行政院國家科學委員會專題研究計畫 成果報告

多晶矽太陽能電池與模組電致發光影像之分析
研究成果報告(精簡版）

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計 畫 主 持 人 ：邱奕契

計畫參與人員：碩士班研究生-兼任助理人員：林子豪

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中 華 民 國 101 年 09 月 25 日

中文摘要： 太陽能電池的瑕疵種類繁多，任何一種瑕疵都有可能降低電池的光電轉換效率。在所有類型瑕疵中，又以出現在電池內部的隱裂最為關鍵。可見光並無法查覺隱藏於電池內部的瑕疵，因此隱裂最不容易被檢查出來。電致發光（Electroluminescence 败 EL）是最常用來檢查太陽能電池模組的技術，然而目前太陽能電池 EL 檢測技術之自動化程度仍低。有鑒於此，本研究採用 EL 技術進行多晶矽太陽能電池（Solar Cell）之檢測，冀望能夠達到自動檢出隱裂的目的。為達成上述目標，本研究首先建構一套能夠讓太陽能電池發光的裝置，其次建構一套能夠捕捉矽晶片所發出之微弱近紅外線光的取像系統，最後研發一套能夠根據 EL 影像亮度差異，自動找出瑕疵的影像分析軟體。

研究結果顯示本研究所規劃之取像系統，能取得清晰的 EL 影像。順利取得 EL 影像後，本研究分兩步驟進行瑕疵的檢測，首先尋找細斷線或粗線缺陷所造成的大面積暗區，其次尋找撞擊後所產生的蜘蛛絲狀小裂紋。結果顯示本研究所規劃之流程可以有效找出玷污、微裂紋、裂痕、斷線等瑕疵，瑕疵偵測率約 90.43%。

中文關鍵詞： 瑕疵檢測、多晶矽太陽能電池、電致發光檢測、EL 檢測

英文摘要： There are various types of solar cell defects. Any defect might lower the efficiency of photoelectron transformation of a solar cell. Among all defects, invisible micro cracks occurring in the interior of solar wafers are most crucial. Since visible light is not capable of detecting interior defects of a solar cell； it is not easy to reveal invisible micro cracks. At present it is most common to detect invisible micro crack of solar cell by using electroluminescence (EL) technique. Accordingly the present research applied EL technique to inspect polycrystalline silicon solar cells.

In view of most commercialized EL systems are still far from automatic, the present research devoted to develop an automatic EL inspection technology. The research contents and steps are as follows. The first step was to construct a device to enable solar cells to irradiate. The second step was to set up an imaging device to capture weak near infrared light irradiated by solar cells. The last step was to develop an image analysis program capable

of automatically detecting different types of defects by using the intensity difference in EL images.
The experimental results show that our imaging system is capable of capturing clear EL images of solar cells. After that, the inspection was carried out in two steps. The first step was to detect large dark areas caused by broken finger or defected bus bar. The second step was to locate spidery crack caused by impact forces. The inspection results show that the proposed inspection flows succeed in discovering various defects including stains, micro cracks, large cracks, broken grid fingers, and defected bus bars. The overall flaw detection rate is about 90.43%.

英文關鍵詞： Electroluminescence, Micro Crack, Solar Cell, Flaw Detection, EL Inspection.

行政院國家科學委員會補助專題研究計畫 ☑成 果 報 告
□期中進度報告

多晶矽太陽能電池與模組電致發光影像之分析

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計畫主持人：邱奕契 教授
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計畫參與人員：林子豪

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中 華 民 國 101 年 08 月 31 日

多晶矽太陽能電池與模組電致發光影像之分析
The Analysis of Electroluminescence Images of Multicrystalline Silicon Solar Cells and Modules

中文摘要

太陽能電池的瑕疵種類繁多，任何一種瑕疵都有可能降低電池的光電轉換效率。在所有類型瑕疵中，又以出現在電池內部的隱裂最為關鍵。可見光並無法查覺隱藏於電池內部的瑕疵，因此隱裂最不容易被檢查出來。電致發光（Electroluminescence • EL）是最常用來檢查太陽能電池模組的技術，然而目前太陽能電池 EL 檢測技術之自動化程度仍低。有鑒於此，本研究採用 EL 技術進行多晶矽太陽能電池（Solar Cell）之檢測，冀望能夠達到自動檢出隱裂的目的。為達成上述目標，本研究首先建構一套能夠讓太陽能電池發光的裝置，其次建構一套能夠捕捉矽晶片所發出之微弱近紅外線光的取像系統，最後研發一套能夠根據 EL 影像亮度差異，自動找出瑕疵的影像分析軟體。

研究結果顯示本研究所規劃之取像系統，能取得清晰的 EL 影像。順利取得 EL 影像後，本研究分兩步驟進行瑕疵的檢測，首先尋找細斷線或粗線缺陷所造成的大面積暗區，其次尋找撞擊後所產生的蜘蛛絲狀小裂紋。結果顯示本研究所規劃之流程可以有效找出玷污、微裂紋、裂痕、斷線等瑕疵，瑕疵偵測率約 90.43%。

關鍵詞：瑕疵檢測、多晶矽太陽能電池、電致發光檢測、EL 檢測

Abstract

There are various types of solar cell defects. Any defect might lower the efficiency of photoelectron transformation of a solar cell. Among all defects, invisible micro cracks occurring in the interior of solar wafers are most crucial. Since visible light is not capable of detecting interior defects of a solar cell; it is not easy to reveal invisible micro cracks. At present it is most common to detect invisible micro crack of solar cell by using electroluminescence (EL) technique. Accordingly the present research applied EL technique to inspect polycrystalline silicon solar cells.

In view of most commercialized EL systems are still far from automatic, the present research devoted to develop an automatic EL inspection technology. The research contents and steps are as follows. The first step was to construct a device to enable solar cells to irradiate. The second step was to set up an imaging device to capture weak near infrared light irradiated by solar cells. The last step was to develop an image analysis program capable of automatically detecting different types of defects by using the intensity difference in EL images.

The experimental results show that our imaging system is capable of capturing clear EL images of solar cells. After that, the inspection was carried out in two steps. The first step was to detect large dark areas caused by broken finger or defected bus bar. The second step was to locate spidery crack caused by impact forces. The inspection results show that the proposed inspection flows succeed in discovering various defects including stains, micro cracks, large cracks, broken grid fingers, and defected bus bars. The overall flaw detection rate is about 90.43%.

Keywords: Electroluminescence, Micro Crack, Solar Cell, Flaw Detection, EL Inspection.

1. 前言

任何物體都會發光，太陽能電池內部的矽晶片也不例外。EL 造影 (Electroluminescence Imaging) 的原理是使用電流讓材料發光，此現象稱為電致發光或電激發光。EL 檢測法就是利用電致發光的原理，將偏壓電流導入太陽能電池提升矽晶片的能階，讓矽材料發出波長介於 800nm 至 1100nm 之微弱近紅外光。利用近紅線攝影機取像即可獲得所謂的 EL 影像。透過影像處理與分析即可判定太陽能電池是否具有瑕疵。當太陽能電池出現局部缺陷時，會影響太陽能電池該部份的發光亮度，因此發光亮度的差異可凸顯瑕疵之所在。一般來說，EL 檢測法主要是根據平均亮度的差異，判斷太陽能電池是否具有破損、漏膠、斷線、裂痕、微隱裂、及污跡等缺陷。圖 1 所示為太陽能電池之 EL

影像及各式瑕疵代表圖。

值得一提的是，儘管 EL 技術可用來檢查太陽光電產品是否有瑕疵，惟多數機台仍處於半自動化階段。更確切的說，目前之 EL 檢測技術並未達全自動化的境界，而是在取得 EL 影像後交由人工進行判讀。為了不被淘汰，諸多廠商正卯足全力積極朝全自動化目標邁進。

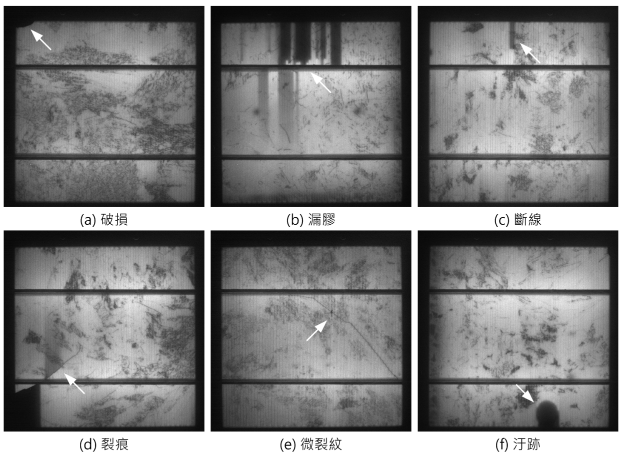

圖 1、太陽能電池 EL 影像所呈現之各式瑕疵代表圖，其中白色箭頭所指處為瑕疵之所在。

2. 研究目的

投入太陽能電池瑕疵檢測研究的學者很多，惟大都是利用可見光進行檢測。可見光檢測法是可以檢測出存在於太陽能電池表面，包括汙跡、斷線、掉削、白點、刮傷、裂痕、及破片等瑕疵。但是對於存在於電池內部的瑕疵，例如隱裂及異物，則因為攝影機看不見而無法將其檢測出來。如前所述，現今之 EL 檢測設備幾乎都仍停留在半自動化的程度。有鑑於此，發展專門用來檢查太陽能電池是否有隱裂或異物之自動化 EL 檢測系統確有其必要性。

3. 文獻探討

在諸多 EL 文獻中，其中以 Takahashi 等人[1]於 2006 所發表的文章最具代表性。該文提出利用 EL 影像對太陽能電池裂痕及缺陷進行隨線檢測的技術。該研究使用能夠偵測到 300-1200 nm 波長光線的 CCD 進行取像，為了避免 CCD 接收到其他來源的光線，取像是在暗室內進行。為了解決 EL 影像內之瑕疵不夠明顯的缺點，Fuyuki 與 Kitiyanan [2]於 2009 年提出對太陽能電池加熱的構想。

在取得 EL 影像後，如何將瑕疵檢測出來是一大挑戰，然而經過詳細的文獻回顧後發現，目前國內學術界及研究機構從事與本研究相關之學者相當少，已發表研究結果者，僅彭成瑜等人[3]。該研究呼籲必須儘速建立缺陷影像與失效關聯之判別法則。陳秋惠與劉定坤提出自動缺陷檢測流程[4]，在取得太陽能電池 EL 影像後，透過框選太陽能電池範圍並計算範圍內整體的亮度值的方式，當整體亮度值低於設定之閥值時，即可判定微光電轉換效率過低。

Insidecrack Inspection System 是國內宏明科技自行開發之系統，可用來檢查太陽能電池晶片及模組是否有裂痕、缺損、及雜質等瑕疵，其解析度為 350 μm/pixel。欽揚科技[5]所開發之 EL-CT01A 內裂檢查機可用來檢查 5~6 吋多晶矽太陽能電池或模組是否具有裂痕、缺損、雜質、擴散深度及接觸或傳導不良區域等缺陷。立曄科技[6]所販售之 EL 檢測機可讓使用者判斷太陽能電池/模組是否具有亮度不足、指狀斷路、暗區、微裂紋等缺陷。

國外相關研究較多[7, 8]。Köntges 等人[9]是以 1376×1040 像素之 CCD 攝影機對由 60 片電池構成之太陽能模組取像，並採用 VIM (Voltage Imaging technique for PV Modules)技術對太陽能模組之 EL 影像進行分析。使用 EL 檢查太陽能電池、陣列、模組、或面板之廠商包括德國 Basler 與 eatEyes、以及日本 NISSHINBO 等。Basler 所開發之 VisionFit Cell inspection 檢測系統可以在 1.0 秒內完成太陽能電池的檢測。檢測之瑕疵類型包括微裂紋與暗區兩種。GreatEyes 所開發之 Lumi Solar Professional System 使用 16 bits，1024×256 之 NIR 攝影機擷取太陽能電池或模組影像，可用來檢查電池或模組是否有微裂紋、異物、分流電阻、網印瑕疵、及錫膏等瑕疵。NISSHINBO 推出一序列 EL 檢測設備，從單一電池的檢測到多個電池所構成的太陽能陣列都能檢測。例如 PVE1200-C 可用來檢測 5 吋及 6 吋多晶矽太陽能電池，最大檢測面積為 220 mm×470 mm，主要是用來檢查微裂紋。PVE1116i-S（圖 2）

可用來檢測 10 × 6 太陽能模組內部之裂痕，檢測速度為 60~70 sec/module，最大檢測面積為 1100 mm × 1650 mm，影像解析度為 1000×1000 pixels。

圖 2、NISSHINBO 公司之 EL 太陽能模組檢測系統。

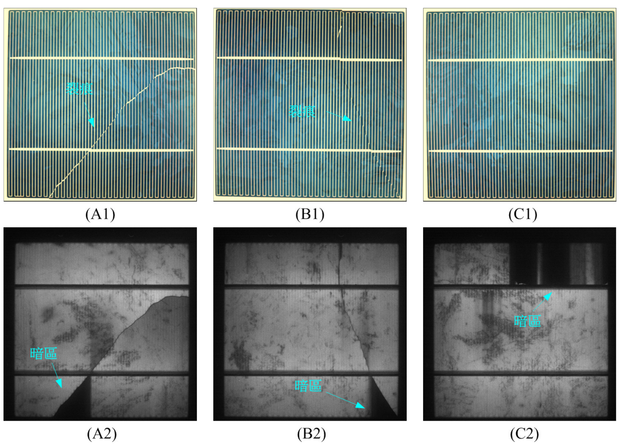

圖 3、多晶矽太陽能電池可見光影像（上圖）與 EL 影像（下圖）的比較。

4. 研究方法與設備

電致發光造影是利用矽基太陽能電池在通以偏壓電流後，會發出波長介於 800nm 至 1100nm 之近紅外線光的特性，搭配波長相近之近紅外線攝影機即可取得 EL 影像。本研究針對太陽能電池及模組進行檢測，目標是要找出具有微裂紋、裂痕、斷線、玷污、及異物等缺陷之太陽能電池/模組。一般來說，EL 檢測技術成功與否取決於：❶是否能讓太陽能電池/模組產生電致發光效應？❷是否能順利取得 EL 影像？❸是否有能力根據 EL 影像之灰階差異，正確找出瑕疵？本研究的主要目標是發展太陽能電池 EL 影像分析演算法。

4.1 檢測方法與原理

EL影像中各像素點的亮度與超額少數載子密度（excess minority carrier density）的總數成正比。當太陽能電池出現缺陷時，少數載子密度會降低，導致瑕疵出現處之亮度相對較暗。舉例來說，當太陽能電池有裂痕時(圖3(A1)及圖3(B1)），電流將無法通過裂痕後面的區域；沒有電流通過的區域就不會有電致發光，因而形成EL影像中的暗區，如圖3(A2)及圖3(B2)所示，此即為EL檢測技術的基本原理。圖3(C2)所示暗區是電極缺陷所造成的，然而從圖3(C1)所示之可見光影像卻是看不出異常，由此可見EL檢測的重要性。

值得一提的是，單晶矽太陽能電池之EL影像相對單純，透過灰階差異就可以很容易地判斷有無瑕疵。然而對多晶矽太陽能電池而言，複雜的晶格背景以及晶格發光不完全等因素，經常導致EL影像內晶格像素的灰階與瑕疵的灰階沒有太大的差異，大大提高EL影像判讀的困難度。有鑑於目前之EL影像分析軟體，其瑕疵之正判率仍不理想，本研究將根據電致發光原理，開發EL影像瑕疵檢測軟體。

4.2 實驗設備

圖 4 所示為本研究建構之 EL 檢測機，主要設備包括導電座、電源供應器、NIR 取像裝置及鏡頭如圖 5 所示。導電座連接至電源供應器的正負極，NIR 取像裝置則連接至電腦主機。

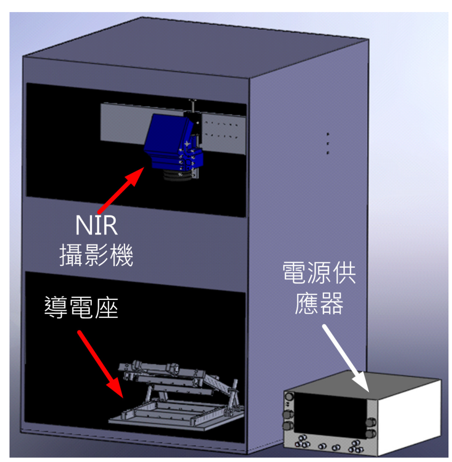

圖 4、太陽能電池 EL 檢測設備示意圖。

圖 5、太陽能電池EL檢測設備各組件之實體圖。

太陽能電池所發出的螢光非常的微弱，任何外來光線的亮度可能就已凌駕電致發光效應所產生的光，導致錯誤的 EL 影像分析結果，因此本研究將整個取像設備及太陽能電池置入暗房，防止外來光線進入。

太陽能電池承載台：承載台上裝設有電源連接機構，將太陽能電池放置其上即可形成電流迴路。電池的電極線連接至電源連接機構的正、負極接點，亦即將直流電源供應器之正極接到太陽能電池的正極（背面的 Bus Bar），負極接到太陽能電池的負極（正面的 Bus Bar），並施以恆定電流。電流導通後電池內部矽晶片之電荷開始移動，當帶負電的電子與帶正電的電洞結合時會發出近紅外線光（800~1100 nm）。

電源供應器：此可調式電源供應器能夠提供 0~15V 之電壓以及 0~12A 之電流給太陽能電池，使太陽能電池發出微弱的螢光。本研究使用之電壓及電流分別為 4.0V 及 6.0A。如果電致發光過於微弱，可提高電流增加太陽能電池的發光強度。但是必須注意電流不可過高，否則可能會燒壞太陽能電池。

NIR 取像裝置：電致發光檢測系統需要一台對 800~1100 nm 波長敏感之高感度 NIR 攝影機。此外必須選擇一個合適的鏡頭，讓置放於承載台上的太陽能電池能夠完全納入攝影機的視野（Field of View，FOV）。再者，由於電子與電洞重組時所發出之近紅外線光相當微弱，因此攝影機之曝光時間必需夠長（1.00 至 10.0 秒為常用值）。本研究採用德國 ProgRes progressive scan，36bit 之 1394 彩色攝影，搭配 Schneider XNP 1.4/17 IR 鏡頭，工作距離約為 392.5 mm，取得之 EL 影像其解析度約為 0.15 mm/pixel。

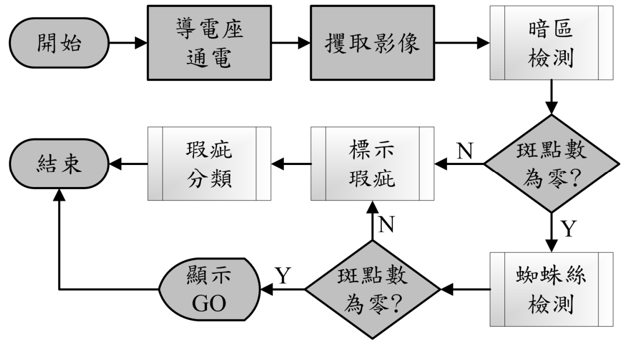

圖 6、太陽能電池 EL 瑕疵偵測流程圖。

4.3 檢測流程

本研究針對多晶矽太陽能電池所發展之 EL 影像瑕疵偵測流程，請參考圖 6 所示之流程圖。檢測的第一步是對太陽能電池通電並擷取其 EL 影像。第二步是進行暗區檢測法，檢查太陽能電池是否有大面積的暗區。檢查是否有暗區的方式是根據暗區檢測法所輸出之斑點數來判斷。斑點數不為零代表有瑕疵，則在螢幕上標示瑕疵的位置並結束本片太陽能電池的檢測，直接進入下一個循環的檢測。反之，斑點數為零代表無暗區瑕疵，則進入蜘蛛絲檢測流程。蜘蛛絲檢測法主要是用來檢查太陽能電池是否有因為外力撞擊所產生之蜘蛛絲狀裂紋。同樣的，是否具有蜘蛛絲狀裂紋，也是根據輸出之斑點數來判斷。斑點數不等於零代表有蜘蛛絲狀裂紋，在螢幕上標示裂紋位置並直接進入下一個循環的檢測；反之，則在螢幕上顯示 GO，代表通過檢測並進入下一個循環的檢測。

4.3.1 暗區檢測方法與流程

針對暗區本研究所規劃之檢測流程如圖 7 所示，以下就流程中各個步驟做說明。

Step 1: 使用 5×5 X 字形中值濾波對圖 8(a)所示之 EL 影像進行濾波，將振幅小於設定值之雜訊移除。

Step 2: 使用 Entropy 二值化將影像中可能之瑕疵分割出來。圖 8(b)所示為中值濾波及 Entropy 影像分割後之結果影像。

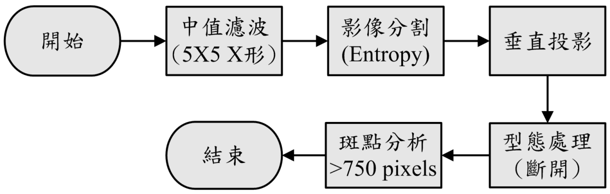

圖 7、暗區檢測流程圖。

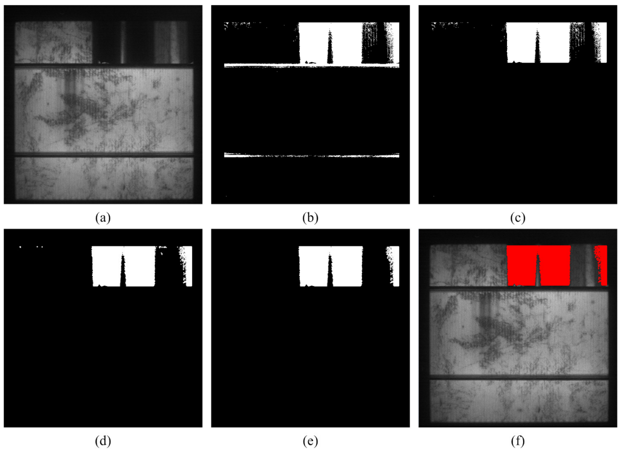

圖8、暗區檢測流程及其結果：(a)具電極線缺陷之原始EL影像；(b)中值濾波及影像分割後之結果影像；(c)去除Busbar後之結果影像；(d)斷開後之結果影像；(e)斑點分析後之結果影像；(f)將暗區以紅色標示在原始影像上之結果影像。

Step 3: 使用垂直投影法找出 Bus Bar 的位置並將其移除，結果如圖 8(c)所示。

Step 4: 使用斷開運算移除小面積的島嶼，結果如圖 8(d)所示。

Step 5: 使用斑點分析法(Blob Analysis)取得影像內之斑點數及面積並將面積小於 750 個像素之斑點移除，結果如圖 8(e)所示，可見小面積之物體已被剃除。

Step 6: 以紅點標示瑕疵，結果如圖 8(f)所示。

4.3.2 蜘蛛絲檢測方法與流程

針對蜘蛛絲所規劃之檢測流程如圖 9 所示，以下依流程之處理程序，逐步說明如下：

Step 1: 由於撞擊點之灰階值較小，本研究採用 Niblack 影像分割法將可能之撞擊點分割出來，結果如圖 10(b)所示。

Step 2: 使用垂直投影找出 Bus Bar 的位置並將其移除，結果如圖 10(c)所示。

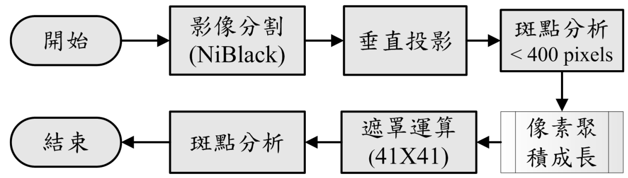

圖9、蜘蛛絲檢測流程圖。

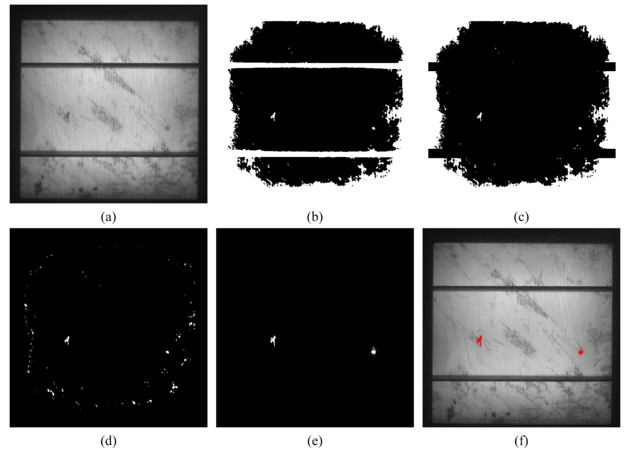

圖 10、蜘蛛絲檢測流程及其結果：(a)具裂痕之原始 EL 影像；(b)中值濾波及影像分割後之影像；(c)去除 Busbar 之影像；(d) 斑點分析後之影像；(e)尋找種子點做為遮罩之中心點，對 41x41 之矩形區域進行二值化處理後之影像；(f)將撞擊點以紅色標示在原始影像上。

Step 3: 使用斑點分析取得影像中之物體數及其面積，並將面積大於 400 像素之斑點移除，處理後之結果如圖 10(d)所示。

Step 4: 利用像素聚積成長法，找出局部灰階較低之種子點。

Step 5: 根據裂紋之特性設計 41×41 之遮罩，讓裂紋由種子點成長出去。

Step 6: 使用斑點分析法取得影像內物體之數目及面積，並將面積小於門檻值之斑點去除，結果如圖10(f)所示。

5. 結果與討論

多晶矽太陽能電池可能出現的瑕疵包括汙跡、裂痕、電極缺陷、破片及微裂紋等。上述瑕疵可分成表面瑕疵及內部瑕疵兩大類。表面瑕疵是指出現在太陽能電池表面之瑕疵，例如汙跡、裂痕、電極缺陷及破片。內部瑕疵是指隱藏於太陽能電池內部之微裂紋及異物。使用

可見光檢測可以有效的偵測出表面瑕疵，但是對於內部瑕疵則無用武之地。雖然本研究是以檢測內部瑕疵為主，惟實驗結果顯示對於裂痕、電極缺陷及破片等表面瑕疵一樣有效。檢測時首先將電流及電壓調至預設值（4V, 6A），接著將太陽能電池放在導電座上。開啟電源將電流導入，電池受激發開始發光，10 秒後即可取得清晰的 EL 影像。將 EL 影像傳送至影像處理電腦進行分析，即可得知電池是否有瑕疵。

本研究共取得 115 張多晶矽太陽能電池影像，其中具有瑕疵之影像有 39 張，無瑕疵影像有 76 張，檢測結果如表 1 所示。由表中可見汙跡、電極缺陷、破片及裂痕都可以正確地被找到。微裂紋影像有 31 張，其中 27 張成功檢出，4 張失敗。造成微裂紋誤判的主因是瑕疵與背景的灰階對比過低，導致程式將其誤判為無瑕疵。無瑕疵影像有 76 張，其中 69 張正確被判定為無瑕疵影像，假警報則有 7 張。誤判的原因是演算法將晶格發光不完全的小暗區也判定為瑕疵。整體而言，本研究之瑕疵檢出率為 90.43%。以下將檢測結果分成表面瑕疵以及內部瑕疵兩部份來說明。

5.1 表面檢測結果

施加電壓與電流激發太陽能電池發出螢光，當瑕疵對電流之流動造成影響時，瑕疵所在位置的發光會較微弱，因而灰階值較低。表面檢測包含汙跡、破片、電極缺陷、及裂痕等。

<u>汙跡</u>：太陽能電池表面具有汙跡時，激發出之螢光會較微弱，使得汙跡所在位置具有較低的灰階值。透過此原理，可以很容易的將汙跡檢測出來，檢測結果如圖 11 所示。

<u>裂痕</u>：此處之裂痕屬於肉眼不易看見的微觀裂痕。裂痕將導致電流無法通過，造成大面積的暗區。慶幸的是，暗區之灰階值比平均灰階值低許多，因此根據灰階差異可以很容易的找出裂痕所在位置。檢測結果如圖 12 所示

<u>電極缺陷</u>：電極為電流流動的主幹道，當電池之電極具有缺陷時，EL 影像會出現大面積的暗區。同樣地，暗區之灰階值較低，因此透過影像亮區與暗區之差異，暗區可以很容易被偵測出來，結果如圖 13 所示

<u>破片</u>：破片係指肉眼可見的巨觀瑕疵，破片會減少太陽能電池發光的面積，影響發電效率。破片一樣會造成大面積之暗區，因此也可以很容易地被檢測出來，檢測結果如圖 14 所示。

表 1 檢測結果

瑕疵類別	汙跡	電極缺陷	破片	裂痕	微裂紋	無瑕疵
影像張數	1	3	2	2	31	76
正確	1	3	2	2	27	69
錯誤	0	0	0	0	4	7

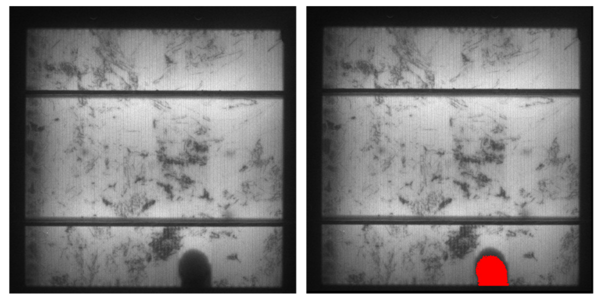

圖 11、汙跡檢測結果：左圖為原始影像；右圖為檢測結果。

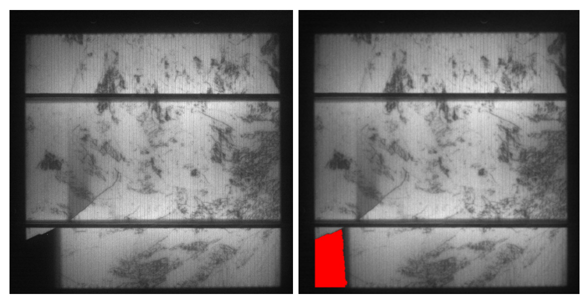

圖 12、裂痕檢測結果：左圖為原始影像，右圖為檢測結果。

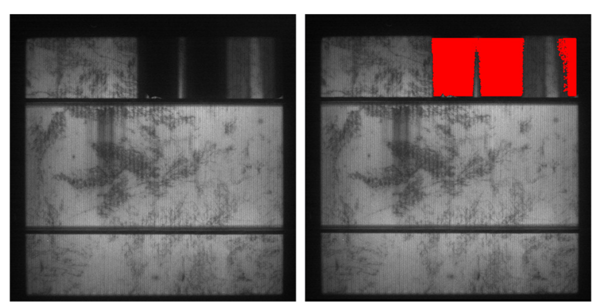

圖 13、電極缺陷檢測結果：左圖為原始影像；右圖為檢測結果。

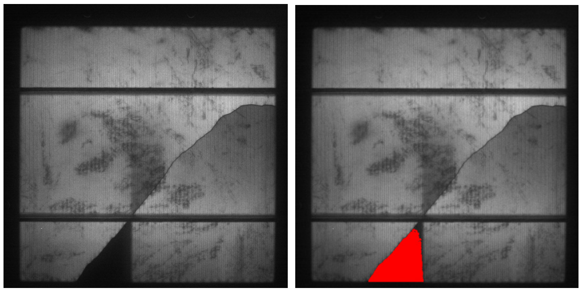

圖 14、破片檢測結果：左圖為原始影像，右圖為檢測結果。

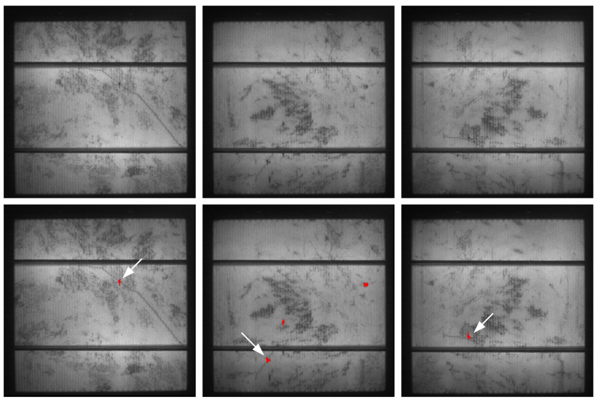

圖15、微裂紋之檢測結果：上圖為原始影像；下圖為檢測結果。

5.2. 內部檢測結果

內部瑕疵是指隱藏於太陽能電池內部的瑕疵，包括隱裂及異物。內部瑕疵從外表是看不見的，使用可見光檢測系統是檢測不出來的，儘管如此，透過本研究所設計之 EL 檢測系統，還是可以順利的將其檢測出來。請參考圖 15，上圖為使用 EL 取像系統擷取所得之影像，下圖為利用蜘蛛絲檢測法檢測之結果，其中紅色標示處代表蜘蛛絲狀裂紋撞擊點所在位置。

5.3 討論

本研究應用電致發光技術設計一套 EL 系統，可針對多晶矽太陽能電池之表面瑕疵及內部的微裂紋進行檢測，由於用可見光系統對檢測內部的微裂紋成效不彰，必須使用電致發光技術激發矽基材料發出微弱螢光搭配近紅線攝影機才能將隱藏於太陽能電池內部之微裂紋檢測出來。本研究使用德國 ProgRes CCD 解析度為 1360×1024 之近紅外線面掃瞄攝影機，搭配 SCHNEIDER 公司所生產的 XNP 1.4/17 定焦鏡頭，視野範圍為 180mm(H)×170mm(V)與影像解析度為 132.4um×166um。在取得瑕疵影像後，如何將瑕疵檢測出來是一大難題，由於多晶矽太陽能電池的晶格會導致材料發光不完全產生許多暗區，大大的增加了檢測上的困難程度。結果證明了本研究設計的電致發光檢測系統，可以正確檢測出電池表面的汙跡、裂痕、電極缺陷、破片與隱藏於內部之微裂紋。

6. 結論與建議

太陽能電池的檢測，從前段 Wafer 的生產與中段太陽能電池製程都極為重要。至於後段模組的檢測更為重要，因為太陽能模組是由多片太陽能電池組裝而成，只要模組內有任何一片太陽能電池具有瑕疵或焊接不良都會導致發電效率的大幅下降。

本研究所建構之 EL 設備是以檢測單片太陽能電池為主，未來可以延伸至模組的檢測。然而欲檢測太陽能模組，以實驗室現有之設備是不足的，除非提升攝影機的解析度以及電源供應器之電壓和電流。此外，鏡頭亦必需更換成廣角鏡頭才能看得到整個太陽能模組。另外值得一提的是，EL 的應用雖然相當廣，卻無法應用在太陽能晶片(Solar Wafer)的檢測上。這是因為 EL 檢測時必需通電，而晶片並無電極。

7. 成果自評

德國 Basler[12]所推出的 VisionFit Cell Inspection 可檢查 5 吋及 6 吋多晶矽太陽能電池是否有微裂紋、裂痕及暗區，曝光時間 0.55~1 秒、影像處理時間 0.8 秒。德國 graphikon[13]所推出之 G/SOLAR ELI 檢測系統，可用來檢測 5 吋及 6 吋的太陽能電池，檢測項目包括電極缺陷、裂痕及肉眼看不見的微裂紋等瑕疵，曝光時間需 1.5 秒。

本研究檢測一片太陽能電池所花的時間也是以 1.8 秒為目標。惟受限於經費，本研究採用的是 1360×1024 解析度之近紅外線攝影機，在性能上不僅對近紅外線光譜的靈敏度較差，曝光時間也需 10 秒才能完成 6 吋多晶矽太陽能電池之檢測。如欲滿足快速檢測的需求，攝影

機必須選擇對近紅外線光譜靈敏度較佳之「高解析度 InGaAs 近紅外線攝影機」，但是一台都需要百萬元，其價格非本研究負擔的起。

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行政院國家科學委員會補助國內專家學者出席國際學術會議報告

101 年　4 月　2 日

附件三

報告人姓名	邱奕契	服務機構及職稱	中華大學/機械工程學系/教授
時間會議地點	March 27~29, 2012; ICMSE 2012; 中國\福建省\廈門市	本會核定補助文號	
會議名稱	(中文) 2012 年製造科學與工程國際學術會議 (英文) The 3rd International Conference on Manufacturing Science and Engineering		
發表論文題目	(中文) (1) 微鑽頭之參數最佳化使用機器視覺技術並結合田口法. (2) 以邊角點偵測法為基之微端銑刀磨耗自動檢測系統 (英文) (1) Parametric Optimization of Micro Drilling using Machine Vision Technique Combined with Taguchi Method. (2) Micro-end-milling Wear Automatic Inspection System Based on Effective Corner Detection Method		

報告內容應包括下列各項：

一、參加會議經過

製造科學與工程國際學術會議（EI indexed）是提供全世界研究製造科學及工程之專家與研究人員發表新技術以及研究成果的主要研討會之一。研究人員也可透過此一機會交換心得或向各領域之專家學者請益。去年之會議（ICMSE'2011）是在吉林舉行，2009 年之會議（ICMSE'2009）是在珠海舉行。本人於台北時間三月二十七日從桃園中正國際機場二航廈出發，不明原因起飛時間延誤了約一個小時，抵達福建廈門時已近午餐時間。會議是在廈門國際會議展覽中心舉行。二十八日之開幕式是在四樓的國際會議廳舉行，之後由大會邀請之兩位 Keynote Speeches 進行專題演說，第一位是 Harbin Institute of Technology 的 Zhou, Yu 教授。第二位是 Beijing University of Aeronautics & Astronautics 的 Zhong, Qunpeng 教授。二十八日的其他時間也是安排 Keynote Speeches。本屆 ICMSE 會議之分組討論集中在二十九日發表，上午分五個場地進行，下午分四個場地進行。

與會心得

1. 製造科學與工程國際學術會議是製造領域中重要會議之一，可惜的是收錄的論文主題相當雜，有些看上去不相干的論文也收錄，實為美中不足之處。
2. 與會專家所提之問題都相當深入，提供之意見也相當值得參考，對後續之研究有相當大的幫助。
3. 由於事先已取得大會議程，對於有興趣之研究及其發表時間及場地可充分掌握，因此可獲益良多。
4. 會中認識許多不同國家的學者，最重要的是這些學者之研究領域相當接近，對往後之學術交流有莫大的幫助。

二、考察參觀活動(無是項活動者省略)

無

三、建議

無

四、攜回資料名稱及內容

1. 大會議程
2. The Proceeding of 2012 International Conference on Manufacturing Science and Engineering

五、其他

無

Xiamen, China

E-mail: mfong@hkitrc.org

6th, February , 2012

Payment Receipt

Paper No: V4241

Paper Title: Micro-end-milling Wear Automatic Inspection System Based on Effective Corner Detection Method

Author: Yu-Teng Liang,Yih-Chih Chiou

Affiliation: Ta Hwa Institute of Technology

The registration fee as below amount has been received by Hong Kong Industrial Technology Research Centre.

Registration fee	**USD 450**

Yours sincerely

Dr. Mark Fong

Secretary, ICMSE2012

Xiamen, China

E-mail: mfong@hkitrc.org

6th, February , 2012

Payment Receipt

Paper No: V4242

Paper Title: Parametric Optimization of Micro Drilling using Machine Vision Technique Combined with Taguchi Method

Author: Yu-Teng Liang,Yih-Chih Chiou

Affiliation: Ta Hwa Institute of Technology

The registration fee as below amount has been received by Hong Kong Industrial Technology Research Centre.

Registration fee	**USD 350**

Yours sincerely

Dr. Mark Fong

Secretary, ICMSE2012

March 24-25 Xiamen, China

Notification of Paper Acceptance

Dear Authors,

The Scientific Committee has completed its review of your paper submitted for the 3rd International Conference on Manufacturing Science and Engineering (ICMSE 2012). The final decision is made base on the peer-review reports, the scientific merits and the relevance.

We are pleased to inform you that your paper as follow has now been accepted by the Scientific Committee of ICMSE 2012 and will be published in international journal "Advanced Materials Research", and will be indexed by EI COMPENDEX,Thomson ISTP and Elsevier SCOPUS.

Manuscript Number	V4241
Authors	Yu-Teng Liang, Yih-Chih Chiou
Title	Micro-end-milling Wear Automatic Inspection System Based on Effective Corner Detection Method

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Micro-end-milling Wear Automatic Inspection System Based on Effective Corner Detection Method

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Keywords: Rhombus Micro-end-mill, Machine Vision, Corner Detection, Taguchi Method, SPC Inspection Technique.

Abstract. The objective of this study is to measure flank wear of dry milling 6061 aluminum alloy of different PVD (Physical Vapour Deposition) multilayer coatings (including TiN, TiCN, and TiAlN) single edge rhombus micro-end-milling tools. All of the experiments were designed using the Taguchi method in order to obtain robust results. In order to realize the level of importance of each machining parameter, the $L_9(3^4)$ orthogonal array, analysis of variance (ANOVA), and signal-to-noise (S/N) ratio were determined. The tool wear images are captured using a machine vision system incorporated with an effective corner detection algorithm. During the milling test, we fixed spindle speed at 6000 rpm and feed rate at 0.0125 mm/rev to investigate the correlation between side clearance angle and coating materials. The experimental results show that TiCN-coating mills generate minimum flank wear and longest tool life.

Introduction

During any automated machining process, the effect of tool wear on machining accuracy is an important factor. In order to ensure the precision of machining over long periods of operation, an online monitoring system is necessary to compensate for any errors due to tool wear. Depending on the purpose of monitoring, tool condition monitoring can be divided into two types, viz. breakage condition monitoring and wear condition monitoring [1-3]. Micro-milling is one of the most widely used material removal processes in the microminiaturization industry. In addition, the micro-end-milling process [4,5] has received increasing attention. The purpose of milling is to achieve excellent shape accuracy and surface quality. This goal is highly dependent on the performance of cutting tools and machining conditions and the stability of the cutting edge will also affect the tool performance and surface finish quality, and ultimately, tool life.

Cutting plays a crucial role in the manufacturing sector. Current research into cutting, such as the optimization method, Taguchi method, or experimental modal analysis, establishes the relationship between the cutting conditions and tool life or cutting force, and uses this as the basis for real-time monitoring processes. In a study to determine optimal cutting parameters, Tsao [6] used the Taguchi method to design quality engineering experiments and explore the effect of different conditions such as coating layers, drilling spindle speed, and feed rate on the drilling force and tool life of *JIS SUS 304* stainless steel drills. Ke et al. [7] used theoretical formulas to calculate the effect of drill geometry, chip shape formation, cut debris patterns, and different cutting conditions on cutting stress, and coupled their theoretical findings with experiments to predict the quality of machining in an attempt to minimize unnecessary tool wear. Peña et al. [8] proposed a monitoring system to understand the relationship between measured cutting force, burr formation, and burr height of drilled aluminum alloy (Al7075-T6). Lee et al. [9] discovered that an increase in burr height correlated with a decrease in tool life. Therefore, characteristics of burr formation were explored to control and optimize parameters that minimize burr formation, thus improving tool life.

The experiment of this research is to monitoring the tool wear of different coated milling based on the Machine vision technology of cutters tool in the milling operation. The tool wear images of the cutters are captured and processed using a machine vision system incorporating with the subpixel edge detection technique, corner detection algorithm and SPC Inspection technique.

Experimental Setup and Method

Taguchi Method. Mills were treated with TiN, TiCN, and TiAlN multi-layer coating surfaces and under dry Milling test. To examine the influences of various control factors on tool wear, a $L_9(3^4)$ orthogonal array as shown in Table 1 was employed.

Table 1. Design parameters and levels in milling process.

Sample	Control Factor	Level 1	Level 2	Level 3
A	Side Clearance Angle	10 º	12 º	14 º
B	Coating Layer	TiN	TiCN	TiA1N
C	Feed Rate [mm/rev]	0.0075	0.0100	0.0125
D	Spindle Speed [rpm]	6000	6500	7000

Tool Wear Monitoring Equipment. Fig. 1 shows the set-up of the experimental hardware. The milling tests were conducted on a LEADWELL V30 vertical machining center. The workpiece is a 6061 aluminum alloy. The experiment used single edge rhombus micro-end-mills of various side clearance angles to mill the workpiece.

(a) (b) (c)

Fig. 1. (a) Experimental setup; (b) Machine vision system; (c) Tool wears phenomena

Corner Detection Method and Procedure. The flowchart for the proposed corner detection algorithm is depicted in Fig. 2 As can be seen, the corner detection procedure consists of six steps.

Capture Tool Image → Image Segmentation → Edge Detection and Sorting → B-spline Smoothing → Curvature Evaluation → Gaussian Filtering → SPC Thresholding → Coordinates of Vertices

Fig. 2. Flow chart of the proposed corner detection method

Automated Feature Detection. To quickly and accurately identify features, we used the essence of statistical process control (SPC), in this case using the threshold value of $\overline{X}$ as the basis to calculate the upper and lower chart control line (UCL, LCL), defined as

Average： $$\overline{X} = \sum_{i=1}^{n} \frac{x_i}{n} . \quad (1)$$

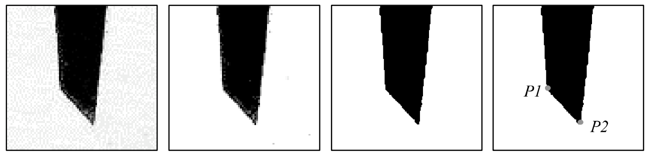
Standard Deviation： $$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}} . \quad (2)$$

Thus:

$$UCL = \overline{X} + 3\sigma . \quad (3)$$

$$LCL = \overline{X} - 3\sigma . \quad (4)$$

Measurement of Mill Wear. Fig. 3 shows the images of tool segmentation before and after the image processing. The original images of micro-end-mills are shown in Fig. 3(a), Fig. 3(b) and (c) show the binarized image and morphological operator image, respectively. Fig. 3(d) shows the detected vertices by referring to the smoothed curvature curve. Thus, after smoothed by Gaussian filter, the vertex detection method performs perfectly.



(a) (b) (c) (d)

Fig. 3. Result of the tool wear analysis

Experimental Results and Discussion

Experimental Analysis Using the Taguchi Method. The experimental results obtained according to the Taguchi method are tabulated in Tables 2 and 3. Table 2 shows the measured wear, both cutting-edge wear and side flank wear, and the calculated S/N ratios. Table 3 shows the response table derived from the nine S/N ratios as shown in Table 2. It is evident that the analysis of Table 3 leads to the determination of an optimum parameter setting $A_1B_2C_3D_1$ causing minimum wear, that is, $A_1B_2C_3D_1$ is the best combination of parameters for achieving the desired cutting performance.

Table 2. The $L_9(3^4)$ Orthogonal table, the measured wears, and the S/N ratio

No	A	B	C	D	Cutting Edge Wear (mm)	Side Flank Wear(mm)	S/N(dB)
1	1	1	1	1	0.195	0.053	16.90
2	1	2	2	2	0.093	0.114	19.66
3	1	3	3	3	0.152	0.123	17.19
4	2	1	2	3	0.106	0.193	16.15
5	2	2	3	1	0.069	0.081	22.47
6	2	3	1	2	0.074	0.252	14.62
7	3	1	3	2	0.156	0.232	14.08
8	3	2	1	3	0.220	0.206	13.42
9	3	3	2	1	0.062	0.286	13.68

Table 3. Signal to noise response of flank wear measurement for micro-end-milling

Control Factor	Level 1	Level 2	Level 3	Max-Min	Ranking
A	17.914	17.749	13.731	4.813	1
B	15.716	18.518	15.164	3.354	2
C	14.983	16.498	17.912	2.929	3
D	17.685	16.120	15.589	2.096	4

To see the effective parameters and their confidence levels on the milling of 6061 Al-alloy, statistical analysis of variance (ANOVA) were performed. The analysis results are shown in Table 4. The four control factors are listed in descending order of importance as follows: side clearance angle, coating layer, feed rate and spindle speed. Their significances are 46.07%, 26.58%, 17.61%, and 9.74%, respectively. It is clear the contribution rate of spindle speed is relatively low.

Table 4. ANOVA statistical test results

Sources of Variation	Degree of Freedom	Sum of Squares	Variance	Significance (%)
A	2	33.682	16.841	46.07
B	2	19.429	9.715	26.58
C	2	12.872	6.436	17.61
D	2	7.122	3.561	9.74
Total	8			100

Confirmation Experiment. the predicted mean of the quality characteristic (flank wear η) has been predicted as:

$$\eta = \overline{A}_2 + \overline{B}_2 + \overline{C}_3 + \overline{D}_1 - 3\overline{T} = (17.749) + (18.518) + (17.912) + (17.685) - 3(16.460) = 22.48 \text{ (db)}. \quad (5)$$

Thus a 95% confidence interval (CI) for the predicted mean of optimum quality characteristic on a confirmation test is estimated using the following two equations:

$$\mathrm{CI} = \sqrt{\mathrm{F}(\alpha, 1, \mathrm{f}_e)\,\mathrm{V}_e\left[\frac{1}{\mathrm{N}_{\mathrm{eff}}} + \frac{1}{\mathrm{R}}\right]}\,. \quad (6)$$

These results are shown in Table 5 and it is observed that the S/N ratios obtained from the confirmation experiments is 22.39, which falls within the predicted 95% confidence interval; these results were within the CI of the predicted optimal values of the cutting tool characteristics.

Table 5. Results of the confirmation experiments for tool wear

Optimal control parameters	Prediction	Experimental
Recommend level	$A_1B_2C_3D_1$	$A_1B_2C_3D_1$
S/N ratio for tool wear (db)	22.48	22.39
95% confidence interval of predicted range of optimum tool wear		

Conclusions

The experiments were to mill 6061 Al-alloy using micro-end-mills. The results could be useful in selecting a suitable combination of parameters for dry milling 6061 Al-alloy by using micro-end-mills and are summarized as follows:

1. The tool wear can be on-line measurements of machine vision inspection technique incorporating with corner detection algorithm and SPC Inspection technique.
2. The effect of edge detector and smoothing on the performance of the extract vertex algorithm has been explored in detail.
3. The best combination of the four control factors is $A_1B_2C_3D_1$. In other words, the optimum parameters for dry milling 6061 Al-alloy are 10 degrees side clearance angle, TiCN coating, 0.0125 mm/rev feed rate, and 6000 rpm spindle speed.

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Parametric Optimization of Micro Drilling using Machine Vision Technique Combined with Taguchi Method

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Keywords: Micro Drill, PMMA Polymer, Machine Vision, Taguchi Method, Flank Wear.

Abstract. The objective of this study is to optimize the micro drilling of PMMA (Polymethyl methacrylate) polymer with multiple performance characteristics. In Taguchi method, a three level orthogonal array has been used to determine the S/N ratio. Analysis of variance was used to determine the most significant process parameters affecting the holes roughness. Coated deposition, spindle speed and feed rate are optimized drilling parameters when the performance characteristics, which include tool life and surface roughness, are taken into consideration. The results indicated that the TiAlN-coating drills generate least wear and best holes quality. Finally, confirmation experiments were conducted to confirm the validity of the results.

Introduction

Machining is an important process in mechanical manufacturing. Conventionally, drilling constitutes about 40% of all material removal processes [1], and is one of the most often used methods in machining. The purpose of machining is to achieve excellent shape accuracy and surface quality. This goal is highly dependent on the performance of cutting tools and machining conditions (i.e. variations in surface coatings, feed rate, and spindle speed), and the stability of the cutting edge will also affect the tool performance and surface finish quality, and ultimately, tool life. Various real-time inspection techniques have been developed to monitor and measure tool wear indeed. In general, these techniques can be broadly categorized as either direct or indirect measurement. As the name suggest, direct measurement techniques measure the size of the tool wear directly by using microscopes, tactile sensors, or machine vision techniques [2-4].

Dry cutting [5-7] is a processing method that does not require the use of cutting fluids. It is a common opinion among machine engineers that the addition of cutting fluid during cutting will increase tool life. However, the intermittent addition of cutting fluid results in uneven cooling of the tool, exposing the cutting tool to various extents of cooling and heating, which results in cracking and ultimately breakage. This ultimately reduces tool life. Variations in processing methods have generated different demands on the design of cutting tools. Indeed, the presence of a coating has a cooling effect on the cutting tool, as isolates the tool from any heat generated during cutting. As a result, tool sharpness and hardness can be maintained for an extended period of time.

In this study, the Taguchi method [8] was used to analyze the effect of spindle speed, feed rate, cutting depth, and other factors of various coated cutting tools on flank wear, which is indicated by the anti-wear ability of the cutting tool. The results obtained will be used to determine a set of parameters that presents the minimum amount of flank wear, and to provide reference data for industry. Tool wear detection is achieved by first capturing images of the various coated drill, then comparing and analyzing the images of drill flanks before and after cutting using machine vision technology. Coupling analyzed images with cutting conditions, the life-span and extent of tool wear of each cutting tool is predicted. Furthermore, analyses were conducted on the signal-to-noise ratio (S/N ratio) and response charts for cross-comparison.

Experimental Setup and Method

Experimental Equipment. This study will be conducted at the LEADWELL V-30 machining center, using disposable coated micro drill (ϕ 0.3 mm) to through holes on PMMA workpieces with thicknesses of 1.0, 2.0, or 3.0 mm. The experiment is designed using the Taguchi orthogonal array to reduce time and the number of processing steps. Tool wear monitoring and measurements will be analyzed using image analysis.

Drilling Experiments. Micro drills were treated with TiN, TiCN, and TiAlN multi-layer coating surfaces and the spindle speeds used in the experiment were (1) 6000rpm, (2) 6500rpm, and (3) 7000rpm. Feed rates were (1) 0.0075mm/rev, (2) 0.0100mm / rev, and (3) 0.0125 mm / rev under dry drilling test conditions, In the study, a $L_9(3^4)$ orthogonal array was selected to check the influences of the four control factors, the four control factors with three levels each are shown in Table 1.

Table 1. Experimental control factor and factor levels

Levels of Experimental Factors	Experimental Control Factors			
	Coating Layer	Feed Rate [mm/rev]	Spindle Speed [rpm]	Depth of Cut [mm]
1	TiN	0.0075	6000	1.0
2	TiCN	0.0100	6500	2.0
3	TiA1N	0.0125	7000	3.0

Drill Wear Measuring Using Machine Vision. Utilizing the CNC machining center drilling machine for testing, the drill head of each tool was coded to move to a predetermined position, where a ring light source turns on and a CCD camera captures an image of the drill flank. This was conducted at regular intervals after a fixed number of processes. In conventional drilling, tool wear usually begins at the tangent-plane of the drill bit after successive holes drillings. This study aims to measure the tool wear of the drill tip, which is defined by the distance between the two furthest points of a drill flank image, as shown in Fig. 1.

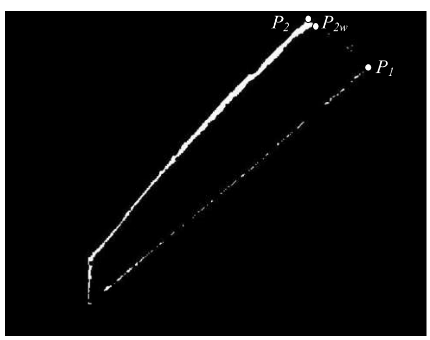

Fig. 1. Actual positions of edge features

The coordinates of the above-mentioned feature points can be obtained from Fig. 1 as $p_1\,(x_1, y_1)$, $p_{2w}\,(x_3, y_3)$, and can be used to calculate the geometry of the edge of the drill flank. Comparing this with the same feature points of a pristine drill bit $p_1\,(x_1, y_1)$, $p_2\,(x_2, y_2)$ and performing a calculation using W_{fo} as the maximum amount of wear, the maximum wear of the drill flank (W_f) is defined as:

$$
\begin{aligned}
W_f &= W_{fo} - W_{fn} \\
&= \sqrt{(x_2-x_1)^2+(y_2-y_1)^2} - \sqrt{(x_3-x_1)^2+(y_3-y_1)^2} \, .
\end{aligned}
\tag{1}
$$

Where W_{fo} is the edge dimension of the pristine drill and W_{fn} is the edge dimension of the drill after successive hole drilling.

Experimental Results and Discussion

Analysis of Dry Machining Technology. More than a decade has passed since the advent of dry machining technology. This technology is considered a new green manufacturing technology; when compared with wet machining, it not only has improved production efficiency and reduced production costs but it is also conducive to environmental protection. Accordingly, this is an ideal and clean machining method. The energy saving, environmentally friendly, and low cost aspects of dry machining are particularly significant considering the increasing demand towards environmentally friendly manufacturing processes in the 21st century. Coating treatments of cutting tools exhibit similar properties to cooling fluids and can behave as both a protective layer and as a thermal isolation barrier to prevent heat transfer to the tool itself. As a result, the cutting tool can maintain its hardness and sharpness over an extended period of time. In the realm of dry machining technology, tool coating technologies have significant impact on the life of cutting tools.

Experimental Analysis Using the Taguchi Method. The experimental results according to Taguchi method are shown in Table 2. Before proceeding to the grey relational analysis, the experimental results were normalized. Table 2 shows the grey relational coefficient and the grey relational grade for each drilling experiment. In general, a large value of relational coefficient corresponds to a better experimental result. In other words, the higher the relational coefficient, the closer the experimental result to the ideal normalized value. The performance ranking of the nine drilling tests are shown in Table 2. Derive from the nature of the orthogonal array; the effect of each control factor on the grey relational grade at each level can easily be separated. Table 3 show the response table of relational coefficient for each control factor at each level. As can be seem, A_3, B_1, C_3, D_2 are the control factor levels that will provide the highest predicted S/N ratio.

Table 2. Experimental results of flank wear and surface roughness

No.	A	B	C	D	Flank wear (mm)			Surface roughness (μm)			Grey Relational Coefficient [ξ]		Grey Relational Grade [γ]	Rank
					Test 1	Test 2	mean	Test 1	Test 2	mean	Flank wear	Surface roughness		
1	1	1	1	1	0.045	0.038	0.0415	0.952	0.914	0.933	0.492	0.480	0.486	6
2	1	2	2	2	0.035	0.038	0.0365	0.881	0.835	0.858	0.585	0.584	0.585	3
3	1	3	3	3	0.042	0.047	0.0445	0.860	0.912	0.886	0.449	0.541	0.495	5
4	2	1	2	3	0.065	0.048	0.0565	0.853	0.848	0.851	0.333	0.597	0.465	7
5	2	2	3	1	0.048	0.056	0.0520	1.053	1.180	1.117	0.373	0.333	0.353	9
6	2	3	1	2	0.037	0.030	0.0335	1.027	0.987	1.007	0.660	0.377	0.519	4
7	3	1	3	2	0.020	0.015	0.0175	0.706	0.724	0.715	0.843	1.000	0.922	1
8	3	2	1	3	0.041	0.045	0.0430	1.054	1.035	1.045	0.477	0.379	0.428	8
9	3	3	2	1	0.023	0.029	0.0260	0.989	1.163	1.076	1.000	0.358	0.679	2

Table 3. Response of flank wear measurement for micro dilling

Control Factor	Level 1	Level 2	Level 3	max–min	Rank
A	0.522	0.446	0.676	0.230	1
B	0.624	0.455	0.564	0.169	2
C	0.478	0.576	0.590	0.112	4
D	0.536	0.655	0.513	0.142	3

The purpose of the ANOVA is to realize the influences of each control factors on drilling performance. As can be seen from the analysis results shown in Table 4, control factor A has the greatest effect on tool life and surface finish. The four control factors in descending order of significance are coating layer, feed rate, depth of cut, and spindle speed.

Table 4. ANOVA Statistical Test Results

Control Factor	Degrees of Freedom	Sum of Squares	Variance	Significance (%)
A	2	0.0275	0.0138	44.81
B	2	0.0148	0.0074	24.03
C	2	0.0075	0.0038	12.34
D	2	0.0116	0.0058	18.83
Total	8			100

Confirmation Experiment. The last step of the grey-Taguchi method is to verify the improvement of the performance characteristic using the optimal levels of parameters that were derived in the last step. The predicted relational coefficient and the optimal parameter setting are shown in Table 5. It is evident that the confirmation experiment did yield the highest relational coefficient.

Table 5. Process performance at the optimal parameter levels

Coating Layer	Feed Rate (mm/rev)	Spindle Speed (rpm)	Depth of Cut (mm)	Flank Wear (mm)	Surface Roughness (μm)	GRG
TiAlN	0.0750	25000	2	0.0192	0.834	0.922

Conclusions

The present study deals with the application of the machine vision Technique Combined with Taguchi method to the optimization of micro drilling parameters, using flank wear as the performance metric. An optimal combination of drilling parameters can minimize tool wear. A confirmation experiment, which adopted the optimal levels of drilling process parameters, was carried out to verify the effectiveness of the Taguchi method. The experimental results indicate that the Taguchi method is quite suitable for investigating the complex interrelationship among various parameters in drilling. The experimental results indicate that the Grey-Taguchi method is quite suitable for investigating the complex interrelationship among various parameters in drilling PMMA.

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Parametric Optimization of Micro Drilling Using Machine Vision Technique Combined with Taguchi Method
10.4028/www.scientific.net/AMR.468-471.2487

國科會補助計畫衍生研發成果推廣資料表

日期:2012/08/30

國科會補助計畫	計畫名稱: 多晶矽太陽能電池與模組電致發光影像之分析
	計畫主持人: 邱奕契
	計畫編號: 100-2221-E-216-003- 學門領域: 自動化檢測技術

無研發成果推廣資料

100 年度專題研究計畫研究成果彙整表

<table>
<tr><td colspan="3">計畫主持人：邱奕契</td><td colspan="5">計畫編號：100-2221-E-216-003-</td></tr>
<tr><td colspan="8">計畫名稱：多晶矽太陽能電池與模組電致發光影像之分析</td></tr>
<tr><td colspan="3" rowspan="2">成果項目</td><td colspan="3">量化</td><td rowspan="2">單位</td><td rowspan="2">備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等）</td></tr>
<tr><td>實際已達成數（被接受或已發表）</td><td>預期總達成數(含實際已達成數)</td><td>本計畫實際貢獻百分比</td></tr>
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<tr><td>研究報告/技術報告</td><td>0</td><td>0</td><td>100%</td><td></td></tr>
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<tr><td>博士生</td><td>0</td><td>0</td><td>100%</td><td></td></tr>
<tr><td>博士後研究員</td><td>0</td><td>0</td><td>100%</td><td></td></tr>
<tr><td>專任助理</td><td>0</td><td>0</td><td>100%</td><td></td></tr>
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</table>

其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)	無

	成果項目	量化	名稱或內容性質簡述
科教處計畫加填項目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

■達成目標

□未達成目標（請說明，以 100 字為限）

□實驗失敗

□因故實驗中斷

□其他原因

說明：

2. 研究成果在學術期刊發表或申請專利等情形：

論文：□已發表 □未發表之文稿 ■撰寫中 □無

專利：□已獲得 □申請中 ■無

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其他：（以 100 字為限）

無

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

太陽能電池的檢測，從前段 Wafer 的生產與中段太陽能電池製程都極為重要。至於後段模組的檢測更為重要，因為太陽能模組是由多片太陽能電池組裝而成，只要模組內有任何一片太陽能電池具有瑕疵或焊接不良都會導致發電效率的大幅下降。研究結果顯示本研究所規劃之取像系統，能取得清晰的 EL 影像，所規劃之流程可以有效找出玷污、微裂紋、裂痕、斷線等瑕疵，瑕疵偵測率約 90.43%。

本研究所建構之 EL 設備是以檢測單片太陽能電池為主，未來可以延伸至模組的檢測。然而欲檢測太陽能模組，以實驗室現有之設備是不足的，除非提升攝影機的解析度以及電源供應器之電壓和電流。此外，鏡頭亦必需更換成廣角鏡頭才能看得到整個太陽能模組。另外值得一提的是，EL 的應用雖然相當廣，卻無法應用在太陽能晶片(Solar Wafer)的檢測上。這是因為 EL 檢測時必需通電，而晶片並無電極。

德國 Basler[12]所推出的 VisionFit Cell Inspection 可檢查 5 吋及 6 吋多晶矽太陽能電池是否有微裂紋、裂痕及暗區，曝光時間 0.55~1 秒、影像處理時間 0.8 秒。德國 graphikon[13]所推出之 G/SOLAR ELI 檢測系統，可用來檢測 5 吋及 6 吋的太陽能電池，檢測項目包括電極缺陷、裂痕及肉眼看不見的微裂紋等瑕疵，曝光時間需 1.5 秒。本研究檢測一片太陽能電池所花的時間也是以 1.8 秒為目標。惟受限於經費，本研究採用的是 1360×1024 解析度之近紅外線攝影機，在性能上不僅對近紅外線光譜的靈敏度較差，曝光時間也需 10 秒才能完成 6 吋多晶矽太陽能電池之檢測。如欲滿足快速檢測的需求，攝影

機必須選擇對近紅外線光譜靈敏度較佳之「高解析度 InGaAs 近紅外線攝影機」，但是一台都需要百萬元，其價格非本研究負擔的起。