

# 具有高感測範圍之 非晶矽薄膜電晶體光感測器

研究生：游騰瑞

指導教授：戴亞翔 博士

國立交通大學

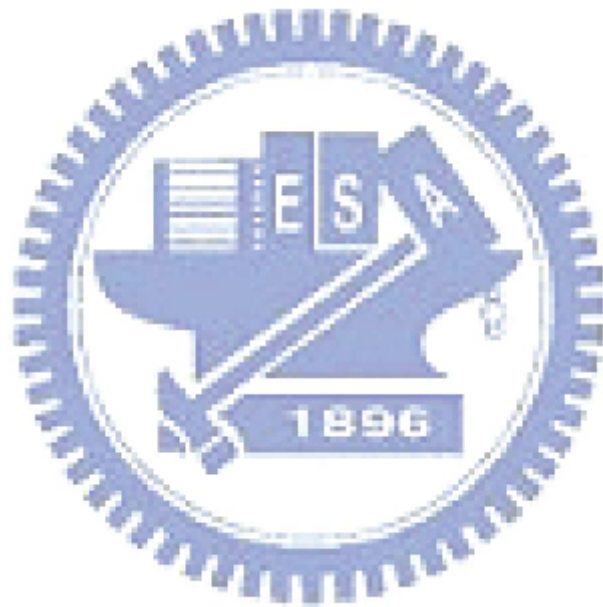
顯示科技研究所

## 摘要

非晶矽薄膜電晶體(a-Si TFTs)最近在液晶顯示器(AMLCD)的周邊電路整合應用上，之所以會是眾所注目的焦點，是因為其具有較低的製造成本，而將顯示器周邊電路整合於同一片玻璃基板周圍，也已經被廣泛地研究了。為了實現所謂的高附加價值以及有輸入功能的薄型化面板，除了將這些周邊電路整合至玻璃基板外，將一些電路整合至畫素上已是必要的考量，尤其是應用於行動裝置上。從各式各樣的不同高階功能如：環境光感測器、影像掃描、觸控式面板等，整合一個非晶矽光感測器似乎是一個最重要的關鍵技術。在這些高附加價值的功能之中，環境光感測器可以藉由偵測面板週遭環境光強度來控制背光源的亮度，進而達到降低功率消耗並且改善螢幕的清晰度。

在本篇論文中，我們先針對非晶矽薄膜電晶體在鹵素燈照射下的光特性做仔細的研究，並進一步確認元件在不同的操作區域內的光效應。我們還提出一種利用相同於非晶矽薄膜電晶體製程的新型光感測電路，故可在不變動製程步驟和不增加成本的情況下達到整合的目的。這個含有源極隨耦器的新型電路，可以感測到不同光照強度下的光漏電流訊號，將此電流訊號轉換成類比的電壓訊號。根據實際電路在環境光 0~63315lux 下的量測結果，我們確定此光感測電路可以準確

地完成感測和讀出訊號。然而，我們分析了對光感測準確性影響的因素，還提出了校正方法，使具有高感測性範圍之環境光感測器，在 0~63315 lux 之間，將提供良好的感測準確性(誤差<10%)。



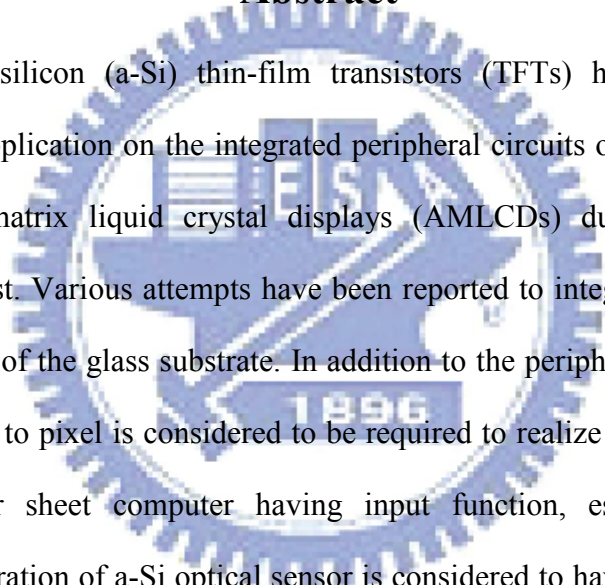
# **Study on the a-Si TFT Light Sensor with Wide Dynamic Range**

Student : Teng-Jui Yu

Advisor : Dr. Ya-Hsiang Tai

**Department of Display Institute  
National Chiao Tung University, Hsinchu, Taiwan**

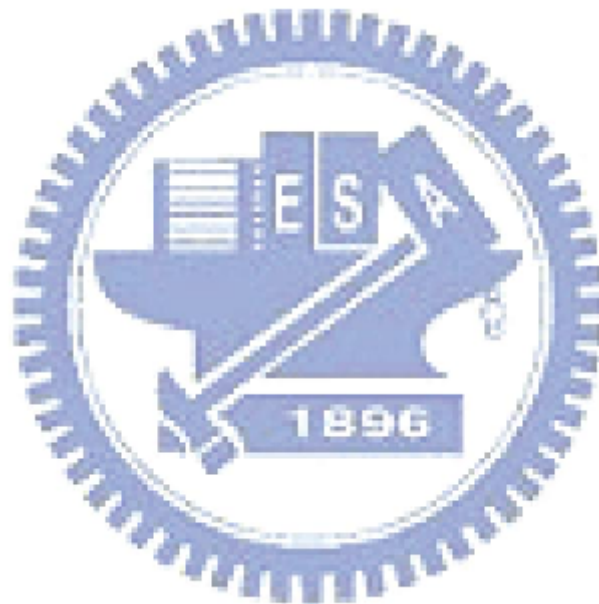
## **Abstract**



Amorphous silicon (a-Si) thin-film transistors (TFTs) have attracted much attention in the application on the integrated peripheral circuits of display electronics such as active matrix liquid crystal displays (AMLCDs) due to its lower the manufacturing cost. Various attempts have been reported to integrate display circuits to peripheral area of the glass substrate. In addition to the peripheral area integration, circuit integration to pixel is considered to be required to realize so-called high-value added display or sheet computer having input function, especially in mobile equipments. Integration of a-Si optical sensor is considered to have a potential to be a key technology for various kinds of advanced functions such as ambient light sensors, image scanners, touch panel, etc. An ambient light-sensing function, which is one of several high-value added functions, can contribute to low power consumption and improve visibility by detecting ambient light around the display panel and controlling the brightness of the display panel.

In this thesis, we present a detailed experimental study of the a-Si TFTs behavior under halogen lamp illumination and identify the different TFT operating regimes. We also propose the light-sensing circuits using the identical a-Si TFTs fabrication

processes without any extra cost. The proposed circuit, which has a source follower, can sense the photo leakage current under different illumination intensities and convert the current to analog voltage signal. Through the measurement of the proposed circuit under light variation from 0 to 63315 lux, we confirmed that the proposed light-sensing circuit can perform sensing and readout operations accurately. However, we analyze the possible factors that can affect the sensing accuracy and propose the calibration methods to provide good sensing accuracy (error < 10%) in the wide dynamic range of ambient light from 0 lux to 63315 lux.



# Acknowledgements

首先要感謝的是我的指導教授 戴亞翔博士；老師積極認真的研究態度、大膽前瞻的眼光、講求效率的處事原則及謹慎周全的思慮，以及準確的判斷，總是能適時對學生的研究，形成很大的助力。感謝老師總是鼓舞我們、激發我們，用心的指導我們，並且提供許多新穎的研究想法，讓我受益良多。而在做研究之餘，老師也不忘提醒大家做人處事的態度，不論在言教還是身教，都給予我們最好的榜樣。在此，對老師致上最深的敬意。

接著要感謝士哲學長、彥甫學長在研究方面給予啟蒙指導，助我解決研究過程中的諸多疑惑；感謝畢業的學長姐們：憲哥、曉嫻、龍哥、首席、小黑、祥帥，你們親切的態度，在需要時能不吝伸出援手，讓我很快的熟悉環境，使我成長茁壯；更要感謝的是一起奮鬥的同學紹文、柏廷、國珮、耿維，研究所兩年裡共同討論課業上的知識，也一起努力解決實驗上的問題，有你們的相扶相持是我的榮幸；也要感謝學弟妹們：趴趴、少宏、小瓜呆，隔壁實驗室的智昱、小豬、立峯、虛胖，謝謝你們豐富了我的生活、也擴展了我的視野。也因為有了你們，實驗室時常充滿了歡笑，兩年的碩士生涯有了大家的陪伴，使我的碩士生活既充實也充滿了溫馨。

更要感謝我的家人以及女友淑玲，總是在背後默默的支持及鼓勵，給予我高度的肯定，才有今日成長的我，都是因為你們真誠無私的愛與無可替代的存在，才能讓我堅持到最後，在此向他們送上最真摯的感謝。

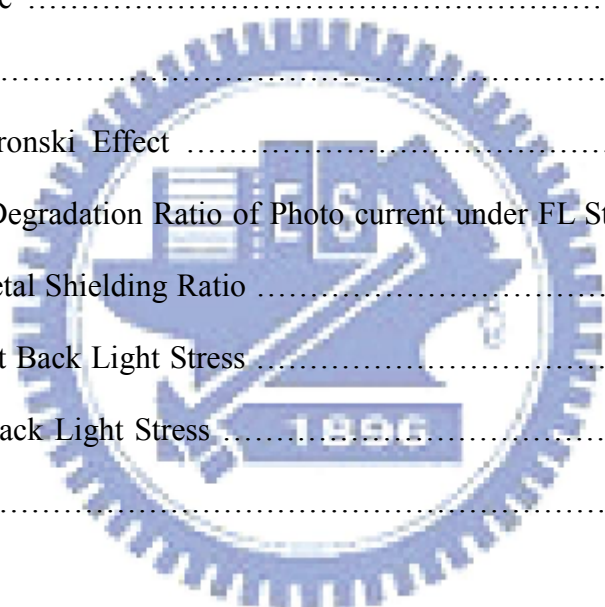
最後再感謝我的口試委員：張鼎張、冉曉雯和劉漢文 教授，感謝你們的建議和指導；也感謝交大，讓我能在如此優良的環境中，順利完成論文並取得碩士學位。

騰瑞 2009.06.16

# Contents

<b>Chinese Abstract</b> .....	<b>I</b>
<b>English Abstract</b> .....	<b>III</b>
<b>Acknowledgements</b> .....	<b>V</b>
<b>Contents</b> .....	<b>VI</b>
<b>Figure Captions</b> .....	<b>VIII</b>
<b>Table Lists</b> .....	<b>XIII</b>
<b>Chapter 1 Introduction</b>	
1.1 Background .....	1
1.2 Motivation .....	2
1.3 Thesis Organization .....	3
<b>Chapter 2 Photo Effect on Device</b>	
2.1 The Different Structures of a-Si TFTs .....	6
2.2 Photo Effect of Front Light Illumination .....	7
2.3 Analysis of Sensitivity in ON and OFF regions .....	8
<b>Chapter 3 Light-Sensing Circuit</b>	
3.1 Conventional Light Sensing Circuit.....	18
3.2 Sensor Structure and Operation Principle .....	19
3.2.1 Off Region Sensing Circuit ( 3T1C ) .....	19
3.2.2 ON Region Sensing Circuit ( 4T2C ) .....	20

3.3 Simulation .....	21
3.3.1 Simulation Method .....	21
3.3.2 Simulation Method Result .....	21
3.3.3 Discussion .....	22
3.4 Digitization .....	23
<b>Chapter 4 Error Factors</b>	
4.1 Uniformity .....	38
4.2 Temperature .....	38
4.4 Back Light .....	39
4.4 Staebler-Wronski Effect .....	41
4.4.1 Same Degradation Ratio of Photo current under FL Stress .....	41
4.4.2 Top Metal Shielding Ratio .....	43
4.4.3 Without Back Light Stress .....	43
4.4.4 With Back Light Stress .....	45
4.5 Discussion .....	46
<b>Chapter 5 Conclusions</b> .....	66
<b>References</b> .....	67



# Figure Captions

## Chapter 1

Fig. 1-1 The linearity between the illuminance and the photocurrent  
of lateral PIN photodiodes with area =1000/11000/121000  $\mu\text{m}^2$   
(Ref. *Hyun-Sang Park et al.,SID'08*) ..... 5

## Chapter 2

Fig. 2-1(a) The cross-section views of Conventional-Gate a-Si TFTs structure ..... 10

Fig. 2-1(b) The cross-section views of Gap-Gate a-Si TFTs structure ..... 10

Fig. 2-1(c) The cross-section views of Dual-Gate a-Si TFTs structure ..... 10

Fig. 2-2 Conventional gate TFT transfer characteristics in the dark and under  
illumination at  $V_{ds}=10\text{V}$  including regions (i) ON (ii) subthreshold  
(iii) OFF..... 11

Fig. 2-3 (a) and (b) Gap-Gate TFT transfer characteristics in the dark and under  
illumination at  $V_{ds}=10\text{V}$  including regions (i) ON (ii) subthreshold  
(iii) OFF..... 12

Fig. 2-4 (a) and (b) Dual-Gate TFT transfer characteristics in the dark and under  
illumination at  $V_{ds}=10\text{V}$  and  $V_{GB} =10\text{V}$  including regions (i) ON  
(ii) subthreshold (iii) OFF ..... 13

Fig. 2-4 (c) and (d) Dual-Gate TFT transfer characteristics in the dark and under  
illumination at  $V_{ds}=10\text{V}$  and  $V_{GB} = -10\text{V}$  including regions (i) ON  
(ii) subthreshold (iii) OFF ..... 14

Fig. 2-5 The relationships between photo current and illumination intensity



of Gap-Gate TFTs for several bias conditions in (a) the ON region and (b) OFF region, respectively .....	16
Fig. 2-6 show the comparison of the relative photo sensitivity between ON and OFF region (a) after normalized , (b) after differentiation .....	17

### Chapter 3

Fig. 3-1 Original light sensing circuit design .....	24
Fig. 3-2 Source follower as the readout part of sensor .....	24
Fig. 3-3 Photograph of the fabricated 2T1C light-sensing circuit .....	25
Fig. 3-4 Experiment result of light sensing circuit (a) in the dark (b) under illumination .....	26
Fig. 3-5 (a) Schematic of proposed 3T1C light-sensing circuit and (b) timing sequence .....	27
Fig. 3-6 (a) Schematic of proposed 4T2C light-sensing circuit and (b) timing sequence .....	28
Fig. 3-7 Illumination dependence of $I_D$ - $V_D$ characteristic and its fitting formula in (a) OFF region and (b) ON region .....	29
Fig. 3-8 (a) Schematic of conventional source follower (b) Wave form of the output signal when the input triangular signal is 5V to 14V .....	31
Fig. 3-9 SPICE simulation results of TFT (W/L=20um/5um) (a) OFF region sensing, (b) ON region sensing .....	32
Fig. 3-10 (a) The modified 3T1C light-sensing circuit model for simulation (b) The modified 4T2C light-sensing circuit model for simulation (c) its time diagram .....	33
Fig. 3-11 (a) 3T1C light-sensing circuit model and (b) 4T2C light-sensing circuit model simulation results under illumination and in the dark .....	34

Fig. 3-12 (a) output voltage and (b) relative error results of the light-sensing circuits under different illumination intensity in ON region and OFF region .....	35
Fig. 3-13 (a) Pixel of the fabricated 3T1C light-sensing circuit .....	36
Fig. 3-13 (b) Pixel of the fabricated 4T2C light-sensing circuit .....	36
Fig. 3-14 (a) Simplified block diagram of digitization circuit and (b) its signal diagrams .....	37

## Chapter 4

Fig. 4-1 (a) OFF current variations of a-Si TFTs of 4 devices .....	47
Fig. 4-1 (b) ON current variations of a-Si TFTs of 4 devices .....	47
Fig. 4-2 Error analysis of ON current variation between the measured light intensity and the illuminated light intensity .....	48
Fig. 4-3 (a) The OFF current versus illumination intensity at 35°C, 40°C, and 45 °C .....	49
Fig. 4-3 (b) The ON current versus illumination intensity at 35°C, 40°C, and 45 °C .....	49
Fig. 4-4 Error analysis of temperature variation ( $\pm 5^{\circ}\text{C}$ ) between the measured light intensity and the illuminated light intensity in (a) OFF region and (b) ON region .....	50
Fig. 4-5 (a) The ON current versus temperature at $V_{gs}=10\text{V}$ , $V_{ds} = 10\text{V}$ .....	51
Fig. 4-5 (b) The temperature coefficient versus temperature curves of 4 devices ...	51
Fig. 4-5 (c) Error analysis of temperature variation ( $\pm 3.5^{\circ}\text{C}$ ) between the measured light intensity and the illuminated light intensity in ON region .....	52
Fig. 4-6 Simulate a-Si TFT's real situation on panel .....	52
Fig. 4-7 (a) The OFF current versus FL illumination intensity without BL and with BL .....	53

Fig. 4-7 (b) The ON current versus FL illumination intensity without BL	
and with BL .....	53
Fig. 4-8 The relation between the measured light intensity and the illuminated light	
intensity in (a) OFF region and (b) ON region .....	54
Fig. 4-9 Error analysis of backlight effect between the measured light intensity and	
the illuminated light intensity in (a) OFF region and (b) ON region .....	55
Fig. 4-10 (a) Gap gate TFT transfer characteristics with SW effect at $V_{DS}=10V$ ...	56
Fig. 4-10 (b) $I_D$ - $V_D$ characteristics of OFF region and ON region with SW effect ...	56
Fig. 4-11 (a) Drain current versus front light stress time with different intensity ...	57
Fig. 4-11 (b) The power-law time dependence between drain current	
and stress time .....	57
Fig. 4-12 (a) The top metal floating shielding (ES process) .....	58
Fig. 4-12 (b) The inverted bottom metal floating shielding (BCE process) simulating	
the top metal shielding devices .....	58
Fig. 4-13 Drain current versus open ratio (a) before stress and (b) after stress .....	59
Fig. 4-14 The $I_D$ /Open-ratio versus open-ratio (a) before stress and	
(b) after stress .....	60
Fig. 4-15 (a) $I_D$ /Open-ratio versus open-ratio under 50000 lux illumination	
with different stress times .....	61
Fig. 4-15 (b) Error analysis of SW effect after calibration between the measured	
light intensity and the illuminated light intensity .....	62
Fig. 4-16 (a) Optical stress with different light intensities and (b) $I_D$ /Open-ratio versus	
open-ratio under 50000 lux illumination with different stress times and	
different stress light intensities .....	63
Fig. 4-16 (c) Error analysis of optical stress with different light intensities after	
calibration between the measured light intensity and the illuminated	

light intensity .....	63
Fig. 4-17 (a) The drain current versus illumination intensity curves with different optical stress times by 19160 lux FL and 16673 lux BL at $V_{DS}=10V$ .....	64
Fig. 4-17 (b) Error analysis of optical stress by 19160 lux FL and 16673 lux BL between the measured light intensity and the illuminated intensity .....	64
Fig. 4-18 The position of ambient light sensor in the display .....	65



# Table Lists

## Chapter 2

Tab. 2-1 The comparison of the  $R_{L/D}$  under illumination and in the dark and the current level is shown in its inset among conventional-gate, gap-gate, and dual-gate TFT ..... 15

## Chapter 3

Table 3-1  $I_0(L)$  and  $R_0 = I/A_0(L)$  at  $V_g = -10V$  with the illumination intensity variation ..... 30

Table 3-2  $I_0(L)$  and  $R_0 = I/A_0(L)$  at  $V_g = 10V$  with the illumination intensity variation ..... 30

