The Application of White Light Interferometry in the Graphic Arts

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Abstract

White light interferometry is a non-contact technique for the characterization of surface topography. As it is a non-contact and non-destructive method it can be used for all types of materials (solids, liquids, rubbery, sticky, etc.). The instrument is based on the light interference principle. The light from the single source passes through the beam splitter and is directed to the sample surface and the reference mirror. The beams of reflected light from those two surfaces recombine and form the pattern of interference “fringes”. The maximum fringe contrast for each point of the sample occurs when the surface is at the best focus. During the vertical scanning the light interference signal from each point of the sample is recorded by the computer. The fringe signal is demodulated by the appropriate advanced computer algorithms and translated into the information about the surface topography of the sample.

The instrument and software (Wyko NT1100 Optical Profiler, by Veeco, USA) allow for quick and accurate characterization of surfaces. Among the surface characterization options and parameters that can be obtained are the surface topography – 2D and 3D images, virtual cross-sections, surface roughness, surface area, volume, line width, step height and much more. The instrument is well suited to be used for R&D as well as problem solving in the Graphic Arts Industry. For example, surface topography determines a number of important properties such as print quality, print density, gloss and visual appearance. The optical profilometry provides a unique view which can quickly resolve surface contributions to print performance. Several examples of surface characterization of the model systems and real samples will be presented in this paper.

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To demonstrate the capability of the white light interferometry the following properties of the selected samples were characterized using the Wyko NT1100 Optical Profiler:

- Surface topography, roughness and the virtual cross-sections of different samples
- Surface area of smooth (glass) and rough (paper) samples
- Volume calculations – calibration standard vs. the flexographic anilox roller
- Line width and height – the flexographic print on the plastic film
- Step height – calibration standard vs. the gravure print and adhesive film
- Ink film thickness measurement – step technique – limitations of the method and possible errors while measuring prints on the transparent film.

In addition, the examples of practical application of white light interferometry for problem solving (selected case studies) were also presented:

- Characterization of surface (sample/air interface) and the interface (clear film/substrate) of the sample coated with transparent film
- Identification of the root cause of "skipped" dots in the gravure printing

The experimental data presented in this paper shows very clearly that the white light interferometry is a very useful and powerful (quick and accurate) method for the characterization of surface topography of the samples. One can anticipate that this new technique will find wide application in the Graphic Arts Industry in the coming years.

Introduction

The schematic diagram of the white light interferometer and the photograph of the commercial instrument (Wyko NT1100 optical profiler) are presented in Fig. 1. Optical profilers can use two different techniques, both based on the light interference principle (Deck and de Groot, 1994), (Olszak et. al., 2001), and Harasaki and Wyant, 2000). The phase-shifting-interferometry (PSI) is used to measure smooth surfaces and very small steps. The narrow bandwidth monochromatic light beam (filtered white light) from a single source is directed to the beam splitter. Half of the incident beam is directed to the reference mirror and half to the test sample. The beams reflected from the reference mirror and test sample surface recombine and form the interference "fringes". When using this option the objective of the instrument does not move and instead the reference mirror is moved by the piezoelectric transducer (known and controlled distance). This move generates the difference in the optical paths (phase shift) between the reflected light beams (the reference and test sample) and causes the interference. This interference may be constructive at some points and destructive at others and forms an interferogram. The instrument software processes the phase shift data from the interference signal and calculates the surface heights of all points on the surface.

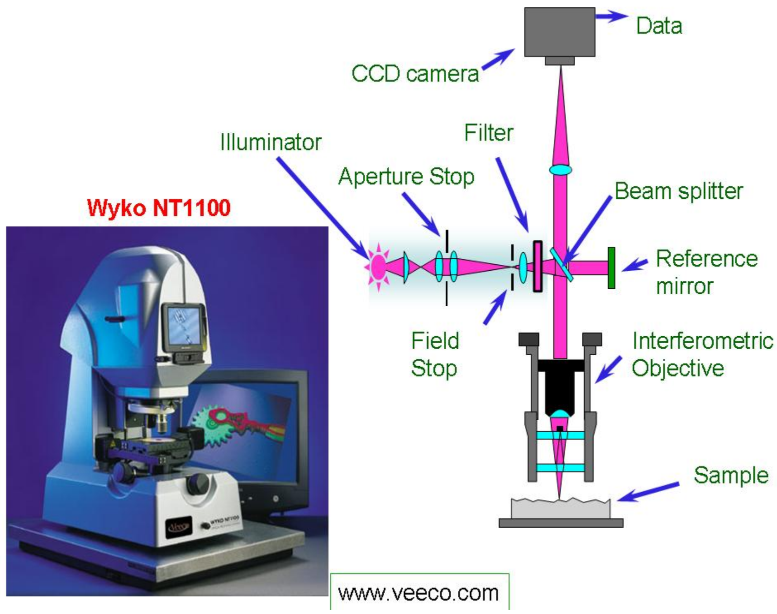


Fig. 1. Schematic diagram of white light interferometer and the photograph of Wyko NT1100 Optical Profiler.

In the vertical-scanning-interferometry (VSI) the white light beam from a single source is directed to the beam splitter. Half of the incident beam is directed to the reference mirror and half to the test sample. The beams reflected from the reference mirror and test sample surface recombine and form the interference "fringes". When using this option the instrument head with interferometric objective moves through the focus during the vertical scanning. The white light has a short coherence length due to a very broad spectral bandwidth. The contrast of fringes is the highest at the best focus of the surface point and falls off quickly when the scanning head moves away from focus.

The interference of the coherent light beams of the same amplitude (A) may be constructive (two waves in phase) or destructive (two waves out of phase - 180° shift) – see the schematic diagram in Fig. 2. In the former case the resulting wave has an amplitude equal to the sum of the amplitudes of the interfering waves ($A_i = 2A$) but in the latter case the resulting wave has zero amplitude ($A_i = 0$). When the phase shift of the interfering waves changes ($0° \leq \theta \leq 180°$) the amplitude of the resulting wave also changes accordingly ($0 \leq A_i \leq 2A$).

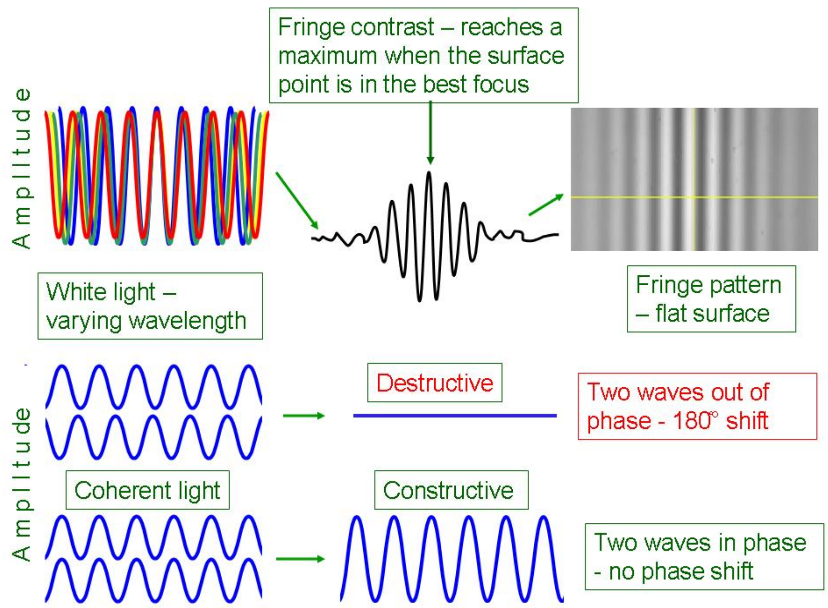


Fig.2. Light interference – schematic diagrams.

As white light consists of the electromagnetic waves of different frequencies (broad bandwidth) the light source has a very short coherence length – see Fig. 2. The highest contrast of the interference fringes can be obtained only when the sample surface is at the best focus. Because the PSI mode can be used for evaluation of a very smooth surface (Z-range ~160nm) e.g. silicon wafers or optical elements this mode will not be discussed in this paper.

In the VSI mode (Z-range ≤ 1mm) the instrument detector measures the fringe modulation corresponding to each focus point on the surface as the instrument head moves vertically down. Before the measurement the objective is placed slightly above the best focus position. During scanning one can observe how the focus of the fringes changes on the instrument screen. The position of the head at the best focus for each point on the surface is recorded by the computer. The fringe signal can be demodulated by the appropriate advanced computer algorithms and translated into the information about the surface topography of the sample. The examples of the fringes observed for two different samples – flat and smooth glass surface and a gravure print on the plastic film – are presented in Fig. 3.

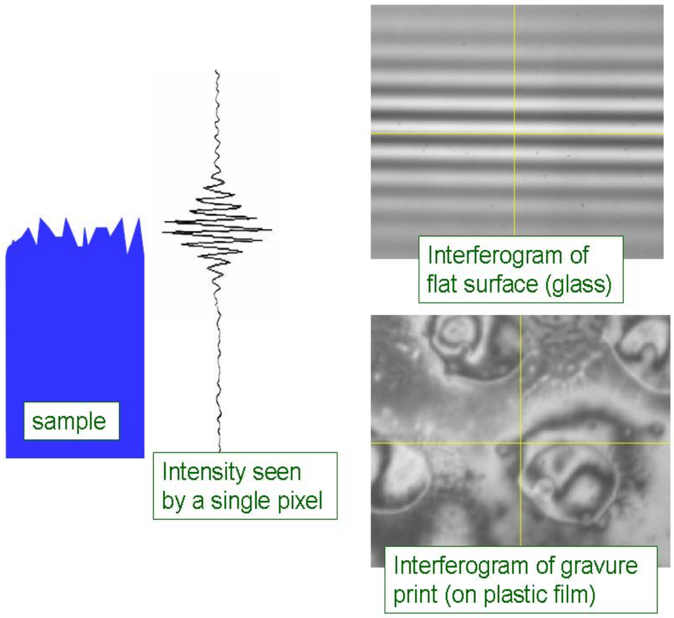


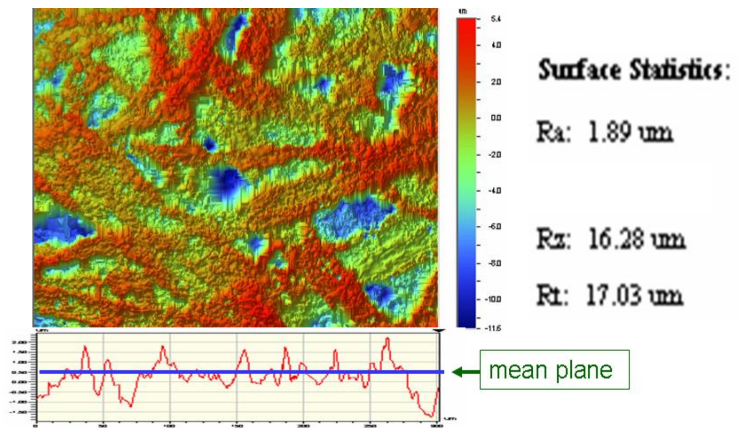
Fig. 3. Schematic diagram of light intensity seen by a single pixel of the CCD camera and the examples of the interferograms generated at different surfaces.

Possible Measurements Using Interferometry

The white light optical profilometry offers a wide gamut of measurements and analysis options that are very important for the Graphic Arts Industry (e.g. surface roughness and topography, surface area, volume, height, width etc.).

Surface roughness and topography and surface area

Surface topography is a three-dimensional representation of surface irregularities. The surface can be rough, smooth, wavy, bumpy or curved depending on the magnitude and spacing of the peaks and valleys. Roughness relates to closely spaced irregularities (the distance is much smaller than the size of the image element e.g. gravure cell or printing dot) and does not characterize the surface flatness. Waves, voids and bumps are larger surface features and they can be of the same size or larger than the image elements. Roughness is super-imposed on the waviness, bumps and voids. The most commonly used roughness parameters are R_a, R_z and R_t (or R_{max}) – see Fig. 4. The image in Fig. 4 represents the surface of un-coated paper



R_a – *average roughness* – the arithmetic mean of the absolute values of the surface departures from the mean plane in the dataset

R_z – *average maximum height of the profile* – the average of the ten highest and ten lowest points in the dataset

$R_{t(max)}$ – *maximum height of the surface* – the vertical distance between the highest and the lowest points in the dataset

Fig. 4. The 3D image (top view) of the paper surface with the cross-section profile and definitions and values of roughness parameters for that sample.

The Wyko NT1100 software calculates roughness parameters from the collected dataset. When calculating the R_z the software identifies the highest point in the dataset and masks the area of 11x11 pixels around that point. This procedure is repeated for other points (low and high). The example 3D image (top view) of the paper surface and values of roughness parameters are presented in Fig. 4. The surface topography can be represented in the form of the 2D image, 3D image (top view and angle view) and virtual cross-sections of the area tested (vertical and horizontal) – see Fig. 5. The software allows for direct measurements of the surface features by moving the cursors on the interactive screen in the selected areas of the image. The surface area index, defined as a ratio of the total (real) surface area over the lateral surface area, is a measure of the surface roughness and texture. The surfaces with index values close to unity describe smooth and flat surfaces. The larger the surface area index values the rougher and/or wavier the surface is. The examples of smooth (glass) and rough (paper) surfaces and the corresponding surface areas and index values are presented in Fig. 6.

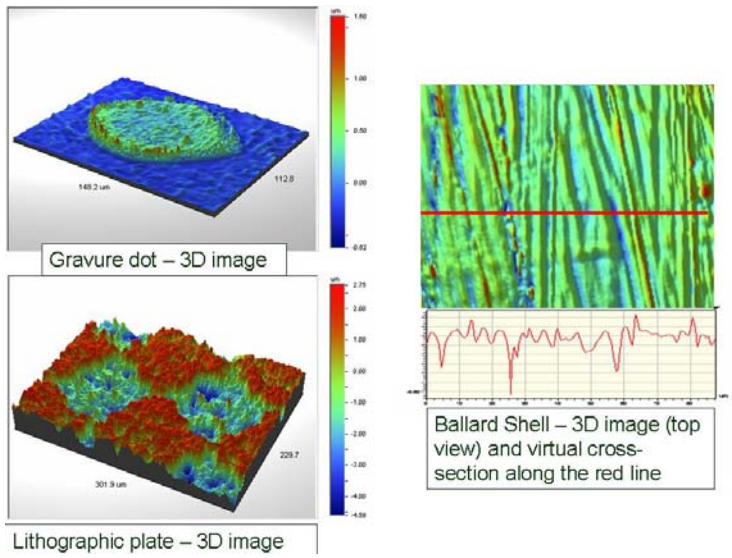


Fig. 5. The example images of 3D surface topography: lithographic plate (angle view); gravure dot on plastic film (angle view) and Ballard Shell (top view) with the cross-section profile along the selected line.

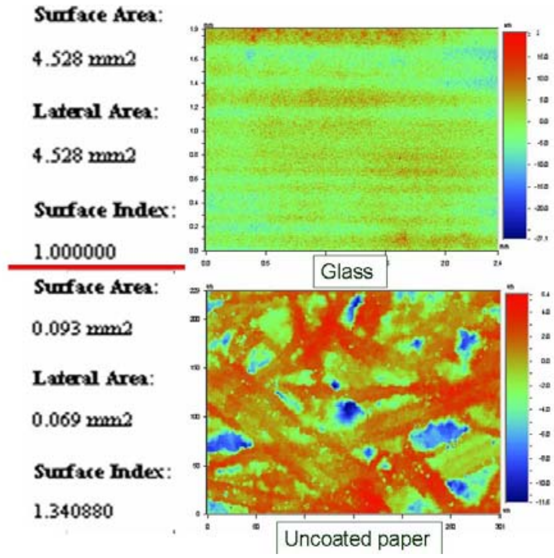


Fig. 6. The 2D images of the surfaces (glass and paper) and calculated values of their surface area index.

Knowledge on the surface roughness, texture and topography is very important for many materials used in Graphic Arts (Zecchino, 2003) such as e.g. lithographic plates (the non-image area of the plate may carry different amounts of water depending on the surface roughness and texture); Ballard Shells (appropriate roughness of the gravure cylinder surface is necessary to ensure good lubrication and minimize the cylinder wear); printing substrates (papers plastic films, boards), etc.

Volume

A calculation of the volume of complex shaped objects is not an easy task. The optical profiler software allows for quick and easy evaluation of the volume of different objects, even complex shapes such as anilox roller cells, lithographic plate porous surface, etc., (Stout and Zecchino, 2002). The volume estimated by the instrument is the volume of the space between the real surface and a plane parallel to the reference plane that intersects the maximum peak. The reference plane intersects the lowest point in the dataset. The total as well as normalized (volume per unit area of the sample) volumes can be calculated in this way. The volume measurements can be skewed by the surface contamination. However, the instrument software offers masking techniques that can exclude e.g.

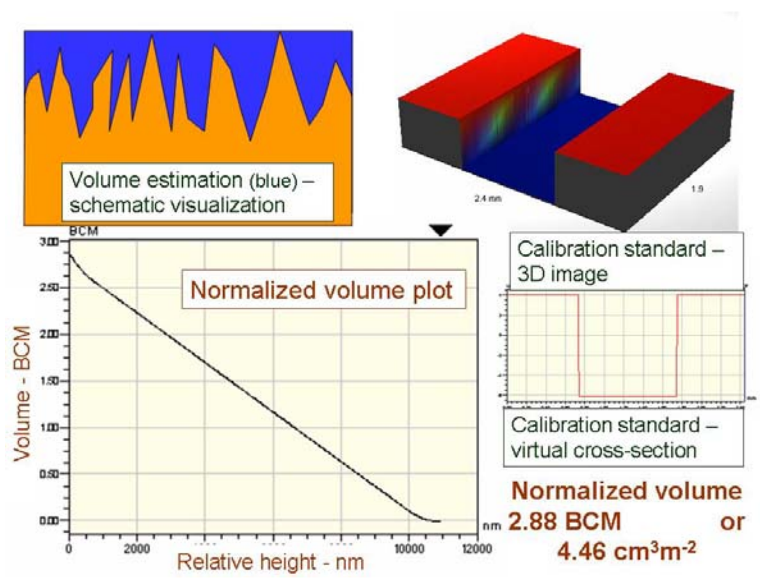


Fig. 7. The schematic visualization of the volume estimation. The 3D image (angle view) of the calibration standard (well defined groove on the surface of glass), its cross-section profile and the plot of normalize volume vs. the relative height (see the text for explanation).

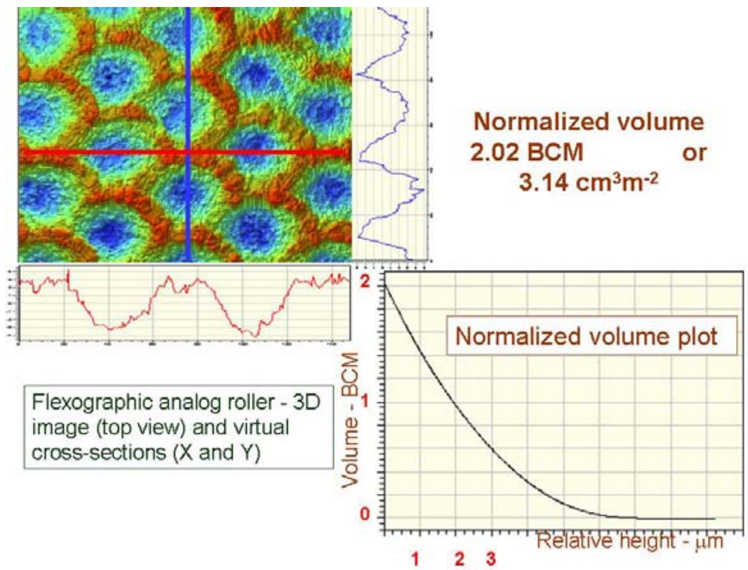


Fig. 8. The 3D image (top view) of the flexographic anilox roller, cross-section profiles along the selected lines (X and Y) and the plot of normalize volume vs. the relative height.

contaminated area from the analysis. Details on the use of different types of masks can be found in the literature (Cherry et. al., 2005). Two examples of volume calculations are presented in Figs 7 and 8 – the calibration standard and flexographic anilox roller, respectively. As the calibration standard groove had a cuboidal shape the plot of normalized volume vs. the relative height is a straight line with a constant slope – see Fig. 7. The relative height plane is a plane at any arbitrary position below the maximum height of the surface. The plot of normalized volume for the anilox roller cells is not a straight line due to the different (non cuboidal) shape of the cells – see Fig. 8.

Step height – thickness measurements

The step height option allows for the characterization of regular and irregular steps. The 3D image (angle view) of the calibration standard (very well defined regular step) and its virtual cross-section along the selected line (white) are presented in Fig. 9. The interactive cross-section image allows for direct step measurements in the selected area. This method can be used for direct determination of the film thickness of e.g. ink, coating, adhesive etc. when the reference surface (unprinted surface) is also available for the measurement (e.g. print edge or pinhole).

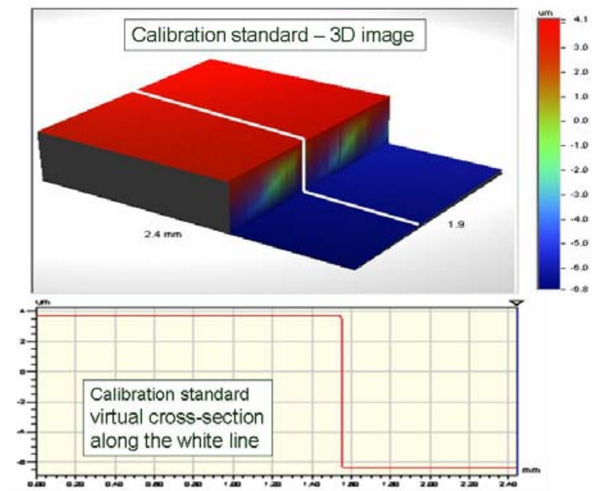


Fig. 9. Estimation of the step height. The 3D image of the calibration standard (angle view) and the cross-section profile along the selected line – see the text for explanation.

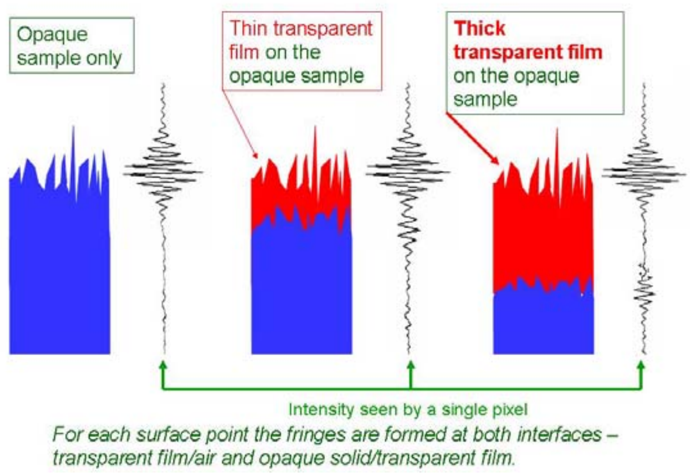


Fig. 10. Schematic visualization of the interference fringes formed at different surfaces: opaque sample; opaque sample covered with a thin transparent film (film thickness <3μm) and opaque sample covered with a thick transparent film (film thickness >3μm).

When the relatively thick (>3μm) transparent film is present on the surface of the sample (e.g. clear coating or laminated print) the thickness of the transparent film can be measured at any point on the surface and its 2D, 3D images and cross-sections can be obtained by using a special version of the software that is capable of the independent recording and analysis of the datasets collected at different interfaces (Zecchino et. al., 2004). The instrument head scanning through such sample can record two independent sets of fringes – one originating at the top surface (clear film/air interface) and the second one formed at the sample/clear film interface – see Fig. 10 for a schematic diagram.

Line width and height

The width and height of the line can be evaluated from the virtual cross-section of the print – see the example presented in Fig. 11 (line printed on the transparent plastic film). The measurements can be done directly by placing the cursors (X and Y) in the selected area of the print. When the scanning range is selected in such a way that it covers all interfaces – see Fig. 12 – then the interaction between the datasets collected at different interfaces can take place. This along with the "wild" data collected due to the unwanted reflections may cause that the final dataset has nothing to do with the real situation (the

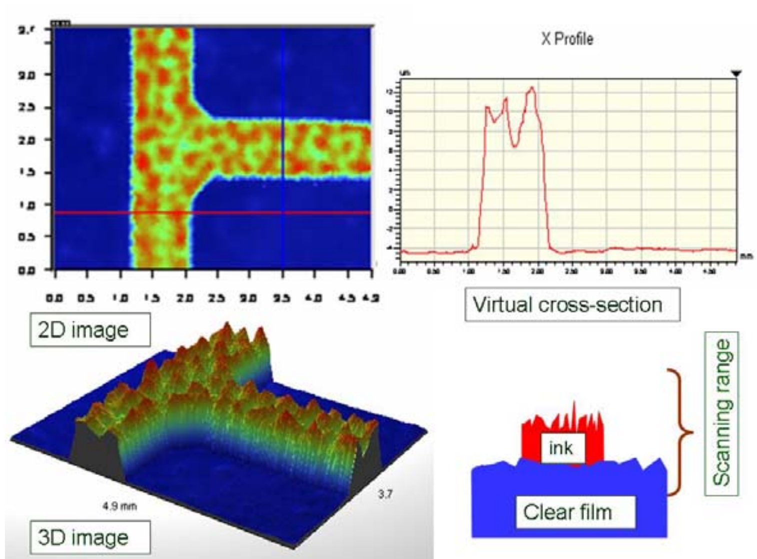


Fig. 11. Evaluation of the line width and height from the cross-section profile of the print along the selected lines – flexographic print on plastic film. The diagram of the measurement and 2D and 3D images of the sample are also presented – scanning range covers only the top surface of the sample.

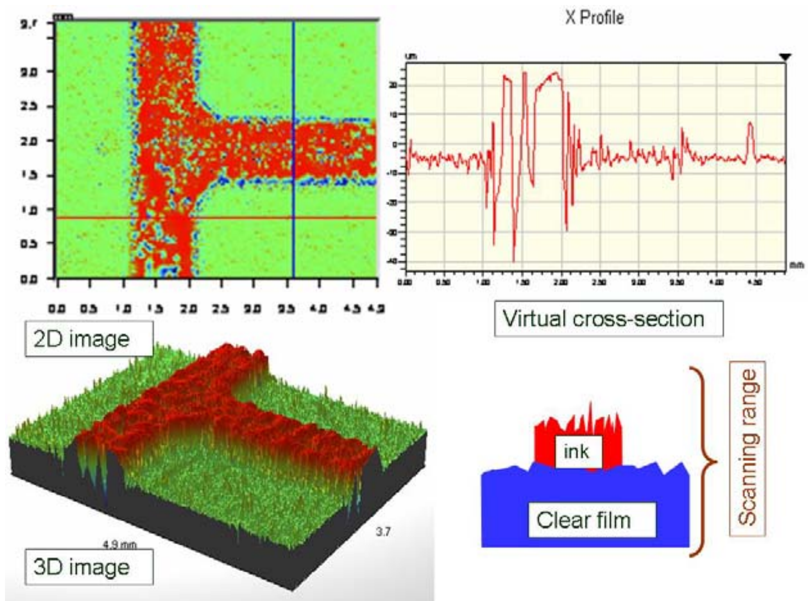


Fig. 12. Evaluation of the line width and height from the cross-section profile of the print along the selected lines – flexographic print on plastic film. The diagram of the measurement and 2D and 3D images of the sample are also presented – scanning range covers all interfaces. **The images obtained represent the non-existing surface created by mixing the datasets collected at different interfaces.**

instrument collects only one dataset – some fringe signals can be erased by the signal collected later) and the instrument finally creates the image of non-existing surface – see the example presented in Fig. 12. Therefore one has to control the scanning range when dealing with such samples and using the basic version of the software.

Case Studies - Examples

We have applied the technique of white light interferometry widely for supporting R&D and technical service projects in our laboratory. Three other detailed examples of such application are presented below.

Orange Peel Pattern on the Metallized Laminated Print

The reverse printed polyester (PET) film was vacuum metallized prior to the lamination and then laminated to the paperboard (extrusion lamination). The final product showed a heavy “orange peel” pattern in the metallized areas. The example photomicrograph of the pattern is presented in Fig. 13 along with the 3D image of the same area. Comparison of the photomicrograph and the 3D

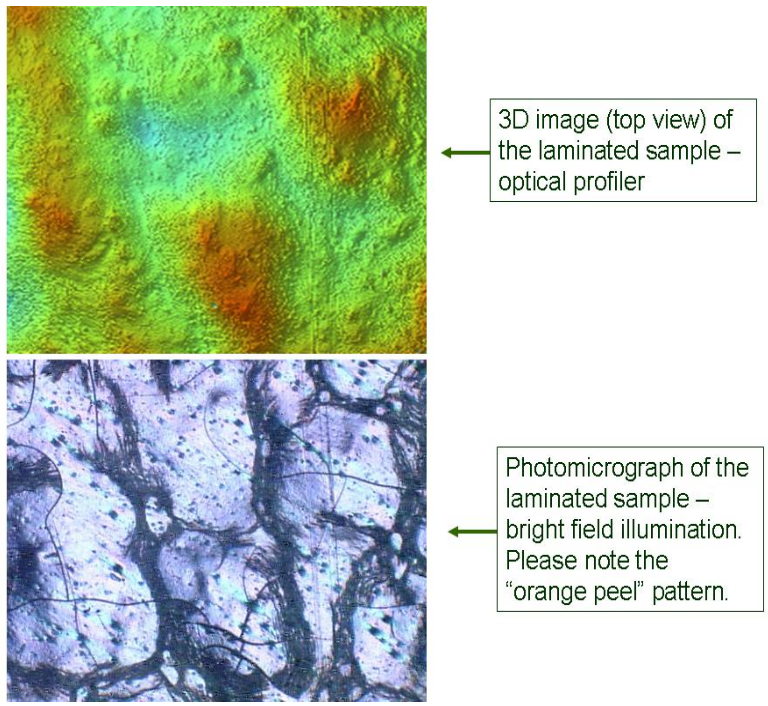


Fig. 13. The orange peel pattern on the surface of laminated print (metallized printed PET film – extrusion lamination to the paperboard surface) – photomicrograph and 3D image of the same area of the sample. Note that the dark lines (orange peel) pattern is observed only in the valleys.

image shows that the dark line pattern of the irregular shape is observed only in the valley areas on the surface. The topography images of the top surface (PET film) and the interface (PET film/metal) in the area of the dark lines presented in Fig. 13 show very clearly the presence of "wrinkles" in the interfacial region – see Fig. 14. Using the virtual cross-section method, the height and spacing of the wrinkles could be measured – see Fig. 15. Presence of wrinkles at the interface (metal layer) causes light scattering and thus dark appearance under the bright field illumination – Fig. 13 – and is responsible for the orange peel appearance of the print. The wrinkles were formed in the valley areas of the board as a result of stresses present in the laminated structure after the exposure of the laminated structure to the high temperature (extrusion lamination).

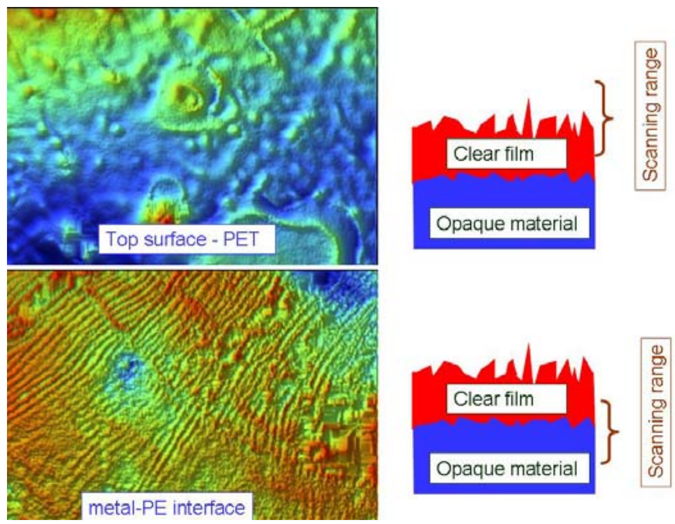


Fig. 14. The orange peel pattern on the surface of laminated print (metallized printed PET film – extrusion lamination to the paperboard surface) –3D images at two different interfaces: top surface (PET film/air interface) and metal/polyethylene (extruded film) interface. The diagrams show how the images were collected at those interfaces – compare the scanning ranges.

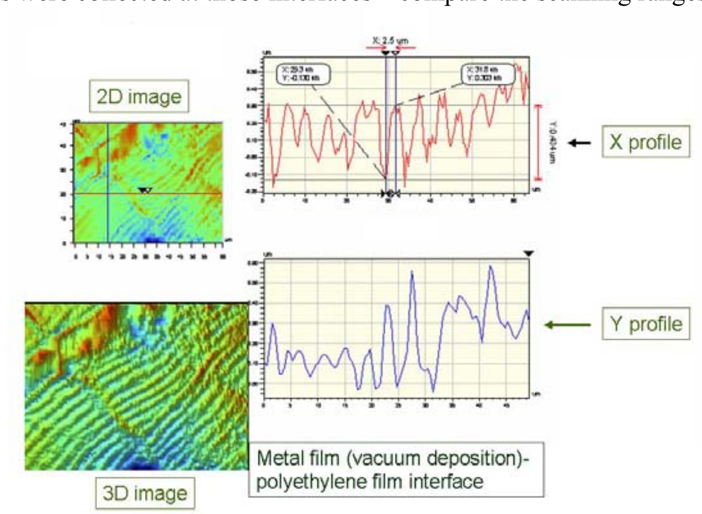


Fig. 15. The orange peel pattern on the surface of laminated print (metallized printed PET film – extrusion lamination to the paperboard surface) – 2D and 3D images and virtual cross-sections along the selected lines at the metal/polyethylene (extruded film) interface. Note the presence of wrinkles – submicron height with the spacing ~3µm

Gravure Printing – skipped dots

Snowflaking (skipped dots) is a very common print defect observed in the gravure printing. The example photomicrograph of such a defect is presented in Fig. 16 along with the 3D image of the same area. As it can be seen in Fig. 16 the skipped dots correspond very well to the paper voids (large valleys). Presence of bumps and voids on the paper surface makes the direct contact of some gravure cells with paper surface impossible (no ink transfer). The cross-section of the skipped dots area of the print shows the presence of valleys (~7 µm deep and ~300 µm in diameter). Bottoms of such deep valleys are never in the physical contact with the gravure cylinder – no ink transfer. The flatness of paper surface is a paramount factor in achieving good printability in gravure printing (no skipped dots - no snowflaking). Any deviation from the surface flatness e.g. bumps or voids on the surface can contribute to the rough printing and skipped dots. Gravure print may be free of any defects when printed on the rough (spacing between the peaks much smaller than the gravure cell size) but flat surface – see Fig. 16. On the other hand very rough print can be obtained during printing on a very smooth surface that is bumpy and contains voids. Therefore, the conventional roughness parameters (e.g. R_a, R_z, and R_{max})

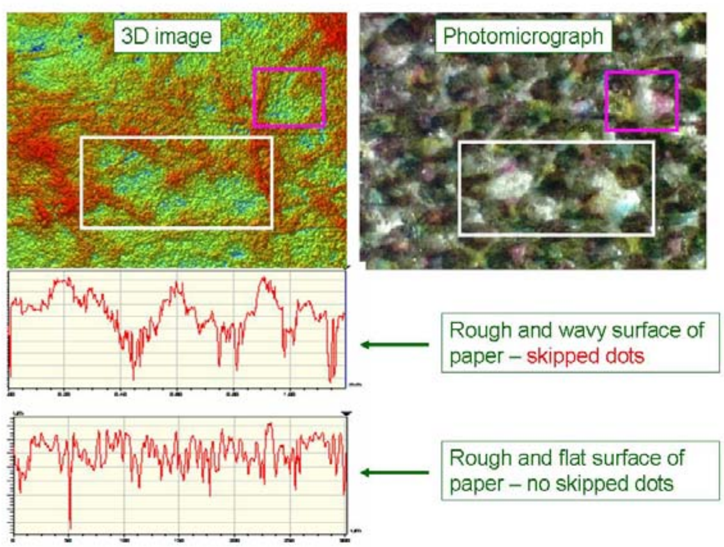


Fig. 16. Skipped dots (snowflaking) in the gravure printing – the photomicrograph, 3D image of the same area of the print and the virtual cross-section across the skipped dots area. Note the presence of deep valleys on the paper surface that were responsible for snowflaking. Rough but flat surface may be free of skipped dots.

may not be good predictors of printability as they are insensitive to the surface feature spacing (Zecchino, 2003). It is known from the literature that snowflaking is mostly due to the paper surface topography (presence of bumps, voids and protruding cellulose fibers and thus lack of direct contact of some gravure cells with paper surface). The population of skipped dots depends on the gravure cell size, the size and height of the voids, protruding fibers and bumps as well as the local paper compressibility.

Ink and adhesive film thickness measurements- step technique

The step height evaluation method described in Fig. 9 allows for measurements of the film thickness. Two examples of such measurements (ink and adhesive films) are presented in Fig. 17. The film thickness of e.g. ink or coating can be determined by the SEM imaging – cross-section of the selected area of the sample. To measure the film thickness using the SEM method one has to use

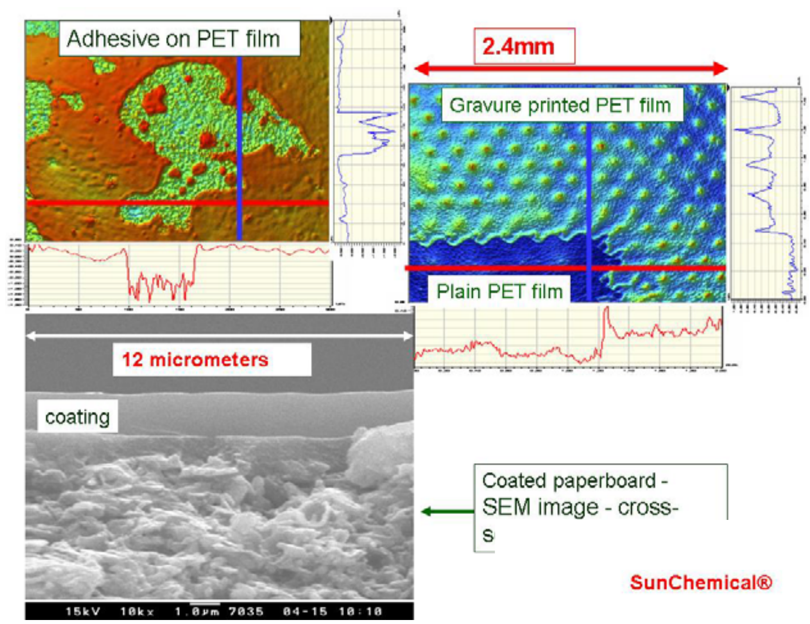


Fig. 17. Determination of ink film thickness using the step technique – see Fig. 9. The 3D images of different samples and their cross-section profiles along the selected lines (X and Y): adhesive film on printed PET film (top view) and gravure printed PET film (top view) – see the text for explanation. The SEM image (cross-section) of the coated paperboard is presented for comparison – determination of coating film thickness. Note the difference in the size of the area analyzed between the SEM image and the image acquired with the optical profiler, 12 micrometers and 2400 micrometers, respectively.

high magnifications. This reduces significantly the size of the area that can be analyzed. This is important as the coating or ink film thickness may vary significantly from spot to spot. For instance, in Fig. 17 the length of the area analyzed with SEM was only ~ 12 micrometers while the area analyzed with the optical profiler was ~2400 micrometers. The important feature of the interferometric technique is the fact that the resolution in Z-direction does not depend on the size of the area analyzed.

Summary/Conclusions

Based on our experience one can conclude that the white light interferometry is well suited to be used for the R&D as well as problem solving in the Graphic Arts Industry. This technology (Wyko NT1100) has the following advantages:

- Non-contact and non-destructive technique (required surface reflectivity >1%;
- Vertical scanning range up to 1 mm.
- Large field-of-view – up to 8.2 mm (data stitching option is available for larger areas).
- Resolution in Z-direction is independent of the field-of-view (the same accuracy for small and large areas tested).
- Fast image acquisition - time ranges from seconds to minutes (depending on the resolution and Z distance to be scanned).
- No sample preparation prior to the measurement.
- Significant time savings in sample analysis.

This technique is applicable to any surface including sticky adhesives, wet inks and coatings, soft and rubbery materials e.g. flexographic plates, lithographic blankets) etc. The list of possible applications of this technique in the Graphic Arts Industry includes (but is not limited to):

- Surface topography, surface area, roughness and the virtual cross-sections of different samples (printing substrates, printing plates, Ballard Shells, prints, etc.).
- Volume calculations – e.g. flexographic anilox roller cells, gravure cylinder cells, volume of porous layer of lithographic plate (non-image area), etc.
- Measurements of surface features using the 3D and 2D images and virtual cross-sections: width and height (lines, bumps and voids); film thickness (inks and coatings) – step technique; thickness of transparent films (e.g. clear coating) – step technique or special software
- Characterization of surface (sample/air interface) and the interface (clear film/substrate) of the sample coated with transparent film e.g. thick clear coating films, reverse printed films and laminated structures.

- Problem solving – e.g. identification of the root cause of “skipped” dots in the gravure printing

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