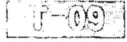

# Effect of annealing temperature and ambient gases on the phosphorus doped *p*-type ZnO

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We report on the thermal activation of phosphorus (P)-doped *p*-type ZnO thin films grown by radio frequency (RF) magnetron sputtering. Phosphorus doped ZnO thin films were activated to obtain *p*-type ZnO in the $N_2$, Ar, and $O_2$ ambient at different annealing temperatures. The hole concentration of *p*-type ZnO in $O_2$ ambient showed a lower hole concentration ($2.01\times10^{17}$ at 850 ℃) compared to those of samples annealed in $N_2$($4.8\times10^{18}$at 850 ℃) and/or Ar ($4.5\times10^{18}$ at 850 ℃) ambient. The measurement of activation energy of phosphorus dopant and the effect of ambient gases on the hole concentration indicated that the dissociation of Zn-O and P-O are suppressed in the $O_2$ ambient and the phosphorus replaces oxygen atoms to increase the hole concentration.