Understanding The Working Principles of Perovskite Solar Cells by Impedance Spectroscopic Analysis

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Introduction

- Why Perovskite? The growing demand for renewable energy has led to considerable development in photovoltaics (PVs). As a newcomer in PV field, organometal halide perovskite (ABX₃) has rapidly reached a power conversion efficiency (PCE) of nearly 20%. However, perovskites exhibit a dense charge trapping that may induce hysteresis, and there is ion migration phenomenon inside the material that may induce mechanical stress and further material degradation. These phenomena will affect the performance and stability of perovskite solar cells.

- Why Impedance Spectroscopy? Impedance spectroscopy is a powerful tool to quantitatively analyze the underlying charge trapping and ion migration processes, which helps us understand the nature of the perovskite materials and to improve the performance for future commercialization of perovskite solar cells.

Method

1. Experimental Design
Impedance spectroscopy (IS) measures the impedance response of a system over a wide range of frequencies. A bias voltage or current is applied to the device, and a small ac signal with changing frequency is used to obtain the impedance response under certain biasing point.

2. Equivalent Circuit Analog
The analysis of solar cells by IS has often been based on an equivalent circuit representing the working processes of devices. Equivalent circuits for the impedance response can be developed from proposed hypotheses involving reaction sequences, mass transfer and physical phenomena. Figure 2 is an example of a simple model composed of one resistor and one capacitor.

Results

1. Charge Trapping and Dielectric Properties
1.1 Device Structure
![Illustration of a planar solar device structure](image1)

1.2 Impedance Results under Illumination
![Complex impedance plot of samples with CH₃NH₃⁺ (MA), HC(NH₂)₃⁺ (FA) and without perovskites under bias voltage of 0.6V](image2)

![Dielectric constant of MA devices under different bias voltage](image3)

Firstly we observed a significant turn-back loop for MA devices at the low frequency region (under 2Hz). This is correlated with hysteresis phenomenon, where MA devices show a larger hysteresis than other samples, and experiments have shown that the charge trapping is huge in bulk perovskite and perovskite/TiO₂ interface. These correlated phenomena may be due to the dielectric relaxation or charge trapping. We also observed a giant dielectric constant in perovskite under illumination (10⁶ times larger than original value), which sharply increases from ~100Hz. And the value is 10⁴ times larger than that of under dark. This giant dielectric constant may be due to illumination or charge injection into devices.

2. Effects of Ion Migration
![Solid-state devices designed to reveal the effect of ion migration with the structure of (a) FTO/Perovskite/Electrolyte/Perovskite/FTO (b) FTO/PEDOT/Perovskite/Electrolyte/Perovskite/PEDOT/FTO](image4)

Different interfaces are used and devices with IPA and IPA+MAI can study the electrochemical properties of perovskite with and without external ions, which reveals information on internal ion motion.

Conclusion

In conclusion, with the help of impedance spectroscopy, we found a significant turn-back loop of perovskite solar cells with huge charge trapping and its giant dielectric constant phenomenon. And we also evaluated the effects of ion migration in perovskite. Results show that the ion migration level in perovskite is relatively large, and illumination and electric field can both influence the charge transfer and ion absorption on the interfaces. Future work will be done on changing ions and interfaces to establish a comprehensive equivalent circuit for understanding the working principles of perovskite solar cells.

References

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