Innovative high pressure high temperature solid state synthesis of InN and GaN

Lorenzo Fornari[1,2]*, Elena Del Canale[1,2], Chiara Coppi[1,2], Giovanna Trevisi[1], Giulia Spaggiari[1], Edmondo Gilioli[1], Davide Delmonte[1].
*lead presenter: lorenzo.fornari@imem.cnr.it
1 IMEM-CNR, Italy
2 Doctoral school in Material Science SCVSA department, University of Parma, Italy

Indium nitride (InN) and Gallium nitride (GaN) are III/V group, isostructural (i.e., wurtzite type cell) and direct band gap semiconductor materials, which are vastly studied by the scientific community due to their interesting and complementary electrical and optical properties. More specifically, InN has E_g of 0.69 eV (short wave infrared) [1], while, on the contrary, GaN possesses E_g of 3.47 eV (near UV) [2]. This huge discrepancy of their physical characteristics comes from an enormous difference in the lattice parameters, determined by the In-N 30%-larger bond. Consequently, if GaN is obtained in several forms (e.g. films and single crystals) through different complementary techniques, InN synthesis results to be far more complex, ineffective and with low yield, usually involving the use of toxic reactants and solvents [3-6]. Noteworthy, the low dissociation temperature and instability of this compound establishes the very weak nature of the In-N bond, which limits the InN application at the lab scale and mainly confined to research scopes.

Here we introduce the innovative high pressure/high temperature InN and GaN solid state synthesis, performed through a multi-anvil apparatus. The presented processes are simple nitridation reactions of the respective binary oxides by Li_3N, which are vastly available and relatively low-cost reagents. Surprisingly, our comprehensive study allowed to find a small thermodynamic interval where both materials can be obtained, precisely at 3 GPa and 500°C. These (P,T) conditions are in the operational range of the piston cylinder end-loaded apparatus, which is a simple, robust, effective, toxic-free and low-cost system which permits to produce large amount of material. This translates, at least for InN, in a lower production price and consequently in a higher industrial scalability with respect to the currently available techniques previously described; at the same time, it opens some perspectives in the study of the direct reaction of (In,Ga)N solid solutions, which still represent one of the principal challenges in the scientific community of semiconductors.

References

[1] Monemar, B., Paskov, P. P., & Kasic, A. (2005). Optical properties of InN—the bandgap question. Superlattices and Microstructures, 38(1), 38-56.
[2] Rais-Zadeh, M., Gokhale, V. J., Ansari, A., Faucher, M., Théron, D., Cordier, Y., & Buchaillot, L. (2014). Gallium nitride as an electromechanical material. Journal of Microelectromechanical Systems, 23(6), 1252-1271
[3] Cross, G. B., Ahmad, Z., Seidlitz, D., Vernon, M., Dietz, N., Deocampo, D., ... & Kozhanov, A. (2020). Kinetically stabilized high-temperature InN growth. Journal of Crystal Growth, 536, 125574.
[4] Ruffenach, S., Moret, M., Briot, O., & Gil, B. (2010). Recent advances in the MOVPE growth of indium nitride. physica status solidi (a), 207(1), 9-18
[5] Fehlberg, T. B., Umana-Membreno, G. A., Nener, B. D., Parish, G., Gallinat, C. S., Koblmüller, G., ... & Speck, J. S. (2006). Characterisation of multiple carrier transport in indium nitride grown by molecular beam epitaxy. Japanese journal of applied physics, 45(10L), L1090
[6] Chirico, P., & Hector, A. L. (2010). Solvothermal synthesis of gallium and indium nitrides using lithium amide. Zeitschrift für Naturforschung B, 65(8), 1051-1057