Studies of Electron Trapping in III-Nitrides

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It has been recently discovered that electron injection into (Al)GaN doped with Magnesium, Manganese, or Carbon using either 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 and lifetime [1-5]. 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 Mg-doped p-region as a result of electron injection [6]. The observed electron injection effects were attributed to the charging of the meta-stable centers associated with the above-referenced impurities.

The systematic optical and electrical studies were carried out on the representative range of GaN and AlGaN samples to determine the activation energy for the effects of electron injection. The values for the activation energies are summarized in the Table 1. For (Al)GaN doped with Mg, the activation energy is close to the thermal ionization energy of the Mg-acceptor and increases consistent with increasing Al content in the lattice. In the case of Mn-doped GaN, electron-beam induced excitation from the Mn^{3+} neutral acceptor state was demonstrated to thermalize with an activation energy of 360 meV. The activation energy of the electron injection effects for GaN doped with Carbon is consistent with a defect state 40 to 70 meV deep in the gap [7].

1. L. Chernyak, A. Osinsky, V. Fuflyigin, E.F. Schubert, "Electron Beam-Induced Increase of Electron Diffusion Length in p-type GaN and AlGaN/GaN superlattices", *Appl. Phys. Lett.*, **77**, 875 (2000).
2. L. Chernyak, G. Nootz, A. Osinsky, "Enhancement of minority carrier transport in forward biased GaN p-n junction", *Electron. Lett.*, **37**, 922 (2001).
3. W. Burdett, A. Osinsky, V. Kotlyarov, P. Chow, A. Dabiran, L. Chernyak, "Impact of Aluminum concentration and Magnesium doping on the effect of electron injection in p-$Al_xGa_{1-x}N$", *Solid-State Electron.*, **47**, 931 (2003).
4. W. Burdett, O. Lopatiuk, A. Osinsky, S.J. Pearton, L. Chernyak, "Optical signature of electron injection in p-AlGaN", *Superlattices and Microstructures*, **34**, 55 (2004).
5. W. Burdett, O. Lopatiuk, L. Chernyak, M. Hermann, M. Stutzmann, M. Eickhoff, "Electron injection-induced effects in Mn-doped GaN", *Appl. Phys. Lett.*, submitted (2006).
6. L. Chernyak**,** A. Schulte, A. Osinsky, J. Graff, E.F. Schubert, "Influence of electron injection on performance of GaN photodetectors", *Appl. Phys. Lett.*, **80**, 926 (2002).
7. M. Lisker, A. Krtschil, H. Witte, J. Christen, A. Krost, U. Birkle, S. Einfeldt, D. Hommel, "Influence of Carbon Doping on the Photoconductivity in GaN Layers", *Phys. Stat. Sol.* (b), **216**, 593 (1999).

Table 1.
Electron injection-induced effect activation energies for samples under investigation.

Sample	**Activation Energy**
p-GaN:Mg (MOCVD)	178 meV
p-GaN:Mg (MBE)	190 meV
p-$Al_{0.15}Ga_{0.85}N$:Mg (MOCVD)	232 meV
p-$Al_{0.2}Ga_{0.8}N$:Mg (MBE)	252 meV
GaN:Mn (MBE)	360 meV
GaN:C (MOCVD)	80 meV