Polarization doping for III-nitride optoelectronics

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The paper considers new opportunities for design of various optoelectronic devices opened by the use of polarization doping in III-nitride heterostructures, including distributed polarization doping (DPD) in graded-composition alloys. The polarization doping is routinely exploited in HFETs for a long time. In contrast, this concept has not yet been applied to LEDs, laser diodes, and solar cells until recently, in spite of its great potential advantage – capability of producing holes with high concentrations that can never be achieved by conventional impurity doping.

Basic ideas underlying the concept of polarization doping, including estimates for highest achievable hole concentrations in various materials and analysis of ways for intentional control of the doping profiles in device structures are discussed in the paper. Recent experiments supporting the concept of polarization doping, demonstrating feasibility of using DPD in optoelectronic devices, and providing essential data on the carrier properties are reviewed in the paper.

Using simulations, we apply the concept of DPD to find promising ways for solution of a number of practically important problems like (i) improvement of *p*-doping in deep UV LED structures, (ii) development of ohmic *p*-type contact to AlGaN alloys with high aluminum content, and (iii) development of III-nitride tunnel junctions capable of forward bias operation, which is vital for the tandem solar cell fabrication. A parabolic variation of the AlGaN alloy composition in a deep-UV SQW LED structure is found to provide a rather uniform hole distribution across the *p*-contact layer with the bulk concentration as high as ~4-8×10^{18} cm^{-3}. In this case, the contact layer was assumed to be not intentionally doped with impurities at all. At the composition gradients quite reasonable from the practical point of view, the calculated resistances of the ohmic contacts formed to graded-composition AlGaN alloys have appeared to be much lower compared to the resistances of conventional Ni-Au contacts to *p*-GaN:Mg. In addition, the DPD-mediated ohmic contacts exhibit much weaker temperature dependence of their resistances. Various tunnel junction designs utilizing the polarization doping are considered by simulations. We suggest an effective *p*-GaN/InGaN/*n*-GaN tunnel junction capable of conducting high currents (up to ~1-4 kA/cm^2) under both forward and reverse biases. Such junctions can be used to connect in series the cascades in the III-nitride tandem solar cells and to form alternative low-resistance ohmic contact to *p*-layers of UV LEDs. These and other relevant simulation results are discussed in detail in our paper.

Supplementary information

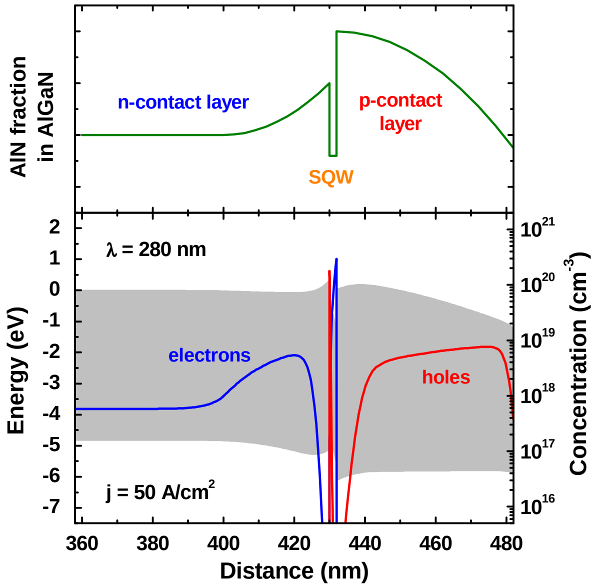

Fig.1 Schematic composition profile (top) and simulated band diagram and carrier concentrations (bottom) in a prototype of GaN-free UV LED with polarization-doped *p*-contact layer. Here, grey shadow indicates the energy gap, while lines are the electron and hole concentrations. Notice the uniformly distributed hole density in the graded-composition AlGaN to be close to 5×10^{18} cm^{-3}, which can never be obtained by impurity doping.

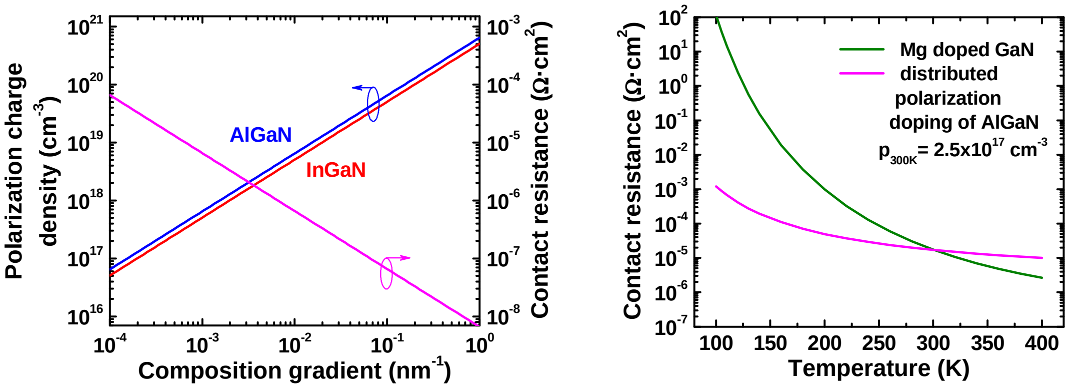

Fig.2 Distributed polarization charge density in graded-composition alloys and calculated *p*-contact resistance to AlGaN materials as a function of composition gradient (left). Comparison of the contact resistance dependences on temperature for Mg-doped GaN and polarization-doped AlGaN (right).

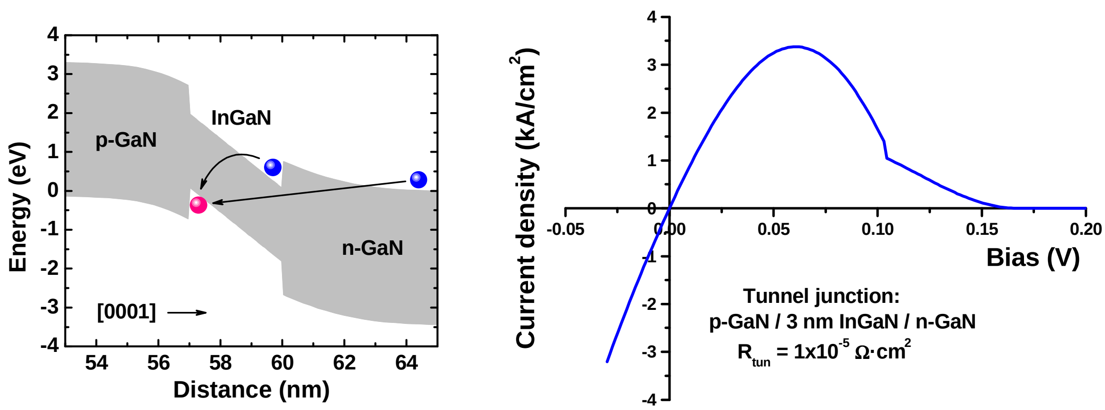

Fig.3 Band diagram and tunneling pathways in a *p*-GaN/InGaN/*n*-GaN junction contributing to the tunneling current (left). Simulated current-voltage characteristic of the *p*-GaN/InGaN/*n*-GaN tunnel junction demonstrating feasibility of the forward-bias operation necessary for III-nitride tandem solar cells (right).