2-2-3. Perovskite Solar Cells

Overview

This solar cell uses an ionic crystal with a perovskite structure with the composition ABX_3 (Fig. 1) as the semiconductor, in which the X site is a halogen such as iodine. The semiconductor exhibits strong visible light absorption (absorption coefficient 100,000 cm^{-1}) and high performance in power generation which are not found in oxide-type perovskites. This crystal is an excellent intrinsic semiconductor with an extremely long lifetime and diffusion length of photoexcited electrons, and is also used in light-emitting devices (LEDs) due to its highly efficient light-emitting properties. The crystalline thin film (approx. 1 μm thick) used for power generation is formed by solution processing with crystallization reactions. The solar energy conversion efficiency of the thin film element (Fig. 1), made by joining charge (electron, hole) transport layers, exceeds 27%, which is equal to or greater than that of crystalline silicon solar cells.

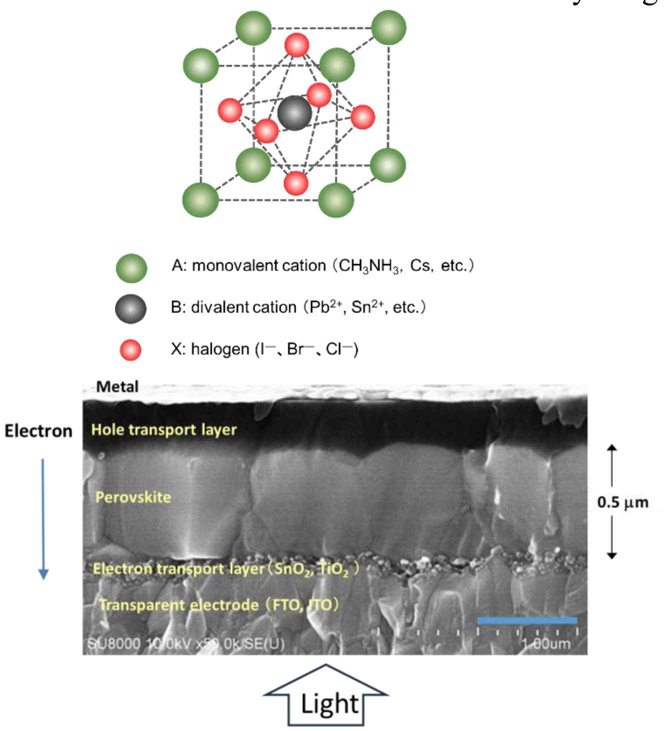

Figure 1. Perovskite crystal structure and solar cell layer structure

Current Status and Frontiers

Academic reports began in Japan in 2006, and since papers were published in 2009 and 2012, research has spread worldwide, and the power conversion efficiency (PCE) has increased to close to the theoretical limit (about 30%). Although the mainstream method of film formation is a chemical crystallization, physical vacuum deposition has also achieved high efficiency. The advantage of perovskite semiconductors is their high open circuit voltage in power generation due to their defect tolerant properties that are not easily affected by crystal defects. In addition, research is also active on the use of perovskite devices to indoor power generation, as their efficiency does not decrease under low-intensity indoor lighting. Because they are ionic crystals, they are hygroscopic, and structural design to prevent the deterioration caused by this is a challenge. Below are some examples of research developments.

1. Efficiency enhancement for inverted structure devices

Compared to the structure in Fig. 1, devices with an inverted arrangement of the hole transport and electron transport layers (HTL, ETL) are becoming the mainstream of research, with the inorganic NiO_x and organic fullerene (PCBM) for the HTL and ETL.

2. Device based on self-assembled monolayer (SAM)

In an inverted structure, a SAM layer is formed as a hole-selective layer at the interface between the electrode substrate (ITO, FTO) and the perovskite, and research is spreading to academic and corporate development to improve PCE and durability.

3. Molecular engineering to passivate interfaces

Functional organic molecules are used to suppress the charge recombination loss by structural defects on the surface of the crystal grains and at the interface between the perovskite and the charge transport layer, leading to improved performance and durability. .

4. Development of large-area practical modules

Practical high-voltage output modules that have multiple series-connected power generation layers arranged on an electrode substrate are developed, and demonstrations of lightweight, flexible solar cells have begun.

5. Development of high efficiency tandem solar cells

The development of a tandem cell in which a perovskite semiconductor film (visible light absorption) is formed on the surface of a silicon crystal semiconductor (infrared absorption) achieved a PCE of approximately 35%.

6. Preparation of lead-free perovskite materials and device fabrication

PCE of devices using Sn, Bi, etc. instead of Pb is limited to a maximum of about 15%.

References

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Future Perspectives and Directions

Technologies for improving practical durability (material hydrophobicity, sealing of elements) will progress, and it is predicted that sales of practical modules will begin by 2030 (Sekisui Chemical in Japan, etc.). Instead of solution processing, film formation using vacuum deposition methods may evolve and be used in practical development.

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