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Hydrogen shallow donors in ZnO and SnO_2 thin films prepared by sputtering methods

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In this paper, we report that the effects of hydrogen doping on the electrical and optical properties of typical transparent conducting oxide films such as ZnO and SnO_2 prepared by magnetron sputtering. Recently, density functional theory (DFT) calculations have shown strong evidence that hydrogen acts as a source of n-type conductivity in ZnO. In this work, the beneficial effect of hydrogen incorporation on Ga-doped ZnO thin films was demonstrated. It was found that hydrogen doping results a noticeable improvement of the conductivity mainly due to the increases in carrier concentration. Extent of the improvement was found to be quite dependent on the deposition temperature. A low resistivity of 4.0×10^{-4} Ω·cm was obtained for the film grown at 160 °C with H_2 10% in sputtering gas. However, the beneficial effect of hydrogen doping was not observed for the films deposited at 270°C. Variations of the electrical transport properties upon vacuum annealing showed that the difference is attributed to the thermal stability of interstitial hydrogen atoms in the films.

Theoretical calculations also suggested that hydrogen forms a shallow-donor state in SnO_2, even though no experimental determination has yet been performed. We prepared undoped SnO_2 thin films by RF magnetron sputtering under various hydrogen contents in sputtering ambient and then exposed them to H-plasma. Our results clearly showed that the hydrogen incorporation in SnO_2 leads to the increase in carrier concentration. Our experimental observation supports the fact that hydrogen acting as a shallow donor seems to be a general feature of the TCOs.