Physics of Electron Injection-Induced Effects in III-Nitrides

Leonid Chernyak and William Burdett
University of Central Florida
Physics Department
4000 Central Florida Blvd.
Orlando, FL 32816-2385, USA

One of the problems in GaN-based bipolar devices is a small minority carrier diffusion length. Another problem is related to an effective p-type doping, with Mg being the only technologically feasible acceptor. Electrically active Mg acceptors create levels in the GaN forbidden gap, on average, at ~ 170 meV above the top of the valence band. The fairly deep Mg-acceptor position in the gap results in relatively low majority hole concentration in p-GaN, which is typically in mid 10^{17} cm^{-3}. In addition, even deeper levels, likely related to Mg doping and located at 1.1, 1.4, and 2.04 eV above the top of the valence band, were found in GaN.

It has been recently discovered that electron injection into p-(Al)GaN, using either an electron beam of a Scanning Electron Microscope or a forward bias application to p-n junction or Schottky barrier, leads to a multiple-fold increase of minority carrier diffusion length [1,2]. It has also been demonstrated that forward biasing a GaN-based photovoltaic detector results in a several-fold responsivity enhancement due to a longer minority carrier diffusion length in the detector's p-region as a result of electron injection [3]. The observed electron injection-induced effects were attributed to the charging of the Mg-related levels [1,4].

The systematic studies were carried out on the representative range of p-type GaN and AlGaN samples as well as AlGaN/GaN superlattices, homogeneously and modulation (barrier only) doped with Mg, to determine the activation energy for the effect of electron injection. This activation energy was found to be in the range from 190 to 260 meV (see Table 1), which is close to the thermal ionization energy of the Mg-acceptor in AlGaN. The obtained results are in agreement with the previously proposed model of minority carrier transport enhancement due to charging of Mg-centers in p-AlGaN [1,4]. The activation energy of the electron injection effect observed in $Al_{0.2}Ga_{0.8}N$ is consistent with the deepening of Mg-acceptor level due to the incorporation of Al into GaN lattice. The activation energy in the $Al_{0.2}Ga_{0.8}N$/GaN superlattice, homogeneously doped with Mg, indicates that the main contribution to the effect comes from the capture of injected electrons by the wells.

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Table 1.
Electron injection-induced effect activation energies for samples under investigation. After refs. [5,6].

Sample	**Activation Energy**
Bulk p-GaN (MOCVD)	178 meV
Bulk p-GaN (MBE)	190 meV
Bulk p-$Al_{0.2}Ga_{0.8}N$ (MBE)	252 meV
Homogeneously doped p- $Al_{0.2}Ga_{0.8}N$/GaN SL	189 meV
Modulation doped p- $Al_{0.2}Ga_{0.8}N$/GaN SL	267 meV