n- GaugeST Case Study: Thickness & Refractive Index Measurements on a Stent and Balloon sample using Beam Profile Reflectometry

Abstract

One stent sample incorporating a balloon was provided to Nightingale-EOS Limited to evaluate the capability of Beam Profile Reflectometry (BPR), as implemented in the Nightingale-EOS *n*-GaugeST tool, for characterising its coating. High-quality raw data was obtained from the sample and analysis of the data revealed the overall coating thicknesses to be in the range expected. It was also possible clearly to observe the effects of strain in the film.

Principle of Beam Profile Reflectometry

Beam Profile Reflectometry (BPR) is a technique first used for measuring thin films on silicon wafers. Prior to the introduction of BPR, measuring reflectance as a function of angle involved complex and expensive hardware arrangements where both the light source and detector needed to be moved each time a new angle was selected.

As Figure 1 illustrates, BPR overcomes this limitation by using a high-magnification lens to bring a collimated laser beam to a sharp focus. At the focal point, which is typically less than 1µm across, light falls on the sample with the whole range of different angles-of-incidence through which the lens bends the light in order to achieve focus. After reflection, the lens recollimates the reflected light and there is a one-to-one correspondence between the physical location of a ray of light within the recollimated beam and the angle at which that ray was reflected from the surface. It is therefore possible to measure reflectance as a function of angle of incidence for a wide range of angles (typically, for a ~100X lens, a range of 0-60 degrees) simultaneously, with a very short data acquisition time, using an apparatus with no moving parts.

When the beam profile is viewed after reflection from a coated surface or membrane, a characteristic 'bulls eye' pattern is seen due to the pattern of light and dark fringes that form as a result of the interference between rays reflected from the top of the film and those which penetrated to the bottom before being reflected. The amplitude of the fringes depends only on the refractive indices of the materials in the film. The period of the fringes is determined by the film thickness. It is therefore possible to decouple the effects of thickness and refractive index and measure the two classes of parameter independently.

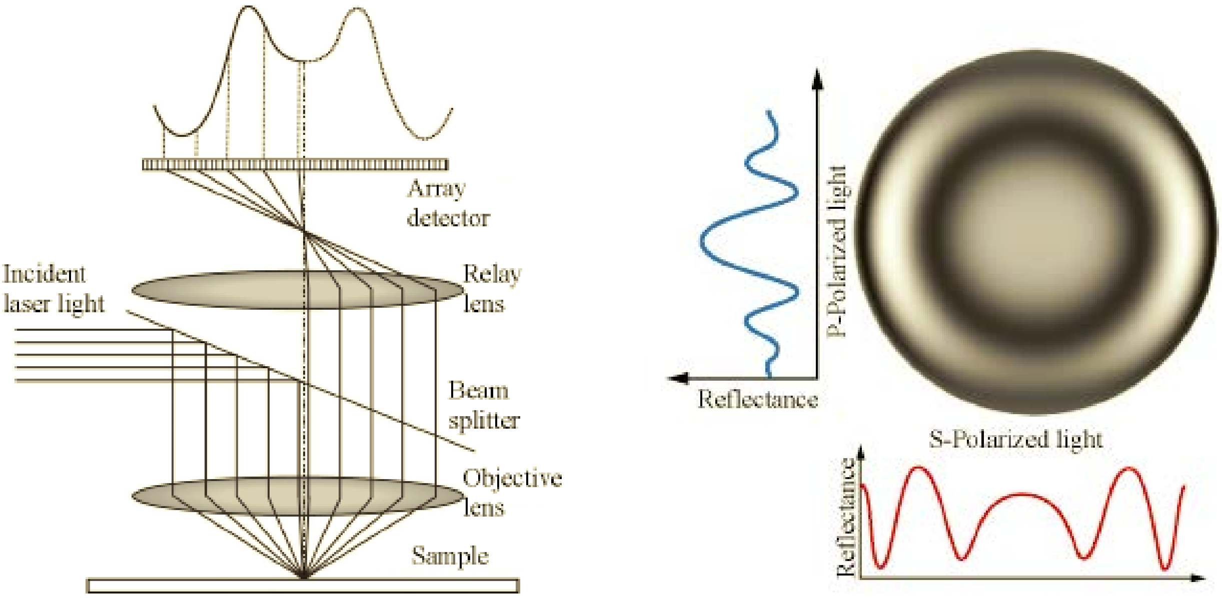


Figure 1: Schematic representation of a Beam Profile Reflectometry (BPR) system

While the ‘bulls eye’ pattern is symmetrical, as shown above, in the case of a flat level surface, if the surface is tilted or curved then a bulls eye pattern is still obtained but the centre moves around according to the orientation of the sample surface at the point where the beam is focused. Figure 2 shows an example of this. By locating the fringe centre automatically and taking proper account of the effect of sample tilt upon the fringe patterns, it is possible to obtain accurate measurements even from surfaces which are significantly tilted (typically, up to ±20°) and to measure the surface orientation as well as the thickness and index. This greatly simplifies the taking of measurements from devices with complex or unpredictable shapes, since so long as the laser spot can be focused upon the sample surface there is no need to ensure that the surface is horizontal.

Compared to other measurement techniques, BPR’s principal advantages are:

- There is no need for prior knowledge about the material’s refractive index (*n*), since this can be measured simultaneously with the thickness.
- There is no need for the orientation of the sample surface to be known at the time when the measurement is made: good results are obtained even if the sample surface is tilted by ±20° when data is acquired.
- There is no need to scan the laser beam through the sample from one surface to the other, relying on the accuracy of a mechanical stage to obtain the measurement: the technique is entirely static and relies on no moving parts either in the optics or the sample-handling, save for what is required to locate the beam on the right part of the sample.

Calibration

The *n*-GaugeST system was calibrated with reference to a set of fused silica (pure SiO_2) discs with thicknesses ranging from ~20µm to ~200µm. A ‘master set’ of discs has been measured on the cmpany’s behalf by the UK’s National Physical Laboratory; these have been used to calibrate a reference *n*-GaugeST in our laboratory, and the reference tool is then used to certify secondary ‘transfer’ standards which can be supplied to customers alongside an *n*-GaugeST system. The system used for this demonstration had been calibrated with reference to transfer set certified on the reference tool. We therefore have a high level of confidence that the calibration of the tool was accurate to within 1µm on all except possibly the ~50µm wafer, where the accuracy is within 2.5µm.

Sample analysis

Measurement using the GaugeST begins with locating the laser spot on the correct part of the sample using the system’s built in optical inspection system. Once the spot is focused upon the required point, the 100X lens is used to acquire the raw BPR data. Figures 2 and 3 show the spot located on one the stent, using a 5X and 20X objective lens respectively. The shape of the strut can clearly be seen, and a high-quality image of the coating surface is obtained - in this case quite smooth, though showing some cracking and ‘crazing’.

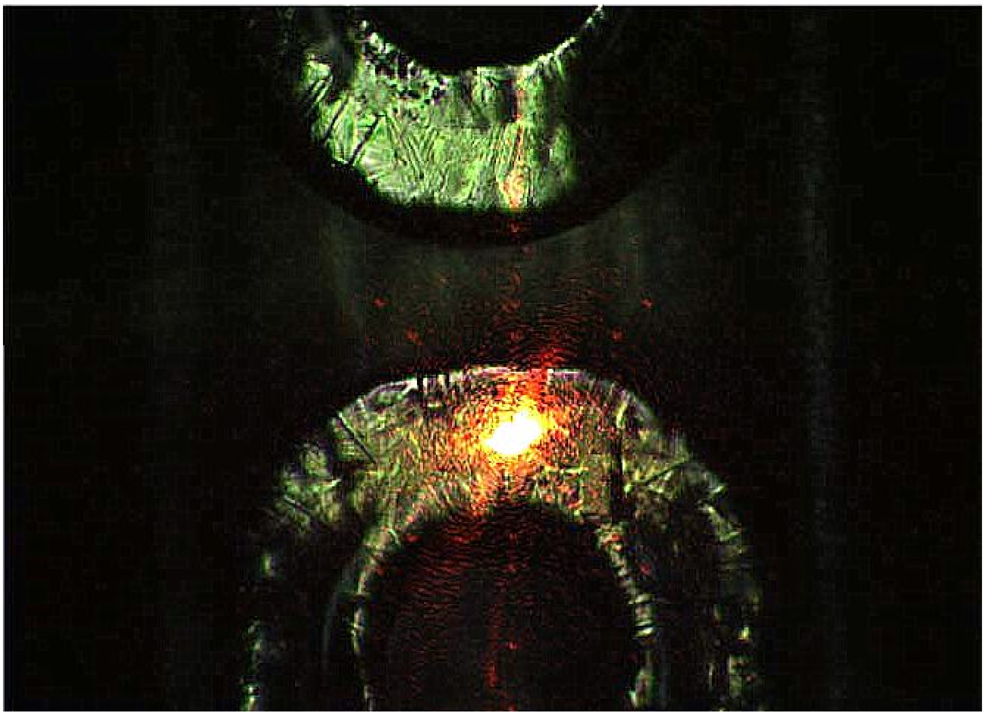


Figure 2: Stent viewed on n- Gauge in 5X magnification.

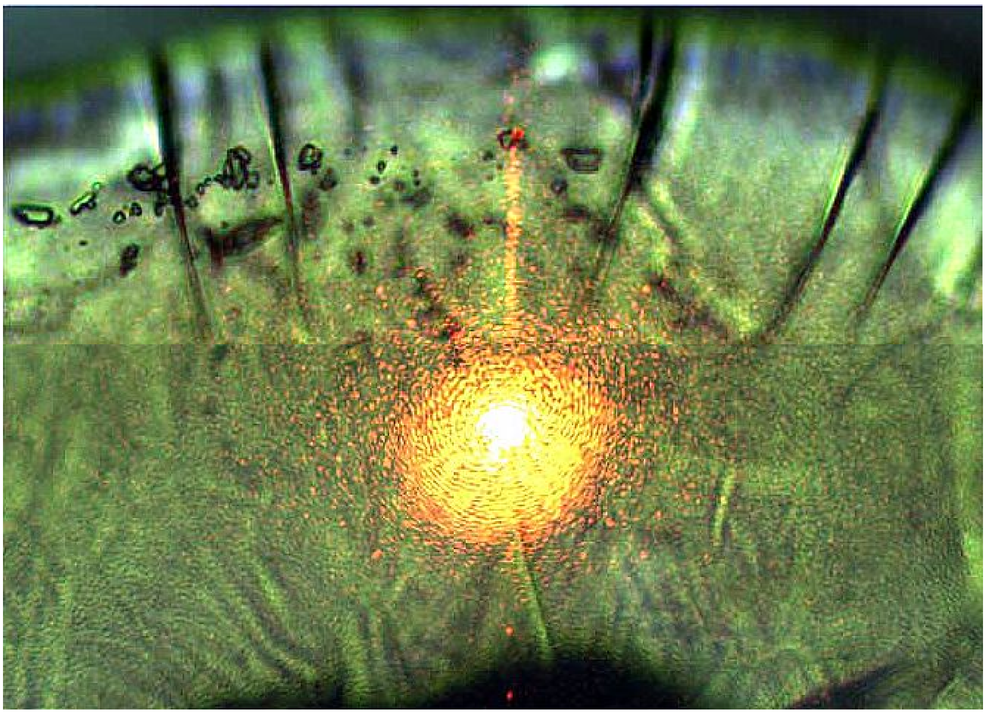
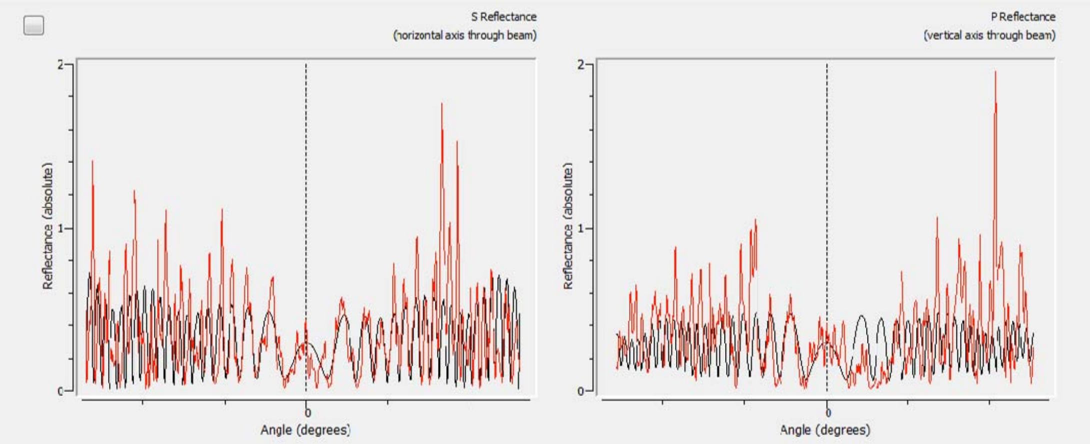


Figure 3: Stent viewed on n- Gauge in 20X magnification.

Results

The sample was measured using random points on the stent struts to collect data. Generally speaking the quality of the coating was as illustrated in figures 2 and 3, generally smooth but with some defects in the vicinity of tight curves. To collect the best quality beam profile data, the spot was located in areas where there were as few defects as possible in the neighbourhood of the beam spot.

Raw data was modelled using a number of alternative approaches, beginning with the simplest model of a single polymer film on the substrate, and then adding extra effects such as surface roughness, strain, and multiple film layers until the best overall fit to the raw data was obtained. The substrate properties were held fixed at the values typical for medical grade (316) stainless steel, though some surface roughness was allowed for. In all cases, the refractive indices of the film was measured in tandem with its thicknesses.



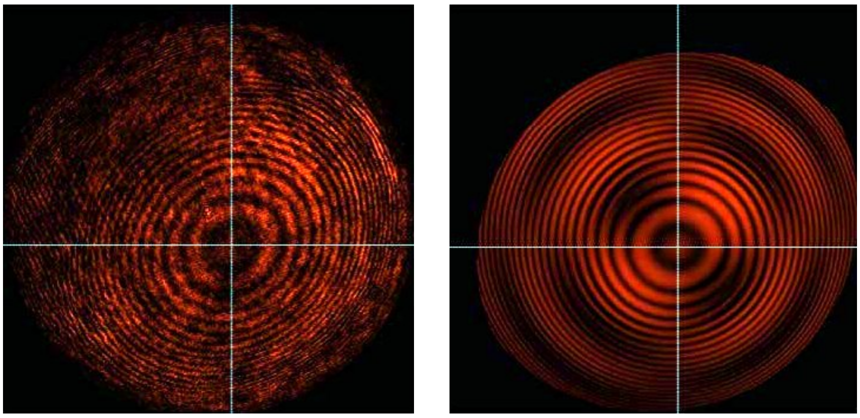


Figure 4:
Raw (left) and modelled data for a model consisting of 31.52μm of strained polymer with an index of 1.773.

Conclusion

The results shown here indicate that the *n*-GaugeST is able to obtain valuable measurement data from stents. The technology delivers the necessary information to characterise such samples, and software can be developed to streamline the process of data analysis in any given application.

Note: The data and conclusions in this case study are provided for information only and are not be used or interpreted for any other purpose.

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