R2R in-situ defect detection system for thin film barrier coatings used for flexible PV's

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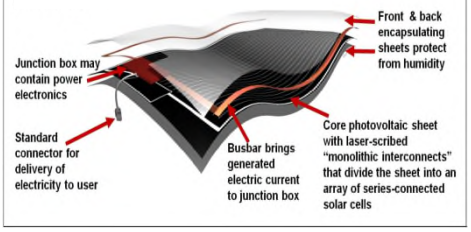
A brief introduction

A flexible PV is is assembled from several functional layers



A brief introduction

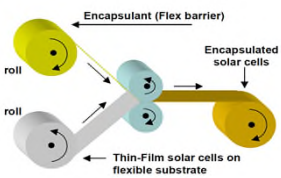
1) High volume large area foil production often involve the deposition and patterning of multi-layer thin films on large area substrates and foils. To achieve high yield in the coating and patterning processes the films must be uniform and largely perfect over most of the area of the foil.
2) There is an increased risk of defects forming as the number of interfaces increases in the multi-layer films.
3) Inspection of the foil surface at production speed with sufficient resolution to detect the presence of problem defects on the starting foil surface and the defects as they appear during the coating and patterning processes.
4) Effective inspection is the key for further process such as applying local repair techniques to remove the defects from the film surface.
5) Currently there is no effective inspection method that can be applied for the above applications where defects are above several um height or foil deviation is over several um

Challenges

1) Non-contact surface measurement with nanometre vertical resolution and over a few tens micrometres vertical measurement range
2) Robust against environmental and mechanical disturbance of roll-to-roll film production line
3) Robust against film surface vibration and deformation on the production line

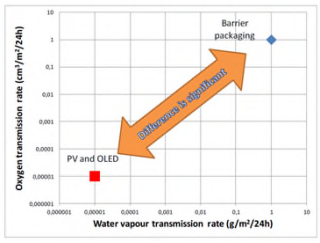
Flexible PV modules

Flexible PV modules are manufactured using roll to roll (R2R) technology. These modules require a flexible barrier material to prevent water vapor ingress.



PV Encapsulation requirements

- The WVTR of present barriers is in the range of 10^{-1} g/m²/day, while it should not be higher than 10^{-4} g/m²/day to assure life-times of 20 years and more.
- A robust, transparent flexible encapsulation method for flexible PV modules is needed.



***IEC61646-2**, "British Standards Institution," in Thin-film terrestrial photovoltaic (PV) modules – Design qualification and type approval ed: BSI, 2008, pp. 5-36.*

Environmental Degradation

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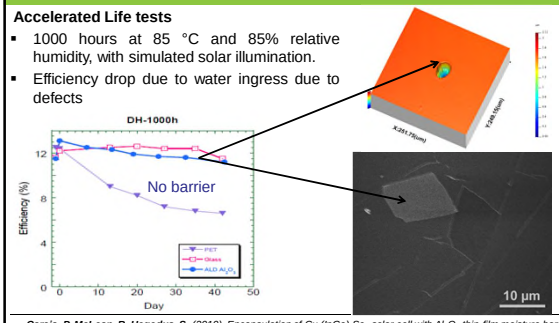
Accelerated Life tests

- 1000 hours at 85 °C and 85% relative humidity, with simulated solar illumination.
- Efficiency drop due to water ingress due to defects



Carcia, P. McLean, R. Hegedus, S. *(2010). Encapsulation of Cu (InGa) Se_2 solar cell with Al_2O_3 thin-film moisture barrier grown by atomic layer deposition. Solar Energy Materials and Solar Cells. 94 (12), p2375-2378.*

NanoMend

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NanoMend - Nanoscale Defect Detection, Cleaning and Repair for Large Area Substrates

Aim: To develop technologies that are able to detect and correct micro and nano-scale defects in roll-to-roll produced films in order to improve product performance, yield and lifetime.

NANOMEND · SEVENTH FRAMEWORK PROGRAMME · Flisom Flexible Solar Modules · Fraunhofer · University of HUDDERSFIELD · cpi · IBS Precision Engineering · storgenso · NPL National Physical Laboratory · ISRA VISION · ISOVOLTAIC · Open your mind. LUT. Lappeenranta University of Technology

Functional elements of flexible photovoltaic cells

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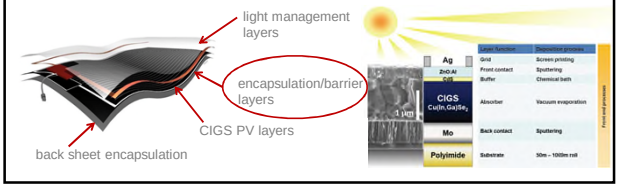
Flexible photovoltaic (PV) cells

- Active technology - CIGS (Copper indium gallium (di)selenide)
- Roll-to-roll process – potential for low cost PV modules
- Control of efficiency degradation over product lifetime vital.

Flexible Photovoltaic Modules



Al_2O_3 Vapour Barrier Layer

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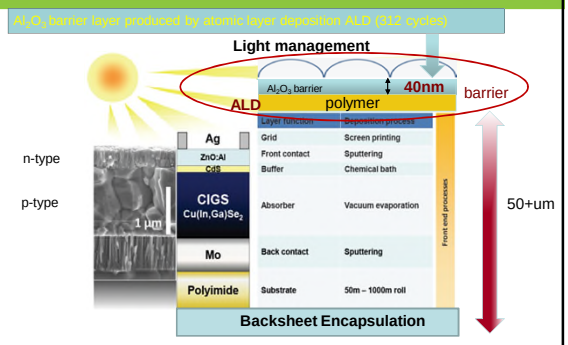

Defects classification system

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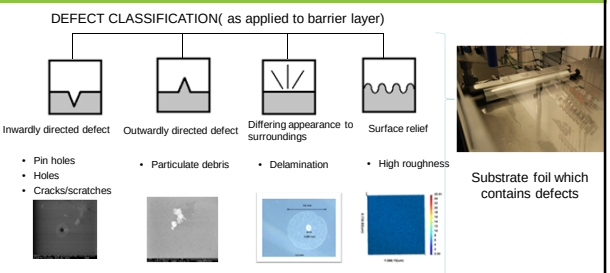

According to NanoMend research the inwardly and outwardly directed defects are in the range of a few micrometre to a few tens micrometre laterally, a few nanometre to tens micrometre vertically, the delamination defects are in a range of a few millimetres to a few tens millimetres laterally

Classification based on Rebiggiani "On polishability of tool steels" 2013 - defects in polishing of tool steels PhD Thesis Halmstad Sweden.

Technologies developed in the CIMAM ---Wavelength scanning interferometry

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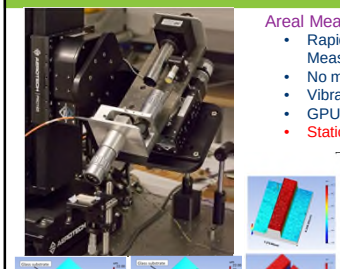
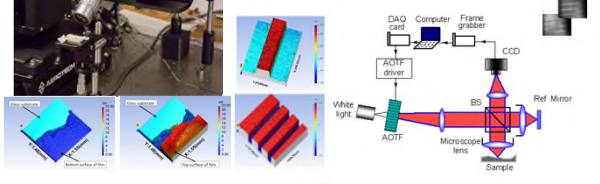
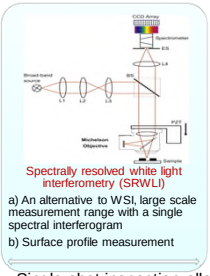


Areal Measurement

- Rapid Thin Film and Structured Surface Measurement
- No mechanical movement required
- Vibration isolating capability
- GPU enabled parallel data processing
- Static substrate needed



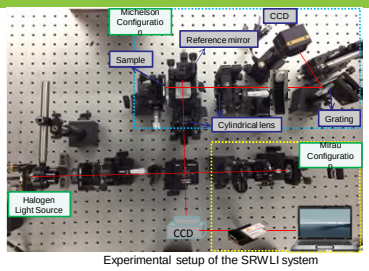
Technologies under development in the CIMAM ---- Spectrally Resolved White Light Interferometry



Spectrally resolved white light interferometry (SRWLI)

a) An alternative to WSI, large scale measurement range with a single spectral interferogram

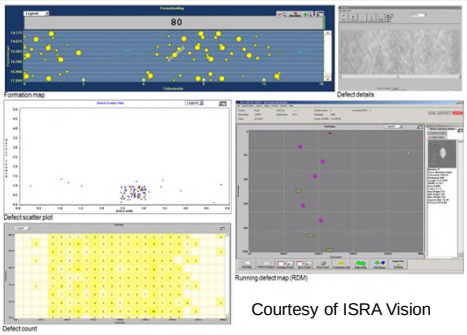
b) Surface profile measurement



Experimental setup of the SRWLI system

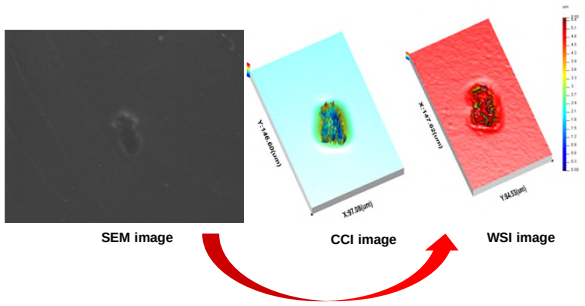
- Single shot inspection allow the film to be inspected in production process
- Multi-sensors configuration will make full coverage inspection possible
- Moving substrate capability

Required Analysis: Running defect map using multi sensors configuration



Courtesy of ISRA Vision

Defects detection comparison studies



SEM image — CCI image — WSI image

Current Build Status

Traverse stage

- It will be used to translate the WSI cross the foil

Autofocus stage

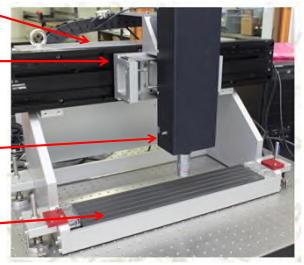
- It will be used to auto-position the WSI head so its focal point is at the top layer of Al_2O_3 barrier

WSI

- It will be used for surface measurement.

Air bearing stage

- It can hold the foil without any mechanical contact to a specific height by an array of air based actuators.



Installation and set up the system

(07/07/14-11/07/14)

Initial tests

- A series tests on the R2R film shown the system was able to perform the defect inspection for the first dozens of individual tests.
- Test results became corrupt after a few dozens of tests.
- To find out the source of this problem, a series tests on the system operating conditions, auto-focus system and its repeatability and the system alignments have been conducted.
- The test results are critical and will provide guidance for future system adjustment and operation.

Repeatability test of the autofocus system on the standard sample

- The tests conducted on the surface of a NPL Bento Box calibration standard
- The z positions of the tests are recorded in the above table.
- The autofocus system only works on the condition that the surface is aligned with less than 5 fringes in the imaging field
- The repeatability of the autofocus system is 5.48 µm on the calibration standard surface when the surface is properly aligned.

Test	z position (mm)
1	0.596
2	0.602
3	0.587
4	0.598
5	0.592
6	0.602
7	0.595
8	0.594
9	0.595
10	0.611
11	0.607
12	0.6
13	0.597
14	0.596
15	0.593
16	0.596
17	0.599
18	0.601
19	0.601
20	0.598
21	0.607
22	0.594
Mean	0.598
Standard deviation	0.005

Repeatability test of the autofocus system on uncoated PET film

- The tests conducted on uncoated PET film with 35um thickness and 400 mm width.
- Five traverse stage positions are selected for the tests.
- Autofocus repeatability is around 10 µm at three positions, which is adequate for the test.
- The autofocus at the other two positions were not functioning.
- The causes are due to the local surface tension and slope.

Test	Y=150	Y=240	Y=330	Y=420	Y=510
1	1.543	0.555	1.614	1.618	1.653
2	1.547	0.595	1.605	1.548	1.661
3	1.541	0.658	1.631	1.555	1.67
4	1.548	0.555	1.635	1.556	1.669
5	1.569	0.682	1.622	1.547	1.67
6	1.554	0.587	1.62	1.553	1.674
7	1.576	0.583	1.628	1.53	1.664
8	1.545	0.812	1.636	1.553	1.659
9	1.561	0.57	1.633	1.56	1.677
10	1.531	0.643	1.62	1.546	1.665
11	1.559	0.606	1.611	1.558	1.669
12	1.564	0.881	1.622	1.642	1.666
13	1.564	0.505	1.624	1.625	1.656
14	1.558	1.578	1.642	1.631	1.648
15	1.565	1.604	1.626	1.64	1.65
16	1.561	1.623	1.617	1.634	1.657
17	1.54	1.617	1.622	1.615	1.663
18	1.573	0.535	1.612	1.621	1.652
19	1.56	0.607	1.622	1.632	1.643
20	1.549	0.627	1.636	1.634	1.64
21	1.553	1.583	1.628	1.636	1.656
22	1.562	0.501	1.63	1.642	1.65
Mean	1.559	0.841	1.624	1.594	1.660
Standard deviation	0.012	0.431	0.009	0.042	0.010

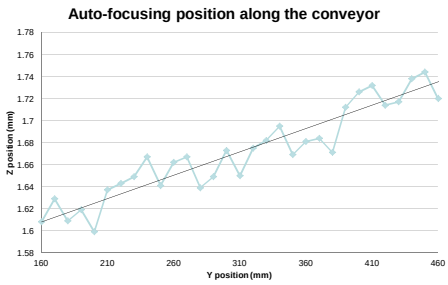
Repeatability test of the autofocus system on gold coated PET film

- The tests conducted on gold coated PET film with 125um thickness and 350 mm width.
- Five traverse stage positions are selected for the tests.
- Autofocus repeatability is around 12 µm at all five positions, which is adequate for the test.
- This was achieved due to the increase of the thickness of the film has reduced the local surface slope of the film
- The high reflection of the gold coated film is not the main reason for the good test results

Test	Y=160	Y=240	Y=320	Y=400	Y=480
1	1.619	1.647	1.689	1.715	1.759
2	1.639	1.647	1.663	1.717	1.752
3	1.649	1.627	1.673	1.724	1.748
4	1.638	1.668	1.681	1.737	1.792
5	1.645	1.633	1.702	1.728	1.774
6	1.627	1.63	1.673	1.745	1.759
7	1.636	1.653	1.673	1.751	1.763
8	1.637	1.621	1.663	1.719	1.753
9	1.627	1.664	1.678	1.724	1.769
10	1.625	1.638	1.683	1.711	1.768
11	1.639	1.641	1.669	1.703	1.782
12	1.623	1.663	1.705	1.712	1.759
13	1.641	1.636	1.679	1.724	1.758
14	1.628	1.635	1.673	1.719	1.752
15	1.626	1.651	1.684	1.724	1.754
16	1.628	1.645	1.659	1.735	1.752
17	1.638	1.666	1.667	1.739	1.758
18	1.663	1.647	1.657	1.743	1.779
19	1.633	1.613	1.679	1.719	1.777
20	1.643	1.622	1.689	1.719	1.743
21	1.639	1.636	1.656	1.711	1.743
22	1.661	1.65	1.674	1.709	1.755
Mean	1.637	1.642	1.676	1.724	1.761
Standard deviation	0.011	0.015	0.013	0.013	0.013

Parallelism test on gold coated PET film using autofocus positions

- The traverse stage is tilted against the conveyor
- The bending of the traverse stage can be ignored
- The traverse stage is about 140 µm apart in Z direction in about 300 mm apart in Y direction.



Conclusions

1. R2R film inspection systems have been explored in the CIMAM of University of Huddersfield
2. The autofocus system is adequate if the tested film surface is aligned to within 5 fringes in the whole image field for most of the tested films.
3. The tension system of the R2R film production line should be finely adjusted to reduce the local stress and local waviness for a better autofocus and better measurement results. For thin films, such as the 35 µm thickness uncoated PET film tested, this issue is more critical than for thick film (the 125 µm thick gold coated PET film).
4. To achieve an inspection which is valid for all the inspected surface strip is possible on the condition that the inspected surface is within the coherence range of the WSI
5. The system can be used for inspection without any problems if the system has been adjusted and operated at its optimised condition, which is: parallelism between the traverse stage and the conveyor surface such that it is within a few micrometres, local stresses and waviness caused by the tension system are mainly eliminated.

Acknowledgement

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Thank you!

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