A nanocrystalline SnO_2 solar cell sensitized by a perylene derivative produced 0.9% efficiency under AM1.5 ($J_{SC} = 3.26$ mA cm^{-2} and $V_{OC} = 0.45$ V) [136]. With a TiO_2 solar cell (1 cm^2) sensitized by eosin yellow, one of the 9-phenylxanthene dyes produced 1.3% efficiency ($J_{SC} = 2.9$ mA cm^{-2}, $V_{OC} = 0.66$ V, and $ff = 0.67$) [137]. A mercurochrome/ZnO solar cell (0.09 cm^2) attained 2.5% efficiency ($J_{SC} = 7.44$ mA cm^{-2}, $V_{OC} = 0.52$ V, and $ff = 0.64$) under AM1.5 irradiation [90, 91].

Cyanine and merocyanine dyes have also been used as photosensitizers [138–142]. A nanocrystalline TiO_2 solar cell based on a merocyanine dye photosensitizer (surface area, 0.25 cm^2) produced an efficiency of 4.2% ($J_{SC} = 9.7$ mA cm^{-2}, $V_{OC} = 0.62$ V, and $ff = 0.69$) under AM1.5 (100 mW cm^{-2}) [141]. Aggregates of the merocyanine dye formed on the TiO_2 surface result in expansion of the absorption area, especially in the long-wavelength region, resulting in improvement of light-harvesting performance [141].

We synthesized new coumarin derivatives that can absorb visible light from 400 to 700 nm and prepared nanocrystalline TiO_2 solar cell. Under AM1.5 irradiation, an efficiency of 5.6% was attained (area = 0.25 cm^2, $J_{SC} = 13.8$ mA cm^{-2}, $V_{OC} = 0.63$ V, and $ff = 0.64$) [143, 145] (recently we attained 6.0% efficiency). A maximum IPCE of 76% was obtained at 470 nm. The photocurrent performance of this solar cell is almost equal to that of the N3 dye/TiO_2 solar cell, indicating a promising prospect for organic dye photosensitizers. Design and development of new organic dyes with absorption in the near-IR region and large absorption coefficients are needed to improve DSSC performance using organic dye photosensitizers.

In addition to organic dyes, natural dyes extracted from plants can also be used as photosensitizers [34, 146, 147]. A nanocrystalline TiO_2 solar cell using a santalin dye extracted from red sandalwood can produce 1.8% efficiency under 80 mW cm^{-2} irradiation [147]. Cherepy *et al.* reported that a nanocrystalline TiO_2 solar cell using flavonoid anthocyanin dyes extracted from blackberries can convert sunlight to electrical power at an efficiency of 0.6% ($J_{SC} = 1.5 - 2.2$ mA cm^{-2} and $V_{OC} = 0.4 - 0.5$ V) under AM1.5 [34]. The maximum IPCE was 19% at the peak of the visible absorption band of the dye. They also observed a fast electron injection of <100 fs from cyanin dye into the conduction band of TiO_2 as measured by time-resolved transient absorption spectroscopy [34].

15.3.3 New Electrolytes

Room-temperature ionic liquids (molten salts) have been extensively studied as replacements for volatile organic solvents in electrochemical devices such as batteries because of their high ionic conductivity, electrochemical stability, and nonvolatility. Of these properties, nonvolatility is the most critical for ensuring the long-term stability of electrochemical devices. Such room-temperature ionic liquids have also been utilized and studied in DSSCs in place of liquid electrolytes [84, 148]. Ionic liquids used in DSSCs include imidazolium derivatives, such as 1-hexyl-3-methylimidazolium iodide (HMImI) [84] and 1-ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl)imide (EMIm-TFSI) [148]. Matsumoto *et al.* reported that an N3 dye-sensitized TiO_2 solar cell using an EMIm salt having hydrofluoride anions, $H_2F_3^-$ or $H_3F_4^-$, as the electrolyte solvent produced 2.1% efficiency under AM1.5 ($J_{SC} = 5.8$ mA cm^{-2}, $V_{OC} = 0.65$ V, and $ff = 0.56$) [148]. If the viscosity