RE-V Monopnictide Films for Tunable-Frequency Transparent Ohmic Contacts

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The development of transparent Ohmic contacts requires materials with simultaneously high transparency and high conductivity in the transmission window of interest. The most common transparent Ohmic contacts are indium tin oxide (ITO) and Al:ZnO (AZO); however, both have transmission peaks in the visible range with rapidly decreasing transparency at longer wavelengths. ErAs has been proposed as a transparent epitaxial Ohmic contact in the important telecommunications window at 1.55 µm.[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. Additionally, it has been shown that ErAs films can be overgrown with high-quality III-V materials via an embedded growth mode technique,[2] providing a path towards epitaxial integration of Ohmic contacts into the device structure. Because of these promising results from the Er-V material systems, it is of interest to explore the full extent of the RE-V system to develop contacts that may be lattice-matched to different substrates, as well those that offer other spectral transparency windows. Here, we report differences in the spectral transmission properties of LuAs and ErAs. We also demonstrate the growth of alloyed $La_xLu_{1-x}As$ films, which offer tunable lattice-constant and spectral transparency windows, as well as reasonable electrical properties across the composition range.

Samples were grown by solid-source molecular beam epitaxy in an EPI Mod. Gen II system on (100) semi-insulating GaAs substrates. LuAs is of particular interest because it is the most closely lattice-matched binary RE-V monopnictide to GaAs, and allowing for thick layers to be grown coherently. The transmission spectra, seen in Figure 1, of a thick LuAs film, when compared to a similarly thick film of ErAs, are qualitatively similar; however, the most notable distinction is a shift of the peak transmission to ~1.3 µm for LuAs. This makes LuAs ideal for incorporating into 1.31 µm telecommunications devices. Additionally, the peak transmission of the thicker LuAs film is 1.5x that of the ErAs. Moreover, the transmission window is 20% broader. Resistivity measurements of ErAs and LuAs films show moderate values of ~70 µΩ-cm[1] and ~77 µΩ-cm, making them comparable to the best reported AZO values of ~85 µΩ-cm. The combined properties of moderate resistivity, transparency at near-infrared wavelengths, and close lattice-matching of LuAs to GaAs make it an attractive material for near-infrared transparent Ohmic contacts.

We also investigated the incorporation of lanthanum into LuAs films, forming $La_xLu_{1-x}As$, and observed that their optical, electrical, and structural properties depend strongly on the La mole fraction. Alloy compositions were swept from 5%-35% La content; 67 nm films were grown on (a) 200 nm GaAs buffer layers, then (b) 5 ML LuAs seed layer, and (c) capped with 15nm of GaAs. Optical absorption measurements (Figure 2) were performed to study the optical properties, and X-ray diffraction ω-2Θ measurements (Figure 3) were employed to quantify the shift in lattice parameter of the alloy films. The transmission window redshifted with increasing La content; of particular note is that $La_{0.35}Lu_{0.65}As$ possesses a broad transmission window covering the 1.5-2.0 µm range, while maintaining a moderate resistivity of ~120 µΩ-cm. Moreover, $La_{0.35}Lu_{0.65}As$ is nearly lattice-matched to InP (lattice constant of 5.84 Å), making it potentially attractive for InP-based telecommunications devices operating at 1.55 µm. In conclusion, we demonstrate the potential of binary and ternary RE-V monopnictide alloys for epitaxial transparent Ohmic contacts, as well as the potential for lattice-matching to technologically-important substrates.

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References

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[2] A.M. Crook, H.P. Nair, D.A. Ferrer, and S.R. Bank, Applied Physics Letters **99**, 072120 (2011).

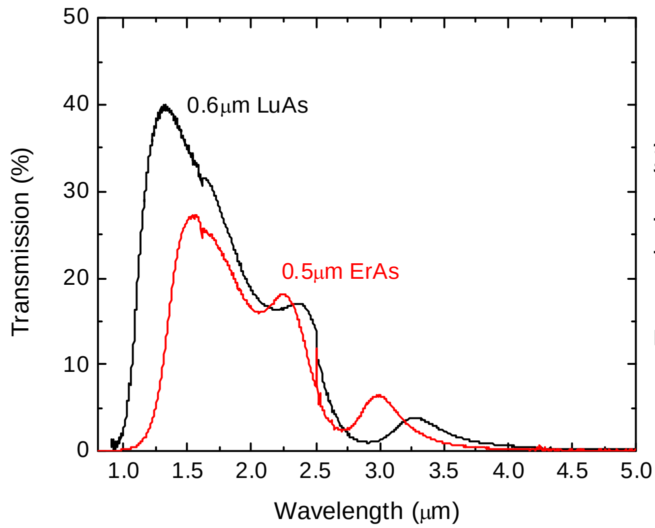

Figure (1): Transmission spectra of a 0.6 µm film of LuAs and a 0.5 µm film of ErAs. LuAs displays superior transmission over the technologically important near-IR 1.3-1.55 µm range, despite being thicker. Absorption peaks shifted by ~0.15 µm to longer wavelengths for LuAs, as compared with ErAs.

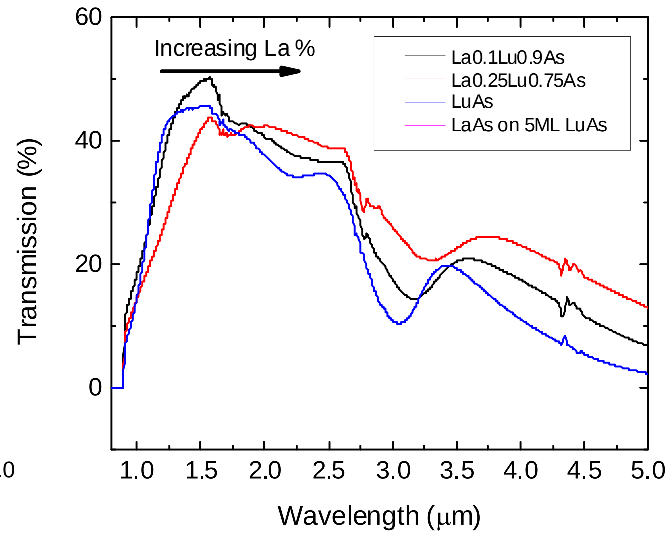

Figure (2): Transmission spectra of 67 nm thick LaLuAs alloy films, demonstrating shift of peak transmission window in increasing La content.

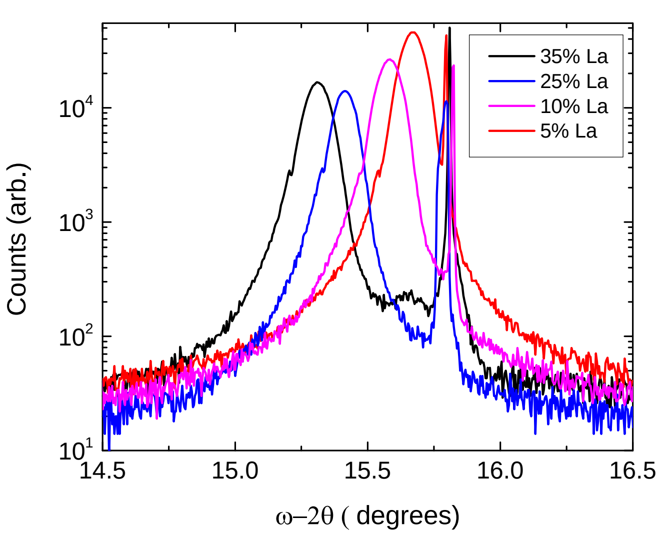

Figure (3): XRD *ω*-2*Θ* scans of LaLuAs alloys grown on a 5 ML LuAs seed indicating the shift in lattice parameter with increasing La content.

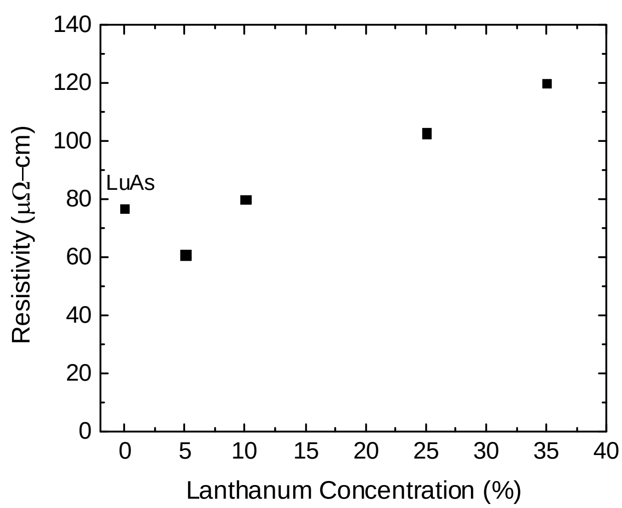

Figure (4): Resistivity measurements of 67 nm thick LaLuAs alloy films, showing moderate resistivity in films with up to 35% La content.