Challenges in growth of nitride semiconductors epi structures: minimizing effects of dislocations and point defects

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Nitrides of (AlGaIn)N are the second group of semiconductors (after Si-Ge) taking into account the markets. White LEDs, blue/green laser diodes (LDs) are used not only in lighting industry and projectors (3D laser projectors operating without goggles are being developed), but in Quantum Technology (atomic clocks, gravity sensors, etc), in military applications, in medicine and many others. Moreover, AlGaN-based high-power and high-frequency transistors are creating new huge markets in electro-mobility and photovoltaics.
Despite of the big market-successes, nitride semiconductors are still being intensively studied because technology of (AlGaIn)N is much more difficult than of other semiconductors (Si-Ge, (AlGaIn)(AsP)). The biggest issue is that nitrides decompose at temperatures much lower than their melting points. For example, GaN decomposes at temperatures below 1000^{O}C, whereas its melting point is around 2500^{o}C and above 60 kbars. These thermodynamic properties exclude growing GaN crystals from melt by Czochralski or Bridgman methods. Therefore, most of the devices (LEDs and transistors) are fabricated on foreign highly lattice-mismatched substrates (sapphire or Si) what results in a high threading dislocation density.
In the first part of the talk, I will discuss how the dislocations threading from the GaN substrates influence growth of the MOVPE (Metalorganic Chemical Vapour Phase Epitaxy) epitaxial structures of AlGaN and InGaN, doped with silicon (n-type) and magnesium (p-type).
However, dislocations are not the only problem in nitrides technology. All epitaxial layers are grown at temperatures of 700-1100^{o}C, what is a low-temperature regime (comparing to melting points). In such growth conditions, point-defects of high concentrations are formed.
In the second part of the talk, I will show experimental results how point defects (mainly gallium vacancies) influence diffusion of atoms: Al and In, as well as dopants Mg, H, and Si. The new results will include:

i) Very high diffusion of magnesium atoms as compared to diffusion of silicon explained by electric properties,
ii) Homogenization or decomposition of the InGaN Quantum Wells grown at about 750^{o}C and exposed to higher temperatures (above about 900^{o}C). These two effects depend on temperature stress, but also on indium content in InGaN, indium fluctuations, well thickness, doping changing mobility of the gallium vacancies.

The changes of the buried epi-layers during high-temperature stress depend not only on the presence of extended (dislocations, V-pits, stacking faults) and point (vacancies) defects, but also the annealing atmosphere: H_2, NH_3 and TEGa (the latter is blocking vacancy diffusion from the surface).
The experimental results obtained for simple test-structures of GaN, InGaN, AlGaN have served in optimizing a complicated epi structure of laser diodes emitting in blue and green spectral region. This optimization has been done in order to achieve the best efficiency and life-time of the devices.