Manufacturing Metrology for c-Si Module Reliability/Durability

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Introduction

- Many degradation modes develop during or as a result of processing steps for the manufacturing of photovoltaic (PV) modules
- It is desirable to identify metrology that can be performed during manufacturing to predict failures or unacceptable degradation for PV modules in the field
- c-Si U.S. PVMC aims to perform a literature review of the effects of module manufacturing steps on module reliability and durability
- The goals of this work are to:
  - ◊ Provide a comprehensive review of the current state of manufacturing metrology for improved PV reliability and durability
  - ◊ Identify failure modes and degradation mechanisms induced during manufacturing
  - ◊ Determine in-line and off-line measurement/characterization techniques
  - ◊ Create a master list of metrology techniques
  - ◊ Perform a gap analysis and identify where improvements can be made
  - ◊ Assess trends and new challenges for advanced materials and device concepts

Table 1. Processes and production areas carried out during PV module manufacturing

Process / Production Area	Feedstock and Wafering	Cell Manufacturing	Module Manufacturing
	Polysilicon Production	Wet Chemical Processes (e.g. saw damage removal, texturing, PSG removal, edge isolation)	Stringing and Tabbing
	Ingot/Brick Production	Emitter Formation (e.g. in-line P doping, $POCl_3$)	
	Wafer Production	ARC / Passivation Deposition	Lamination
		Screen-Printing and Co-Firing	

References

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Lamination

- In modules polymers are used as:
  - ◊ Encapsulants
  - ◊ Edge-seals
  - ◊ Structural sealants
  - ◊ Back and front covers
- Laminate creep/loss may cause:
  - ◊ Internal component motion/fracture
  - ◊ Reduced electrical insulation
  - ◊ Delamination at interfaces
  - ◊ Increased moisture ingress
  - ◊ Loss of structural integrity
  - ◊ Loss of connectivity (open circuits)
  - ◊ Exposed wires
  - ◊ Compromised electronic grounding
  - ◊ Electrical arcing
  - ◊ Falling components

Inhomogeneities

- Contamination control and module hermeticity during field deployment is important[1]
  - ◊ Contamination causes discoloration resulting in thermal-runaway
  - ◊ Contamination induced cracking of the silicone
- A white or milky pattern is observed in many modules at the cell perimeter and interconnection ribbons[2-4]
  - ◊ Indicates non-uniformity of lamination/curing

Mechanical Degradation

- Expansion induced by temperature changes in PV modules constrained by the adjoining layers results in thermomechanical stresses
  - ◊ Cracking of harder silicones during cold weather is attributed to thermal misfit[1]
- Information about stress inside the laminate can be obtained from a PV module geometry scan[5]

Loss of Insulation / Moisture Ingress

- As the conductance of the insulation increases with time, the leakage currents may eventually be unacceptably high[6]
  - ◊ This mode of failure is associated with influx of water, with effects of elevated temperature or ultraviolet irradiation
- A good dielectric:
  - ◊ Absorbs little water - even at elevated temperature/humidity combinations
  - ◊ Exhibits a low ionic concentration and mobility in the presence of water

Impact of Processing Steps on Lamination

- c-Si PV cells and modules
  - ◊ Fabricated by a leading PV manufacturer during 1985-89
  - ◊ p-type silicon wafers
  - ◊ Used a phosphorous-rich diffusion glass layer as a P source by P diffusion during p-n junction formation
  - ◊ After diffusion, the P-rich diffusion glass layer was not removed from the cell surface
- The modules were field deployed in:
  - i) A hot & dry climate for <8 years
  - Ii) A hot & humid climate for <9 yrs
  - iii) An extremely harsh hot & humid environment: high insolation, cyclones, high levels of atmospheric salt & sea-water flooding for ~4 yrs
- The modules were returned because of delamination that ranged from some to several to all in the array

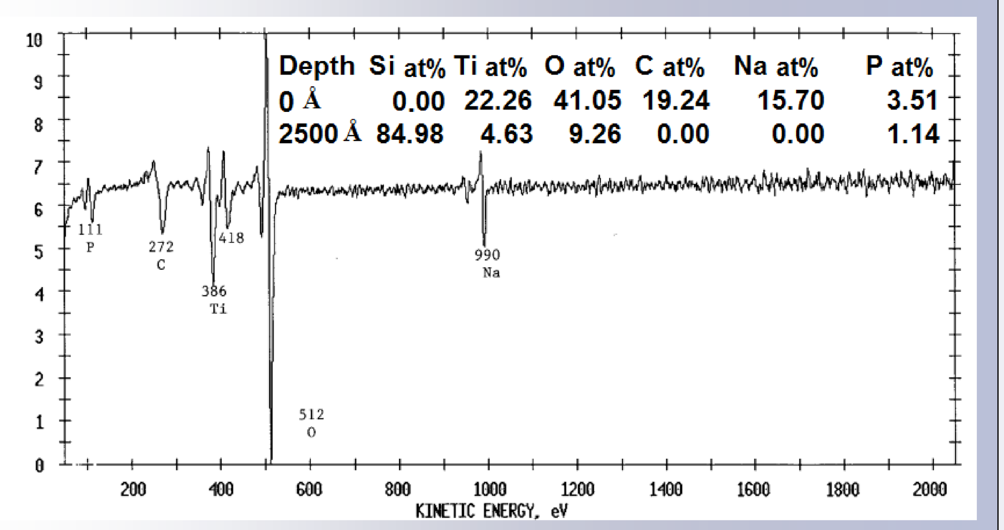

Figure 1. Auger electron spectroscopy (AES) survey (hot and dry). The inset shows atomic concentrations of the elements

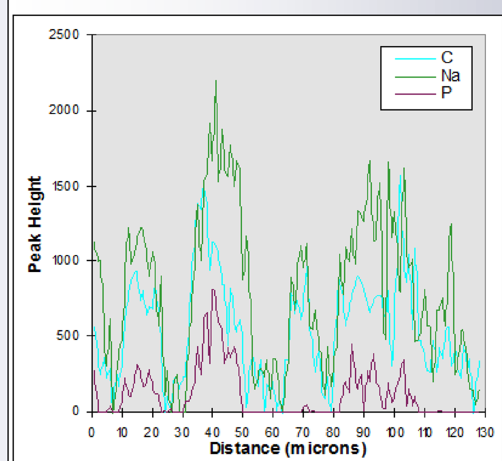

Figure 2. AES line scan for C, Na, and P (hot and humid)

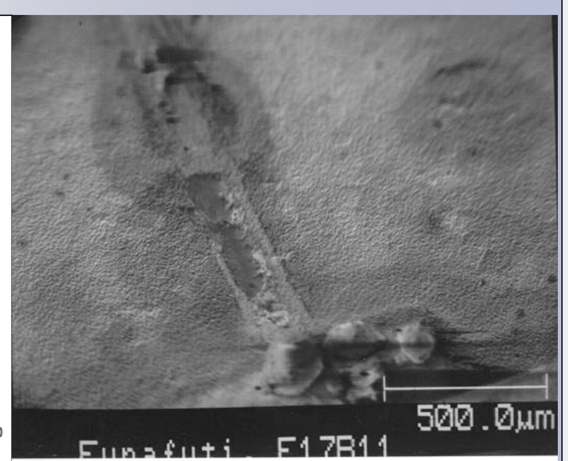

Figure 3. SEM image of corroded grid line in the harsh coastal climate

- The loss of adhesional strength, measured by rotational torque also ranged from some to severe to most
- The problem was traced to the P-rich diffusion glass layer that was left on the cells
  - ◊ Eliminated after modification of the process by removing the diffusion glass

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