Carrier Extraction Enhancement at InN/p-GaN Interface Heterojunction under Reverse Bias Voltage

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The unique physical properties of indium nitride (InN) such as low effective mass, high electron mobility, saturation velocity and direct band gap make it a potential material for optoelectronic and microelectronic devices such as light emitters/detectors, high electron mobility transistors (HEMT) [1]. By changing the composition of indium (In) in gallium nitride (GaN), the band gap of $In_{1-x}Ga_xN$ can be tuned from 0.7 *eV* to 3.4 *eV* covering a broad range of spectrum from near infrared to ultraviolet regions [2]. Quantum confinement in InN is also an attractive effect, which could lead to carrier multiplication (CM), enhance the Auger photogenerated carriers and effectively improve absorption over a wide range of visible spectrum. Under applied voltage CM effect can be enhanced and used for design of detectors and photodiodes. However, the growth of high quality InN is a big challenge mainly due to low dissociation temperatures, high equilibrium vapor pressure of nitrogen and lack of lattice matched substrates [1, 3].

In this work, we demonstrate good quality InN films, grown by pulsed MOVPE at 610^{o}C temperature, with low defect concentration and a smooth interface with magnesium (Mg) doped p-GaN. An efficient optoelectronic InN/p-GaN heterojunction is demonstrated by measuring carrier extraction under unbiased conditions, whereas applied bias voltage enhances significantly the external quantum efficiency (EQE) in the ultraviolet (UV) to visible spectral region (300-550 nm).

Efficient electron-hole pair generation and extraction in InN/p-GaN heterojunction grown by MOVPE was achieved. The depletion region was estimated via simulations at 22.8 nm at the InN/p-GaN interface which extended by 4 times more into p-GaN than InN showing good rectifying behavior and carrier extraction without external electrical field. Under increased reverse voltage bias the EQE in the blue spectral region (300-550nm) exceeded unity due to carrier multiplication and photoconductivity at the enlarged depletion region width.

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Supplementary information

The InN/p-GaN heterojunction investigated in this study were grown on a 5 μm thick undoped GaN buffer layer and sapphire substrate by MOVPE (AIXTRON 3x2 FR reactor). Trimethylgallium (TMGa), trimethylindium (TMIn) and ammonia (NH_3) have been used as precursors for gallium (Ga), indium (In), and nitrogen (N), respectively. Bis(cyclopentadienyl) magnesium (Cp_2Mg) was used as precursor for Mg p-type doping. The GaN templates on sapphire were grown using a standard two-step growth method. Then, a 600 nm p-GaN was grown on the undoped 5 μm thick GaN layer followed by a 20 minutes annealing at 850 ^{o}C under nitrogen ambient to activate Mg acceptors states in the p-GaN. At last, 300 nm thick InN layer was grown on the p-GaN under 400 mbar pressure using TMIn precursor with multiple flow interruptions method. One growth cycle duration was 27 s, where TMIn and NH_3 were supplied into the reactor for the first 7 s and then only NH_3 was supplied for the next 20 s. The overall number of growth cycles was 600. The InN layers growth process was split into two steps. InN began to grow at 570^{o}C for the first dozens of growth cycles; then the growth temperature was increased at a constant rate until 610 ^{o}C (first step). For the remaining growth cycles, the temperature was kept at 610^{o}C (second step). The V/III ratio was stabilized at 9968 during the "ON" pulse of InN growth process. Figure 1 shows InN growth process and final heterostructure.

Figure 2 shows and energy band diagram in the InN and p-GaN interface. Depletion region was estimated via simulations at 22.8 nm at the InN/p-GaN interface which extended by 4 times more into p-GaN than InN showing good rectifying behavior and carrier extraction without external electrical field.

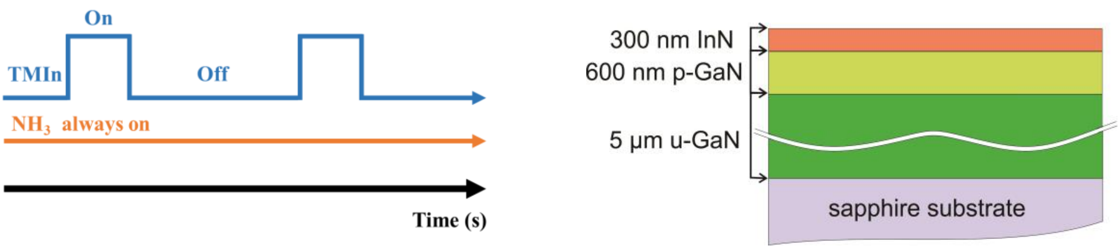

Figure 1. InN growth process (left) and final heterostructure (right).

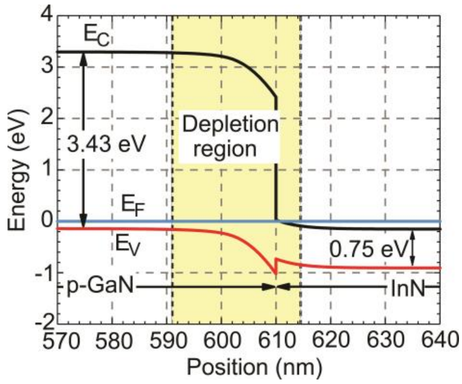

Figure 2. InN/p-GaN interface energy band diagram. The E_C stands for conduction band, E_V for valence band and E_F for Fermi level, respectively.