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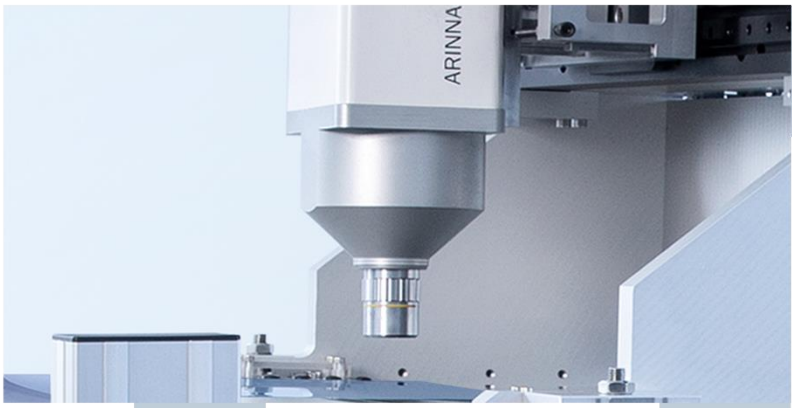
IN-LINE INTERFEROMETRY FOR PRECISION IN ROLL-2-ROLL PRODUCTION



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1 Introduction

In the production of flexible electronics, such as organic LEDs or photo-voltaic foils, nanometer scale features critical to the device performance are often implemented. In-line 3D metrology of such profiles promises to revolutionize the production process by avoiding time consuming off-line measurements for process control. Achieving such measurements in a roll-2-roll environment is a precision challenge. In-line interferometry has been developed for this purpose delivering nanoscale accuracy on a moving flexible foil. Control techniques have been developed to track both in the travel and orthogonal direction. Stabilisation techniques have been developed for the vertical direction. Foil handling is optimized to reduce damage to sensitive foils. The system has been demonstrated on a pilot line, handling PV with ultra-low reflectivity, measuring nanometer features which is a world first.

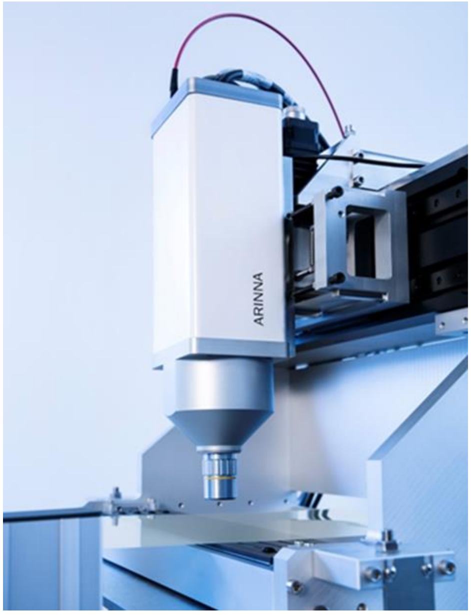

Figure 1 ARINNA interferometer

2 Wavelength Selective Interferometry

An areal interferometer has been developed for quality control of surface features at the nano and micro scale in production. The measurement technique employed by ARINNA (Figure 1) is based on the principle of wavelength scanning interferometry (WSI). The technique involves the capture of a set of interferograms across a range of wavelengths incident on the sample or product. The interferometer is able to measure discrete step heights and surface quality with a vertical resolution <2nm [1]. In-line measurement of printed electronic foils requires the ability to measure low reflective samples, “capture” of the moving foil, stabilization techniques and methodologies to overcome residual surface vibrations. An in-line system was developed to measure laser scribes in Organic Printed Voltaic (OPVs). Scribe depths are of the order of 100nm and width 1 µm.

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2.1 Dancer development

Figure 2 Schematic of dancer. Dark blue -standard rollers, light blue- cylindrical porous media air bearings (airturns).

Nanometer features on foils moving at 1-5m/minute were targeted. Several potential strategies for capturing images from a moving web were explored, including mechanical (chasing the foil) or electronic (tracking in the camera). Given limited integration space in the final manufacturing line a dancer solution was chosen. A schematic is shown in Figure 2. At T0 the left airturn (cylindrical porous media air bearing) starts in the lower position while the right airturn starts in the higher position. When the buffer action is started the left airturn moves with half the speed of the web in the vertical direction towards position two. The right airturn follows the left airturn with the same speed in the opposite direction. At T1 the right airturn lies in the lowest position and the reverse process begins. Four contact rollers and two air turns are used so that front contact is not made with the sensitive web. Buffering is triggered by a marker on the foil. Alternatively, it can be set of user chosen intervals. In Figure 4 the dancer is shown as built.

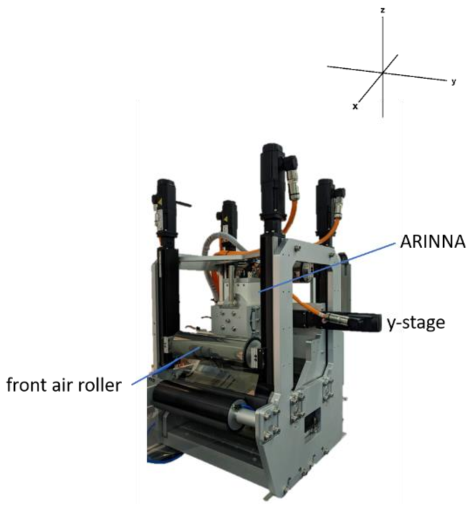

Figure 3 Dancer

During laser scribe measurements, ideally the web should be stationary. Most critical is the movement perpendicular to the travel direction, which should be smaller than the width of the laser scribe, hence of the order of 1µm.

To evaluate the dancer performance new object tracking software was implemented. This software can track an arbitrary object for the duration of the interferometer image capture, by analysing the movement of the object during the wavelength sweep used to measure the surface. So not only the marker on the edge of the web can be analysed but any position on the web. This software is used to detect the x/y accuracy the dancer achieves.

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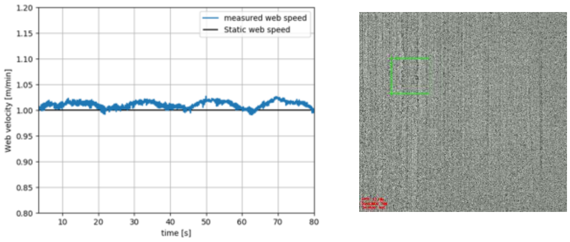

Figure 4 Left - encoder measured web speed. Right - marker detected, position used to verify dancer velocity accuracy.

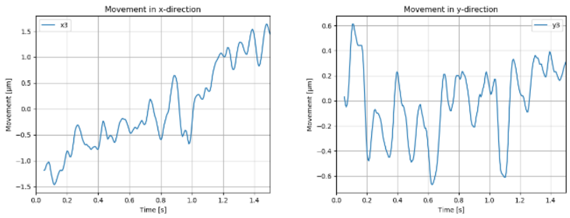

Figure 5 Left: x-position of laser scribe on web during dancing (std. dev. 0.8µm. Right: y-position (std dev. of 0.3µm).

In Figure 4 left, the encoder measured web speed at the entrance to the dancer is shown in the IBS line. In Figure 4 right, object detection on a laser scribe is shown. In Figure 5 the measured displacement of the web with the improved speed monitoring is shown. The data left shows the x-direction performance which was measured as stable with an 0.8µm RMS. From the data right, an RMS value of 0.3µm has been achieved in the y-direction.

2.2 Web stabilisation

Laser scribe depths can be measured by the interferometer to an accuracy of nanometers. It is critical that the web is stable in the vertical z-direction during measurement to achieve these accuracies. Typical motion of webs in the z-direction during production is of the order of more than 300µm (previously measured by IBS). To stabilise the web below the ARINNA in the vertical direction, an air table has been placed under the web. The air table utilizes both vacuum and air pressure to set pretension on the web and cancel any vibrations from the roll to roll line. To cancel any vibration induced by the dancer motors, the metrology frame is decoupled from the dancer frame. Figure 6 shows the z-stability during dancing to be of the order of +/- 0.25µm.

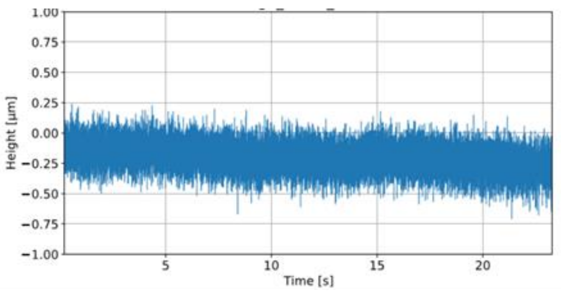

Figure 6 z-stability of web during dancing and stabilisation with air table.

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2.3 Vibration compensation

With the foil stabilised in x, y and z the surface topology can be measured. Within the interferometer, compensation is applied for residual vertical motion of the foil during data capture. Advanced modelling identified a number of improvement opportunities, including enhanced hardware filtering and optimised microprocessor speeds, to increase the bandwidth of this vibration compensation. Applying these improvements enhanced the bandwidth of the vibration compensation from 280Hz to 650Hz. This in turn has enabled stable measurement of webs floating on the air table.

3 In-Line Measurement

The OPV samples to be measured are shown in Figure 7. Laser scribes are made at four stages in the processing of these devices. Scribe depths vary from 100nm for the P1A type to 1.5μm for the P3. Scribe widths are of the order of 1μm.

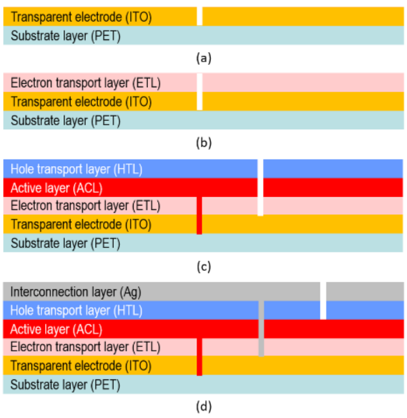

Figure 7 Schematic representation of the organic electronics stack, with (a) the P1A type, (b) the P1B type, (c) the P2 type, and (d) the P3 type laser scribes

OPV samples are by definition low reflective. Thus ARINNA was optimised to enable measurement at low return light levels. This included both hardware updates to increase the incident light and software updates to accommodate potentially higher noise levels. To our knowledge the measurements presented here are the first ever topological surface measurements for such materials.

When manufacturing such devices SEM measurements have typically been used to assess laser scribes. A small piece of the print run is removed and sent for analysis, which typically takes more than a week. Measurements provide 2D data only, indicating a scribe width. Quantitative interpretation of the images is used to confirm the form of the scribe (wall edges, debris etc.) First measurements from the interferometer were compared to SEM.

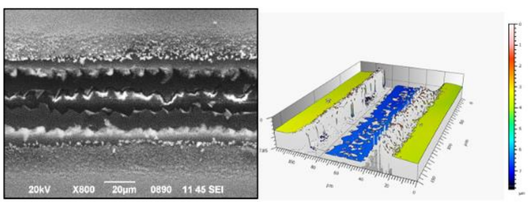

Figure 8 Comparison between SEM image (left) and ARINNA interferometer measurement (right) for P3 scribe.

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In Figure 8 an example is shown, where features apparent at the base of the scribe are also present in the surface topology measurement of the interferometer. In Figure 9 measurements are shown for P1A scribes in PET/IMI where the laser power has been varied from 20 to 80%. The scribe width is seen to increase continuously from 20µm to 70µm. At the same time, the scribe depth is seen to increase between power of 20 to 24% and thereafter plateau at the nominal depth of 100nm, as the scribe has cut through to the PET.

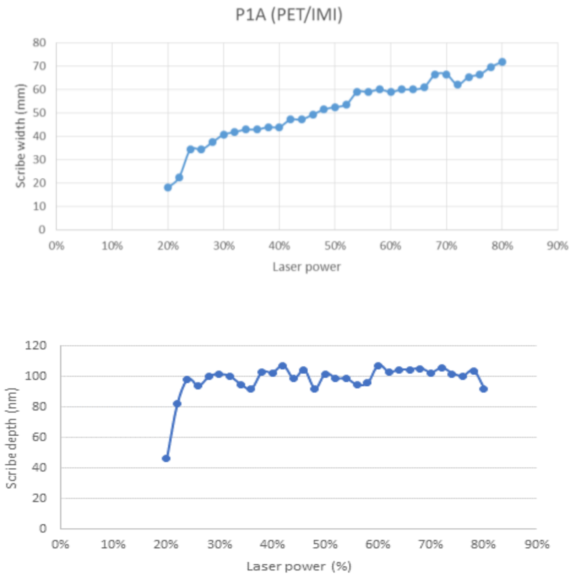

Figure 9 Measured P1A scribe width (upper graph) and depth (lower graph) as a function of laser power.

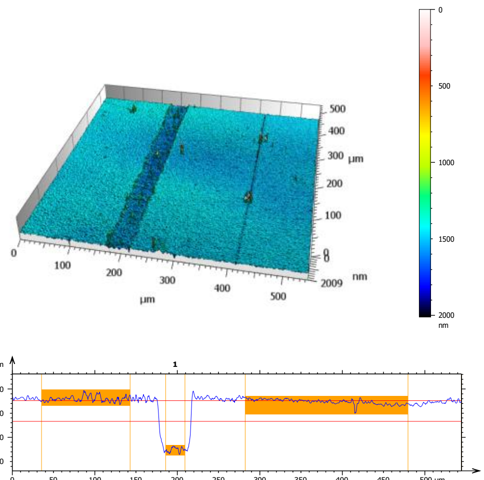

Figure 10 P1A scribe in PET/ITO on foil moving at 1m/min

In Figure 10 measurement of a P1A scribe on PET/ITO is shown, measured in-line with a foil speed of 1m/min. Cross-section shows a scribe depth of 100nm in line with the expected ITO layer thickness.

The system has been developed to provide automated measurement at a pre-defined time interval. Automatic feature extraction is performed for surface features, in this instance the scribe width and depth. A validity check is

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made against pre-set tolerance values. TCP/IP communication of the depth and width is sent to a client to allow for laser power adjustment. A typical trend graph is shown in Figure 11.

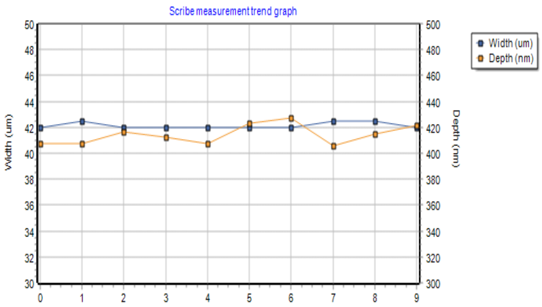

Figure 11 Trend graph of laser scribe and width taken in-line.

Statistical analysis of 100s of sampled data measurements was used to identify the impact of factors including light intensity, exposure time and interferometer optical settings. From these, optimum conditions were identified. A dataset with the preferred settings comprised 367 measurements. The mean depth obtained from this set for a laser scribe of nominal depth 100 nm was 104.7 ± 1.0 nm. The standard deviation of the measurements was 9.5nm, the standard error of the mean 0.497nm.

A further 100 measurements were taken of the same foil moving at 1m/min as shown in Figure 12. The tolerance range was set between 50 and 150nm. Nine out of the 100 measurements were seen to fall out of the tolerance range. The mean depth obtained from the remaining data set was 96.96nm. The standard deviation of the measurements was 15.3 nm, the standard error of the mean was 1.92nm.

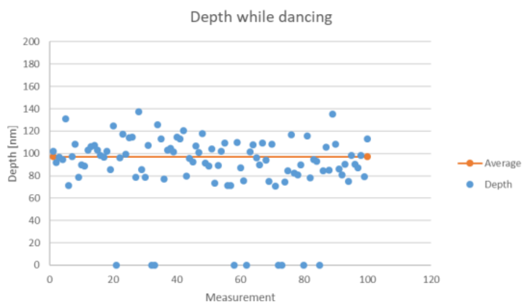

Figure 12 100 scribe measurements measured in-line at 1m/min.

4 Conclusions

For the first time, laser scribes have been measured interferometrically for OPV samples. Measurements have been successfully made in-line across the full width of the web using a dancer combined with autofocus capability and feature extraction.

[1] Robuste Oberflächenmessung mit Interferometrie Mikroproduction,65 04/15.