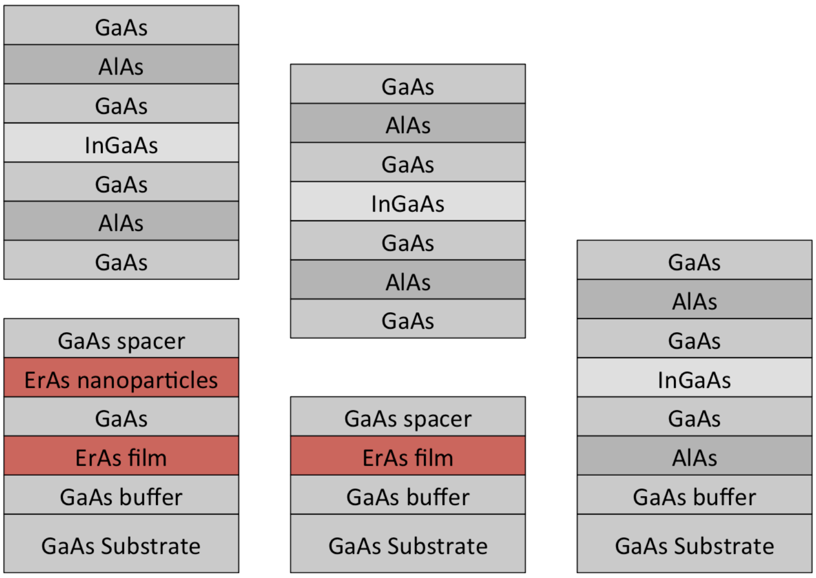

Figure 1: Sample structures for PL investigation of the III-V overgrowth of ErAs films. Break in structure represents location of growth interruption required to cool erbium cell. (a) nanoparticle layer sinks erbium. (b) ErAs film sinks erbium. (c) ErAs-free control sample.

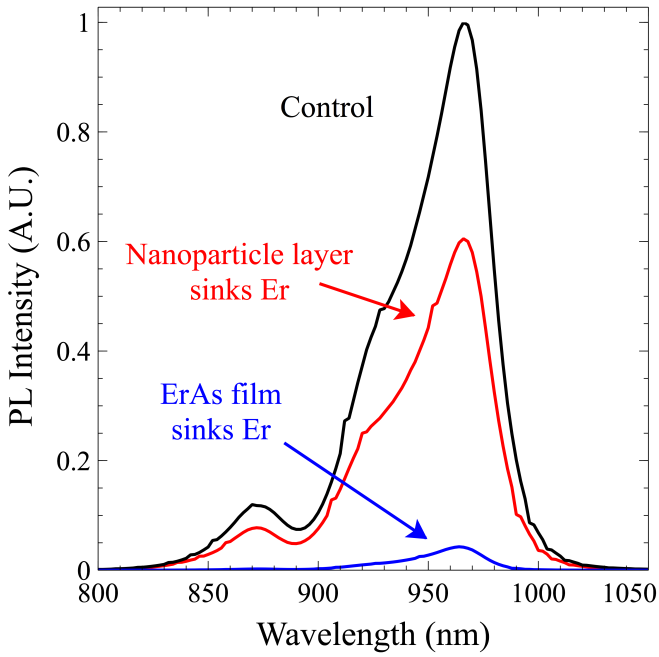

Figure 2: Photoluminescence spectra for sample structures shown in Fig. 1.