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Shallow acceptor complexes in p-type ZnO¹

D.E. ASPNES², North Carolina State University

ZnO films grown on sapphire substrates by organometallic vapor phase epitaxy exhibit p-type behavior when sufficient N is properly incorporated and followed by an appropriate annealing sequence. While substitutional N on the O sublattice is a deep acceptor, shallow acceptor complexes involving N, H and V_{Zn} can provide useful 10^{18} cm^{-3} p-type films. Taking advantage of Raman, SIMS, and Hall-effect data, we establish a two-step growth scheme to form a metastable double donor complex, $N_{Zn}-V_O$, then convert it to a single shallow acceptor complex, $V_{Zn}-N_O-H^+$ during *in situ* annealing in N_2O . The $V_{Zn}-N_O-H^+$ complex accepts electrons at ionization energies of 134 meV, rendering it an efficient p-type dopant at room temperature.

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²Collaborators: J. G. Reynolds, C. L. Reynolds, Jr., J. E. Rowe (all NC State University); A. Mohanta (AMRDEC, Huntsville, AL); H. O. Everitt (AMRDEC, Huntsville, and Duke University)