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ROOM-TEMPERATURE FERROMAGNETIC PROPERTIES IN Mn-DOPED RUTILE TiO$_2$-$\delta$ THIN FILMS

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A room-temperature ferromagnetic behavior was observed for Mn-doped reduced titanium dioxide (TiO$_2$-$\delta$:Mn) thin films with rutile structure synthesized by a sol-gel method. The TiO$_2$-$\delta$:Mn films were found to be semiconducting with p-type electrical conductivity. The observed ferromagnetism is believed to be intrinsic but not related to free carriers such as holes. Oxygen vacancies are likely to contribute to the room-temperature ferromagnetism. The trapped carriers in oxygen vacancies can mediate a ferromagnetic coupling between neighboring Mn$^{3+}$ ions. Spectroscopic ellipsometry measurements on the films revealed that the band-gap energy showed a red-shift by Mn doping. The red-shift can be understood in terms of spin-exchange interactions between the Mn$^{3+}$ ion and the carrier.