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# Process control, performance limits and dopant activation of Al-doped ZnO grown by reactive pulsed magnetron sputtering

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Al-doped ZnO (AZO) films which combine maximum carrier mobility (μ), moderate free electron densities ($N_e$) and high surface roughness are of special interest for application as transparent front electrode in thin film solar cells. They posses high optical transmission in the visible and near infrared spectral range and enable a superior light trapping behavior.
Reactive magnetron sputtering using a wide range of Al target concentrations ($c_{Al}$) in connection with precise process control is used to grow high quality polycrystalline AZO films exhibiting optimum values of $\mu > 45 cm^2/Vs$ and $\rho < 2.3x10^{-4}$ Ωcm.
The present work is focused on systematic investigations of the influence of process parameters like oxygen partial pressure and substrate temperature ($T_s$) on AZO film properties. The observed dependence of carrier mobility on $N_e$ in AZO is discussed in the framework of ionized impurity scattering and clustering as well as grain boundary limited transport which predicts a fundamental physical limit of μ.
The $c_{Al}$ is shown to have a strong impact on the optimum process conditions and also on film structure. Ion-beam analysis confirms an Al enrichment in the films with increasing $T_s$ which correlates with the commonly observed deterioration of electrical properties at high $T_s$ values. In combination with Hall-effect measurements it is possible to estimate the fraction of electrically active Al in the ZnO matrix, which is rarely reported in a quantitative and systematic manner.

**Keywords**
transparent conductive oxide
reactive magnetron sputtering
zinc oxide
doping
activation