

# A Study of perovskite solar cell with $\text{Fe}^{3+}/\text{Ga}^{3+}$ doped $\text{TiO}_2$ layer

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## Abstract

Recently, organic-inorganic lead halide perovskite solar cells (PSCs) have emerged as an extremely attractive photovoltaic device. Perovskite has a structure of a large number of solar cells, which is very promising for the rapid commercialization of large-scale, low-cost solar cells. PSCs have many advantages as it uses simple processing techniques and inexpensive raw materials. The conduction band of  $\text{TiO}_2$  used in many PSCs coincides well with the conduction band of the perovskite active layer. In addition,  $\text{TiO}_2$  has excellent stability and conductivity and can be obtained by various deposition methods at a low cost. However,  $\text{TiO}_2$  traps electrons in oxygen vacancies and Ti lattice sites, which leads to recombination, which in turn reduces the efficiency of the device. In this study, we investigated the effects of  $\text{Fe}^{3+}$ ,  $\text{Ga}^{3+}$  ions on the efficiencies of PSCs by doping them in a compact and mesoporous layer of  $\text{TiO}_2$ .  $\text{Fe}^{3+}$ ,  $\text{Ga}^{3+}$  with an atomic radius similar to that of  $\text{Ti}^{4+}$  can replace Ti cations, and  $\text{Fe}^{3+}$ ,  $\text{Ga}^{3+}$  doped  $\text{TiO}_2$  is considered to be a better candidate for photoelectric performance of PSCs.

## 1. Introduction

During the last three decades, the development of renewable energy technologies has received substantial attention to overcome the effects of energy crisis, environmental pollution, and global warming. Among the various renewable and sustainable energy resources, solar power is the most remarkable, because of its abundance, global availability, and cleanliness. [1] Recently, organic-inorganic lead halide perovskite solar cells (PSCs) have emerged as an extremely attractive photovoltaic device. [2-5] Perovskite has a structure of a large number of solar cells, which is very promising for the rapid commercialization of large-scale, low-cost solar cells. PSCs have many advantages as it uses simple processing techniques and inexpensive raw materials. Perovskite materials have the general formula of  $\text{ABX}_3$ , where A is generally methyl ammonium ( $\text{CH}_3\text{NH}_3^+$  or MA), B is a metal ion, such as Pb or Sn, and X represents a halogen ion, such as I, Cl, or Br. A distinct advantage of lead-based perovskites (i.e.,  $\text{MAPbX}_3$ ) is that their band gap can be easily tuned from 1.2 to 2.3 eV by varying the composition of cations and anions. [6-7] The conduction band of  $\text{TiO}_2$  used in many PSCs coincides well with the conduction band of the perovskite active layer. In addition,  $\text{TiO}_2$  has excellent stability and conductivity and can be obtained by various deposition methods at a low cost. In this regard, in many PSCs,  $\text{TiO}_2$  is widely used as the ETL owing to its excellent electronic properties.[8-11]

However,  $\text{TiO}_2$  traps electrons in oxygen vacancies and Ti lattice sites, which leads to recombination, which in turn reduces the efficiency of the device. Therefore, the generation of oxygen vacancies and reduction in the number of defects of  $\text{TiO}_2$  facilitate the development of stable PSCs. Many studies have shown that the efficiency can be effectively improved by reducing the recombination of  $\text{TiO}_2$  by doping appropriate metal ions.

In this study, we investigated the effects of  $\text{Fe}^{3+}$ ,  $\text{Ga}^{3+}$  ions on the efficiencies of PSCs by doping them in a compact and mesoporous layer of  $\text{TiO}_2$ .  $\text{Fe}^{3+}$ ,  $\text{Ga}^{3+}$  was dissolved in ethanol and mixed with a  $\text{TiO}_2$  solution in various ratios. The metal ion can effectively enhance the electron transfer of  $\text{TiO}_2$ .  $\text{Fe}^{3+}$  with an atomic radius similar to that of  $\text{Ti}^{4+}$  can replace Ti cations, and  $\text{Fe}^{3+}$ ,  $\text{Ga}^{3+}$  doped  $\text{TiO}_2$  is considered to be a better candidate for photoelectric performance of PSCs. Upon the doping with  $\text{Fe}^{3+}$ , the conductivity increased and the recombination decreased, which increased the efficiency of the PSC.

## 2. Results & discussion

The XRD measurement is performed to reveal the lattice structure. As shown in Figure 1 (a), the  $\text{Ga}^{3+}$ ,  $\text{Fe}^{3+}$ -doped  $\text{TiO}_2$  layer consists of the anatase phase, as the  $\text{Ga}^{3+}$ ,  $\text{Fe}^{3+}$  ion radius is very similar to that of  $\text{Ti}^{4+}$  and thus the  $\text{Fe}^{3+}$  dopant cannot change the lattice of  $\text{TiO}_2$ .

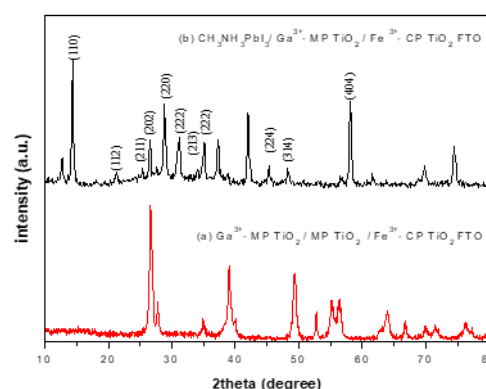


Fig. 1 XRD patterns of  $\text{MAPbI}_3$ ,  $\text{Fe}^{3+}$ ,  $\text{Ga}^{3+}$  -  $\text{TiO}_2$ .

Figure 1 (b) shows the XRD pattern of  $\text{TiO}_2/\text{CH}_3\text{NH}_3\text{PbI}_3$  with peaks at 13.8, 19.7, 23.1, 24.2, 28.1, 31.5, 40.3, and 42.8° attributed to the (110), (112), (211), (222), (224), and (314) lattice planes, respectively.

Figure 2 (a) is a mesoporous  $\text{TiO}_2$  layer made of diluted 18NR-T. Figure 2 (b) is a cross-sectional view of a mp- $\text{TiO}_2$ /

Ga-doped mp-TiO<sub>2</sub> layer prepared by spin-coating a mesoporous 18NR-T. Figure 2 (b) is a cross-sectional view of a mp-TiO<sub>2</sub>/Ga-doped mp-TiO<sub>2</sub> layer prepared by spin-coating a mesoporous TiO<sub>2</sub> layer prepared by adding gallium nitrate to a solution of the same concentration. Figure 2(C) is a cross-sectional view of the PSC produced, and CP-TiO<sub>2</sub> layer was prepared by mixing iron nitrate and TiO<sub>2</sub> sol. The Fe<sup>3+</sup> doped TiO<sub>2</sub> / mesoporous TiO<sub>2</sub> / Ga<sup>3+</sup> doped TiO<sub>2</sub> / perovskite / HTL / electrode structures were fabricated.

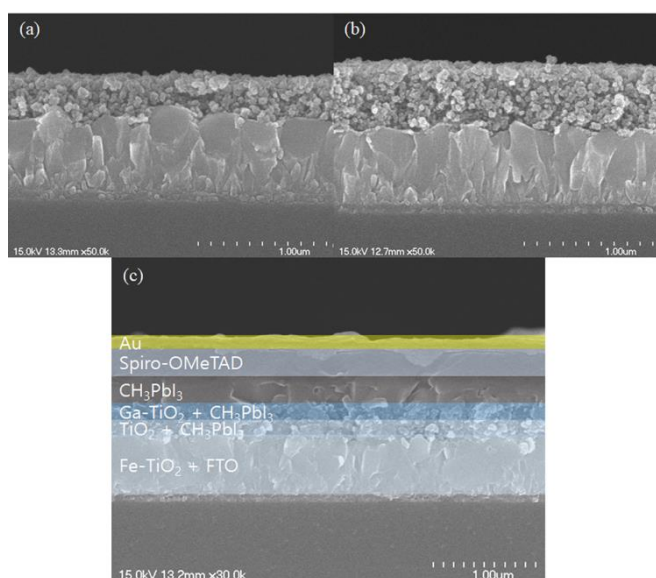


Fig. 2 Scanning Electron Microscope images of (a) mesoporous TiO<sub>2</sub> layer, (b) Gallium doped mesoporous TiO<sub>2</sub> layer on mesoporous TiO<sub>2</sub> layer and (c) Fabricated perovskite solar cell.

Figure 3 is a graph of the absorbance of the TiO<sub>2</sub> layer. It can be seen that the bandgap changes when iron is doped and when gallium is doped, which suggests that a valence band can be distributed between the FTO and the perovskite layer.

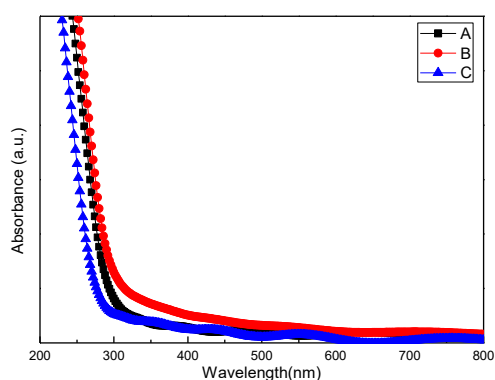


Fig. 3 The absorbance graph of (a) mesoporous TiO<sub>2</sub> layer, (b) Fe doped TiO<sub>2</sub> layer and (c) Ga doped TiO<sub>2</sub> layer.

The J-V curve in Figure 4 shows that the PSCs photovoltaic properties are improved. The corresponding photovoltaic properties are summarized in Table I. Oxygen vacancies or Ti lattice sites are converted to Ti<sup>3+</sup> by stoichiometric defects in the TiO<sub>2</sub> lattice. Therefore, the Ti<sup>3+</sup> lattice defects can induce low energy levels and the conduction band can trap electrons

and reduce the electron transport efficiency, leading to recombination. The increase in open-circuit voltage ( $V_{oc}$ ) is worth discussing. When TiO<sub>2</sub> is doped with metal cations, the TiO<sub>2</sub> energy level is changed and the  $V_{oc}$  value is increased.

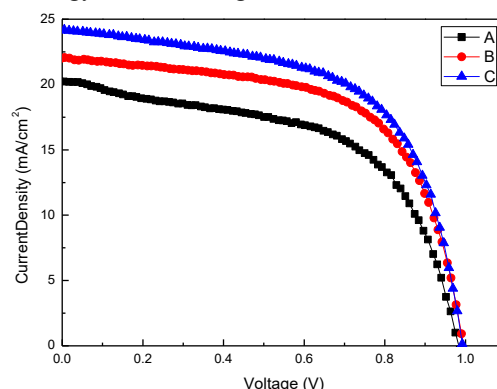


Fig. 4 J-V curves of the PSCs of (a) CP TiO<sub>2</sub>/MP TiO<sub>2</sub>, (b) Fe<sup>3+</sup>-CP TiO<sub>2</sub>/MP TiO<sub>2</sub>, (c) Fe<sup>3+</sup>-CP TiO<sub>2</sub>/Ga<sup>3+</sup>-MP TiO<sub>2</sub>.

Table I Current density-voltage characteristics of best performing perovskite solar cell

	$V_{oc}$ (V)	$J_{sc}$ (mA/cm <sup>2</sup> )	FF (%)	$\eta$ (%)
(a)	0.978	24.25	48.37	11.47
(b)	1.010	23.18	60.19	13.84
(c)	0.993	24.16	59.96	14.39

### 3. Conclusions

We fabricated PSCs based on MAPbI<sub>3</sub> using Fe<sup>3+</sup> and Ga<sup>3+</sup>. The TiO<sub>2</sub> layer doped with Fe<sup>3+</sup> and Ga<sup>3+</sup> has a uniform surface, and electron recombination is reduced to improve electrical conductivity. The PSC exhibited a short-circuit current density ( $J_{sc}$ ) of 24.16 mA/cm<sup>2</sup>,  $V_{oc}$  of 0.993 V, FF of 59.96%, and efficiency ( $\eta$ ) of 14.39%. Therefore, the use of the Fe<sup>3+</sup>, Ga<sup>3+</sup>-doped TiO<sub>2</sub> layer is a promising approach for fabrication of high-performance PSCs.

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