出國報告（出國類別：國際會議）

參加國際會議 AM-FPD’13 心得報告

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摘要

本研討會的目的是針對有關新一代的平面顯示器之研究開發，提供一個會議平台讓相關的學者作交流討論，促進此一研究領域更為蓬勃發展。今年研討會的 4 個主題分別是：(1)Flat Panel Display (FPD)，(2)TFT Technologies (TFT)，(3)Photovoltaics (PV)，(4)Thin-Film Materials and Devices (TFMD)。平面顯示器已經成為現代人不可或缺的電子元件，它們被應用在個人電腦、電視、電子看板、行動電話或平板電腦可移動的設備等等，都是最主要的零件。AM-FPD'13 國際研討會提供了我們有關這項研究領域最專業的交流場域，其中有數百篇論文的投稿，參與會議的各國學者眾多，參加之後，能瞭解平面顯示器最新的研究發展動態，帶回最新的研究資料，值得我們繼續鑽研，並提升我們實驗室研究群的研究能量。

目次

一、目的

AM-FPD'13 國際研討會的目的是針對有關新一代的平面顯示器之研究開發，提供一個會議平台讓相關的學者作交流討論，促進此一研究領域更為蓬勃發展。研討會的歷史極為悠久，從 1994 年在日本東京舉辦以來到今年(2013)已經有 20 年之久，明年(2014)同樣將繼續在京都的龍谷大學舉辦。主動式矩陣平面顯示器(Active-Matrix Flatpanel Displays)包括了薄膜電晶體液晶顯示器（Thin film transistor liquid crystal display，常簡稱為 TFT-LCD）以及主動式矩陣有機發光二極體(AMOLED)，今年研討會的 4 個主題分別是：(1)Flat Panel Display (FPD)，(2)TFT Technologies (TFT)，(3)Photovoltaics (PV)，(4)Thin-Film Materials and Devices (TFMD)。

二、過程

由於預定搭乘的飛機航班（中華航空 CI 156）從桃園機場出發的時間是 7 月 2 日早上 8 點半，而本人的住家位於台南市永康區，為避免行程過於匆忙，於是 7 月 1 日先行到桃園機場附近的之「桃禧航空城酒店」休息一晚，第二天早上六點半整裝後，好整以暇帶著一件行李到桃園機場登機，飛往日本關西機場，到達日本的時間大約是 12 點，取出行李後，搭乘機場巴士直達京都的下榻飯店-京都八條口大和皇家酒店(Daiwa Roynet Hotel KYOTO-HACHIJOGUCHI)，耗時約 90 分鐘。下榻處距離研討會地點-龍谷大學響部(Ryukoku University Avanti Kyoto Hall)非常近，走路不到十分鐘，於是在飯店休息一會兒，就動身到會場報到與註冊，同行的與會人員還有來自同校的電子系閔庭輝教授，以及國立台南大學綠能系的湯譯增教授，註冊完畢取得相關會議文件與資料。針對即將從事這個研究方向的研究人員與技術人員，7 月 2 日當天晚上大會安排有關氧化物薄膜電晶體的製作等訓練課程提供我們參加，但是講員以日文演說，所以我們並未參與此課程。第二天（7 月 3 日）早上 9 點鐘正式開幕，我們除了聆聽有興趣的演講之外，同時我們與參加會議的其他各國學者進行有效的討論與交流。首先參加 **Session 1: Anniversary Session** (9:15-11:15)，主持人是日本 NAIST 的 Y. Uraoka 博士與日本龍谷大學(Ryukoku Univ.)的 M. Kimura 教授，第一場是邀請日本 Sendai Nat'l College of Technol. 的 T. Uchida 教授，講題：40 Years Research and Development on Liquid Crystal Displays，講述近 40 年來液晶顯示器之研發過程；第二場的受邀演講者是來自美國 Texas A&M Univ. 的 Y. Kuo 教授，講題：Progress of Thin Film Transistor Technology - Large-Area Mass Production and Beyond，講述有關 TFT 的研發演進過程；第三場的受邀演講者是日本 Kyushu Univ.的 T. Tsutsui 教授，講題：60 Years of Organic Semiconductor Research and Development in Japan；第四場的受邀演講者是 Japan Display 的 H. Ohshima 博士，講題：Past, Present and Future of Mobile Displays。經過大約 40 分鐘的休息時間，接著進行 **Session 2: Keynote Address** (11:35-12:35)，主持人更換為 Kochi Univ. of Technol.的 M. Furuta 以及 Osaka Univ.的 T. Toyama，第一場的演講人是韓國 Kyung Hee Univ.的 J. Jang，講題：Past, Current and Future TFT Technologies for Display Manufacturing；第二

場的受邀演講者是日本 Tokyo Inst. of Technol.的 M. Konagai 教授，講題：Current Status of Thin-Film Solar Cells and Future Prospects。用過午餐之後，下午開始 **Special Session: Printing/Flexible Display Panels for Large Area, Thin and Lightweight Applications** (13:50-15: 20)，我又參加聆聽兩場演講，講題分別為：Advanced Printing Techniques for Flexible Device Fabrication 與 Flexible AMOLED Display Driven by Amorphous InGaZnO TFTs。之後稍作休息，晚上參加晚宴 **Banquet** (18:00-20:00)，度過充實緊湊的一天。

第三天 7 月 4 日起，我們選擇參加有興趣的場次聆聽演講，例如：Graphene 的成長與元件的應用，他們把 Graphene 用在 FET 與 Bio-Sensor，有不錯的效果；還有講題為 Oxide Based Photosensor Thin-Film Transistor for Interactive Display 的演說也很精彩，收穫很多；另外，有關可撓式太陽電池的研究主題也很吸引人。大會給我們的壁報發表的時間訂在 7 月 4 日（星期四）15:35-17:35，編號為 P-16，有許多學者也對我們的研究主題有興趣並交換意見。本人參與研討會發表的論文如附錄所示。

第四天 7 月 5 日，我們聆聽了 Overcoming Current Limitations of Silicon Thin Film Technology for Flexible Electronics, Natural Resource Limitations to Terawatt-Scale Solar Photovoltaics, Carbon Nanotube-Based Thin-Film Transistors on Plastic Film 等講題的演說，其中最後的講題由日本長崎大學(Nagoya Univ.)的 Ohno 教授做的報告比較吸引我的注意，他們用印刷的技術成功地在可撓式的塑膠基板製作碳奈米管的 TFT，擁有不錯的性能輸出。

第五天 7 月 6 日下午 1 點 10 分我們在關西機場搭乘華航 CI 157，回到台灣桃園機場的時間是下午 3 點，順利結束本次國際研討會的行程。

三、心得及建議

平面顯示器已經成為現代人不可或缺的電子元件，它們被應用在個人電腦、電視、電子看板、行動電話或平板電腦可移動的設備等等，都是最主要的零件。AM-FPD'13國際研討會提供了我們有關這項研究領域最專業的交流場域，其中有近百篇論文的投稿，參與會議的各國學者眾多，參加之後，能瞭解平面顯示器最新的研究發展動態，帶回最新的研究資料，值得我們繼續鑽研，並提升我們實驗室研究群的研究能量。

（附錄）

發表 4 頁論文（大會論文集抽印本）、會場照片 、CALL FOR PAPERS、大會議程

P-16

Characteristics of Photosensors with TiO_2 Nanorods

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TiO_2 nanorod arrays (TNAs) were grown on glass substrates by a chemical solution route and the fabrication of a photodetector (PD) with selective growth of TNAs have been demonstrated in the study. The PDs with TNAs compared to the conventional film-type TiO_2-based PDs, it was found that the UV response of such a device can be increased about 10^4 times. This giant enhancement of photoresponsivity in the fabricated nanorod PDs can be attributed to the existence of TNAs, due to TNAs could provide a directed path for electrical transport and also improve optical absorption for its large surface-area-to-volume ratio.

1. Introduction

Titanium dioxide (TiO_2) is a wide band-gap semiconductor material that is sensitive in UV region as well as applications for biological, oxygen sensitivity, catalysis, and solar energy conversion. The anatase TiO_2 structure has interested a lot of attention within the last decades for its technological applications such as photovoltaic solar cells and photodetectors (PDs) with promising efficiency [1, 2]. Rutile TiO_2 has some advantages over anatase such as higher chemical stability and higher refractive index. One-dimensional (1-D) TiO_2 nanostructures have been the attention of intensive research owing to their unique size-related effect physical properties, mechanical flexibility, and potential development as building blocks for electronic nanodevices [3-5].

The fabrication of large-area ordered assembly of nanowires with controlled orientations and density is essential; nevertheless, it still presents a major bottleneck holding back their potential applications. E. Bae *et al.* reported the crystal phase, shape, and size of TiO_2 particles were found to be greatly dependent on the concentration of PVP in the solution. Addition of hydrophilic polymer PVP enabled control of exposed crystal faces of rutile TiO_2 nanorods in crystallization during hydrothermal treatment [6]. H. F. Lu *et al.* studied amorphous TiO_2 nanotube arrays for oxygen sensors [7]. They were synthesized on a titanium substrate using anodic oxidation in an electrolyte ammonium fluoride and evaluate for low temperature oxygen sensing. The growth mechanism of TiO_2 nanotubes and influence of PT-substrate on the morphology of the prepared TiO_2 nanorod arrays (TNAs) have been discussed by Y. Li *et al* [8]. Besides, a MSM TiO_2 UV detectors with Ni electrodes on Si substrates fabricated by X. Kong *et al* [9]. These reports indicated that TiO_2-based one dimensional nanostructures have attracted much attention due to their excellent properties and important applications. Compared with TiO_2 thin films, TiO_2 nanorod arrays have lower recombination rate for excited electron-hole pair.

In this work, we report the fabrication and characterization of UV photodetectors with TiO_2 nanorods. The TiO_2 nanorods were selectively grown on the gap of Ag electrodes by chemical solution method through a photolithography process. We found the fabricated TNAs photodetectors demonstrated a higher photoresponse and UV-to-visible rejection ratio than the thin film TiO_2 photodetectors.

2. Experimental

Before the device fabrication, the Corning glass substrates were cleaned by sequential ultrasonic treatment in detergent, deionized water, acetone, and isopropyl alcohol. The samples were loaded into the chamber of radio frequency (RF) magnetron sputter system. Finally, 150-nm-thick TiO_2 seed layers were deposited onto the glass substrates using radio frequency magnetron sputter deposition technique. During growth, the working pressure of the chamber was about 5×10^{-2} torr, the RF power was 100 W, and the gas mixing ratio Ar/O_2=10/1, and then the TiO_2 seed layer was annealed at 400 ℃ for 2 hours. The 100-nm-thick Ag electrodes were deposited onto the TiO_2 film by electron beam evaporation to serve as Schottky contacts. The active area of the whole device was 2×2 mm^2. Then we employed the photoresists in protecting

the electrode patterns by lithography technique. The hydrothermal precursor solution was prepared by mixing 0.05 M titanium trichloride ($TiCl_3$) aqueous solution saturated with sodium chloride. After the precursor solution was stirred for 5 min, it was transferred into a sealed kettle and then corning substrate was immersed into the precursor solution. The hydrothermal growth of TNAs was carried out at 100±5 ℃ for 7 h. The fabricated PDs were removed from the solution, rinsed with distilled water, and dried in air. Finally, we removed the photoresists from the electrode surface of devices.

The structure of TiO_2 nanorod arrays PDs is shown in Figure 1. Besides, the traditional TiO_2 with 150-nm-thick TiO_2 film were fabricated for comparison, where no TNAs can be found. Photocurrent and dark current of the fabricated MSM devices were performed by a semiconductor parameter analyzer (Agilent HP 4156C). The spectral response of MSM UV PDs was measured by a light source which employed a 300 W Xe lamp and a monochromator covering the range of 300~700 nm.

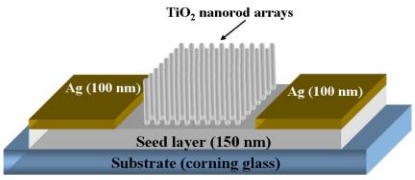


Fig. 1. Schematic for the fabricated UV MSM PDs with TNAs.

3. Results and Discussion

Figure 2(a) shows XRD patterns of the as-grown TiO_2 nanorod arrays prepared by hydrothermal treatment at 100 ℃ for 7 h. It can be seen that the diffraction peaks of TiO_2 appear and can be indexed as the rutile phase and anatase phase of TiO_2. Previous studies [10-13] have reported that the prepared TiO_2 rods via hydrothermal approach in strongly acidic solution are mostly pure rutile phase. According to periodic bond chain (PBC) theory [14], periodic bond chain constructs the crystal. The direction of the strongest chemical bond is usually preferred oriented direction of the crystal. Therefore, the growth of rutile TiO_2 crystal along the [0 0 1] direction is faster than that of the [1 1 0] direction. Figure 2(b) shows that the average optical absorption of the entire TNAs PDs structure in the visible range of 400~700 nm of the spectrum is lower then 1. The results showed that the top of TNAs was pin-like after deposition for 7 h, as shown in Figure 3(a). The [1 1 1] planes observed at the top of the rods were a minor surface in the equilibrium shape of a rutile TiO_2 crystal using the Wulff construction and the calculated surface energies. According to the atomistic simulation reported by Oliver *et al.* [15], Figure 3(b) shows the rutile TiO_2 four surfaces of [0 1 1], [1 1 0], [1 0 0], and [2 2 1] had surface energies of 1.85, 1.78, 2.08, and 2.02 Jm^{-2}, respectively. In past time, the surface identified as the [2 2 1] plane had been thought to be the lower index [1 1 1] plane. The [1 1 1] or [2 2 1] plane affects a very small surface area in the equilibrium shape, but this plane has been considerably difficult by experimental observation. In contrast to the simulation by Oliver *et al.*, our results have shown the presence of the [1 1 1] facet with the large surface area, giving the pin-like morphology. It was also found that a small part of anatase phase was detected by XRD, which might be due to the TiO_2 seed layer on the glass substrate. The length and diameter of as-deposited TiO_2 nanorods are about 700 and 25 nm, respectively. The barrier effect of intercrystalline TiO_2 is greatly decreased by using long nanorods instead of a TiO_2 thin film composed of accumulated nanoscale particles, because they naturally provide a directed path for electrical transport.

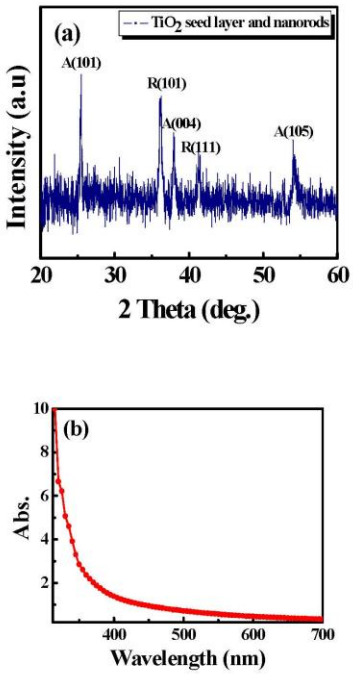
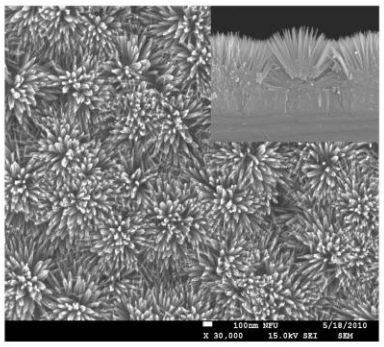
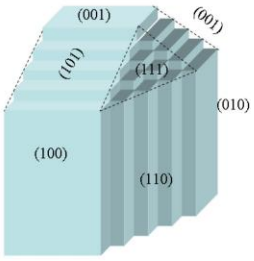


Fig. 2. (a)XRD spectrum of the as-grown TNAs prepared by hydrothermal treatment at 100 ℃ for 7 h. (b) Absorption as a function of wavelength for the transparent TNAs photosensors.



(a)



(b)

Fig. 3. (a) The surface morphology and side view SEM images of TiO_2 nanorod arrays grown on corning glass substrate. (b) The equilibrium state of the crystaline TiO_2 with a rutile phase according to the Wulff construction.

Figure 4 shows current-voltage (*I-V*) characteristics of the fabricated TiO_2 film and TNA PDs with the Ag electrodes measured in dark and 360 nm illumination. With 5 V applied bias, the photocurrent to dark current contrast ratios of the TiO_2 and TNA PDs were 12 and 5×10^2, respectively. Photocurrent of the TiO_2 film and TNA PDs based at 5 V were 4×10^{-11} and 6×10^{-8} A, respectively. The TNAs were more suitable to increase optical absorption that is because the nanorod arrays having higher surface area than film. However, the dark current of the TNA PDs is very large. This may be due to the high background carrier concentration. It is well known that oxygen vacancies exist in n-type semiconducting titania acting as donors, besides the TNAs have many defects of oxygen vacancies that can provide higher carrier concentration and more active sites.

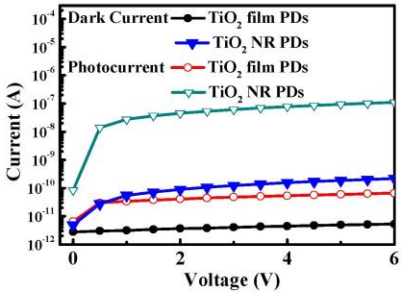


Fig. 4. *I-V* characteristics of the TNA PDs measured in dark and under 360 nm illumination.

Figure 5 shows the spectral responsivities of the fabricated traditional TiO_2 film and TiO_2 nanorod PDs. The responsivity of a detector (R) is defined as

$$R=\frac{I_p}{P_{inc}}=\eta\frac{\lambda(\mu m)}{1.24}\ A/W \qquad (1)$$

where I_p, P_{inc}, η and λ are the photocurrent, the quantum efficiency and the incident light wavelength, respectively. Assume all the photons are absorbed by semiconductor ($\eta = 1$) and 360 nm to the expression. It was found that the maximum responsivities were 4×10^{-5} and 0.1 A/W, respectively. The TNA PDs show much higher photoresponse than the traditional TiO_2 PDs (0.1 A/W, 4×10^{-5} A/W) can be attributed to the large surface- to-volume ratios of TNAs provide a directed path for electrical transport reduce the electron-hole recombination rates and increase absorption. In addition, the spectral presented a passband response between 360 nm and 450 nm. Such a special responsivity is typical for the nitride-based UV PDs, hence we define the UV-to-visible rejection ratio as the responsivity measured at 360 nm divided by the one measured at 450 nm (R360/R450). With such a definition, it was found that UV-to-visible rejection ratios at 5 V applied bias of the PDs were 3.25 and 6.25, respectively.

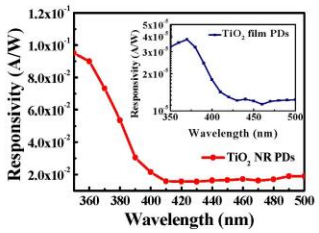


Fig. 5. Measured spectral responsivities of the fabricated traditional TiO_2 film and TNA PDs at 5 V applied bias.

4. Conclusions

In summary, we investigated the characteristics of UV PDs with TiO_2 nanorod arrays (TNAs) selectively grown at low temperature of 100 °C, which show higher photoresponse compared to the thin film TiO_2 PDs. As a result, it can be attributed to the high surface-to-volume ratios of TNAs easily providing a directed path for electron transportation. With an incident wavelength of 360 nm and 5V applied bias, we found that maximum photoresponsivity of the TNA PDs and traditional TiO_2 PDs were 0.1 and 4×10^{-5} A/W, respectively.

Acknowledgements

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研討會會場照片 3