Higher than 90% internal quantum efficiency of photoluminescence in GaN:Zn,Si

M. A. Reshchikov,
Physics Department, Virginia Commonwealth University, Richmond, Virginia 23284
USA

A. Behrends, A. Bakin, and A. Waag
Institute of Semiconductor Technology, Technische Universität Braunschweig,
Braunschweig, Germany

Co-doping of GaN with silicon and zinc leads to bright light emission at a photon energy of about 2.9 eV. Such a co-doping has been used in early LED structures for creating blue light emission. However, after the “invention” of the InGaN quantum well, the Zn-related emission is no longer used in LEDs. New interest in this material could arise from the field of single photon emitters, and high internal quantum efficiency is a prerequisite in this case. Whereas the external quantum efficiency (EQE) can be determined by merely measuring the number of photons emitted by the LED, the determination of the absolute internal quantum efficiency (IQE) of electroluminescence or photoluminescence (PL) in wide-bandgap semiconductors remains a continuing challenge.

In this work, the optical properties of high-quality GaN co-doped with silicon and zinc were investigated with temperature-dependent, continuous-wave and time-resolved PL measurements. Two groups of GaN:Si,Zn samples with different concentrations of Zn (uncapped and capped with AlGaN film), as well as GaN:Si samples with different concentrations of Si, were grown by metalorganic vapor phase epitaxy on c-plane sapphire substrates. The concentration of free electrons in the GaN:Si,Zn samples [(0.5-1.4)×10^{19} cm^{-3}] was determined from the Hall effect and from analysis of the PL data. The concentration of the ZnGa acceptors in these samples (from 5×10^{17} to 1×10^{19} cm^{-3}) was estimated from PL measurements.

The IQE of PL was determined from the analysis of the dependences of the PL intensity on the excitation intensity and temperature, and the simulation of these dependences with a phenomenological model based on rate equations. The model reproduces an important phenomenon: the quenching of a recombination channel with a high IQE causes a rise in efficiency of all the other PL bands. This quenching can be achieved by increasing the temperature or excitation intensity. Quantitative analysis of this phenomenon allows one to determine reliably the absolute IQE of PL. The absolute IQE of the PL in GaN:Si,Zn exceeds 90%, with the largest contribution coming from the blue luminescence band associated with the ZnGa acceptor.

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