of highly efficient solar cell in addition to the conventional *p-n* type solar cells. Basic and theoretical studies of DSSCs and attempts to commercialize them have been intensively pursued. This section discusses recent approaches to improve cell performance and commercialize DSSCs.

15.3.1 New Oxide Semiconductor Film Photoelectrodes

To date, nanocrystalline TiO_2 electrodes have been used predominantly as the photoelectrode in DSSCs, but other oxide semiconductor materials, ZnO [23, 86–92], SnO_2 [23, 51, 91–93], Nb_2O_5 [23, 43, 91, 92], In_2O_3 [23, 91, 92], $SrTiO_3$ [94], and NiO [95], have also been investigated (Table 15.2). Nevertheless, nanocrystalline TiO_2 electrodes have the best performance, and oxide semiconductor materials exceeding the performance of TiO_2 have not been found. The physical properties of the materials, such as the energy level of the conduction band and the electron conductivity, influence the performance of the photoelectrode significantly, affecting cell performance.

Recently, combined photoelectrodes consisting of two oxide semiconductor materials have also been investigated [96–98]. Tennakone and coworkers reported that a DSSC based on a nanocrystalline SnO_2/ZnO-combined photoelectrode and N3 dye produced a highly efficient cell performance equal to that of the TiO_2 solar cell [96, 97]: 8% $\eta(J_{SC} = 22.8$ mA cm^{-2}, $V_{OC} = 0.67$ V, and $ff = 0.50)$ under 90 mW cm^{-2} and 15% η under 10 mW cm^{-2} [96]. They employed a combined film consisting of small particles of SnO_2 (15 nm) and large particles of ZnO (2 μm, 53 wt%). The performance of the combined photoelectrode was improved drastically compared to that of ZnO and SnO_2 electrodes. It is believed that the Ru complex is adsorbed on SnO_2 nanoparticles, and ZnO contributes to the electron-transfer process. These results indicate the possibility of developing non-TiO_2, high-performing electrodes for DSSC, although the detailed mechanism of the new electrode has not been elucidated at this time.

The effect on performance of coating the surface of the TiO_2 electrode with other oxide compounds has been investigated by several groups. Zaban *et al*. prepared a nanocrystalline TiO_2 electrode coated with Nb_2O_5, whose conduction-band level is more negative than that of TiO_2. They measured cell performance of a DSSC using this photoelectrode and N3 dye [99]; the J_{SC} and V_{OC} were improved compared to those of the TiO_2 electrode. Wang *et al*. studied cell performance of DSSC using a nanocrystalline ZnO-modified TiO_2 photoelectrode and N3 dye [100]. In this study, the J_{SC} and V_{OC} were also improved compared to those of the TiO_2 electrode. They believed that the improvement was caused by a positive shift of the conduction-band level of the photoelectrode and suppression of dark current due to the ZnO coating [100].

15.3.2 New Dye Photosensitizers

15.3.2.1 Metal complex photosensitizers

As described in Section 15.1.2.3, the $RuL_2(NCS)_2$ complex (N3 dye), and RuL'$(NCS)_3$ complex (Black dye), were developed and investigated intensively as photosensitizers. Other Ru complex photosensitizers have also been synthesized and characterized, and their