III-nitride nanostructures for UV and IR optoelectronics

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III-nitrides (GaN, AlN, InN) are the materials of choice for green-to-ultraviolet optoelectronics. With their large conduction band offset (around 1.8 eV for GaN/AlN), III-nitrides are also interesting for intersubband (ISB) devices operating in the near-infrared (near-IR) spectral range, particularly in the 1.3-1.55 µm window used for fiber-optic communications [1]. There is also an interest to push the III-N ISB technology towards the THz frequency range. GaAs-based quantum cascade lasers have demonstrated potential as THz sources in the 1.2–5 THz range; however, their operating temperature and spectral range are limited by the emission/absorption of longitudinal optical (LO) phonons at 36 meV (8.7 THz). GaN-based devices have the potential to operate at a higher temperature and in the whole THz spectral range due to its large LO-phonon energy of 92 meV.

However, the optical properties of GaN quantum wells (QWs) are strongly affected polarization-induced internal electric field. As a consequence of the electric field, a reliable view of the charge distribution in a device is only achieved by extending the modelling effort to the whole structure, instead of limiting the calculations to a few periods of the active region. Therefore, the already high design complexity of ISB devices increases further in these materials. A simple solution to this problem consist in using nonpolar crystallographic orientations like *m*-{1−100} or *a*- {11−20} planes [2,3], or semipolar planes [4] (those (*hkil*) planes with at least two non-zero *h*, *k*, or *i* Miller indices and a nonzero *l* Miller index).

An alternative approach to QWs for the fabrication of ISB devices is the use of quantum dot (QD) superlattices. GaN/AlN QDs with intraband absorption in the 1.38-2.0 µm range have been reported [5]. QDs can also be synthesized within nanowires (NWs), which allows better control of the dot height. Self-assembled GaN NWs can be grown almost defect-free on silicon substrates with the large surface-to-volume ratio allowing misfit strain to be elastically released. This expands the possibility of active region design in terms of size and composition. Intraband absorption in the range of 1.4 to 3.5 µm, has been observed in GaN/AlN QDs inserted in GaN NWs [6] and top-down micropillars [7], and a first quantum well IR photodetector implemented in a single NW has been reported [8].

A variety of GaN-based ISB devices (QW/QD/NW detectors, all-optical switches, electro-optical modulators) have been demonstrated in the near-IR [1,8,9]. When decreasing the energy between electronic levels towards the far-IR (> 20 µm), the internal electric field associated to the spontaneous and piezoelectric polarization poses a major hurdle for device design. Nevertheless, THz photodetectors have been demonstrated using polar, nonpolar and semipolar GaN QWs [9].

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