

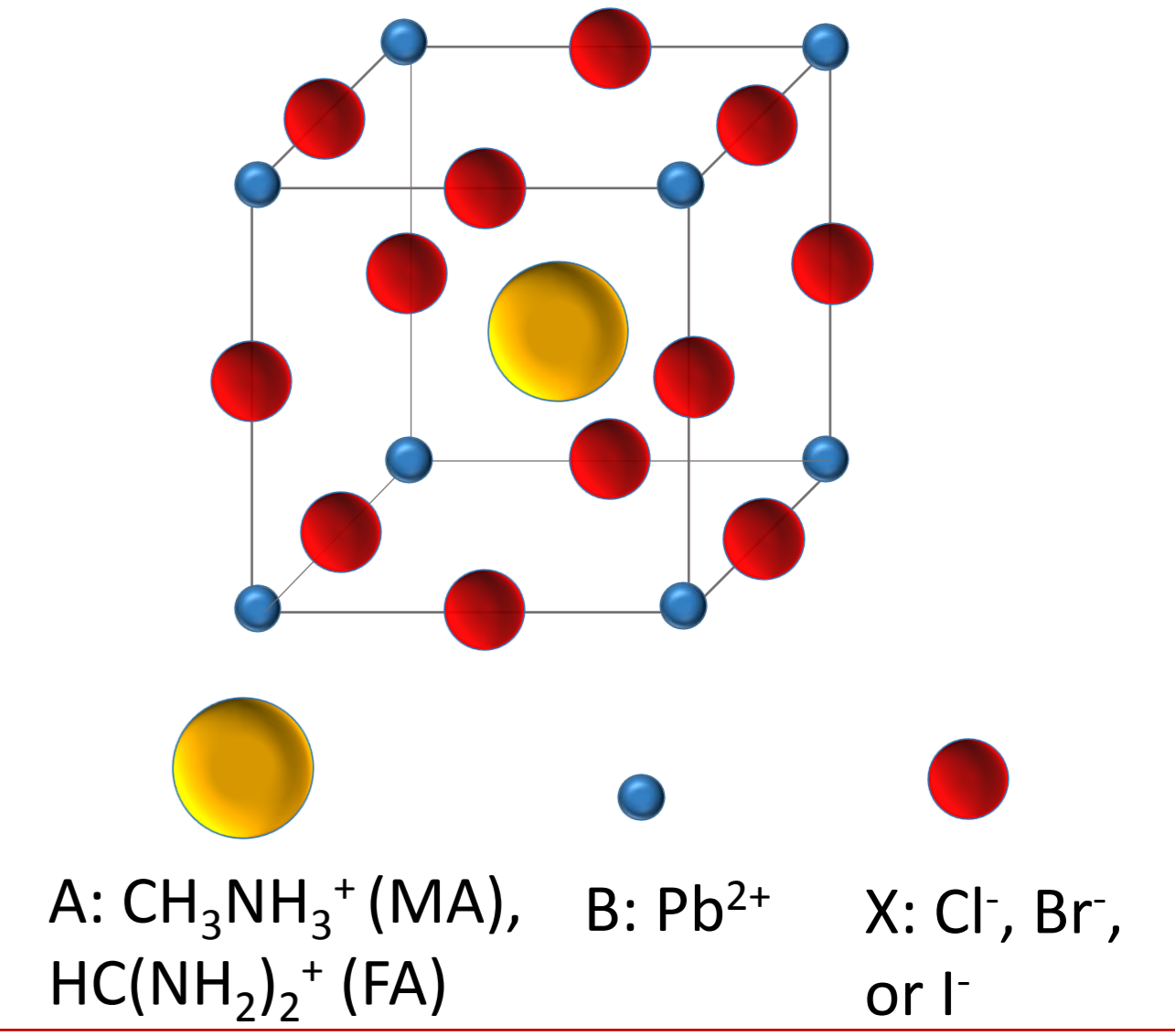


Understanding The Working Principles of Perovskite Solar Cells by Impedance Spectroscopic Analysis

Linkai LI* Supervisor: Ni ZHAO
Department of Electronic Engineering, CUHK
*Email: johnlilinkai@gmail.com

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 (ABX_3) 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.

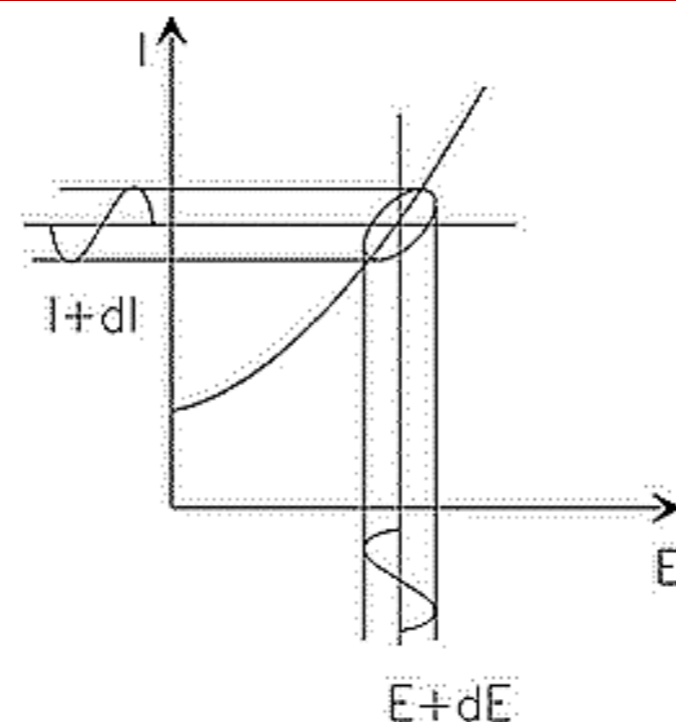
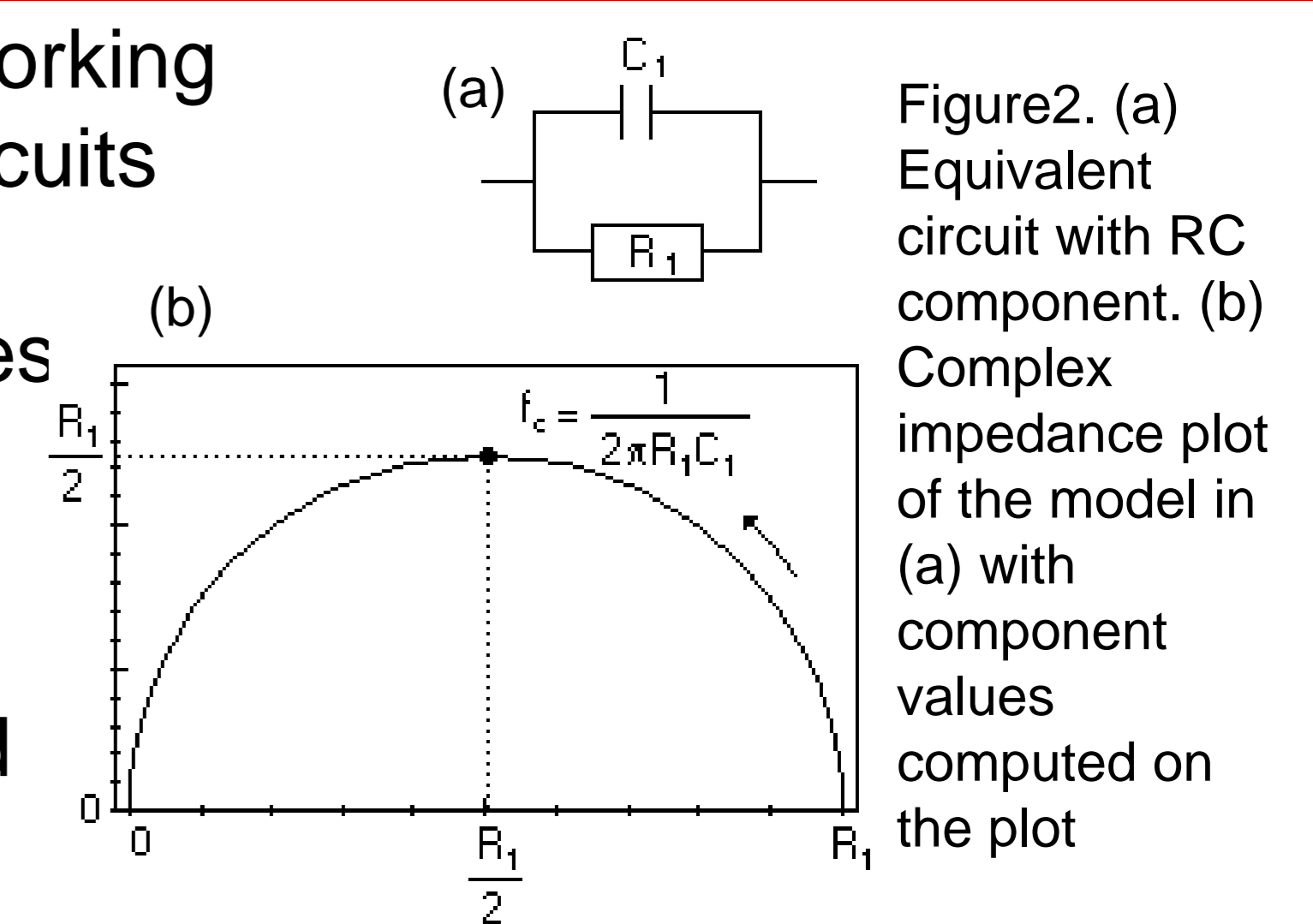


Figure 1. Experimental illustration of impedance spectroscopy

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.



2. Equivalent Circuit Analog

The analysis of solar cells by IS has often been based on an

Results

1. Charge Trapping and Dielectric Properties

1.1 Device Structure



Figure 3. Illustration of a planar solar cell device structure

1.2 Impedance Results under Illumination

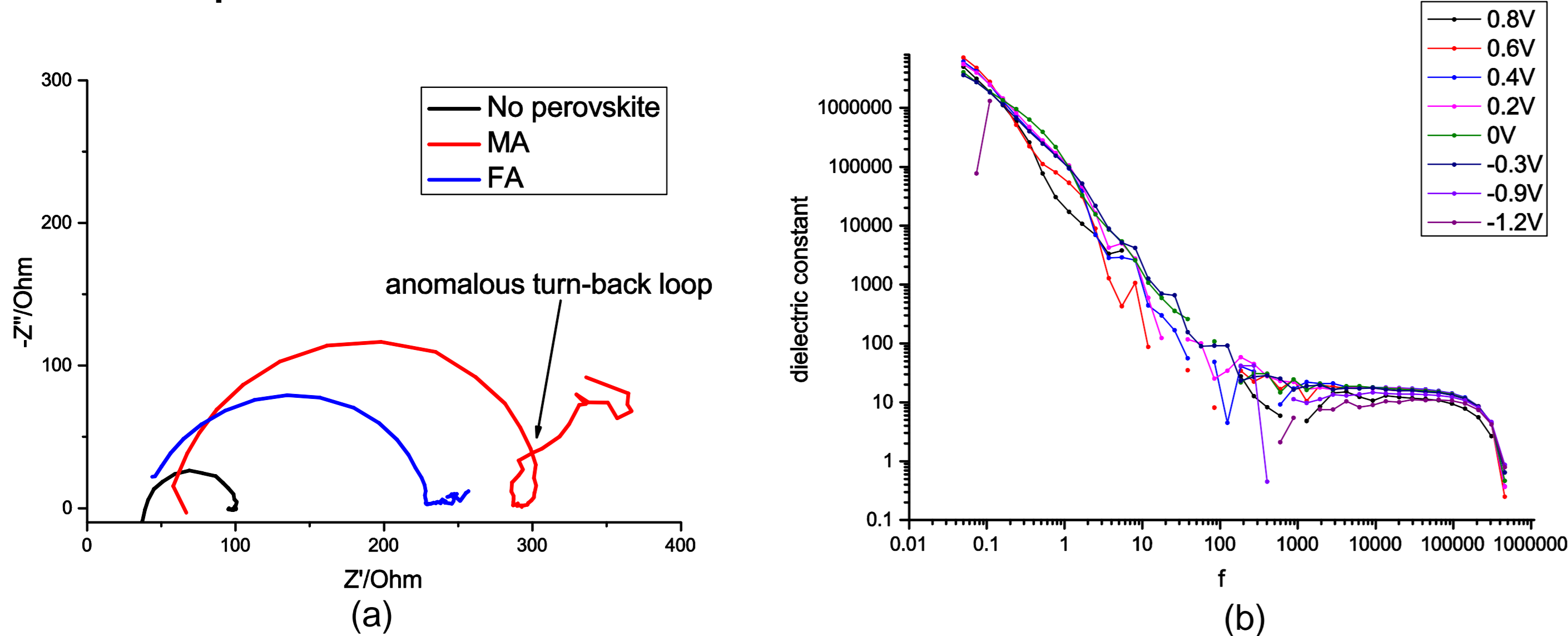


Figure 4. (a) Complex impedance plot of samples with $CH_3NH_3^+$ (MA), $HC(NH_2)_2^+$ (FA) and without perovskites under bias voltage of 0.6V (b) Dielectric constant of MA devices under different bias voltage

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/ TiO_2 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 (10^6 times larger than original value), which sharply increases from ~ 100 Hz. And the value is 10^3 times larger than that of under dark. This giant dielectric constant may be due to illumination or charge injection into devices.

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.

2. Effects of Ion Migration

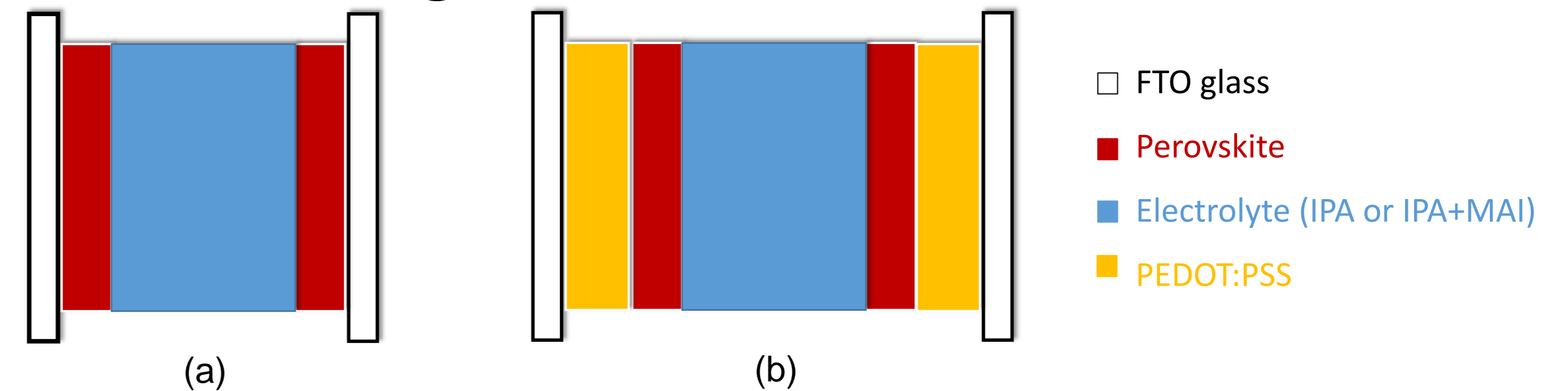


Figure 5. Solid-state devices designed to reveal the effect of ion migration with the structure of (a) FTO/Perovskite/Electrolyte/Perovskite/FTO (b) FTO/PEDOT/Perovskite/Electrolyte/Perovskite/PEDOT/FTO

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.

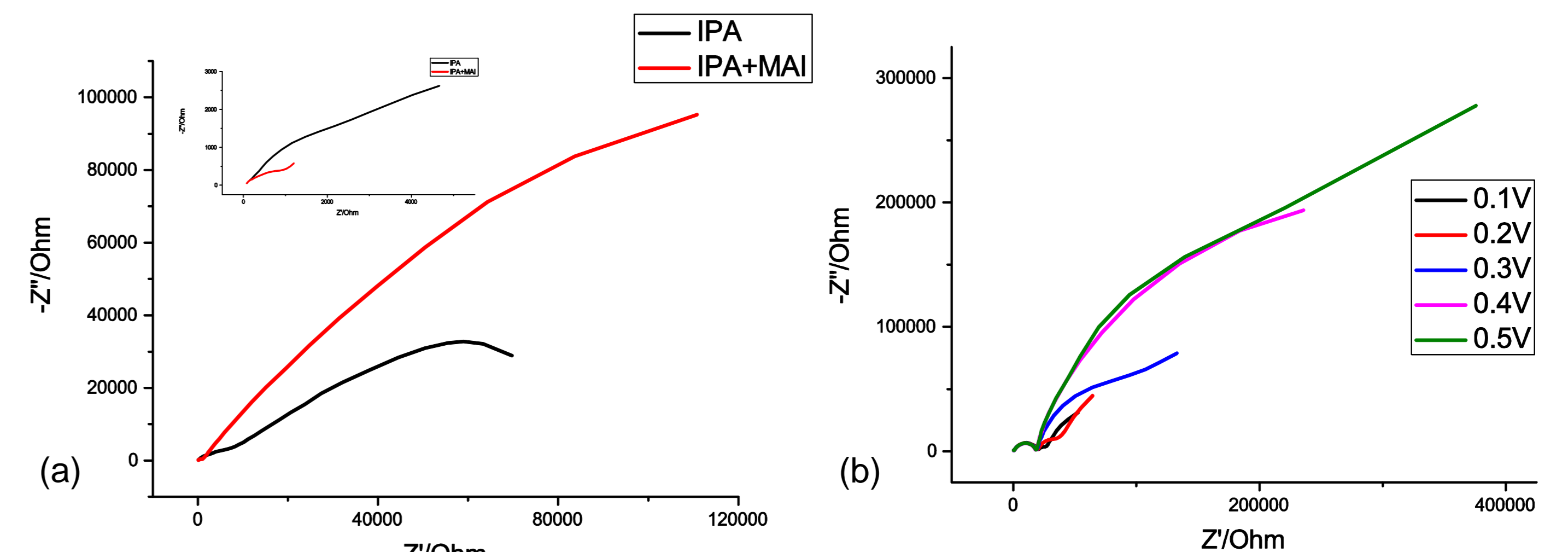


Figure 6. Complex impedance plot of devices (a) no PEDOT and pure IPA and IPA+MAI as electrolyte under illumination, (b) PEDOT buffer layer and IPA with different bias voltages under illumination, and (c) experimental data (red dots) and fitting result (dark line) with PEDOT buffer layer and IPA under 0.2V bias and its equivalent circuit

The results show a relatively large internal ion migration in perovskites, as well as light and voltage sensitive carrier generation and recombination.

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