

Research Article

Photo-Oxidation of Water Using Nanocrystalline Tungsten Oxide under Visible Light

J. W. J. Hamilton, J. A. Byrne, P. S. M. Dunlop, and N. M. D. Brown

Nanotechnology and Integrated BioEngineering Centre, University of Ulster, Jordanstown, County Antrim BT37 0QB, Northern Ireland, UK

Correspondence should be addressed to J. W. J. Hamilton, jwj.hamilton@ulster.ac.uk

Received 21 August 2007; Accepted 24 January 2008

Recommended by Ignazio Bellobono

The photoelectrolysis of water to yield hydrogen and oxygen using visible light has enormous potential for solar energy harvesting if suitable photoelectrode materials can be developed. Few of the materials with a band gap suitable for visible light activation have the necessary band-edge potentials or photochemical stability to be suitable candidates. Tungsten oxide (E_{bg} 2.8 eV) is a good candidate with absorption up to $\lambda \approx 440$ nm and known photochemical stability. Thin films of tungsten oxide were prepared using an electrolytic route from peroxo-tungsten precursors. The tungsten oxide thin films were characterised by FESEM, Auger electron spectroscopy, and photoelectrochemical methods. The magnitude of the photocurrent response of the films under solar simulated irradiation showed a dependence on precursor used in the film preparation, with a comparatively lower response for samples containing impurities. The photocurrent response spectrum of the tungsten oxide films was more favourable than that recorded for titanium dioxide (TiO_2) thin films. The WO_3 photocurrent response was of equivalent magnitude but shifted into the visible region of the spectrum, as compared to that of the TiO_2 .

Copyright © 2008 J. W. J. Hamilton et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

1. INTRODUCTION

In 1969, Fujishima and Honda reported the photoelectrolysis of water using single crystal rutile titanium dioxide under UV irradiation [1]. Since then, the use of titanium dioxide photocatalysis for environmental remediation of air and water has been intensively explored and is well documented [2]. However, TiO_2 is a wide band gap semiconductor (anatase, $E_{bg} = 3.2$ eV) and absorbs light of wavelengths ≤ 387 nm. Therefore, only a small proportion of the solar energy spectrum (<5%) can be utilised. In order to facilitate further advancement in the field of semiconductor photocatalysis using solar energy, researchers are looking at other narrow band materials which absorb in the visible region of the solar spectrum. Unfortunately, visible light absorbing semiconductors are either unstable in contact with water or do not have the necessary band edge potentials necessary for the desired electrochemistry. Tungsten oxide has a reported band gap of 2.6 to 2.8 eV [3] with band edges located at $E_{cb} - 0.3$ V and $E_{VB} + 2.4$ V at pH 7 [4], making it a possible candidate material for

the photoelectrolysis of water using visible light. The preparation of WO_3 is relatively well explored and its use for the photoelectrolysis of water has also been reported [5–14]. Additionally, doped WO_3 and multilayered photocatalysts incorporating WO_3 have been investigated [14–16].

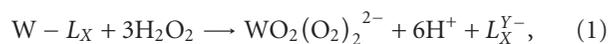
However, the majority of publications concerning preparation and characterisation of WO_3 have produced thin films by sol-gel synthesis. The use of sol-gel synthesis with tungsten alkoxides has been reported to produce porous films with excessive carbon impurities [17]. Zhitomirsky et al. previously reported that many metal oxides, in which the metal of parent compound formed polyperoxoacids on reaction with hydrogen peroxide, could be electrolytically deposited as oxide thin films [18, 19]. Although they did not specifically report the electrolytic deposition of tungsten oxide, other workers have used such a method to produce electrochromic materials [20].

In this work, peroxotungstic acids were produced from a range of precursors. Previous literature [21] has reported the production of peroxotungstates from otherwise highly stable

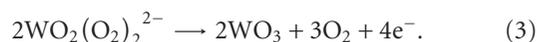
carbide under the action of H_2O_2 . In this work tungsten oxide, tungstic acid, and tungsten dodecaphosphate were used as precursors for the production of polyperoxoacids of tungsten by digestion in H_2O_2 , from which thin films were prepared. Films were characterised by FESEM, AES, and photoelectrochemical methods with comparison to sol-gel TiO_2 films as a reference standard.

2. EXPERIMENTAL

Tungsten oxide thin films were produced via a modified electrolytic route. Peroxoprecursors were prepared by dissolving 2.5 g of tungsten oxide, tungstic acid (Sigma-Aldrich Company Ltd., The Old Brickyard, New Road, Gillingham, Dorset SP8 4XT), or tungsten dodecaphosphate (BDH) in 15 cm^3 of H_2O_2 (30%) and 10 cm^3 H_2O . The precursor slurries were heated at 70°C for 10 minutes to dissolve all the powder starting material, generating a viscous yellow peroxotungsten precursor. During the powder digestion reactions, all tungsten precursors exchange their ligands for peroxo ligands. The peroxotungsten species produced by reaction of tungsten compounds with hydrogen peroxide are a complex mixture. These include monotungstate species $\text{WO}_2(\text{O}_2)_2^{2-}$, $\text{WO}(\text{OH})(\text{O}_2)_2^{2-}$, bitungstate species $\text{W}_2\text{O}_3(\text{O}_2)_4^{2-}$, and more complicated species [22]. For this reaction scheme, only the simplest species produced in the initial reaction is considered (see (1)). During the extended heating, tungsten species undergo condensation/polymerisation reactions, similar to those of a sol-gel precursor (see (2)) [22]. These condensation reactions form complex chains and other structures of repeating peroxotungstate units resulting in an increase in the viscosity of the solution:



WO_3 films were formed by electrochemical oxidation of the peroxotungstates on tungsten foil and gas evolution were observed at the anode during film formation. The presumed anodic half cell reaction is given in (3):



For AES analysis, films were deposited on titanium metal foil to eliminate the tungsten signal of the substrate from interfering. Anodic electrolytic deposition was carried out under a constant current of 10 mA for 200 seconds on 1.5 cm^2 tungsten foil coupons. The deposition time was reduced to 60 seconds on titanium foil samples (1.5 cm^2), for elucidation of the growth mechanism. Constant current anodic deposition was used as this gave more reproducible films in terms of microstructure. After electrolytic treatment, the films were washed with distilled water and dried in air. The tungsten foil samples were annealed at 500°C for 1 hour with a temperature ramp of 5°C min^{-1} .

Titanium dioxide thin films were prepared by a sol-gel route adapted from Murakami et al. [23]. Butan-1-ol

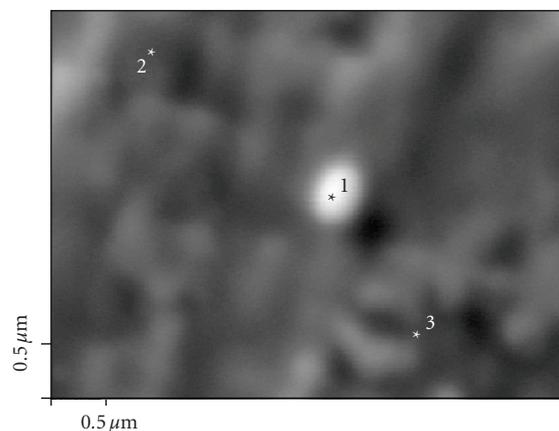


FIGURE 1: SEM showing WO_3 film and locations selected for AES analysis.

(10 cm^3) was added to a round bottom flask, which was placed on a balance and the balance rezeroed. Using a syringe, titanium butoxide was removed from its sealed bottle via the rubber septum. With the tip of the syringe immersed in the butanol, 0.377 g of butoxide was added to the flask. A magnetic stirring bar was added and the flask was sealed with ParafilmTM. The round-bottomed flask was then transferred to a stirrer. Ammonium acetate (0.0973 g) was dissolved in 0.2 cm^3 of distilled water in a micro beaker. The contents of the beaker were then washed into a clean, dry, separating funnel with 15 cm^3 of butan-1-ol and shaken to mix the two solvents. The ParafilmTM was then removed from the neck of the round-bottomed flask and the dropping funnel containing water, solvent, and salt catalyst was attached at the quick fit junction. The contents of the dropping funnel were added dropwise under constant stirring. The reaction solution was finally aged for 1 hour before dip coating (withdrawal rate 6 mm s^{-1}).

Tungsten oxide samples deposited on titanium foil were imaged by field emission SEM and elemental analysis was carried out by Auger electron spectroscopy (Perkin-Elmer Φ 660) with vacuum of 10^{-6} Torr with electrons accelerated from a field emission source at 4 kV accelerating voltage to give a beam current of $\sim 2 \mu\text{A}$.

For electrochemical measurements, electrical contacts were made by attaching copper wire with conductive silver epoxy (Circuit Works, Chemtronics) to the back of the foil (cleaned to remove oxide) and insulated using with negative photoresist (KPR resist, Casio Chemicals) to give an exposed oxide area of 1 cm^2 .

Electrochemical characterisation of samples was performed under potentiostatic control (Autolab PGSTAT30) in a one-compartment glass cell containing a quartz window with a platinum basket counter electrode and a saturated calomel electrode (SCE) reference electrode. All potentials are reported versus SCE. The supporting electrolyte was 0.1 M LiClO_4 and irradiation was provided by a 1 kW Xe arc lamp (ss1000 Spears Robinson) with an AM1 filter to simulate solar conditions. For monochromatic irradiation

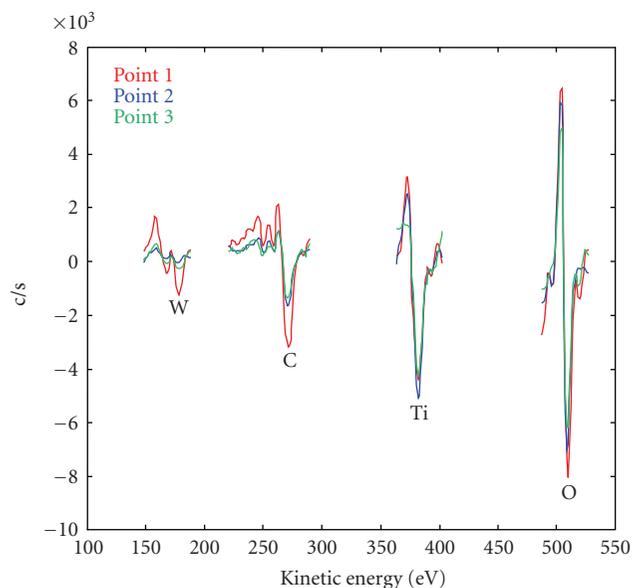


FIGURE 2: AES spectra from points selected in Figure 1.

TABLE 1: Elemental by AES analysis of points in SEM (Figure 1).

| % | C | O | Ti | W |
|---------|-------|-------|-------|-------|
| Point 1 | 33.24 | 32.51 | 19.13 | 15.12 |
| Point 2 | 25.26 | 42.43 | 28.10 | 4.20 |
| Point 3 | 25.83 | 41.87 | 24.05 | 8.26 |

experiments, a monochromator (GM252, set for 10 nm band pass) was positioned between the source (unfiltered) and the photoelectrochemical cell. Linear sweep voltammograms were measured scanning from -1.0 V to $+1.5$ V at a scan rate 10 mV s^{-1} . The current-time response was measured at $+1.0$ V using chopped illumination (chopper Uniblitz vmm-t1, Vincent Associates). The cell temperature was maintained at $25^\circ\text{C} \pm 2^\circ\text{C}$.

3. RESULTS AND DISCUSSION

To examine the electrolytic growth of tungsten oxide, samples were prepared on titanium foil to ensure that the WO_3 thin film grown by the electrolytic process was not simply due to anodisation of the tungsten foil itself. FESEM analysis showed that the films were nonuniform with more WO_3 deposition around the edges of the electrode. The uneven deposition observed is not uncommon for electrodeposited films and is due to edge effects.

The surface of the sample showed grain-like structures (Figure 1). Features were selected for elemental analysis (Figure 1, points 1–3) using AES and the corresponding spectra are given in Figure 2.

The surface showed significant amounts of tungsten and oxygen in addition to the titanium of the underlying support electrode. The concentration of elements in the selected points is given in Table 1.

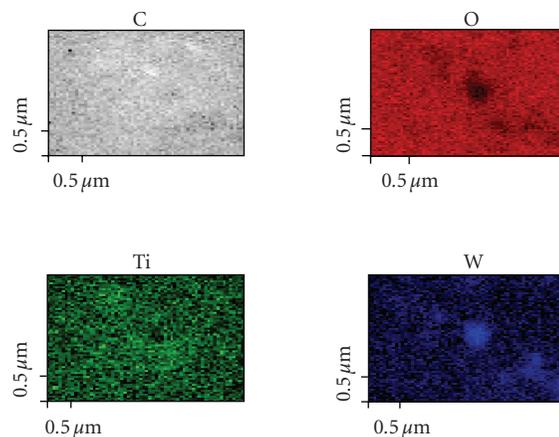
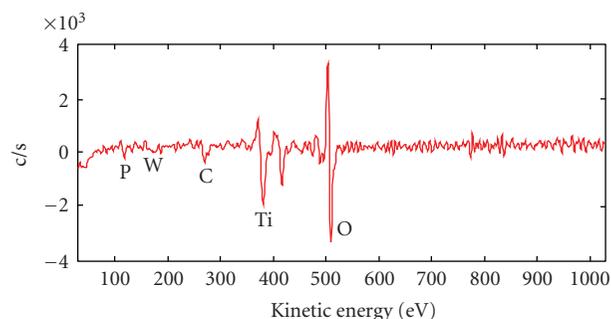


FIGURE 3: Colour coded SEM images showing the elemental distribution on the surface.

FIGURE 4: AES spectrum for the WO_3 film prepared from the dodecaphosphate precursor showing a small signal due to phosphorous contamination.

This analysis showed the WO_3 to have grown in islands with the highest concentration of tungsten measured in the grain-like features (point 1 in Figure 1 and Table 1). This is also shown in elemental colour mapped SEM images produced using AES (Figure 3). In the colour mapped images, the lighter colours indicate higher concentrations of the element and darker colours representing lower concentrations, and black indicating the absence of the element.

Imaging of samples produced from other precursors (tungsten oxide, tungsten dodecaphosphate) showed a similar growth with islands of material building up preferentially at the edges. The samples produced from the tungsten dodecaphosphate precursor contained a small quantity of phosphorus (see Figure 4).

The photoelectrochemical characterisation of the films using LSV showed a typical n -type response with no anodic current observed in the dark and photocurrent potentials more positive than 0.0 V (Figure 5). The films produced from the tungstic acid precursor gave the highest relative photocurrent.

Comparison of photocurrent densities produced from WO_3 thin films and TiO_2 at $+1.0$ V are given in Table 2. The WO_3 films had a higher photocurrent density than that of

TABLE 2: A comparison of photocurrent densities produced under solar simulated conditions at +1.0V.

| Material | Tungsten oxide | | | Titanium dioxide via sol-gel route |
|--------------------------------------|----------------|---------------|---------------------------|------------------------------------|
| Precursor | Tungsten oxide | Tungstic acid | Tungsten dodeca phosphate | |
| Photocurrent (mA cm^{-1}) | 0.674 | 0.974 | 0.134 | 0.266 |

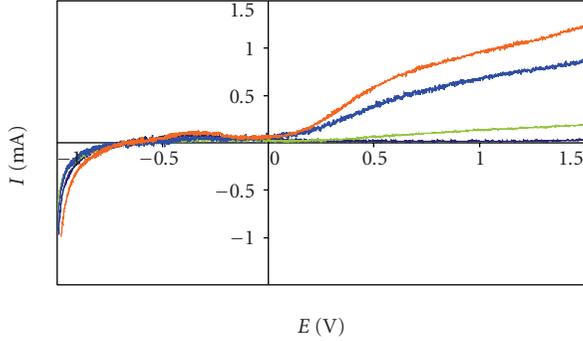


FIGURE 5: Comparison of photocurrent response of WO_3 film electrodes prepared from different precursors, that is, tungsten dodecaphosphate (green line), tungsten oxide (blue line), tungstic acid (red line) and with dark current response (dark blue).

the TiO_2 thin films prepared via a sol-gel route under solar simulated irradiation.

Figure 6 shows the current-time response of the tungstic acid derived WO_3 film under monochromatic irradiation showing a small photocurrent response in the visible ($\lambda > 420 \text{ nm}$ —not normalised to monochromator output).

Using light intensity measurements the photocurrent produced under monochromatic irradiation was used to calculate incident photon to current conversion efficiency

$$\% \text{IPCE} = \left(\frac{J}{I_0 F} \right) \times 100, \quad (4)$$

where J is the photocurrent density, I_0 is the incident light intensity (band pass 10 nm), and F is Faraday's constant. A comparison of the photon conversion efficiency between WO_3 and TiO_2 thin films is given in Figure 7 which shows both materials exhibited $\sim 7\%$ efficiency at peak wavelengths 355 nm and 380 nm, respectively.

The response spectrum of WO_3 extended to longer wavelengths into the visible region of the spectrum.

4. CONCLUSIONS

Surface characterisation of WO_3 films prepared from peroxo-polytungstate precursors confirmed the growth of WO_3 . Photoelectrochemical measurements under simulated solar irradiation showed that the WO_3 films behaved as n -type semiconductors producing anodic current only under irradiation. Comparison of samples produced from different precursors showed that the films prepared using the tungstic acid precursor gave the highest relative photocurrent. The

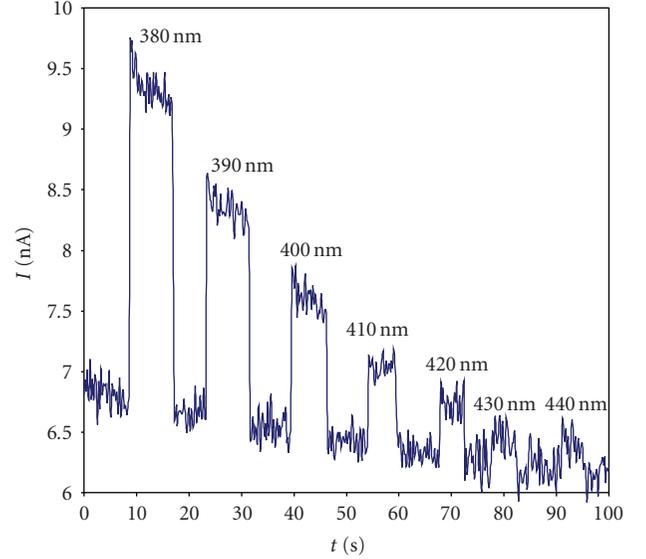


FIGURE 6: Photocurrent response of WO_3 under monochromatic irradiation (bandwidth 10 nm).

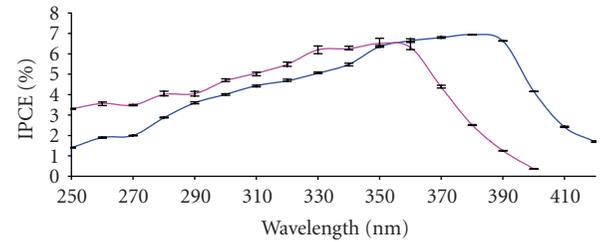


FIGURE 7: Comparison of the %IPCE of TiO_2 (pink line) and WO_3 (blue line) as a function of wavelength.

lower photocurrent from the films prepared from tungsten dodecaphosphate could be attributed to phosphorus impurities in the film. The WO_3 films gave a higher photocurrent response under simulated solar irradiation compared to sol-gel derived TiO_2 films. Photocurrent response spectra measured under monochromatic irradiation showed similar peak efficiency ($\sim 7\%$) at 355 nm for TiO_2 and 380 nm for WO_3 . However, the photocurrent spectral response for the WO_3 films was red-shifted into the visible region of the spectrum. Further work is needed to determine the O_2 and H_2 yield under prolonged, simulated solar irradiation.

ACKNOWLEDGMENT

The authors would like to thank Dr. Naiya Cui for help with AES analysis.

REFERENCES

- [1] A. Fujishima and K. Honda, "Electrochemical photolysis of water at a semiconductor electrode," *Nature*, vol. 238, no. 5358, pp. 37–38, 1972.
- [2] M. Kaneko and I. Okura, *Photocatalysis: Science and Technology*, Springer, Berlin, Germany, 2002.
- [3] C. G. Granqvist, *Handbook of Inorganic Electrochromic Materials*, chapter 2, Elsevier, Amsterdam, The Netherlands, 1995.
- [4] A. Mills and S. Le Hunte, "An overview of semiconductor photocatalysis," *Journal of Photochemistry and Photobiology A*, vol. 108, no. 1, pp. 1–35, 1997.
- [5] J. R. Darwent and A. Mills, "Photooxidation of water sensitized by WO_3 powder," *Journal of Chemical Society, Faraday Transactions*, vol. 78, no. 2, pp. 359–367, 1982.
- [6] G. R. Bamwenda and H. Arakawa, "The photoinduced evolution of O_2 and H_2 from a WO_3 aqueous suspension in the presence of $\text{Ce}^{4+}/\text{Ce}^{3+}$," *Solar Energy Materials and Solar Cells*, vol. 70, no. 1, pp. 1–14, 2001.
- [7] H. Kominami, K. Yabutani, T. Yamamoto, Y. Kara, and B. Ohtani, "Synthesis of highly active tungsten(VI) oxide photocatalysts for oxygen evolution by hydrothermal treatment of aqueous tungstic acid solutions," *Journal of Materials Chemistry*, vol. 11, no. 12, pp. 3222–3227, 2001.
- [8] K. Sayama, R. Yoshida, H. Kusama, K. Okabe, Y. Abe, and H. Arakawa, "Photocatalytic decomposition of water into H_2 and O_2 by a two-step photoexcitation reaction using a WO_3 suspension catalyst and an $\text{Fe}^{3+}/\text{Fe}^{2+}$ redox system," *Chemical Physics Letters*, vol. 277, no. 4, pp. 387–391, 1997.
- [9] J. Desilvestro and M. Neumann-Spallart, "Photoredox reactions on semiconductors at open circuit. Reduction of Fe^{3+} on WO_3 electrodes and particle suspensions," *Journal of Physical Chemistry*, vol. 89, no. 17, pp. 3684–3689, 1985.
- [10] P. Maruthamuthu and M. Ashokkumar, "Hydrogen generation using $\text{Cu(II)}/\text{WO}_3$ and oxalic-acid by visible-light," *International Journal of Hydrogen Energy*, vol. 13, no. 11, pp. 677–680, 1988.
- [11] C. Santato, M. Ulmann, and J. Augustynski, "Enhanced visible light conversion efficiency using nanocrystalline WO_3 films," *Advanced Materials*, vol. 13, no. 7, pp. 511–514, 2001.
- [12] C. Santato, M. Ulmann, and J. Augustynski, "Photoelectrochemical properties of nanostructured tungsten trioxide films," *Journal of Physical Chemistry B*, vol. 105, no. 5, pp. 936–940, 2001.
- [13] G. R. Bamwenda, T. Uesigi, Y. Abe, K. Sayama, and H. Arakawa, "The photocatalytic oxidation of water to O_2 over pure CeO_2 , WO_3 , and TiO_2 using Fe^{3+} and Ce^{4+} as electron acceptors," *Applied Catalysis A*, vol. 205, no. 1-2, pp. 117–128, 2001.
- [14] T. Ohno, F. Tanigawa, K. Fujihara, S. Izumi, and M. Matsumura, "Photocatalytic oxidation of water on TiO_2 -coated WO_3 particles by visible light using Iron(III) ions as electron acceptor," *Journal of Photochemistry and Photobiology A*, vol. 118, no. 1, pp. 41–44, 1998.
- [15] D. W. Hwang, J. Kim, T. J. Park, and J. S. Lee, "Mg-doped WO_3 as a novel photocatalyst for visible light-induced water splitting," *Catalysis Letters*, vol. 80, no. 1-2, pp. 53–57, 2002.
- [16] M. Ashokkumar and P. Maruthamuthu, "Preparation and characterization of doped WO_3 photocatalyst powders," *Journal of Materials Science*, vol. 24, no. 6, pp. 2135–2139, 1989.
- [17] J. M. Bell, I. L. Skryabin, and A. J. Koplick, "Large area electrochromic films—preparation and performance," *Solar Energy Materials and Solar Cells*, vol. 68, no. 3-4, pp. 239–247, 2001.
- [18] I. Zhitomirsky, L. Galor, A. Kohn, and H. W. Henicke, "Electrodeposition of ceramic films from nonaqueous and mixed-solutions," *Journal of Materials Science*, vol. 30, no. 20, pp. 3307–5312, 1995.
- [19] I. Zhitomirsky, "Electrolytic deposition of oxide films in the presence of hydrogen peroxide," *Journal of the European Ceramic Society*, vol. 19, no. 15, pp. 2581–2587, 1999.
- [20] A. Guerfi and L. H. Dao, "Electrochromic molybdenum oxide thin films prepared by electrodeposition," *Journal of the Electrochemical Society*, vol. 136, no. 8, pp. 2435–2436, 1989.
- [21] T. Kudo, H. Okamoto, K. Matsumoto, and Y. Sasaki, "Peroxytungstic acids synthesized by direct reaction of tungsten or tungsten carbide with hydrogen-peroxide," *Inorganica Chimica Acta*, vol. 111, no. 2, pp. 27–28, 1986.
- [22] H. Nakajima, T. Kudo, and N. Mizuno, "Reaction of metal, carbide, and nitride of tungsten with hydrogen peroxide characterized by ^{183}W nuclear magnetic resonance and raman spectroscopy," *Chemistry of Materials*, vol. 11, no. 3, pp. 691–697, 1999.
- [23] Y. Murakami, T. Matsumoto, and Y. Takasu, "Salt catalysts containing basic anions and acidic cations for the sol-gel process of titanium alkoxide: controlling the kinetics and dimensionality of the resultant titanium oxide," *Journal of Physical Chemistry B*, vol. 103, no. 11, pp. 1836–1840, 1999.

Special Issue on Thin-Film Photovoltaics

Call for Papers

Thin-film photovoltaic systems are quickly diffusing in these last years, and they now account for some 12% of solar installations around the world. Thin-film (TF) photovoltaic cells are less expensive to manufacture than the traditional crystalline silicon-based ones and have considerably lowered the barrier to the entry into the photovoltaic energy business. Significantly, the production cost of first solar CdTe modules is now lower than $1\$/W_p$. The sector is thus rapidly switching from the heavy fragile silicon panels to thin-film technologies which use a number of different inorganic and organic photovoltaic semiconductors, and the revenue market share of TFPVs is expected to rise to 20% of the total PV market by 2010.

The present year has remarkably been characterized by the first commercial portable modules by Konarka and the first pilot plant (10 000 m²/year) manufacturing dye-sensitized solar cells for building integration in roofs and facades by CHOSE in collaboration with Dyesol Italia.

The topics to be covered include, but are not limited to:

- Inorganic cells (CIS, CIGS, CdTe, amorphous silicon)
- Organic cells
- Dye-sensitized cells
- Third generation cells
- Papers about scientific breakthrough, technical matters, industrialization, and economic investigation are all welcome. For the already commercialized inorganic cells, recent improvements and achievements for next generation products can be presented.

Before submission authors should carefully read over the journal's Author Guidelines, which are located at <http://www.hindawi.com/journals/ijp/guidelines.html>. Prospective authors should submit an electronic copy of their complete manuscript through the journal Manuscript Tracking System at <http://mts.hindawi.com/> according to the following timetable:

| | |
|------------------------|------------------|
| Manuscript Due | December 1, 2009 |
| First Round of Reviews | March 1, 2010 |
| Publication Date | June 1, 2010 |

Lead Guest Editor

Leonardo Palmisano, Department of Chemical Engineering of Processes and Materials, University of Palermo, Palermo, Italy; palmisano@dicpm.unipa.it

Guest Editors

Aldo Di Carlo, Department of Electronic Engineering, University of Rome, Roma, Italy; dicarlo@ing.uniroma2.it

Gaetano Di Marco, Institute for Physical Chemical Processes, CNR, Messina, Italy; dimarco@me.cnr.it

Stephen M. Goodnick, Engineering Research Center, Arizona Institute for Renewable Energy and Arizona Institute for Nanoelectronics, Arizona State University, Tempe, AZ, USA; stephen.goodnick@asu.edu

Mario Pagliaro, Institute of Nanostructured Materials (ISMN), CNR, Palermo, Italy; mario.pagliaro@ismn.cnr.it

Stanislaw M. Pietruszko, Centre for Photovoltaics, Warsaw University of Technology, Koszykowa, Warsaw, Poland; pietruszko@pv.pl

Special Issue on Polymer Nanocomposite Processing, Characterization, and Applications

Call for Papers

Polymers reinforced with nanoparticles, such as carbon nanotubes, are of great interest due to their remarkable mechanical, thermal, chemical properties as well as optical, electronic, and magnetic applications. In the general research area of polymer nanocomposites, a number of critical issues need to be addressed before the full potential of polymer nanocomposites can actually be realized. While a number of advances have recently been made in the area of polymer nanocomposites, the studies on understanding of the effects of processing parameters on the structure, morphology, and functional properties of polymer nanocomposites are deficient. There is a need for characterization techniques to quantify the concentration and distributions of nanoparticles as well as to assess the strength at the interface between the polymer and nanoparticles. Also, there is a need for the development of better models able to predict the mechanical properties of the polymer nanocomposites as functions of myriad factors including nanoparticle orientation, the type of functional groups, and the molecular weight of polymer chain. The relationships between the structural distributions and the ultimate properties of the polymer nanocomposites also need to be elucidated.

This special issue of the Journal of Nanomaterials will be devoted to emerging polymer nanocomposite processing techniques and call for new contributions in the field of characterization and applications of multifunctional nanocomposites. It intends to cover the entire range of basic and applied materials research focusing on rheological characterization, nanoparticle dispersion, and functional properties of polymer nanocomposites for sensors, actuators, and other applications. Fundamental understanding of the effects of processing and nanoparticles on the polymer structure and morphology, their optical, electrical, and mechanical properties as well as novel functions and applications of nanocomposite materials will be the highlights of this special issue.

Papers are solicited in, but not limited to, the following areas:

- Solution and melt processing of polymer nanocomposites
- Rheological and thermal characterization of nanocomposites

- Generation of nanofibers using extrusion and electrospinning of nanocomposites
- Processing-induced orientation of nanoparticles
- Quantification of nanoparticle dispersion
- Effect of nanoparticle incorporation on polymerization
- In situ nanoparticle formation in polymer matrix
- Noncovalent functionalization techniques and characterization of properties at polymer-nanoparticle interface
- Novel applications of polymer nanocomposites

Before submission authors should carefully read over the journal's Author Guidelines, which are located at <http://www.hindawi.com/journals/jnm/guidelines.html>. Prospective authors should submit an electronic copy of their complete manuscript through the journal Manuscript Tracking System at <http://mts.hindawi.com/> according to the following timetable:

| | |
|------------------------|------------------|
| Manuscript Due | November 1, 2009 |
| First Round of Reviews | February 1, 2010 |
| Publication Date | May 1, 2010 |

Lead Guest Editor

Gaurav Mago, Lubrizol Advanced Materials, Inc., Avon Lake, OH 44141, USA; gaurav.mago@lubrizol.com

Guest Editors

Dilhan M. Kalyon, Highly Filled Materials Institute, Department of Chemical Engineering and Materials Science, Stevens Institute of Technology, Hoboken, NJ, USA; dilhan.kalyon@stevens.edu

Sadhan C. Jana, Department of Polymer Engineering, University of Akron, Akron, OH, USA; janas@uakron.edu

Frank T. Fisher, Department of Mechanical Engineering, Stevens Institute of Technology, Hoboken, NJ, USA; frank.fisher@stevens.edu



Growdiesel
Fuel Forever

Growdiesel Mission announces 2nd Algae Biofuel Summit 2009

Growdiesel Climate Care Council has announced the second edition of its landmark event "Algae Biofuel Summit 2009". It is now accepting papers from researchers and industry experts. The summit is scheduled to be held from 8th to 10th Sept. 2009 in India. The first Algae Biofuel Summit 2008, was a grand success. It was attended by Researchers, Scientists and industry delegates from 21 countries across the globe. Algae Biofuel Summit 2008 was inaugurated by Minister of New & Renewable Energy, Govt. of India. The submit got full support of various other ministries of Govt of India including Department of Science and Technology, Department of Biotechnology, Ministry of New & Renewable Energy and National Agriculture Bank for Rural Development. The speakers and delegates included national and international industry experts, technologists, biofuel companies, scientists, investors, oil companies, policy-makers etc. Over 70 speakers deliberated on all issues encompassing this futuristic emerging industry. It was anonymously concluded by all the global experts that algae are the best source of biofuels on the planet that we know till date. One hectare algae farm on wasteland can produce over 10 to 100 times of oil as compared to any other known source of oil-crops. While a crop cycle may take from three months to three years for production, algae can start producing oil within 3-5 days & thereafter oil can be harvested on daily basis (just like milk).

As per Prof. M. P. Yadav, former vice chancellor of Sardar Vallabh Bhai Patel University and Chairman of Growdiesel Mission, the organizers of Algae Biofuel Summit 2009, this year we expect over 1,000 delegates consisting of industry experts, scientists, innovators, investors and policy makers from across the world. Call for Abstracts for Algae Biofuel summit 2009 is NOW open. Anchor discounted registration for speakers and industry delegates shall open shortly. In line with its policy to support small & medium entrepreneurs, Growdiesel shall be providing special discounted registration opportunities for them.

For list of topics and latest info about this exciting must attend event please visit www.algaebiofuelsummit.com. You can also reserve your seat by filling a pre registration form at www.algaebiofuelsummit.com. For questions or clarifications, please contact: info@growdieselmail.com or growdiesel@gmail.com