論文の内容の要旨

Studies on New Charge Selective and Conductive Interfaces in Organic-Inorganic Thin-film Photovoltaics

(有機無機薄膜太陽電池における新規電荷選択及び輸送界面の研究)

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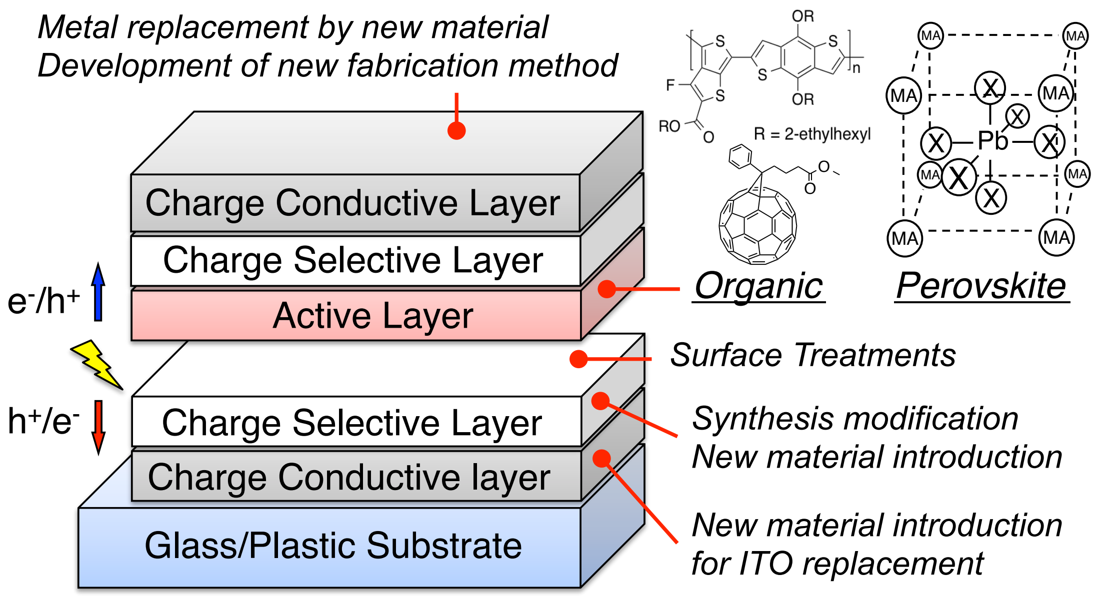
Global warming and nuclear disasters in recent times have urged the society to look towards alternative energy sources, which are pollution-free, infinite, and viable in mass-production. As a result, there has been a remarkable upshift in development of the solar cell research among scientists. Experts forecast that, with technology assuring large-scale, solar cells can contribute nearly a third of electricity consumption worldwide between now and 2030.

Although already-industrialised silicon solar cells possess notably high power conversion efficiencies, they have a combination of disadvantages including heavy weight and high cost which made difficult for them to supersede the conventional energy sources. Opportunities exist for photovoltaics that promise substantial reduction in manufacturing costs and superior functionalities such as flexibility while retaining descent efficiencies. There are two novel technologies that satiate tantalising prospects on these fronts: organic solar cells and freshly emerging mixed organic–inorganic halide perovskite solar cells.

Solar cell devices are mainly composed of active layer, charge selective layer, and charge conductive layer. The active layer absorbs light and generates excitons; the choice of materials for this layer determines the type of solar cells. The charge selective layers are placed above and below the active layer to filter out any unwanted charges followed by the conductive layers, which then extract those filtered charges. The charge selective and conductive layers are the two common essential layers in all types of solar cells. Focusing on these two layers and their interfaces is crucial in solar cell technologies and gaining ground in the energy competition via scientific breakthroughs.

In this thesis, new materials for charge selective/conductive layers in photovoltaic devices were introduced and their interfaces were studied by various approaches (Insetted Figure). They include numerous novel materials, modification of already existing layers, changing fabrication methods, surface treatments and so forth. The investigation in this dissertation starts from the charge conductive layer (electrode) way up to the interface between the charge selective layer and the active layer. Both organic and perovskite solar cells have been utilised here, because neither of them drops as less promising. Since two systems have been used, it was possible to explore common traits shared by both systems, as well as different behaviours unique to each system.



Inset Figure. Illustration of focuses of the research in this thesis

Quick glances at some of the researches done in this work are the following:

- Inflexible and expensive conventional indium tin oxide electrode was replaced by earth-abundant and mechanically resilient carbon nanotubes. Diverse methodologies were employed to improve the properties of carbon nanotubes and led to power conversion efficiencies of around 80% to those of the indium tin oxide counterparts in both organic and perovskite solar cells. Moreover, their flexible applications were successfully demonstrated. In addition to the bottom indium tin oxide electrode, top metal electrode was also replaced to produce window-like transparent solar cells.

- Conductive niobium (2%)-doped titanium oxide film was found to turn its surface layer into a semiconducting and hole-blocking layer upon UV-ozone treatment. This means that the film can now function as both a charge conductor and a selective layer, making the solar cell fabrication simpler and cheaper.

- ZnO quantum dots were synthesised and stabilised by 2-aminoethanol. They were then spin-coated and used in solar cell fabrication directly without usually required thermal annealing. Yet, they performed as good as the conventional ZnO film. Furthermore, sputtering ZnO technique was studied, and found that the sputtered ZnO film gives better performance than the conventional film.

- Surface of the hole-blocking layers in inverted organic solar cells was modified by catechol derivatives or anthracene derivatives. Charged ends of the chemical compounds were adsorbed firmly to the surface of the charge selective layers, inducing a thin layer of fullerenes to enhance the charge extraction. The same effect was observed without use of the surface modifiers when a technique called ‘Waiting effect’ was applied. Literally waiting before spin-coating an active layer solution as drop-cast on the substrate promoted a vertical separation of donor and acceptor species in the active layer.

- MoS_2 nano-flakes were deposited on carbon nanotubes by chemical vapour deposition technique. MoS_2 does not interact directly with P3HT, whereas carbon nanotubes can form π-π bonds with P3HT. Therefore, MoS_2 stuck to carbon nanotubes could form a bulk heterojunction for the first time and function as electron acceptors in solar cell devices.

Different materials and interfaces in the charge selective/conductive layers have been studied in depth. Their applications were successful in terms of enhancement in power conversion efficiency and endowing novel functionalities. Researches here are exceptionally useful in a way that they are applicable not only in photovoltaics, but in other electronic devices as well.