UNIVERSITI TEKNIKAL MALAYSIA MELAKA

N-TYPE PHOTOVOLTAIC CELL RE-CLAIM QUALIFICATION USING CLEANING PROCESS

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MASTER OF MANUFACTURING ENGINEERING
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Faculty of Manufacturing Engineering

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A thesis submitted
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DECLARATION

I declare that this Choose an item. entitled " N-TYPE PHOTOVOLTAIC CELL RE-CLAIM QUALIFICATION USING CLEANING PROCESS" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : ROSLINA AIDA BINTI RAHIMI

Date : ....

APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science in Maufacturing Engineering.

Signature : ....

Supervisor Name : TS DR SAIFUDIN HAFIZ BIN YAHAYA

....

Date : ....

DEDICATION

This thesis dedicated first and foremost to myself. I never expected , in a million years that i would able to write this and come to this journey. I also dedicate this to my lovely daughter Arissa Hannah who are being patience when mama is not around. Thank you darling for your love , kindness and support. And finally , thank you to my parents and siblings who always there whenever i need help and support during my journey in completing this project.

ABSTRACT

Yield loss reduction is one of the continuous actions applied in the manufacturing industry to minimize overall operational costs. This study will focus on improving top defects from the diffusion process in the solar industry. In the diffusion process, scratches on the wafer surface are one of the top Pareto for scrap. One of the opportunities to improve the scrap is the cleaning and removing the diffusion layer back to its original condition before the diffusion process. The objective of the study is to study the cleaning recipe for removing the diffusion layer. Selected recipes will be qualified using reliability testing to ensure no additional impact on the product quality. The qualified cleaning recipe and the process will be validated and compared with the standard production wafer in terms of photovoltaic cell Power Conversion Efficiency, Electrical and Cosmetic Yield performance. This study uses the closed interval method in selecting the HFO_3 parameter range for the cleaning recipe and qualified using Autoclave HAST chamber (ACL) and Reverse Biased Test Dielectric (RBTDE) reliability testing to confirm the product performance is fulfilling the standard specification. The statistical analysis in this study uses JMP software and analysis conducted using t-Test, Wilcoxon Test and Mosaic Plot distribution to ensure the rework wafer quality and performance comparable with the existing production wafer. The selected cleaning recipe observed that the combination parameter of 250ml HFO_3 volume dosing and temperature of 70^{o}C HFO_3 bath showed the closest value to the existing product, which is control data. The Reliability testing result of the selected cleaning recipe passed and qualified under RBTDE and ACL tests which showed a probability value of 0.6494 for 0 hour, 0.4695 for 120hour and 0.6150, respectively, defined as an insignificant difference from the control product data. A higher volume run of the selected cleaning recipe was validated as well, which resulted better mean value at 22.94% for Power Conversion Efficiency and a higher Bin A percentage for Cosmetic Yield with a p-value of <0.0001 while the insignificant difference of Electrical Yield probability value of 0.8177 from control data. The implementation of the cleaning recipe for the diffusion layer rework process can improve the yield loss and, at the same time, benefit the industry due to the lower operational cost from the scrap reduction.

ABSTRAK

Pengurangan kehilangan hasil adalah salah satu tindakan berterusan yang digunakan dalam industri pembuatan untuk meminimumkan kos operasi keseluruhan. Kajian ini akan memberi tumpuan kepada menambah baik kecacatan teratas daripada proses resapan dalam industri suria. Dalam proses resapan, calar pada permukaan sel solar adalah salah satu pareto teratas untuk sekerap. Salah satu peluang untuk menambah baik sekerap ialah membersihkan dan mengeluarkan lapisan resapan kembali kepada keadaan asal sebelum proses resapan. Objektif kajian adalah untuk mengkaji resipi pembersihan untuk menghilangkan lapisan resapan. Resipi terpilih akan layak menggunakan ujian kebolehpercayaan untuk memastikan tiada kesan tambahan terhadap kualiti produk. Resipi pembersihan yang layak dan prosesnya akan disahkan dan dibandingkan dengan sel pengeluaran standard dari segi Kecekapan Penukaran Kuasa sel fotovoltaik, prestasi Hasil Elektrik dan Kosmetik. Kajian ini menggunakan kaedah selang tertutup dalam memilih julat parameter HFO_3 untuk resipi pembersihan dan menggunakan ujian kebolehpercayaan Autoklaf kebuk HAST dan Dielektrik Ujian Pincag Songsang untuk mengesahkan prestasi produk menepati spesifikasi standard. Analisis statistik dalam kajian ini menggunakan perisian JMP dan analisis yang dijalankan menggunakan ujian-t, ujian Wilcoxon dan taburan taburan Mosaic untuk memastikan kualiti dan prestasi sel solar kerja semula setanding dengan sel solar pengeluaran sedia ada. Resipi pembersihan yang dipilih mendapati bahawa parameter gabungan dos HFO_3 250ml dan suhu HFO_3 70^{o}C menunjukkan nilai yang paling hampir dengan produk sedia ada, iaitu data kawalan. Keputusan ujian Kebolehpercayaan resipi pembersihan terpilih lulus dan layak di bawah ujian RBTDE dan ACL yang menunjukkan nilai kebarangkalian 0.6494 untuk 0 jam, 0.4695 untuk 120 jam dan 0.6150, masing-masing, ditakrifkan sebagai perbezaan yang tidak ketara daripada data produk kawalan. Jumlah kuantiti yang lebih tinggi bagi resipi pembersihan terpilih telah disahkan juga, yang menghasilkan nilai min yang lebih baik pada 22.94% untuk Kecekapan Penukaran Kuasa dan peratusan Bin A yang lebih tinggi untuk Hasil Kosmetik dengan nilai p <0.0001 manakala perbezaan Hasil Elektrik yang tidak ketara nilai kebarangkalian 0.8177 daripada data kawalan. Pelaksanaan resipi pembersihan untuk proses kerja semula lapisan resapan boleh meningkatkan kehilangan hasil dan, pada masa yang sama, memberi manfaat kepada industri kerana kos operasi yang lebih rendah daripada pengurangan kecacatan produk.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

ACL	-	Autoclave
APCVD	-	Atmospheric pressure chemical vapor deposition
BRL	-	Boron Rich Layer
BSG	-	Borosilicate Glass
BSoD	-	Boron Spin-on Dopant
CDA	-	Clean Dry Air
CPV	-	Concentrating Photovoltaic
c-Si	-	Crystalline Silicon
CSP	-	Concentrated Solar Power
CTEG	-	Concentrator Thermoelectric Generator
CVD	-	Chemical Vapor Deposition
DI	-	Deionized
DSSC	-	Dye Sensitized Solar Cell
EL	-	Electroluminescence
HAST	-	High Accelerated Stress Test System
HCL	-	Hydrochloric Acid
HCPV	-	High Concentration Photovoltaics
HF	-	Hydrogen Fluoride
HFO_3	-	Fluoric acid
HNO_3	-	Nitric Acid
IBC	-	Interdigitated Back Contact
IR	-	Infrared
KOH	-	Potassium Hydroxide
LCPVs	-	Low Concentrator Photovoltaics
$NaNO_2$	-	Sodium Nitrite
PCT	-	Pressure Cooker Test
PECVD	-	Plasma Enhanced Chemical Vapor Deposition
poly c-Si	-	polycrystalline

PSG	-	Phosphorus Silicate Glass
PV	-	PV
PN		P-type - N-type
RBTDE	-	Reverse Biased Test Dielectric
SEM	-	Scanning Electron Microscopy
SiH_4	-	Silane
SiNx	-	Silicon Nitride
SiO_2	-	Silicon Oxide
SiOx	-	Amorphous Silicon Oxide
USPCT	-	Unsaturated Pressure Cooker Test

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

There is always demand for cost reduction in the manufacturing industry in order for a company to sustain or stay relevant in the industry. Cost reduction can be in terms of labour utilization, switching to alternative material with a cheaper cost, or it can be from scrap yield loss reduction. This study will focus on scrap yield loss reduction and identify rework methods using cleaning machines to improve the yield loss.

The rework process is standard in the industry to reduce yield loss costs to the company. There is numerous method of rework applied in the industry. However, it is crucial to ensure the rework process does not jeopardize the quality of the product. This study will utilize a cleaning machine of N-type silicon photovoltaic technology for rework flow with reliability testing and experiment validation to ensure no additional impact on the quality of the product.

Photovoltaics (PV) is one of the most rapidly growing energy generation options in the modern energy sector. Because of favourable energy policies, PV is one of the primary renewable energy sources being adopted globally to reduce greenhouse gas emissions in the energy sector. Moreover, its unique selling point of scalability and adaptability to any regional condition contributes to its rapid dissemination and successful implementation in various global regions (Kumar et al., 2020). Photovoltaics (PV) generates electricity that utilizes semiconductors that exhibit the photovoltaic effect to convert solar radiation to direct current electricity. Photovoltaic energy generation utilizes solar panels comprised of several photovoltaic solar cells. These cells are assembled into solar panels as part of a photovoltaic system to generate solar power from sunlight. (Kurtz, 2012).

N-type silicon has more electrons than silicon, including phosphorus (making it negatively charged). In contrast, P-type silicon has fewer electrons than silicon and uses boron (making it positively charged cells). For crystalline silicon photovoltaics, the most efficient modules are produced from N-type silicon wafers. This is because N-type silicon seems to have a much higher tolerance for defects than P-type silicon (Macdonald, 2012).

In crystalline silicon photovoltaics, a WET cleaning machine is one of the critical processes that can perform silicon thickness etching and clean the wafer from contamination that adheres to the surface cell. Wafer cleanliness is essential for preparing the wafer before loading downstream or the next process step. On the other hand, a bad cleanliness wafer may cause other quality issues such as bad deposition and printing issues that will lead to electrical junction issues and rejection in the cell tester process. Reject wafers can be considered a loss to the company, and engineers are working hard to ensure fewer rejects or scrap for better yield performance.

1.2 Problem Statement

In the manufacturing industry, scrap is usually generated from a failure in a process. Therefore, an industry maker needs to work towards scrap reduction as it will directly impact the overall operational cost. Scrap somehow can either be discarded, recycle or reworked to salvage it. In photovoltaic wafer manufacturing, one of the biggest scrap issues happens in the boron diffusion process due to operator manual handling. Manual handling is usually because of automation failure that requires manual collection of the wafer in the reject bin. Those defect wafers must be scrapped and thrown away as the handling causes scratches on the diffusion layer that will be captured as electrical shunt loss at the end of the line cell tester.

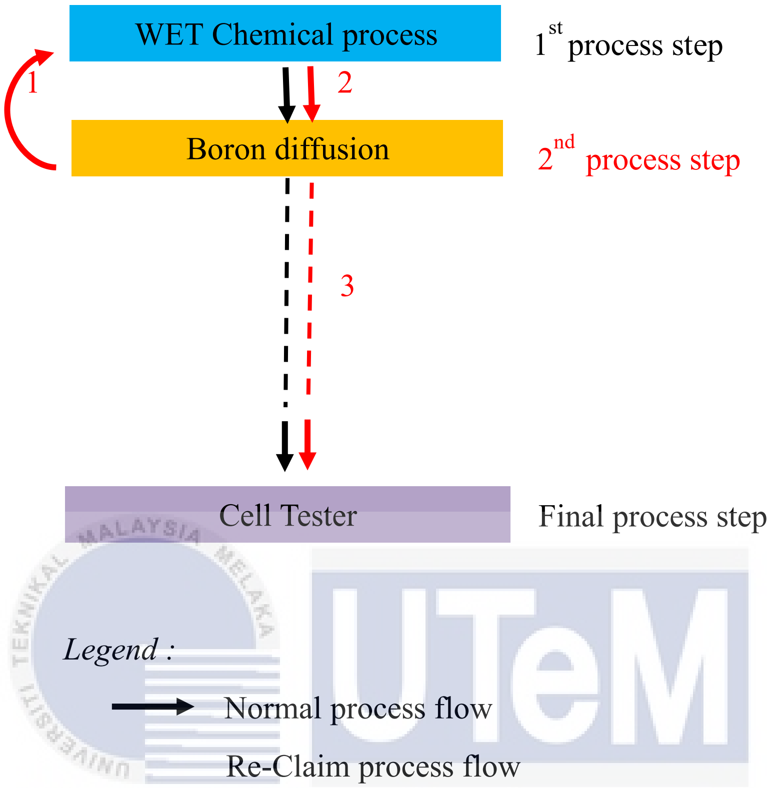

Figure 1.1: Silicon Cell Processing – Normal and Re-Claim Flow (Neuhaus and Münzer, 2007)

There is an opportunity to rework or salvage the scrap wafer if the diffusion layer can be entirely removed and cleaned like the original bare silicon wafer. One of the methods that can perform the boron diffusion removal is the WET chemical process. For this rework process flow, the re-claim will require the wafer for the second run in WET Chemical (cleaning module) to remove the diffusion layer. In this study, developing the cleaning recipe is critical to ensure the cleaning module can remove the diffusion layer and the re-claim flow illustrated in Figure 1.1.

The selected recipe will be verified through reliability testing to ensure the recipe will not impact the product quality. At the same time, monitoring of the N-type silicon thickness is also needed after the re-claim process to ensure no reduced thickness of the silicon layer. Validation of the actual performance of the cleaning recipe will be needed, and the result should be analyzed. It will not cause issues regarding Power Conversion Efficiency, Electrical Yield, and Cosmetic Yield. This study's success will help improve the operational cost as no more wafers will be thrown away and scraped if the defective wafer undergoes the re-claim cleaning process.

1.3 Objectives of the Study

The research objectives for this are such as :

a) To study the cleaning recipe in removing diffusion layer using HFO_3 parameter of chemical dosing volume and bath temperature range.

b) To qualify the cleaning recipe using Reverse Biased Test Dielectric (RBTDE) and Autoclave HAST chamber (ACL) Test for Reliability Testing.

c) To validate experimantal run data of Power Conversion Efficiency (EFF), Electrical Yield and Cosmetic Yield performance of the selected cleaning recipe using JMP Statistical Analysis software.

1.4 Scope of Study

The scope of this research is only suitable for improving defects with scratches in the diffusion process. To remove the diffusion layer, the rework flow will utilize a cleaning module in N-type photovoltaic cell manufacturing. The selected cleaning recipe will be qualified using reliability testing to ensure no other product quality. The wafer that has undergone a cleaning process will be validated from the experimental run and analyzed using JMP software to confirm that this change will cause no impact on the product cell Power Conversion Efficiency, Electrical Yield, and Cosmetic Yield.

1.5 Contribution of Research

Contributions of this thesis are made in the following related areas as the cleaning recipe study will be conducted on $HF0_3$ parameter chemical dosing volume and bath temperature range. The selected recipe will be chosen based on higher effectiveness in removing the diffusion layer. This study approach to the cleaning parameter will develop a cleaning recipe that can remove the damaged diffusion layer defect, thus improving product yield loss.

Verifying the cleaning recipe through reliability testing will ensure that the recipe will not cause product performance degradation. The passing reliability test will ensure that the cleaning recipe will not impact the cell function and is reliable up to the committed product warranty.

The experimental run using a cleaning recipe will provide data for an analytical study on product performance. The analysis conducted using JMP statistical software will able to tabulate Power Conversion Efficiency (EFF), Electrical and Cosmetic Yield performance. The validation result of the experimental data versus the existing product will confirm that the cleaning recipe will not cause additional product issues once implemented.

1.6 Thesis Organization

Chapter 1 presents the background of the study, research problems, objectives of the study, scopes of the study, contributions and significance of the study.

Chapter 2 covers on literature study that starts with a brief overview of current solar technology such as Solar Thermoelectricity, Dye Sensitive Solar Cell (DSSC), Concentrated Solar Power (CSP) and Photovoltaic (PV) Solar Panels. This study mainly uses Photovoltaic (PV) Solar Panels, so a summary of different photovoltaic technology like Thin Film PV modules, Concentrated PV modules and Crystalline Silicon PV modules will be included.