Advancing III-Nitrides Epitaxy: From Kinetics to New Device Applications

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Compound III-Nitride semiconductors are the subject of intense scientific research during the last decade, due to their potential importance in a broad range of (opto-)electronic device applications. Already, commercial products, such as blue-green light emitting diodes (LEDs) and near-UV solid state lasers, are available. Further progress in epitaxy, technology development and physical understanding of this important material system is predicted to have a strong impact on a number of technological fields, with most prominent ones being solid-state lighting, photovoltaic technology, high power/high frequency electronics and UV-VIS optoelectronics. The epitaxial growth of III-Nitrides by molecular beam epitaxy had to overcome a number of problems related to (i) unavailability of suitable substrates, (ii) inertness of molecular nitrogen, (iii) limited surface mobility of nitrogen adatoms and (iv) limitations restricting growth temperatures to much lower values than the ones dictated by the extremely high melting points of the III-N binaries. Additional to those, common problems for all epitaxial growth techniques, are the low miscibility of InN with GaN and AlN, as well as, the large differences in lattice constants between them, facts that complicate the design and realization of heterostructures.

The problem of reduced adatoms' surface mobility was successfully addressed, in radiofrequency plasma assisted molecular beam epitaxy (RF-MBE), by the exploitation of self-surfactant effect of the group-III atoms. Today, RF-MBE conditions, where a metallic adlayer on the growth surface is formed, is the "standard model" for the case of $Al_xGa_{1-x}N$ alloys and lower InN content $In_xGa_{1-x}N$ heteroepitaxial growth. Under those conditions, growth kinetics are radically different than the ones of other traditional compound semiconductors [1].

However, in the case of RF-MBE growth of InN those "standard" conditions are not applicable, due to the faster decomposition rate of InN, as compared to In adatoms' desorption from the growing surfaces. Detailed studies of growth kinetics [2] not only permitted the RF-MBE growth of InN films with "state of the art" properties, but they also offered further insight into the kinetic mechanisms of III-Nitrides compounds in general. Therefore, new growth approaches can be implemented, in the case of GaN, offering the potential of reduced defect densities' material development.

Epitaxial growth by RF-MBE is an out-of-equilibrium process. Therefore it can be particularly efficient in the development of high InN content $In_xGa_{1-x}N$ and $In_xAl_{1-x}N$ ternary alloys [3,4], whose realization was hindered, up to now, by phase separation problems. Homogeneous thin films, with single peaked x-ray diffraction patterns, enhanced optical properties and efficient luminescence, grown in the entire composition range is demonstrated, paving the way for optoelectronic applications covering the full UV to NIR range of the electromagnetic spectrum. In addition, the possibility of controlled heteroepitaxy of III-Nitrides ternary alloys, in their full compositional range, opens new possibilities in advanced heterostructure engineering for enhanced device applications.

The lack of inversion symmetry along the [0001] wurtzite axis, which is the usual growth direction of device quality III-Nitrides thin films, results in the presence of very strong piezoelectric fields in heterostructures. For device applications, these fields can pose restrictions, as is the case of quantum well LEDs, or can be exploited to enhance device performance, as is the case of AlGaN/GaN high-electron mobility transistors (HEMTs). Recently, AlN/GaN HEMTs with record values of two dimensional electron gas, equal to 3.6×10^{13} cm^{-2} were demonstrated and exploited for the fabrication of high current densities and high transconductance transistor devices.

Finally, the realization of advanced III-Nitride resonant tunneling diodes (RTDs), with high peak to valley current contrast ratios will be presented.

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