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Rapid dye-sensitized solar cell working electrode preparation using far infrared rapid thermal annealing

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HIGHLIGHTS

- ▶ TiO_2 sintering time reduces to minutes by far infrared rapid thermal annealing.
- ▶ Sixteen minutes RTA sintering time gives a cell with the efficiency of 4.37%.
- ▶ Rapid removal of solvents and binders gives a compact TiO_2 film structure.
- ▶ RTA technique directly radiates titanium and is ideal for rapid DSSC fabrication.

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ABSTRACT

TiO_2 nanopowder sintering during dye-sensitized solar cell working electrode preparation usually takes hours and is the rate-limiting step to rapid production of dye-sensitized solar cells. Here, we show that by far infrared rapid thermal annealing (RTA) method, TiO_2 working electrode sintering time reduces from hours to minutes. 5 min binders/solvents removal time at 250 °C plus 10 min sintering time at 500 °C in a RTA system gives a cell with the efficiency of 4.37%. Although the rapid removal of binders/solvents causes the TiO_2 film structure collapsing and gives a more compact working electrode structure, the far infrared RTA method directly radiates TiO_2 layer giving binders/solvents removal and sintering within minutes and is ideal for rapid DSSC fabrication.

1. Introduction

Dye-sensitized solar cells (DSSCs) have been intensively investigated during the past two decades since they were initially introduced by Grätzel's group [1,2]. They are promising alternatives to the conventional silicon-based solar cells due to their relatively high energy conversion efficiency and low production cost. A sandwich structured DSSC consists of a dye adsorbed porous semiconductor (usually titanium) layer coating on a transparent substrate as the working electrode, a carbon or metal counter electrode and an electrolyte (usually I^-/I_3^- redox couple) between two electrodes. The working principle of DSSC is the photon excited dye molecules transferring the excited electrons to the conduction band of TiO_2 and then to the transparent-conductive-oxide thin film through TiO_2 networking. The electrons flow through the external load to the counter electrode and reduce the redox mediator I_3^- ions. The reduction of I_3^- generates I^-, which can regenerate the oxidized sensitizer and an electric loop is developed [3,4].

Because of the cost-effective DSSC fabrication process, extensive studies have been carried out to improve the DSSC photovoltaic performances. Many researchers focused on developing powerful dyes, novel electrode materials and/or electrolytes and a DSSC cell with the conversion efficiency over 12.0% is possible [5–11]. Some other researchers developed new technologies for low manufacturing temperature, flexible, and long-term stability cells and the roll-to-roll process can in principle be used for rapid DSSC fabrication [12–14].

When preparing the working electrode, the TiO_2 nanopowders are usually mixed with solvents and binders to form the TiO_2 layer coating solution. After coating, the coated wet film on the transparent substrate is dried and sintered in a 450 °C–500 °C oven for several hours to allow solvent/binder removal and networking formation between the TiO_2 nanopowders [15,16]. The sintering

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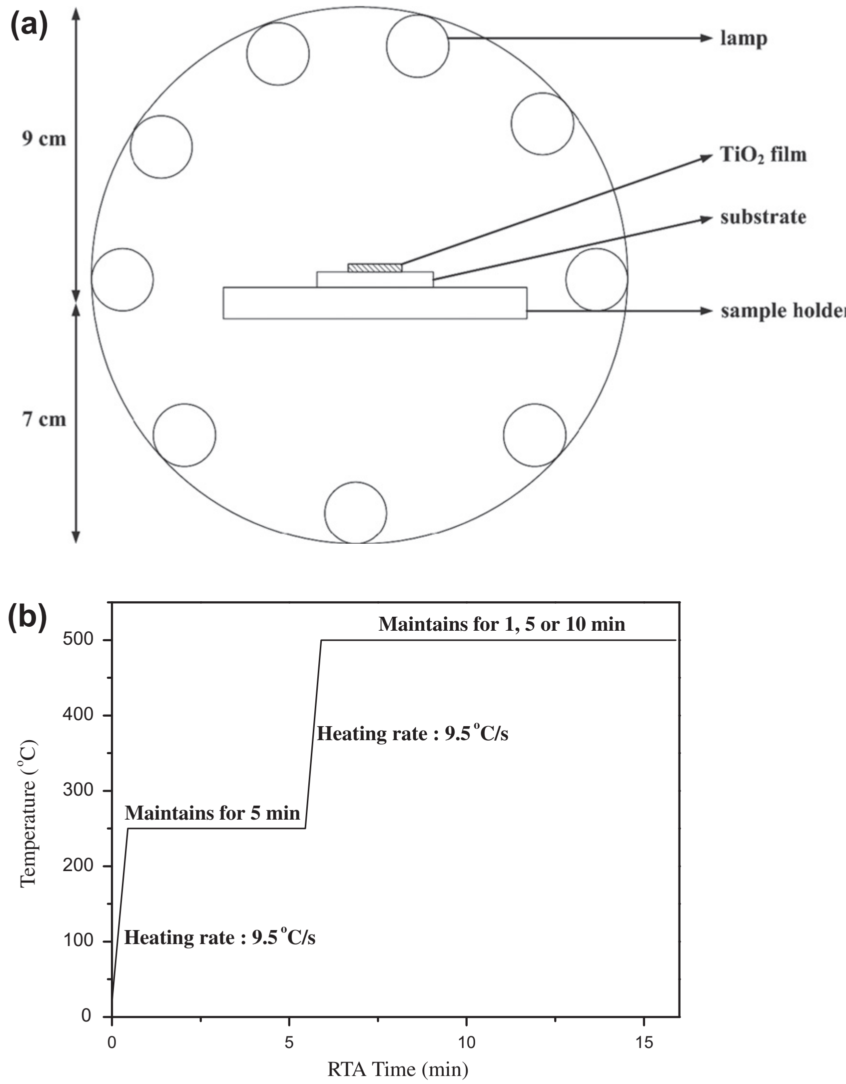

Fig. 1. (a) Schematic drawing of the far infrared RTA system. (b) The temperature profile of the far infrared RTA process.

Table 1
The comparisons of the carrier concentration, mobility, and the resistance between the TiO_2/dye/electrolyte interface of the TiO_2 films sintered after different RTA time.

Working electrode	RTA time at 500 °C (min)	Carrier concentration (cm^{-3})	Mobility (cm^2/V-s)	R_2 (Ω)
P200	1	8.51×10^{11}	5.92	6.53
	5	5.00×10^{11}	7.16	4.93
	10	3.83×10^{11}	7.94	4.74
P25	1	8.07×10^{11}	9.36	6.71
	5	7.11×10^{11}	10.55	6.13
	10	7.02×10^{11}	11.62	5.58
P90	1	9.80×10^{11}	7.48	10.75
	5	7.85×10^{11}	9.02	5.45
	10	7.07×10^{11}	10.14	5.16

Table 2
The X-ray diffraction comparisons of the full width at half maximum (FWHM) of $2\theta = 25.3°$ for TiO_2 electrodes with different RTA sintering time at 500 °C.

Working electrode	RTA time at 500 °C (min)	FWHM of $2\theta = 25.3°$ (radian)
P200	1	0.678
	5	0.643
	10	0.608
P25	1	0.435
	5	0.398
	10	0.379
P90	1	0.708
	5	0.614
	10	0.594

process spends a relatively long time and is the rate-limiting step to the fast roll-to-roll DSSC production (say dozens of meters per minute). Some researchers proposed interesting methods to reduce the TiO_2 nanopowder sintering time by using near infrared, microwave and laser radiations [17–19]. In this work, the far infrared rapid thermal annealing (RTA) method is used for the rapid TiO_2 nanopowder sintering.

2. Materials and method

2.1. TiO_2 working electrode preparation

The TiO_2 working electrode was prepared using either the self-prepared coating paste or the commercially available P200 coating paste P200 (Everlight Chemical Industrial Corp., Taiwan). The procedure for the preparation of the self-prepared coating solution is as follows. (1) 5 g commercially available TiO_2 powders (P25 or