Molecular beam epitaxy of polar/semipolar/nonpolar GaN/AlGaN heterostructures for intersubband devices

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GaN/Al(Ga)N nanostructures have emerged as promising materials for intersubband (ISB) optoelectronics devices, with the potential to cover the whole infrared spectrum. The large conduction band offset (~1.8 eV for GaN/AlN) and sub-ps ISB recovery times make III-nitrides particularly appealing for ultrafast devices in the short-wavelength infrared (SWIR, 1-3 µm) and mid-wavelength infrared (MWIR, 3-5 µm) regions. A variety of GaN-based ISB optoelectronic devices have already been demonstrated, including photodetectors, switches and electro-optical modulators. In addition to these applications, the large energy of GaN longitudinal-optical phonon (92 meV, 13 µm) opens prospect for room-temperature THz quantum cascade lasers and ISB devices covering the 5-10 THz band, inaccessible to GaAs.

The presence of internal electric fields in polar materials imposes an additional confinement which increases the energetic distance between the ISB electronic levels, and constitutes one of the main challenges to extend the GaN-ISB technology towards the far-infrared (FIR). Furthermore, the high piezoelectric constants and lattice mismatch in the GaN/AlN system results in piezoelectric polarization along the [0001] axis, which renders the ISB transition energies sensitive to the strain state, and hampers precise device design. This has motivated research on alternative crystallographic orientations with reduced or zero polarization fields.

Plasma-assisted molecular-beam epitaxy is the growth technique that has provided better results for the study of ISB transitions in III-nitride materials. The low growth temperature prevents interdiffusion and allows interface control at the atomic layer scale. In this presentation, we summarize recent progress in ISB studies of GaN/AlGaN heterostructures.

As a first approach, growing along the polar axis, we analyze multi-layer QW designs that create a pseudo-square potential profile [1]. As an alternative, we introduce the growth of GaN/AlGaN multi-quantum-wells (MQWs) using the semipolar (11-20) orientation by heteroepitaxy on sapphire. Semipolar planes allow a considerable reduction in the internal electric field while presenting a lower in-plane anisotropy than non-polar surfaces. We demonstrate SWIR ISB absorption at 1.5-3.75 µm on (11–22)-oriented GaN/AlN MQWs [2].

Finally, the use of nonpolar orientations allows suppressing the internal electric field and enhancing the ISB oscillator strength, at the price of increasing the lattice mismatch. Comparative evaluation of GaN/Al(Ga)N multi-QWs grown on *a* and *m* nonpolar free-standing GaN substrates shows the best results in terms of structural and optical (interband and ISB) performance for *m*-plane structures [3]. Room-temperature ISB absorption in the SWIR and MWIR ranges is demonstrated in *m*-plane heterostructures, as well as low-temperature ISB absorption in the FIR domain [4].

References:
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