**Enhancement of Ionization Efficiency of Acceptors by their Excited States in Heavily Doped p-Type GaN and Wide Bandgap Semiconductors**

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Abstract

GaN, SiC and diamond have been attractive wide bandgap semiconductors. According to the hydrogenic model, a ground state level (i.e., an acceptor level) of a substitutional acceptor in them is expected to be large because of their dielectric constant lower than Si as well as their hole effective mass heavier than their electron effective mass. For example, the acceptor level for SiC is calculated as 146 meV, and the first excited state level is estimated as 36 meV that is close to the acceptor level of B in Si. Therefore, the excited states should influence the temperature dependence p(T) of the hole concentration in p-type wide bandgap semiconductors.

A distribution function suitable for an acceptor in p-type GaN or p-type SiC is investigated using p(T) obtained by Hall-effect measurements. Since the Fermi levels in heavily doped samples are located between the valence band and the acceptor level, there are a lot of holes at the excited states of acceptors, indicating that a distribution function for acceptors should include the effect of the excited states of acceptors. Two distribution functions for acceptors are considered here; (1) the Fermi-Dirac distribution function that does not include them, and (2) our proposed distribution function that includes them [1-4].

An acceptor density and an acceptor level are determined with the Fermi-Dirac or proposed distribution function from p(T) for heavily Mg-doped GaN, Al-doped 4H-SiC, or Al-doped 6H-SiC. In the case of the Fermi-Dirac distribution function, the determined acceptor density is always much higher than a Mg-doping or Al-doping density determined by secondary ion mass spectroscopy. On the other hand, the estimated acceptor density is close to the doping density in the case of the proposed distribution function. This indicates that the excited states enhance an ionization efficiency of acceptors in the heavily doped case.

In the lightly doped case, the acceptor density determined by the proposed distribution function is nearly equal to that determined by the Fermi-Dirac distribution function. Furthermore, the acceptor density is close to the doping density. This is because there are few holes at the excited states due to large difference in energy between the valence band and the Fermi level.

In summary, the Fermi-Dirac distribution function can only applied to the lightly doped case in p-type wide bandgap semiconductors. On the other hand, the proposed distribution function considering the influence of the excited states of acceptors is appropriate for any acceptor density. Therefore, the excited states of acceptors enhance the hole concentration in heavily doped p-type wide bandgap semiconductors.

References

[1] H. Matsuura, New J. Phys. 4, 12.1 (2002) [http://www.njp.org/].
[2] H. Matsuura, et al., J. Appl. Phys. 94, 2234 (2003).
[3] H. Matsuura, et al., phys. stat. sol. (c) 0, 2214 (2003).
[4] H. Matsuura, J. Appl. Phys. 95, 4213 (2004)