Characterization of Al-Doped TiO_2 Thin Film Synthesized Via Sol-Gel Method for Solar Cell Application

Muhammad Azim Bin Idrus, Dr Fazlena Hamzah

Faculty of Chemical Engineering, Universiti Teknologi Mara

***Abstract*— The scope of this research is to synthesize and characterize a TiO_2 thin film to be used in solar cell application. The Al-doped TiO_2 thin film was synthesized via the sol-gel method. The sample produced was characterized using X-ray diffraction (XRD) and Fourier transform infrared spectroscopy (FT-IR). These XRD characterization was conducted to determine the aluminum bond on the surface of the Al-doped TiO_2 while the FT-IR characterization was used to determine the functional group present. FT-IR spectra of Al-doped TiO2, titania precursor and alumina source is illustrated in Fig. 1. The 3000 cm-1 band was attributed to the hydroxyl group from water and ethanol occluded in the titania pore. The OH bending band of water in gel was observed at 1600 cm-1 while the O-Ti-O band was observed at 1400 cm-1. The presence of additional peaks indicated the dispersion of doping ions was not efficient. By comparison with the alumina dopant, the bands at 1300 cm-1 was attributed to Al-O bonds. The results obtained from the XRD analysis were inconclusive due to the sample exhibiting a wet nature when prepared for the XRD analysis. The XRD analysis should indicate a peak around 25º for the formation of the anatase phase of Al-doped TiO_2 thin film**

Keywords*— *Al-doped TiO_2, Thin Film, Sol-gel, Solar Cell

I. INTRODUCTION

The energy crisis is the concern that the limited natural resources used to power industrial society are diminishing. While they do occur naturally, it takes hundreds of thousands of years to replenish them and as such, governments and researchers are working to make use of renewable resources to decrease the irresponsible use of natural supplies. The energy crisis currently devastating the planet can be the result of a multitude of reasons, these including overconsumption of non-renewable resources, overpopulation, , poor infrastructure, delay in commissioning new power plants, wastage of energy in most parts of the world, poor distribution systems, major accidents and natural calamities and of course unexplored renewable energy options due to the current population being more comfortable with something that has been used for a long time such as fossil fuels instead of looking at different options of energy resources such as solar power [1].

Conventional solar cells are made of silicon and were the most efficient solar cells available for residential use until the emergence of thin film solar cells. There are four types of silicone cells used for production of solar panels which are monocrystalline silicon cells, polycrystalline silicon cells, amorphous silicon cells and hybrid silicon cells. While these account for more than 80 percent of all solar panels around the world. However, these solar cells do in fact have disadvantages such as [2]:

a) Requiring expensive manufacturing technologies
b) Growing and sawing of ingots is a highly energy intensive process
c) Fairly easy for an electron generated in another molecule to hit a hole left behind in a previous photo excitation
d) Much of the higher energy photons at the blue and violet spectrum is wasted as heat.

It has been determined that thin films are less complex and less time consuming to prepare compared to silicon based semiconductors; this in turn reduces the cost of manufacturing [3]. The application of titanium dioxide (TiO_2) in the form of a thin film semiconductor for solar cells has increased over the years.

TiO_2 is a promising photo-catalyst with many advantages such as long-term stability, low cost and non-toxic [4], it is still constrained by the wide energy band gap which makes it capable to respond only to light from the near-UV range of an electromagnetic spectrum and fast recombinant rate of charge carriers [5]. To improve on these limitations, the performance of TiO_2 is enhanced through doping to reduce its energy band gap and to allow it to induce a response from visible light. This is because UV light is only a small fraction of the light spectrum with a range of only 3 to 5 %. For this research, the TiO_2 is doped with aluminum (Al) [6] as it has the most reduction in energy band gap compared to other dopants such as zinc (Zn) [7] vanadium (V) [8] and pure TiO_2 [9]. The band gap difference for each doping material is listed in Table 1.

Table 1: Band gap reduction and percent reduction for various dopants compared to pure TiO_2

Dopant	Band Gap Reduction (eV)	Percent Reduction (%)
Aluminum (Al)	3.10 to 2.80	9.68 %
Zinc (Zn)	3.40 to 3.10	9.68 %
Vanadium (V)	3.71 to 3.65	1.62 %
Pure TiO_2	3.20	-

The main objective of this research is to formulate an Al-doped TiO_2 thin film using sol-gel method and to determine the surface morphology and phase of the formulated Al-doped TiO_2.

II. METHODOLOGY

A. Materials

Chemicals used for the synthesis of the doped TiO_2 are titanium tetra isopropoxide (TTIP) (ALDRICH), acetic acid (EMSURE), aluminum nitrate (Al_2NO_3) (R&M Chemicals), ethanol (HmbG Chemicals), deionized water and optically transparent glass slides.

B. Preparation of precursor solution

TTIP is used in the present study as the titania source. Firstly, 14 ml of TTIP is added dropwise into 40 ml of ethanol under constant stirring. After 30 minutes of constant stirring, 5 ml of acetic acid is added into the solution and this solution was then aged for 30 minutes at room temperature. This solution was labelled as Solution 1 [11].

C. Preparation of metal-dopant solution

Aluminum nitrate (Al_2NO_3) with a concentration of 0.03 mole % was dissolved in 60 ml of deionized water. Once the Al_2NO_3 has solubilized in the deionized water, 5 ml of acetic acid was added. This solution was labelled as Solution 2 [6].

D. Preparation of Al-doped TiO_2 thin film.

Solution 2 was added dropwise into solution 1 under constant stirring. Once all of solution 2 was added into solution 1, the final solution was stirred for an additional 2 hours to form the gel. Optically transparent glass slides were dipped into the gel for a few seconds and dried at 100 ºC in an oven. The films were then dried at room temperature for 2 hours and the coated films were then annealed at 500 ºC for 1 hour [11].

E. Preparation of Al-doped TiO_2 powder for analysis

Half of the final solution was placed in a separate beaker and dried overnight under a temperature of 90 ºC. The powder dried solution was reduced into a fine powder form using a mortar and pestle. The final powder has a yellowish color.

F. Characterization of Al-doped TiO_2

The Al-doped TiO_2 was characterized using X-ray diffraction (XRD, RIGAKU) to determine the crystal phase of the Al-doped TiO_2 and Fourier transform infrared spectroscopy (FT-IR, PERKIN ELMER) to determine the aluminum bond on the surface of Al-doped TiO_2. The XRD was conducted at a voltage of 40 kV and at 10 mA, with an angle range of 20º to 80º with a speed angle of 5º/min.

III. RESULTS AND DISCUSSION

A. FT-IR analysis

FT-IR spectra of Al-doped TiO_2, titania precursor and alumina source is illustrated in Fig. 1. The 3000 cm^{-1} band was attributed to the hydroxyl group from water and ethanol occluded in the titania pore. The OH bending band of water in gel was observed at 1600 cm^{-1} while the O-Ti-O band was observed at 1400 cm^{-1}. The presence of additional peaks indicated the dispersion of doping ions was not efficient. By comparison with the alumina dopant, the bands at 1300 cm^{-1} was attributed to Al-O bonds.

For the FT-IR analysis, the inefficiency of distribution of the alumina dopant was attributed to defects produced during the incorporation of doping ions into the TiO_2 lattice. This can be caused by errors made while preparing the metal dopant solution such as wrong calculations and measurement of the weight of alumina needed to form a dopant solution with 0.03% concentration. Further calculation should be made to ensure a proper dose was used to create the dopant solution.

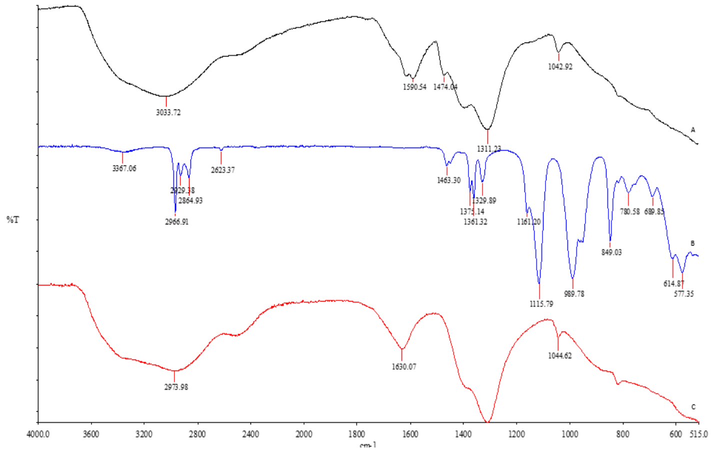

Figure 1: FT-IR spectra of: (black) Al-doped TiO_2 (blue) TTIP (red) Al_2NO_3

B. XRD analysis

Fig. 2 shows the XRD patterns of the sample prepared. The sample shows a lack of any peak which means no conclusion can be made to determine whether the anatase crystal phase attributed to the formation of TiO_2 particles can be seen.

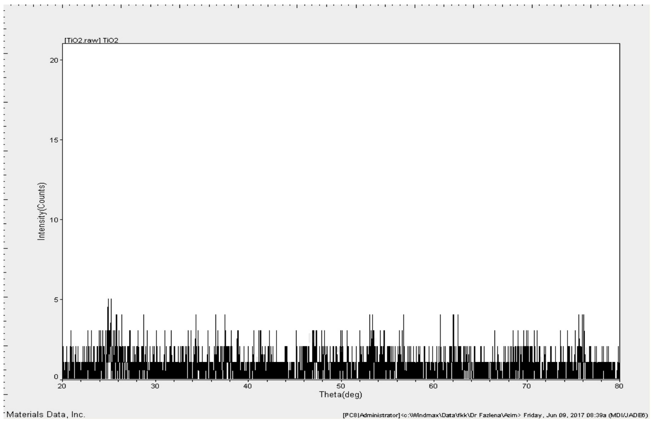

Figure 2: XRD pattern, note the absence of peaks in the pattern

For the XRD analysis, the pattern should typically show a peak as in Fig. 3. The sample should show a pattern which indicates the formation of an anatase form of Al-doped TiO_2 at around 25 which corresponds to the position of pure TiO_2 anatase form which is at 25.4º, 37.8º, 48.3º, 54.1º and 62.8º. the absence of a peak from this sample can be attributed to a few errors.

The sample itself was dried and a fine powder form was achieved. It exhibits a wet pasty form when further preparation was made for the XRD analysis. Due to the sample being reduced to this state, the XRD is unable to form a pattern as the sample itself has to be dry for the analysis to find its peak. Another error which can be attributed is the difference in voltage used, the proposed voltage to be used to energize the sample is 45 kV but limitations of the machine itself only allows for a sample to be energize up to 40 kV.

This problem can be solved by drying the sample at a temperature higher than 90 ºC to ensure it is fully dried. It is also recommended that the sample is stored in an enclosed area to make sure the surrounding humidity does not affect the sample.

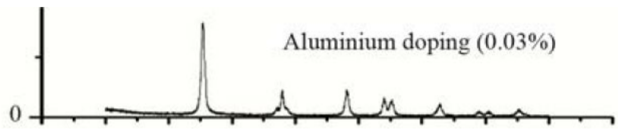

Figure 3: XRD patterns of Al-doped TiO_2

IV. Conclusion

Al-doped TiO_2 sample was successfully synthesized for the research and while characterization for the FT-IR was successful, the XRD analysis was inconclusive. The FT-IR analysis shows that the aluminum doping on the TiO_2 surface was successful, although the presence of additional peaks suggests that the dispersion of the doping ions itself were not very efficient. The XRD should indicate a peak around 25º for the formation of the anatase phase of Al-doped TiO_2 thin film according the literature, but due to the sample exhibiting different characteristics during preparation of XRD analysis, this could not be proven, drying at a higher temperature and storage of synthesized sample at an enclosed area to avoid contamination is suggested.

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