# Evaluation of Perovskite Photo-sensors with Electron-beam Evaporated Titanium Dioxide Films

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Organic electronic devices, such as an organic light emitting diodes (OLEDs), an organic thin-film transistors (OTFTs), an organic sensing devices and an organic solar cells (OSCs) are widely studied. Especially in OSCs, one of the most interesting topics is an organic-inorganic hybrid perovskite solar cell (PeSC) due to their excellent photoelectric conversion efficiency (PCE) along with their low material costs, and its recorded power conversion efficiency. In this situation, we have studied an electron beam evaporation (EBE) of titanium dioxide ($TiO_2$) layer for the electron-transport layer for the PeSC.[1-3] In this time, we have investigated the preliminary evaluation of organic-related perovskite photo-sensors (PePS) by applying reverse-biased voltage to collect the photo-generated carrier for light sensing applications.

Fabrication of the thin film, evaluation of a physical nature of the $TiO_2$ thin film, device fabrication, and measurement setup are virtually identical to that of our previous PeSC experiment.[4] The EBE of $TiO_2$ with thickness of 300 nm was carried out. Then, the $TiO_2$ thin films were annealed with different temperatures of 150~500°C for 1 h. The perovskite layer was prepared by the two-step method using precursor solutions of $PbI_2$ in anhydrous N,N-dimethylformamide and methyl-ammonium iodide (MAI) in ethanol. Then, the substrate was heated with 100°C for 10 min. And then, 2,2,7,7-tetrakis (N,N-di-p-methoxyphenylamine)-9,9-spirobifluorene (Spiro-OMeTAD) solution was prepared and spin coating process was carried out. Finally, a 50 nm thick gold metal was evaporated with an evaporation rate of 1.0 Å/s.

During annealing process, the ITO sheet resistance is increased from 11.1 to 78.9 Ω/□. And the grain-cluster size is increased between 17.2 and 37.1 nm with the temperature between 150 and 500°C, respectively. From an absorption measurements, the band gap of the $TiO_2$ film decreases from 3.31 to 3.10 eV with the increase of annealing temperature from RT to 500°C, respectively.

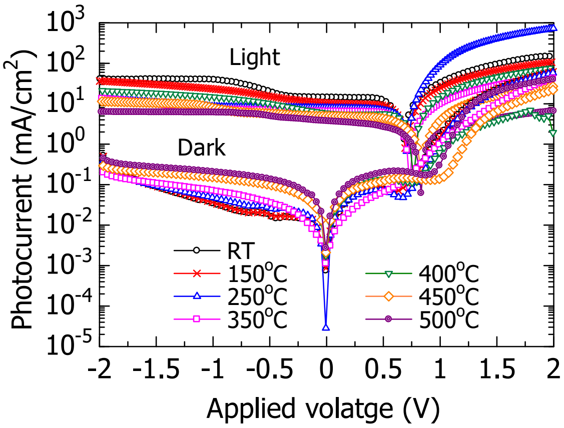


Fig. 1 Photo-sensing characteristics with different temperature of $TiO_2$ annealing conditions.

**Table I.** Photo-sensing characteristics with $TiO_2$ thin films at different annealing temperatures.

| Annealing temperature (°C) | $I_{dark}$ (mA/cm$^2$) | $I_{photo}$ (mA/cm$^2$) | $I_{photo}/I_{dark}$ |
|---|---|---|---|
| RT | $3.47\times10^{-2}$ | 39 | $1.12\times10^{3}$ |
| 150 | $3.61\times10^{-2}$ | 23.3 | $6.45\times10^{2}$ |
| 250 | $4.76\times10^{-2}$ | 8.59 | $1.80\times10^{2}$ |
| 350 | $7.10\times10^{-2}$ | 7.37 | $1.04\times10^{2}$ |
| 400 | 0.174 | 14.7 | 84.5 |
| 450 | 0.153 | 7.94 | 51.9 |
| 500 | 0.209 | 6.11 | 29.2 |

The photo-sensing characteristics with different temperature of $TiO_2$ annealing conditions are shown in Fig. 1. Measured PePS characteristics are shown in Table I. A ratio of photo- and dark-current was $1.1\times10^3$ for the PePS without annealing condition. This current ratio is the best value and gradually decreased with increase in the annealing temperature because of the decrease of photocurrent and increase of dark current. This phenomenon can be explained due to the generation current in the depletion region by[4] $J_{gen}=qn_iW/\tau_e$, where, $W$ is the depletion-layer width, $\tau_e$ is the effective lifetime, $q$ is the unit charge, and $n_i$ is the intrinsic carrier concentration. It is assumed that primary difference of the PePS characteristics with different annealing temperature is arises from the interfacial defects at $TiO_2$/perovskite layers and $TiO_2$ thin film itself, where, traps and some crystal defects induce the generation current. As a result, dark current of the PePS was increased.

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