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Key Materials Aspects for Valence Control of ZnO.

ATSUSHI TSUKAZAKI, Institute for Materials Research, Tohoku University

ZnO has significant advantages for light emitting diodes (LEDs) and lasers from the following reasons; 1) exciton binding energy in ZnO is 60 meV and can be enhanced over 100 meV in superlattices, 2) it is possible to tune the bandgap from 3 eV to 4.5 eV in $Zn_{1-x}Cd_xO$ and $Mg_xZn_{1-x}O$ alloy films having quite small lattice mismatch, and 3) large and high-quality single-crystal wafers are commercially available. In order to harvest these advantages in real devices, reliable technique for fabricating p-type ZnO has to be properly established. Recently we have reported on the improvements of undoped ZnO film quality with inserting a ZnO self-buffer layer onto lattice matched $ScAlMgO_4$ substrate [1]. In view of point defect formation during the epitaxy, we have carefully optimized the growth conditions. We selected nitrogen as an acceptor, because the ionic radius is close to that of oxygen. Here we propose a repeated temperature modulation (RTM) technique for efficient nitrogen doping into ZnO with keeping high crystallinity [2]. By carefully optimizing the conditions, p-type ZnO with a hole concentration of 10^{16} - 10^{17} cm^{-3} can be reproducibly fabricated. We also demonstrated blue electroluminescence from p-i-n homojunction LED [3]. The details of thin film growth, characteristics of p-type ZnO and device performance will be presented.

[1] A. Tsukazaki et al. *Nature Mater.* **4**, 42 (2005).
[2] A. Tsukazaki et al. *Appl. Phys. Lett.***83**, 2784 (2003).
[3]A. Tsukazaki et al. *Jpn. J. Appl. Phys.Lett.*44, L643 (2005).