Table 15.1 Photovoltaic performance of N3 dye-sensitized TiO_2 solar cells

Institute	Cell size [cm^2]	J_{SC} [$mA\,cm^{-2}$]	V_{OC} [mV]	Fill factor	η [%]	Light source	Year
EPFL	0.31	18.2	720	0.73	9.6	AM1.5	1993
EPFL-NREL	0.17	18.6	740	0.73	10.0	AM1.5	1997
Uppsala Univ.	1.0	30.4	610	0.37	6.9	ELH lamp	1994
ISK	0.5	14.2	630	0.71	6.3	AM1.5	1994
Osaka Univ.	0.5	3.9	570	0.67	6.1	21 $mW\,cm^{-2}$	1995
NREL	0.44	14.5	730	0.71	7.5	AM1.5	1997
NIMC	0.13	14.5	698	0.71	7.2	AM1.5	1998
EPFL-NIMC	0.21	15.2	780	0.71	8.4	AM1.5	1999
INAP	144	–	–	–	7.0	AM1.5	1997

EPFL: Swiss Federal Institute of Technology, Switzerland
NREL: National Renewable Energy Laboratory, USA
ISK: Ishihara Sangyo Kaisha Ltd
NIMC: National Institute of Materials and Chemical Research, Japan
INAP: Institut für Angewandte Photovoltaik GmbH, Germany

(approximately 100 $mW\,cm^{-2}$) produced with a solar simulator in the laboratory. Grätzel and coworkers reported $\eta = 9.6\%$ in 1993, and they achieved 10% at NREL in 1997. Other high efficiencies were reported by Lindquist and coworkers, at Uppsala University (6.9%, 1994), NREL (7.5%, 1997), Ishihara Sangyo Kaisha Ltd. in Osaka (6.3%, 1994), and Yanagida and coworkers at Osaka University (6.1%, using 21 $mW\,cm^{-2}$, 1995). Our group achieved 7.2% in 1998, 8.4% in cooperation with EPFL in 1999, and 8.3% in cooperation with Sumitomo Osaka Cement Co. Ltd. in 2000. A venture company, Institut für Angewandte Photovoltaik GmbH (INAP), that has been investigating commercialization of the DSSC in cooperation with EPFL achieved 7% in 1997 using a 144 cm^2 cell (12×12 cm^2). Although these groups have reproduced efficiency values greater than 7%, additional studies must be done to reproduce 10% efficiency.

The establishment of standard measurement conditions for cell performance of DSSC is necessary before cell performance can be estimated exactly because performance depends on measurement conditions, such as light intensity and spectrum. Generally, under low light intensity, fill factor of DSSC is improved because of low photocurrent (i.e. low series resistance), resulting in improved cell performance. The light whose intensity and spectrum are close to AM1.5 irradiation should be used as the light source similar to conventional solar cells. Spectral response (IPCE) performance of DSSCs also depends on light conditions [63]. DSSCs show relatively slow response because of low electron mobility of the TiO_2 film, as described in Section 15.1.4.5. Under high-intensity irradiation, the response of DSSCs increase with electron injection and electron trap filling. Therefore, IPCE performance should be measured by a DC method with high-intensity monochromatic light or an AC method using white bias irradiation and low chopper frequencies (e.g. $<$50 Hz [63]).

15.3 NEW DEVELOPMENTS

DSSCs producing current with 10% efficiency using a Ru complex photosensitizer and a nanocrystalline TiO_2 photoelectrode have been shown to be a significant new type