Manufacturing Metrology Team

The University of Nottingham

Polychromatic Confocal Optical Coherence Tomography to image cross sections of Electro-Optical Polymer Medical Microtubing

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Introduction

- Polymer extrusion is employed for the manufacture of medical polymer microtubing with diameters between 0.2 mm and 14 mm and tolerances as low as ± 20 µm, often with multiple lumens.
- The current best method of imaging its cross-section is via manual inspection under a microscope. This process is destructive, and it is not in-line or efficient.
- The following work presents a substitute for this process, employing 'Polychromatic Confocal Optical Coherence Tomography' (PCOOT) to non-invasively, and in-line to its manufacture, image the cross-section of the microtubing at a resolution of 2 µm.

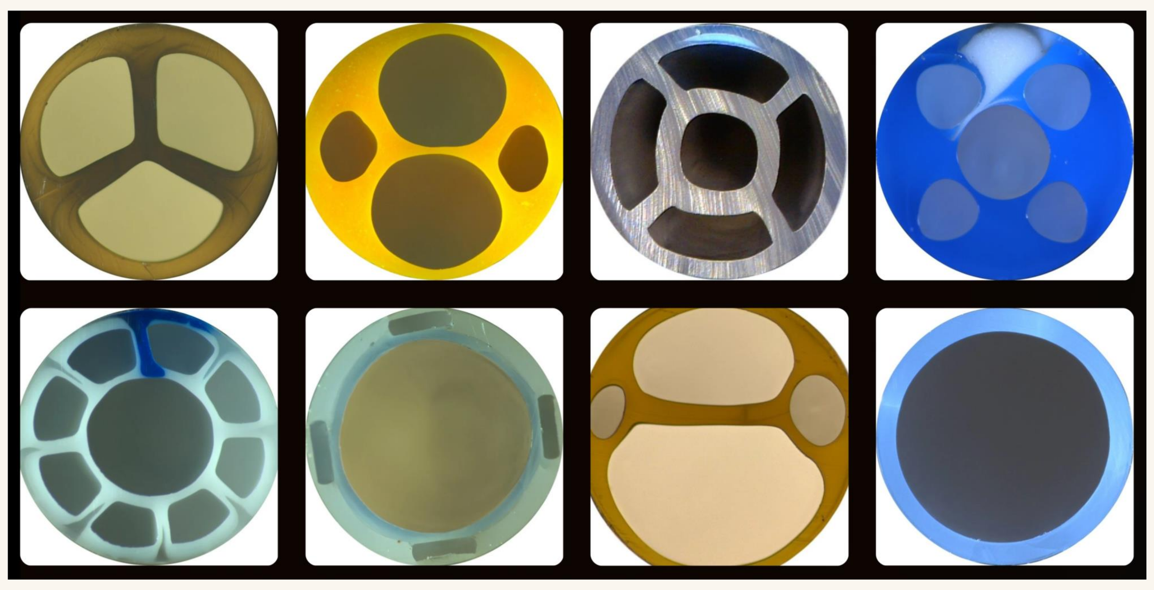
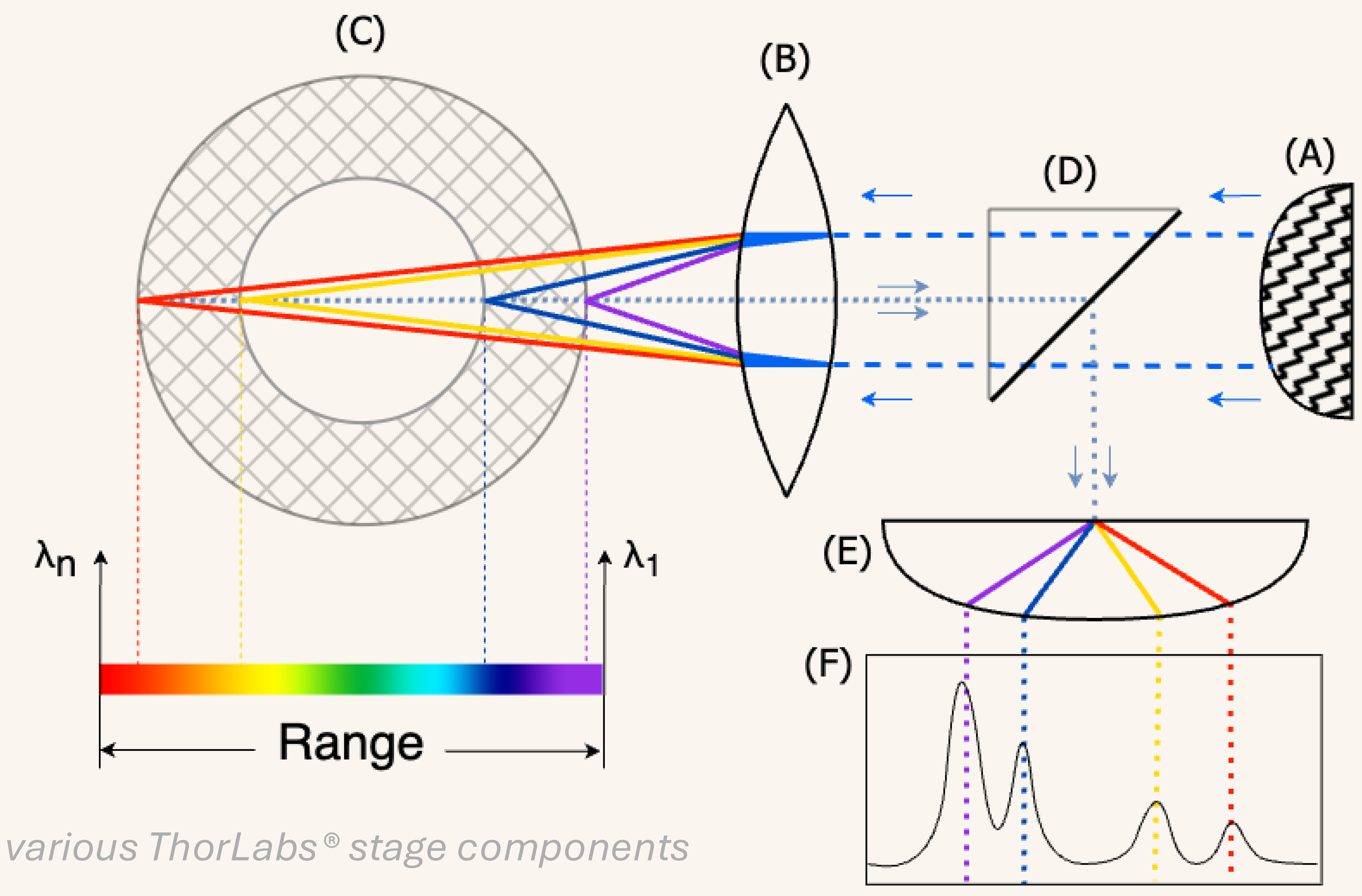


Image courtesy of Enki® microtubing website

Methodology & Setup

Schematic diagram of the confocal device's working principles and their application to a cross-section of microtubing.

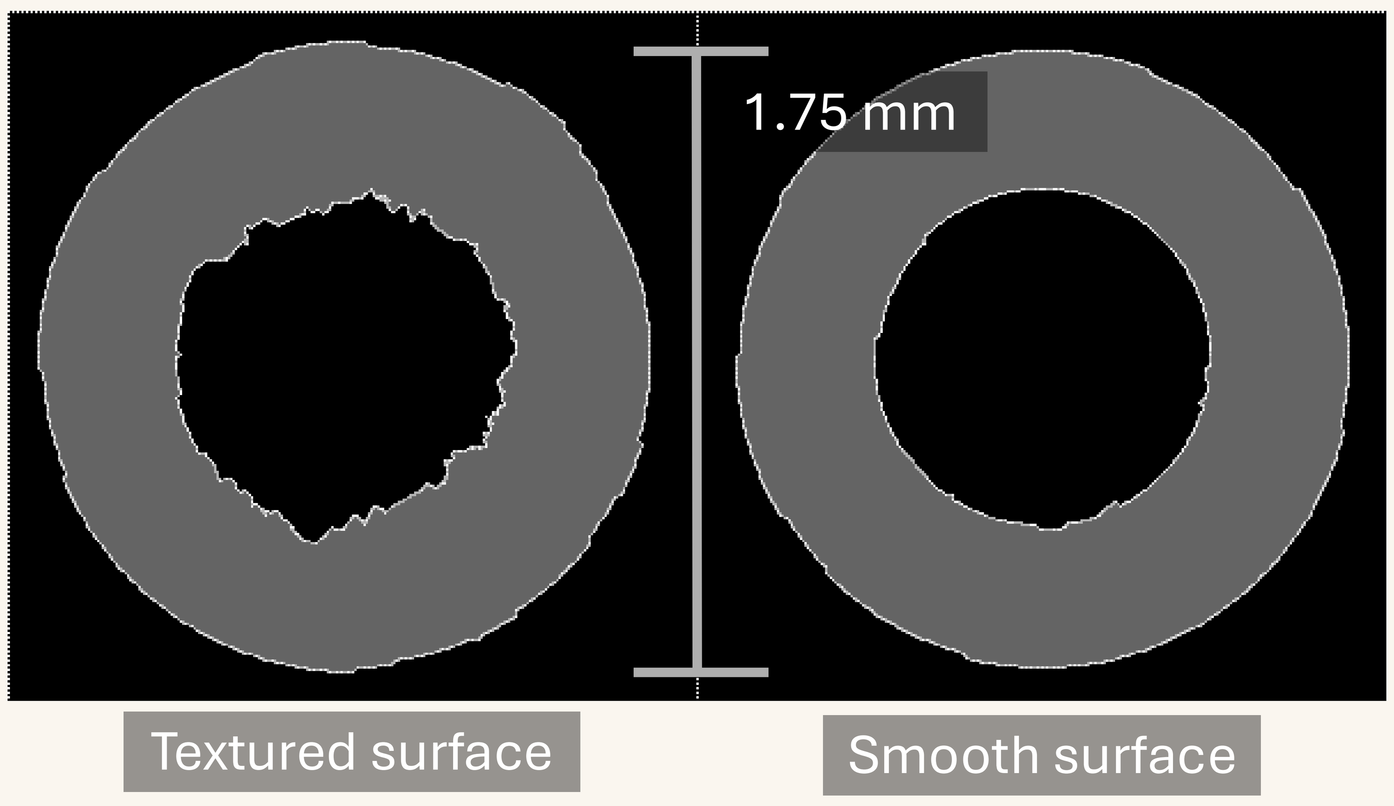
- Polychromatic light is emitted from a source (A), and it is refracted within the objective lens (B) to focus wavelengths of the emitted light across a Range.
- The microtube's (C) polymer-air interfaces cause refractive scattering of light with a wavelength which is respective to the position in the Range. Some of this light is reflected back through the objective lens at an ideal angle, meaning no misalignment due to refraction.
- The reflected light travels back through the optical fibre and into the controller, where it is reflected by a beam splitter (D). The light is then dispersed in a semicylindrical prism (E) and evaluated in a spectrometer (F).
- To achieve a full image, the microtubing was incrementally rotated about its centre and the gathered data was compiled respectfully.



Equipment used includes the Micro-Epsilon® Confocal DT2422 and various ThorLabs® stage components

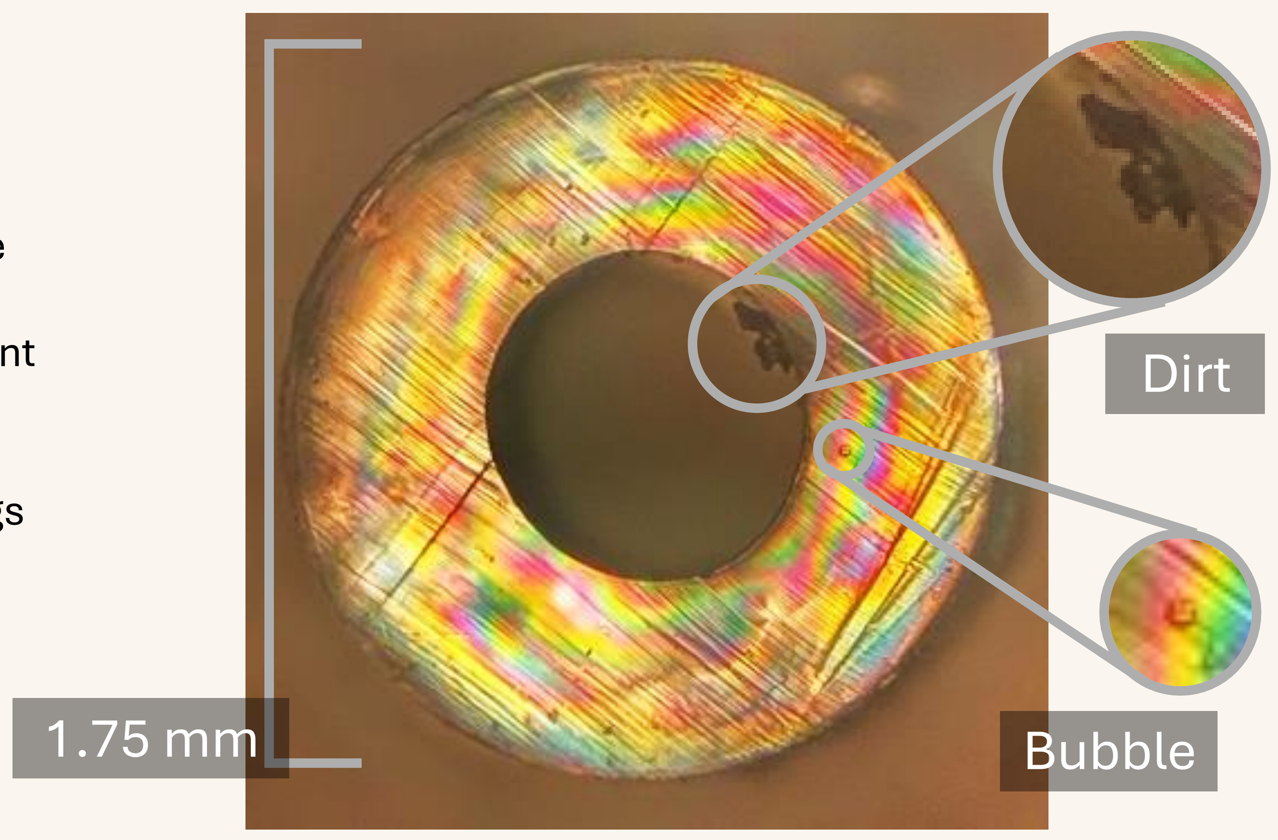
Results

- Compiled data is visualised in adjacent 300 px by 300 px bitmaps in addition to a cut section of the microtubing as seen under a microscope. The colouration of the microtubing is a result of birefringence (see below).
- Non-perpendicular angles of incidence mean that the light refracts within the polymer, resulting in skewed data. This results in a recorded polymer thickness which is smaller than the actual thickness; compare images on the right and below.



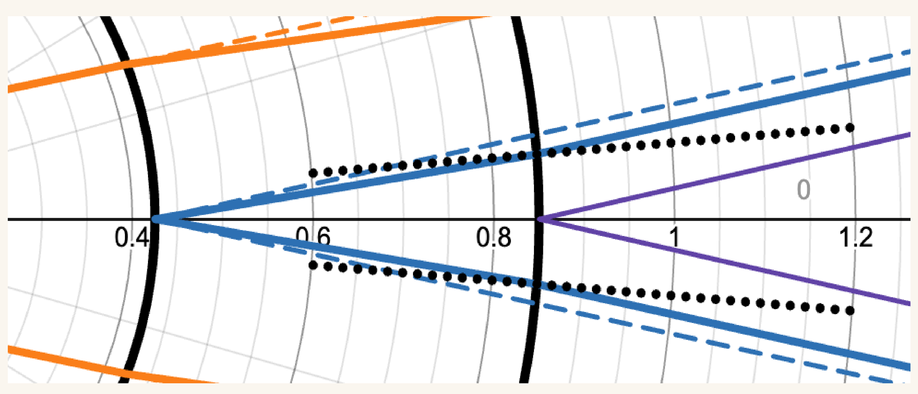
Effect of Birefringence

- Birefringence is an optical property in which the materials refractive index depends on the polarisation and propagation direction of light.
- Birefringence is induced via residual stresses produced in the polymer microtubing during polymer extrusion. The stress patterns are indicated by the colouration of the tubing adjacent and are too complex to quantify.
- This results in orthogonal components of light travelling at different speeds through the polymer, resulting in two readings where only one should be observed.
- A circular polariser was used to mitigate for this effect.



Effect of Refraction

- Refraction occurred at polymer-air interfaces, as illustrated by a to-scale plot of the path of light on the right. Dashed lines indicate the ideal light path, and solid lines indicate the actual light path.
- To mitigate for this, the refractive index must be known and adapted within data processing.



Created using DESMOS®

Conclusions

- PCOOT is an effective micrometre-resolution imaging technology for multi-layered transparent bodies, functioning via the identification of material interfaces at given distances.
- PCOOT is advantageous due to its virtually instantaneous rate of data acquisition, and its multi-layer capabilities.
- PCOOT is effective for application to multi-lumen medical microtubing. This is a complex application.
- In this application, data is often skewed due to refraction and can be mitigated for by adapting results with the refractive index of the material.
- Similarly, complex cross-sectional architecture is difficult to quantify due to multiple instances of refraction.
- The effect of birefringence has been mitigated for by employing a circular polariser.

Future Work

- Repeat with more precise stage components with the aim of reducing noise and improving the consistency of gathered data.
- Reduce the effect of refraction by submerging the body in a fluid of known refractive index.
- Consider combining this technology with other OCT techniques.

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