Growth of High-quality Rocksalt LaAs on LuAs Seeded Templates

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Much attention has been given in recent years to the rare-earth group-V materials.[1] Many of the rare-earth (RE) monopnictides are rocksalt semimetals and can be epitaxially integrated with III-V semiconductors as nanoparticles and thin films. The most investigated material, ErAs, has only a single stable rocksalt phase and has yielded useful properties for device applications including enhanced tunneling, buried semimetallic films, enhanced phonon scattering, and plasmonic response. However, many of the RE-V monopnictides, such as LaAs, have additional stable RE-rich and group-V-rich phases; this greatly increases the difficulty in determining fundamental material properties and inhibits potential device applications. Despite these growth challenges, LaAs is particularly attractive because it represents an endpoint in the RE series, potentially yielding the most extreme materials properties, and has the largest lattice constant of the RE-As materials. Here we demonstrate a new method for growing high-quality, single-crystal, rocksalt LaAs on III-V substrates; this is a proof-of-concept process that has the potential to be applied to other RE-V compounds. We were able to show, with the addition of thin LuAs seed and capping layers, single-crystalline LaAs with enhanced structural quality and electrical properties.

Samples were grown by solid-source molecular beam epitaxy in an EPI Mod. Gen II system. Samples, seen in Figure 1, without LuAs layers consisted of (100) semi-insulating GaAs substrates with a (a) 200 nm GaAs buffer followed by (b) 5-67 nm of LaAs and a (c) 15-30 nm GaAs cap. The growth space was investigated, sweeping substrate temperature, arsenic overpressure, and growth rate; but failed to identify a growth regime for single crystalline rocksalt. The reflection high-energy electron diffraction (RHEED) patterns observed *in situ* during growth (Figure 2a) were indicative of roughened polycrystalline films, under all growth conditions. LaAs films grown on nearly lattice-matched (100) n-type InAs substrates showed similarly defective growth indicating that strain relaxation was unlikely to be the cause of the degraded films. Samples were analyzed *ex situ* using X-ray diffraction; Figure 3 shows the ω-2Θ spectra of these polycrystalline films with multi-phase and multi-crystalline orientation, in agreement with RHEED observations. In order to suppress the formation of non-rocksalt phases on (001) III-V substrates, we inserted a thin (5-10 ML) coherent LuAs layer between the buffer layer and LaAs films as a seed template. For LaAs grown on n-type InAs substrates, a 2.5 ML LuAs seed was employed so as to remain under critical thickness for LuAs on InAs. Bright, streaky 1x1 RHEED patterns were observed Figures 2b, 2c) for LaAs films below the critical thickness; slightly degraded surface morphology was observed in the RHEED pattern after the LaAs film exceeded critical thickness. However, no polycrystalline patterns were observed in the films grown using the LuAs seed. In the ω-2Θ spectra of these samples no peaks from other La-As phases were detected and several Pendellosung fringes were observed, suggesting high crystalline quality. No apparent difference was observed between LuAs seeds of 5 ML and 10 ML thickness. Figure 4 shows a thin anomalous peak in XRD measurements at lower ω-2Θ angles; this anomalous peak was suppressed by inserting a second thin LuAs layer between the LaAs film and GaAs cap, indicating instability of that interface. Reciprocal space maps of the samples grown on GaAs substrates confirm nearly 100% film relaxation. In conclusion, LuAs interfacial layers greatly enhance the quality of epitaxial RE-V compounds that possess multiple stable phases. Growth, electrical, and optical properties of these films will be presented.

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References
[1] C.J. Palmstrom, Annu. Rev. Mater. Sci. **25**, 389 (1995).

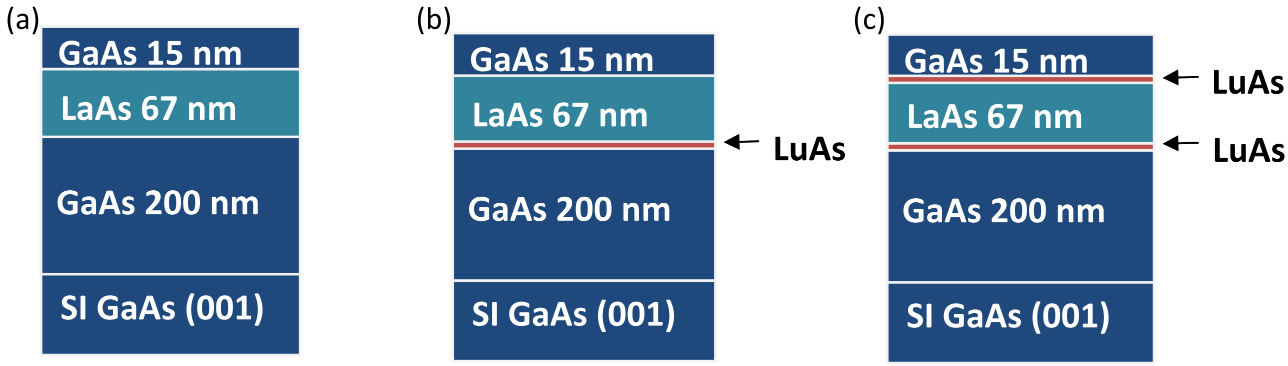

Figure (1): Layer structures: (a) LaAs films on GaAs, (b) LuAs seeded growth 5-10ML of LuAs, and (c) LuAs seeded LaAs film with LuAs diffusion barrier.

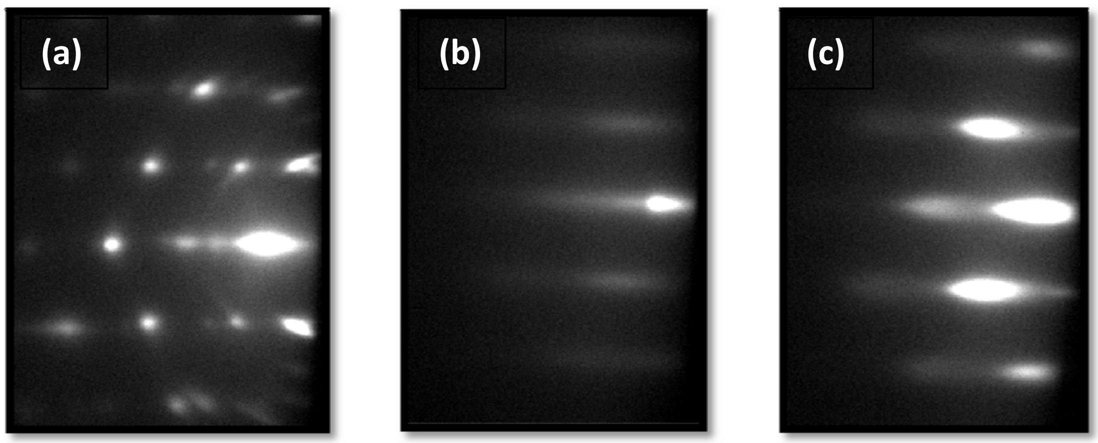

Figure (2): (a) Polycrystalline RHEED pattern during LaAs growth on GaAs (no LuAs seed), (b) 1nm deposition of LaAs on 5 ML LuAs seed, (c) 14 nm deposition of LaAs on 5 ML LuAs seed, spottiness is attributed to roughening of growth surface due to exceeding critical thickness.

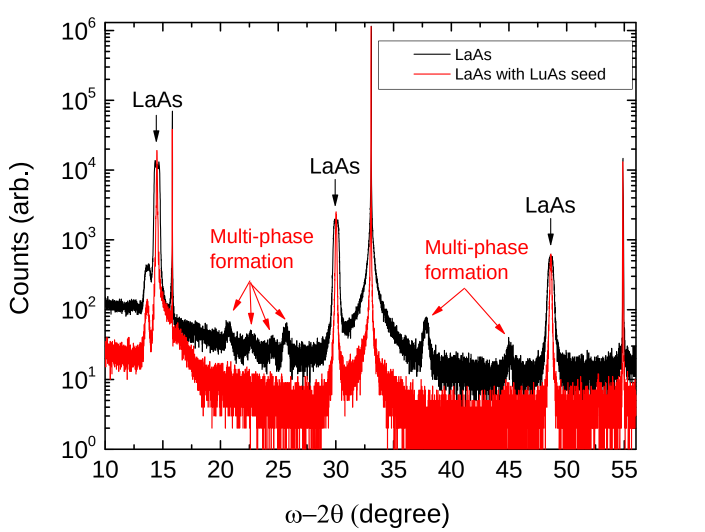

Figure (3): ω-2Θ XRD spectra comparing the multi-phase formation occurring in LaAs films grown directly on GaAs substrates versus the LaAs film grown on the 5 ML LuAs seed. Both films were grown at 460°C and 120x arsenic overpressure.

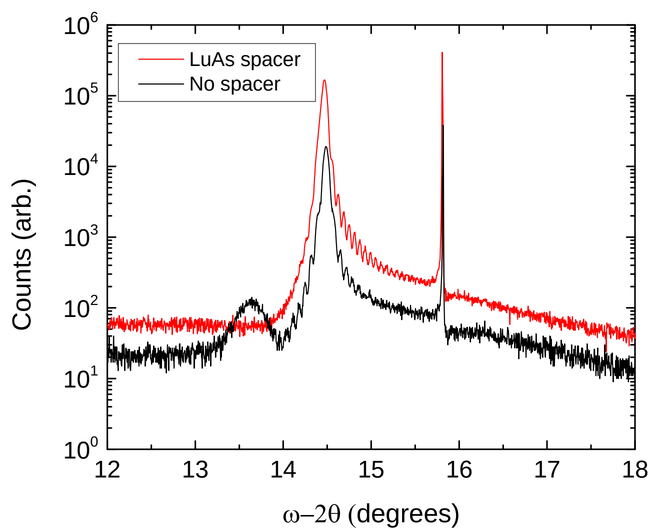

Figure (4): Including a spacer of 10 ML of LuAs separating the LaAs film and the GaAs cap layer removes the side-peak observed in the ω-2Θ scan of the samples.