A simple defect detection technique for high speed roll-to-roll manufacturing

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Abstract

A prototype industrial defect inspection system, which can operate at speeds of up to 1 m s^{-1} and over web widths of 500 mm, is being developed at the National Physical Laboratory (NPL) for roll-to-roll (R2R) manufacturing of highly-transparent materials. The prototype is designed to detect defects with lateral dimensions larger than 10 µm. The findings of a feasibility study for a sensor based on dark-field imaging principles are presented. The design of the sensor is introduced and the preliminary characterisation results are discussed. Off-the-shelf equipment was used including a monochromatic CMOS sensor paired with a telecentric lens. Illumination was supplied by a high-power LED, using a range of illumination wavelengths. The characterisation was performed on custom-made, highly transparent polymer artefacts and the results are presented.

1. Introduction

The advanced manufacturing industry is consistently shifting towards parallel production processes that maintain high feature resolutions (below ten micrometres) in 3D and on large area substrates (exceeding square metres). Consequently, there is an industry driven requirement for in-line inspection systems capable of meeting these challenging requirements (referred to as high dynamic range) though, as suggested in [1], there has only been limited research to address these issues.

NPL is actively tackling the high dynamic range metrology challenge through the enhancement of existing technologies and the development of novel approaches. This paper will review the design and important material characteristics of the artefacts used for characterising the DF sensor, as well as the experimental setup and the results of a preliminary characterisation of a proof-of-concept dark-field (DF) optical sensor are reported. The sensor associates the presence of a defect with the intensity of the scattered radiation traveling from the sample which, if defect-free, should transmit or specularly reflect the incident light.

2. Experimental setup

The DF experimental setup is presented in figure 1. The setup utilises a single illumination arm, a single detection arm and a vertical rack for sample positioning. The angles of incidence and observation are adjustable in the horizontal plane. The detection arm is positioned in an off-axis configuration with respect to the illumination arm to fulfil DF imaging conditions.

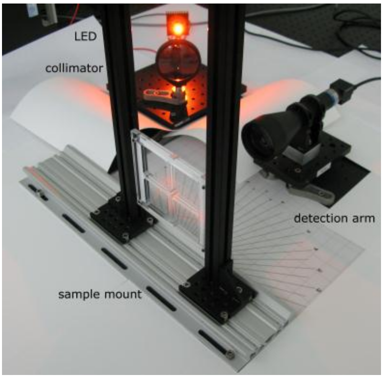

Figure 1: Proof-of-concept DF setup.

A high-power Osram Dragon series narrow-band LED is used as the illumination source. The LEDs are interchangeable to provide a multi-wavelength inspection capability. The light emitted from the diode is collimated by a single plano-convex lens (uncoated, N-BK7, 75 mm diameter) before illuminating the sample.

For detection, a PT Grey Flea 3 CMOS sensor is paired with an off-the-shelf telecentric lens. This sensor configuration provides a 40 mm diameter field of view with the object space numerical aperture of 0.008 and the lateral resolution of approximately 30 μm. Up to 150 frames per second (FPS) can be streamed to the control PC via a USB SS connection.

3. Characterisation of the DF proof-of-concept system

3.1 Artefacts

Two artefacts have been manufactured and used for performance characterisation. Resemblance to the target industrial inspection problem was achieved through the application of polyethylene naphthalate (PEN), which is a material frequently used as a substrate in barrier coating or carrier layer in R2R processes. Due to its high transparency (approximately 85 % in the visible range) PEN is a challenging material for standard optical surface inspection techniques.

Both artefacts were designed to contain common defect types; scratches and pin holes of incrementing lateral dimension. Artefact I was manufactured using an excimer laser (λ = 248 nm) on the optically smoothest, planarised version of the PEN (covered with a 22 nm silica glass layer). Due to the planarisation layer, the smallest feature manufactured was 21.5 µm wide with a clear residual re-melt area visible (see figure 2). Artefact II was manufactured using a femtosecond laser ablation system on the standard PEN. The smallest feature manufactured was 16.5 µm wide (see figure 3). Artefact II exhibits significantly improved edge definition for all the features manufactured when compared with the artefact I.

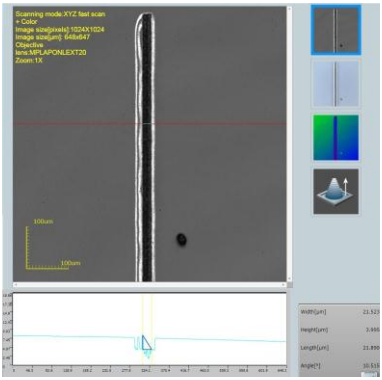

Figure 2: Artefact I – 21.5 µm feature (Measured with confocal microscope).

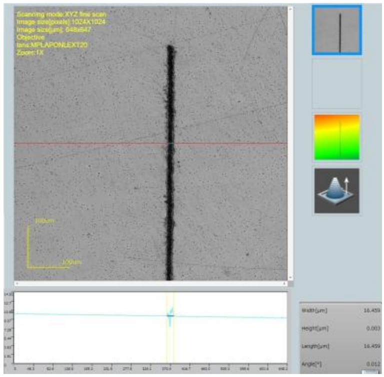

Figure 3: Artefact II – 16.5 µm feature (Measured with confocal microscope).

3.2 Results

Test measurements conducted on artefacts I and II show that the DF demonstrator is capable of detecting the smallest defects that were manufactured (see figure 4 and figure 5). The results remain consistent for all tested wavelengths. The defects were visible at streaming rates of 40 FPS, which is a current software limit of the setup. The angular responses of the DF system are yet to be characterised (presented measurements taken at 35 degrees incidence).

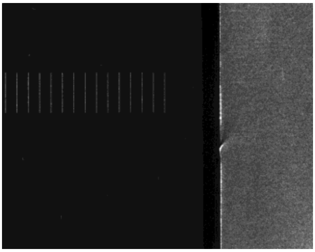

Figure 4: Artefact I. 21.5 µm feature (the rightmost bar) produces a clear intensity spike on the detector. Image represents instrument’s single field of view.

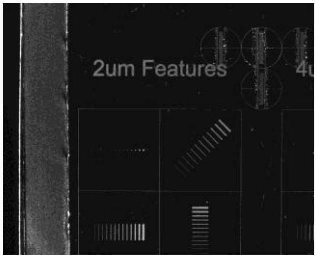

Figure 5: Artefact II. 16.5 µm feature (horizontal bars, leftmost) and larger are visible. Image represents instrument’s single field of view.

4. Discussion and outlook

The preliminary characterisation of the DF defect inspection system proves the capability to detect defects smaller than the lateral resolution of the system on this challenging material. Further measurements are required to select optimal illumination conditions and to verify performance with a moving artefact. A manufacturing technique capable of producing smaller defects must also be investigated. Future work will investigate the addition of interference effects to measure the height of defect structures and the scaling up of the proof-of-concept system to address actual manufacturing scenarios.

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References:

[1] Leach R K, Jones C J, Sherlock B, Krysinski A 2013 The high dynamic range surface metrology challenge *Proc. ASPE, St Paul, USA, Nov*. pp. 149-152.