IPC-OCT

In **P**rocess **C**ontrol with
Optical **C**oherence **T**omography

Activity report for period P1+P2

This report is part of deliverable

D8.5 (Final Project Report: Ref.:
IPC-OCT/D8.5/UAR/DS010506)

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Summary

The activity report covering period P1 and P2 (month 1-27, total duration of the project) has already been issued within deliverable D8.5 (Final report, ref.: IPC-OCT/D8.5/UAR/DS010506) and is given within this document as separate report.

All Workpackages (WPs) have been successfully completed, all objectives have been fulfilled and each milestone (M1-M4) has been reached: a compact prototype OCT scanner operating with a broadband light source has been developed and tested. The targeted depth resolution of 5 µm in materials has been reached and even surpassed (~4 µm). The applicability of the novel scanner has been proven on parts and samples from the individual end-users (direct project partners or from industry supporter group). Comparative studies between OCT, X-ray computed tomography (CT), atomic force microscopy (AFM), micrographs, whitelight interferometry and even synchrotron phase CT resulted in a deeper understanding of the advantages and limits of OCT with respect to the other individual characterisation methods. Field measurements performed at the production site of one partner concluded the evaluation study of the new scanner and demonstrated the usefulness of this new characterisation tool in the production process.

Finally, the project extension of 3 more months has been used to study stability issues of the laser light source and to perform further optimisations and test measurements on selected samples and material systems.

Accompanying dissemination activities, including e.g. trade fair presentations, newspaper and magazine articles, conference contributions and scientific publications, helped to increase the public and expert awareness and to pave the way for an effective exploitation of the project results.

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1. Technical Overview

The main goal and objective of the project was to employ a new, easy to use tomographic method for the in-process control/inspection in industrial production.

A set of objectives has been defined in order to gauge the progress and success of the project's research:

1. **Detailed survey and analysis to define specific requirements of technology users in production processes**

   The exact requirements of the technology users had to be clearly defined to tailor the system to their specific needs. Starting from their technological "problem", the parameters of the future systems were deduced.

2. **Development of a compact broadband light source using photonic crystal fibres for supercontinuum generation and optimisation for use in OCT Scanner System**

   A new broadband source was developed based on supercontinuum generation in photonic crystal fibres (PCFs) using a compact femtosecond pulse source. At least, it was planned to provide a minimal spectral width, so that it is possible to obtain a resolution of 5 µm within materials. This set target has been reached and surpassed. The first prototype was available at midterm (Milestone M1) and has been successfully evaluated in combination with the OCT scanner .

3. **Development of OCT scanner for industrial applications and optimisation of OCT-system for use with new broadband laser source to meet requirements of end-users**

   An OCT-system for industrial applications was developed based on the defined requirements of the end-users. At first, a prototype OCT scanner using a conventional light source was set up for industrial use and was available at midterm, (Milestone M2) and was then modified and combined to form the novel OCT-scanner system (transportable system at M3 (month 20)).

4. **Testing and validation of OCT**

   The capabilities of the novel OCT-system were determined to increase the confidence in this characterisation method. This was accomplished by direct comparison with alternative methods, the most important being computer tomography (Milestone 4: final evaluation at month 27).

5. **Exploitation and Usage of knowledge**

   The capabilities of the OCT-system has been and will be further spread among possible future end-users (industry supporter group). Additional activities to increase the public and specialist's awareness of the novel method (project homepage, trade fair presentations, conference and journal papers) were and will still be covered even after project's end.

Specific Objectives for Months 1-27

Summarising, the specific objectives targeted for initiation and completion within months 1-27 were:

Objective	WP
Determination of technology user's requirements	1
Development and optimisation of broadband light source	2
Development and optimisation of industrial OCT-scanner	3
Evaluation of combined system of light source and scanner	2,3
Comparison with alternative methods (especially: CT)	4
Application of OCT for miniature- and microparts	5
Field measurements with new system at industrial production site	6
Application of OCT on samples of industry supporter group	6
Final assessment of results	6
Definition of exploitation routes	7
Dissemination activities: project homepage, public project description, publications,…	7
Project management	8

2. Technical Progress for whole project duration (Months 1-27):

2.1 Progress Reports by Workpackage

The technical activities by work package are given below, planned personnel effort (PM=personnel month) for each partner per WP is given in brackets:

WP	WP leader	WP Title
1	UAR	Requirements of technology users

Participating partners: HIQ (0.5), IOP (0.5), AP2K (0.5), PKT (0.5), MRT (0.5), SMP (0.5), UAR (2), FHW (2)

Description/Summary for whole project duration

The requirements of the technology users of the novel OCT-scanner were investigated in order to tailor and optimise the measurement system to their specific needs. The partners acting as technology users, namely PKT, MRT and SMP, provided at first test structures and samples of typical products. Standardized survey and inquiry sheets were created and used for each sample type to specify the exact properties (material, geometry, surface structure, colour, features to detect). Furthermore, recommendations on the achievable resolution/accuracy, acquisition speed, instrument size, … of the OCT-scanner were given. Starting from the technological "problem" of the end-users, typical system parameters were deduced for the main envisaged applications, namely:

- required penetration depth
- resolution
- scanning speed
- if applicable: sample handling
- system size (e.g. to be fitted in production line for inline monitoring)
- max. system costs for reasonable return on investment
- additional parameters to be detected (e.g. strain, flow pattern, crack detection)
- software requirements (degree of user-interaction)

The outcome defined the wavelength and spectral width of the broadband light source (see WP2) and the set-up and design of the OCT scanner (see WP3).

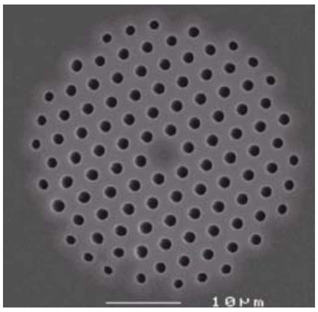
Deliverables
The deliverable D1.1 has been issued in month 4.

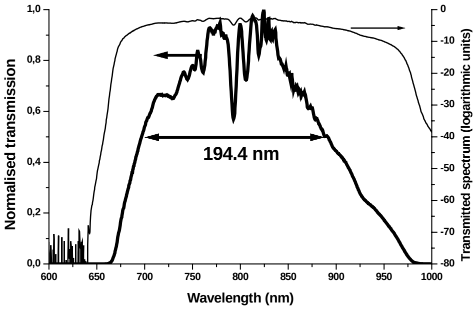
WP	WP leader	WP Title
2	HIQ	Development of broadband light source

Participating partners: HIQ (9.5), UOB (16), UAR (2)

Description/Summary for whole project duration

This WP has been dedicated to the development of a novel broadband light source. A compact ultrafast laser delivering femtosecond pulses (10^{-15} s) has been developed by partner HIQ for this reason. The laser itself is a mode-locked Ti:Sapphire system delivering sub-50fs pulses with a repetition rate of 70MHz and exhibiting an average output power of 140mW. The pulses were then directed into a so called Photonic Crystal Fibre (PCF), where the pulses generate a broad spectrum (supercontinuum (SC)). The PCFs exhibit air-holes arranged in a regular pattern which run through the whole fibre (see cross-section in fig. 1). The geometrical arrangement of the holes is crucial and had to be adjusted to the pulse characteristics of the laser source. The design and fabrication of the PCF has been performed by partner UOB, tests and experiments on the SC generation have been performed in combination with partner HIQ with final tests on the light source performed by partner UAR. It has to be noted that not only a broad spectrum is necessary for OCT, but the spectrum should ideally exhibit a smooth Gaussian shape. This has to be equally considered when designing appropriate PCFs. In order to achieve a broad spectrum with an acceptable spectral shape, partner UOB decided to use tapered PCF fibres. The widest supercontinuum has then been obtained for a fibre taper waist of 40 µm making the fibre an “endlessy single mode fibre” with a full normal dispersion curve with no zero dispersion wavelength. Figure 1 b) shows the final achieved spectrum of the developed light source: a spectral width of nearly 200 nm is obtained with a coupling efficiency of 78%, delivering up to 100 mW at the fibre end. Furthermore, the shape is Gaussian with only small spectral modulations.





(a) (b)

Fig. 1: a) Cross-section of the fabricated PCF-fibre b) Finally obtained broadest supercontinuum spectrum with PCF and femtosecond pulse laser.

In the course of the project, unexplained degradation effects have been experienced for the femtosecond Ti:Sapph. laser prohibiting continuous operation on a time scale of 10.000 hrs MTTF (mean time to failure). These effects occurred only after 500 hours of operation and were the main reason for the project extension of additionally three months, as accepted by the EC: the further research activities to find the source of the instabilities included the investigation of outgassing effects within the laser and chemical reactions taking place at the laser spot during long-term operation of the laser (aging). Subsequent investigation of the degradation symptoms by electron microscopy and elemental analysis have been performed. Partner HIQ finally found silicon deposits on the Titanium-Sapphire crystal of the laser. After removing the silicon from the crystal, the laser showed a good performance again. Additionally HIQ investigated where the silicon came from and found some probable sources e.g. silicone ring of laser sealing, silicone powdered gloves, a.s.o. With these results and the following changes in production HIQ is now able to deliver the laser source with a sufficient long time performance.

Deliverables
The deliverables D2.1-D2.4 have been issued/delivered in months 8, 12, 15 and 20.

WP	WP leader	WP Title
3	IOP	Development of industrial OCT-scanner

Participating partners: IOP (20), UAR (10)

Description/Summary for whole project duration

A compact, robust scanner for industrial applications and based on the OCT measurement principle has been developed by partner IOP and evaluated in depth by partner UAR. Of importance was the optical design to transmit the broad spectrum and to achieve tight focusing onto the sample. Further attention has been paid to increase the measurement rate to several kHz for industrial relevance and to optimise the robustness of the individual modules. Especially the interferometer module inside the scanner head was optimized for minimum vibration susceptibility. A focussing actuator is tightly integrated and able to track distance variations of up to several mm in less than 1/10th of a second. All electronic interfaces were standardized to get access to only one external control unit. In addition, the cable lengths of the optical fibre from the sensor head to the control unit were shown to have no impact on the signal quality, so it is easily possible to mount the compact scanner head on a production machine and the control unit far away. The optical information from the corresponding cable is fed into the control unit to be converted into a computer readable signal. The control unit comprises the following units which can be exchanged or supplemented: Optical-electronical converter, DSP (Digital Signal Processor) and actuator module of external stages. Final tests showed that the following parameters of the whole scanner system were realized:

- Accuracy in depth direction: 0.5 µm
- Acquisition rate: 4 kHz
- Spot size: 7 µm

In a second step, the industrial scanner has been combined with the broadband light source and tested and evaluated in depth by partner UAR. As a final result the initially targeted depth resolution of 5 µm in materials has been surpassed by 20% and the system prototype is now capable of delivering measurements with 4 µm depth resolution. In order to demonstrate this improvement a multilayer foil has been imaged once with a standard system using a superluminescence diode source (SLD) (fig. 2, top image). The individual layers are poorly resolved and the interfaces appear as blurred stripes. Furthermore the image severly suffers from side-lobes generated by the SLD. In contrast, the newly developed compact device clearly resolves all layers (fig. 2, bottom image). Especially the thin functional layer in the middle is accurately imaged.

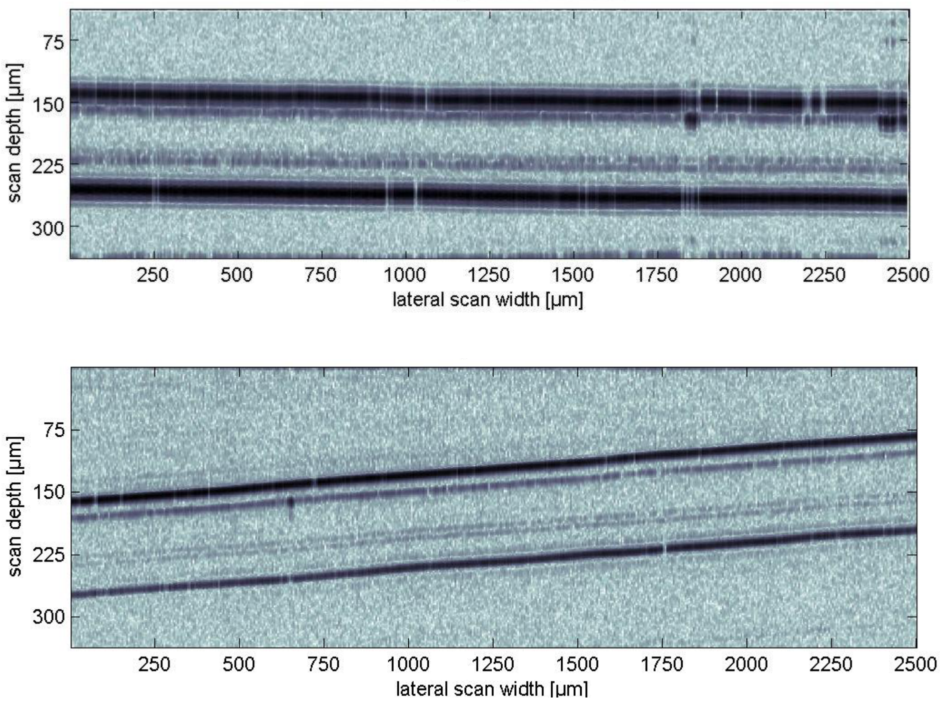


Fig. 2: top: Multilayer foil imaged with a standard light source (SLD).
Bottom: Image taken with new industrial OCT prototype: the individual layers can now clearly be distinguished.

The new scanner system combined with the PCF light source has been further evaluated and tested: it has been shown that the setup surpasses the SLD based OCT version in terms of bandwidth, power and depth resolution. Providing 80 times more power and a four-fold increase in bandwidth, the PCF source exhibits also a comparable noise level at the acquisition frequency of the single element detector (MHz-range) and provides the OCT scanner system with accuracy/repeatability in the nm range. At the end of the project, a repeatability of better than 100 nm could be achieved as it is demonstrated in fig. 3 below.

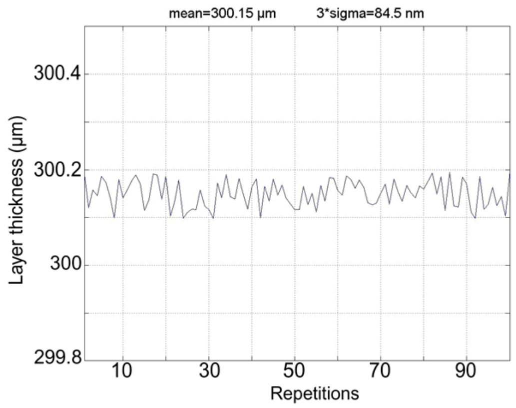


Fig.3: Repeatability test of the scanner showing accuracy better than 100 nm.

An extension of the system with attached galvano-scanner facilitated the investigation of larger specimens and an additionally tested polarisation-sensitive optical unit provided the system with birefringence detection capabilities. Finally, the broadband laser source has been transferred from UAR directly to the site of partner IOP for further improvements in terms of stability and depth resolution, part of an ongoing co-operation of partners HIQ and IOP after the project's end for common exploitation purposes.

Deliverables

The deliverables D3.1-D3.4 have been issued in months 12, 17 and 21.

WP	WP Leader	WP Title
4	FHW	Test of OCT and comparison with alternative methods (CT)

Participating partners: AP2K(10), PKT(5.5), MRT (1), SMP(1), UAR(3), FHW(13)

Description/Summary for whole project duration

The OCT method and the developed prototype have been used to measure typical products and materials of the involved end-user partners (PKT, MRT and SMP). Partners AP2K, UAR and FHW performed the individual measurements and/or evaluated the results, either with OCT or alternative methods like CT, optical microscopy, stereo microscopy and micrograph sectioning, coordinate measuring machine, white-light profilometry and atomic force microscopy in order to generate a deeper understanding of the characteristics (advantages and limitations) of OCT for non-destructive testing (NDT).

The individual samples were made from a variety of polymer materials ranging from special photoresists (SU8) to more conventional materials, like PP or PE (polypropylene and polyethylene) and exhibited different sizes and geometries, reflecting the functionality of the part (see D4.1 and D4.2). For each part, a special measurement problem (defect detection, determination of geometry, …) had to be solved, testing the usability of OCT. In fig. 4 and 5, some of the applications are exemplified, like the detection of defect structures on photoresist moulds on the interface (MRT) or the determination of the linearity of sidewalls in rotor pieces (PKT).

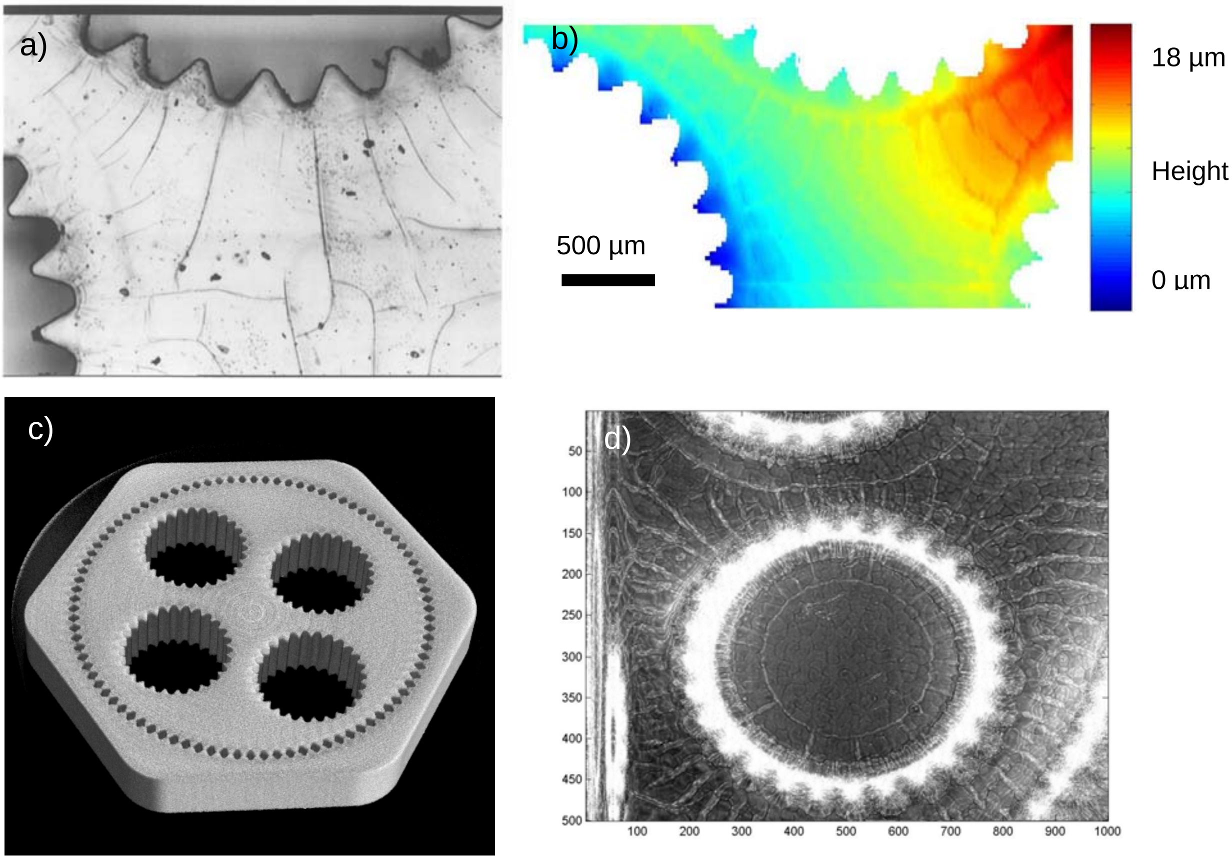


Fig.4: a) microscope image of defect structures on gear wheel moulds from partner MRT, b) OCT topography showing the height of the defect structures, c) CT image of whole structure (defects too small to be detected with CT), d) defect structure imaged in transversal OCT image.

Especially in fig. 5, the complementary aspects of OCT and CT are demonstrated: with CT it is possible to obtain a full 3D data-set of the product for an overall evaluation. The depicted rotor was measured with the maximum possible resolution of the CT (for this sample size and CT settings: ~14µm) and compared to a CAD model. For the determination of the linearity of the inner sidewalls, OCT measurements complemented the evaluation, measuring the inner profiles with higher accuracy in the sub-µm range, necessary for future product improvements.

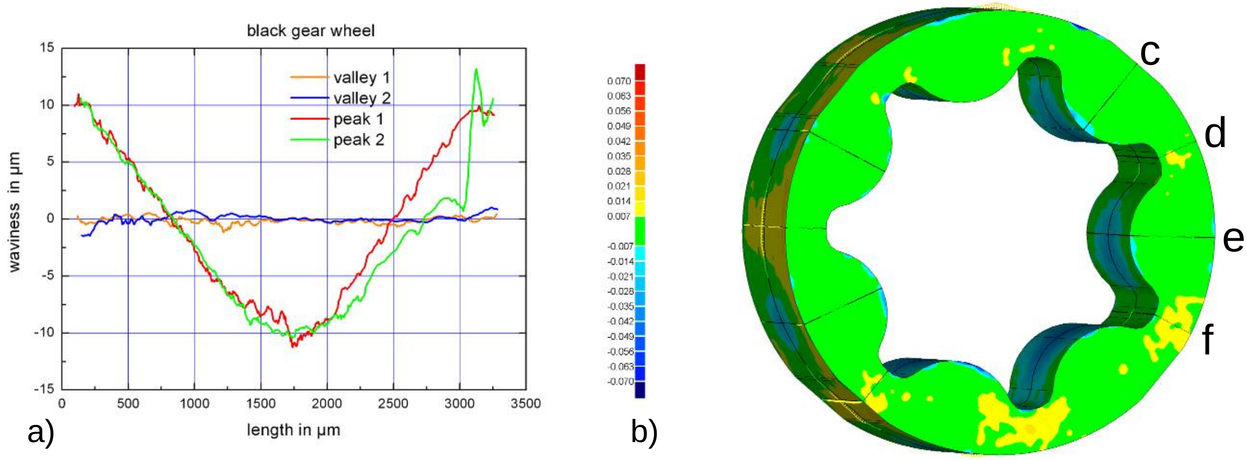


Fig.5: a) OCT measurements on the linearity of the inner sidewalls with sub-µm resolution, b) colour coded picture of the comparison between CAD model and CT scanned structure.

Deliverables

The deliverables D4.1 and D4.2 have been issued in months 12 and 22.

WP	WP Leader	WP Title
5	MRT	Microsystem demonstrator

Participating partners: IOP (1), AP2K(3), PKT(1), MRT (3), SMP(2.5), UAR(4), FHW(4.5)

Description/Summary for whole project duration

As presented above and in the individual deliverables, OCT is very well suited for the investigation of semitransparent samples with better resolution than CT. For samples with some centimetres of size OCT is the better method for detecting structures in layers or regions near to the surface, whereas CT can give full 3D information of the whole sample albeit with lower resolution. Especially for miniature and micro-parts the measurement accuracy and resolution are challenging tasks. Therefore, the tasks within this WP have been dedicated to evaluate in depth the potential of OCT and of the new scanner for the investigation of micro-/miniature parts provided by partners SMP, PKT and MRT.

One main task was the evaluation of the resist structures provided by partner MRT for microparts using Direct-LIGA technology. These resist patterns with very high height-to-width aspect ratios which are produced by X-ray depth lithography. Typical structure dimensions of the resist moulds are space widths of less than 25 µm and simultaneously heights of more than 1 mm, resulting in aspect ratios of higher than 40. Such resist forms cannot be characterised non-destructively with measurement tools which are currently available. The evaluation of other samples included optical waveguides (MRT), fabricated regular surface patterns on lenses (PKT), miniature optical elements (PKT) and very thin foil laminated membranes of fluoropolymers (SMP).

In detail, the characterisation of the miniature optical element (diameter 1.6 mm) of partner PKT included the determination of the corrugation of the top surface of the cap, the determination of the wall thickness and the parallel arrangement of the top surfaces (window for transmission), as depicted in fig. 6.

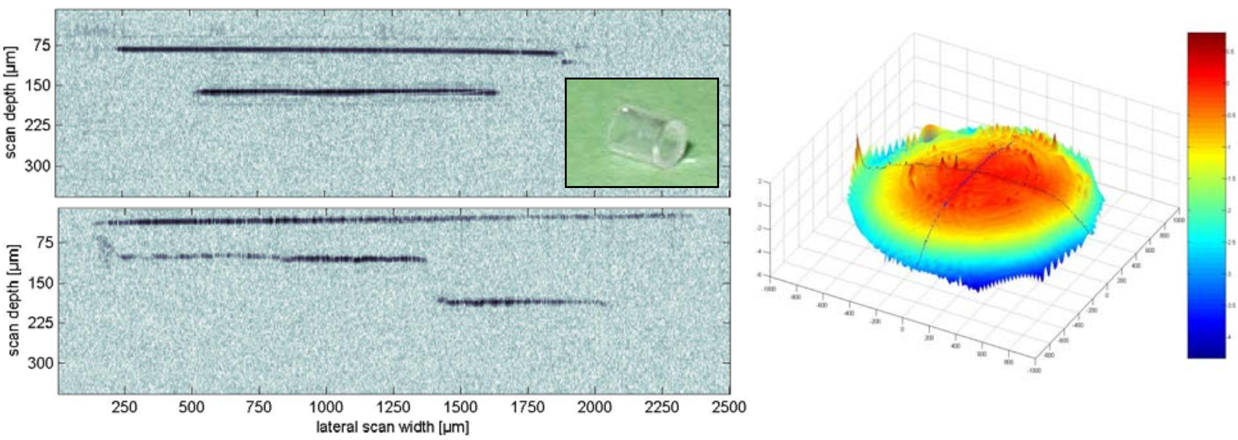


Figure 6: left) measurements of wall thickness of miniature optical part (inset: photograph of part), right) structure of transmittance plane of injection moulded optical element (colour encoded z-axis in µm)

The work of partner MRT was focused on the verification of the to date achieved results, and on the demonstration of the practical value of OCT for the optimisation of X-ray lithographic processing. Extensive test series including several wafers which were processed by X-ray lithography were investigated in this context. The work included in detail:

– coating of 4“ wafers with ultra-thick SU-8 resist (~ 1000 µm layer thickness), and following solvent removal by prebake processing;
– exposure of the resist coated wafers at the synchrotron source with different series of dose values (in cooperation with BESSY GmbH, Berlin);
– experiments with different regimes of post exposure bake (PEB) which triggers controlledly a chemical crosslinking reaction within exposed areas of the resist and makes this areas insoluble;
– development of the resist layers with developer solvent which removes non exposed and non cross-linked resist from the wafer.

The desired resist structures (resp. moulds) with the high aspect ratios mentioned above remain on the wafer. As a secondary effect, the resist is shrinking during the lithographic processing which is causing undesired mechanical stress within the material. Goal of process optimisation is to minimise these effects. The test series were made to demonstrate the suitability of OCT to support effectively this optimisation task.

The OCT measurements were then made by partner UAR and were evaluated at MRT in Berlin. As a result, the practical experience could be confirmed that an exposure dose of 15 J/cm^3 leads to better lithographic results than e.g. 10 J/cm^3. A lower adhesion strength of the resist structures at the substrate is experienced with the lower exposure dose. With OCT it could be proven that higher mechanical stress at the resist-substrate interface plays a role. This fact was a little surprising because with lower exposure dose occurs lower crosslinking which leads to lower shrinking of the resist and so rather lower stress (and not higher) was expected.

Partner AP2K used sets of measurement results of partner UAR for the development of an sidewall reconstruction algorithm for the photoresist-structures of partner MRT. In detail following points had to be addressed:

- The exact position of sample rotation point and the sample rotation angle cannot be precisely determined during experiments, generating large errors in reconstruction algorithm;
- The poor signal/noise ratio of the signal on the inclined walls affects dramatically the reconstruction accuracy;
- Some sample analysis requires a multi-diffraction path, in successive material-air layers.

For avoiding above problems several new techniques were implemented, substantially increasing the initial program complexity:

- The collected data was resampled and filtered (histogram thresholding, averaging, median, look-up-table control) for having a maximum signal to noise ratio;
- The first sample surface was detected by fitting the points' cloud with an inclined line, getting in this way the sample rotation angle;
- Surfaces where a diffraction occurs are determined also by fitting the data with lines;
- A multi-diffraction successive algorithm has been implemented;
- An intuitive representation by overlapping initial data with the diffracted paths has been added.

An actual screenshot of the final software is given in fig. 7.

Finally, the investigation on foil laminates for filter membranes of partner SMP has been performed. A classification of the defects has been made (see D5.1) and helped partner SMP to identify critical points in the fabrication process. The evaluation results will be used for the continuous redesign of these parts. Examples of the membranes evaluation with the novel OCT scanner are given in fig. 8.

Deliverables
The deliverable D5.1 has been issued in month 22.

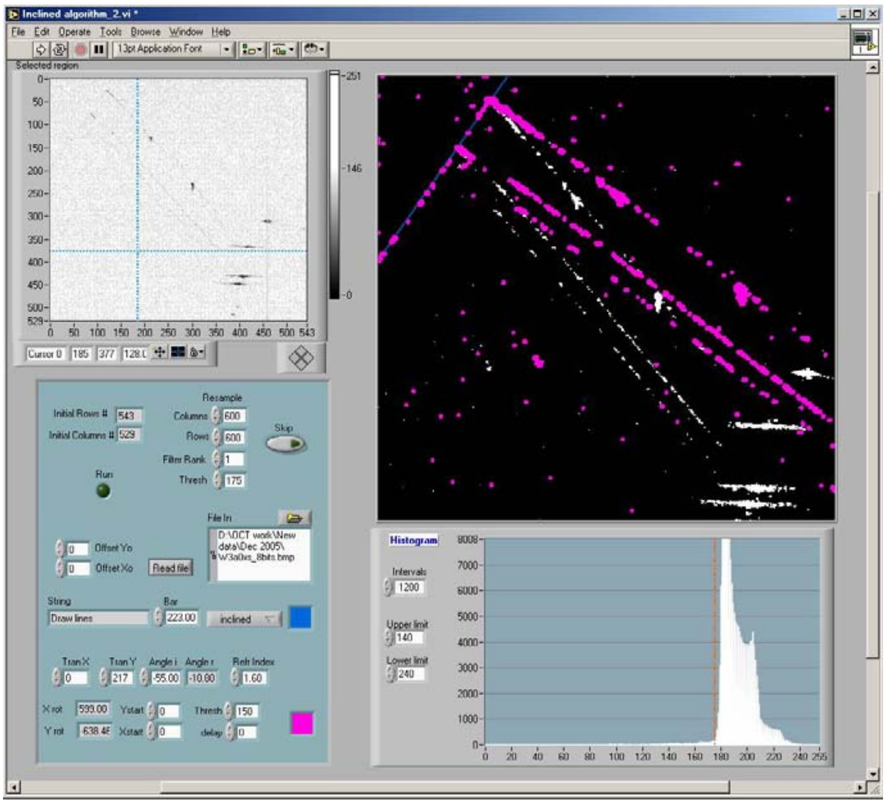


Fig. 7: Screenshot of developed software for sidewall reconstruction of photoresist mould structures

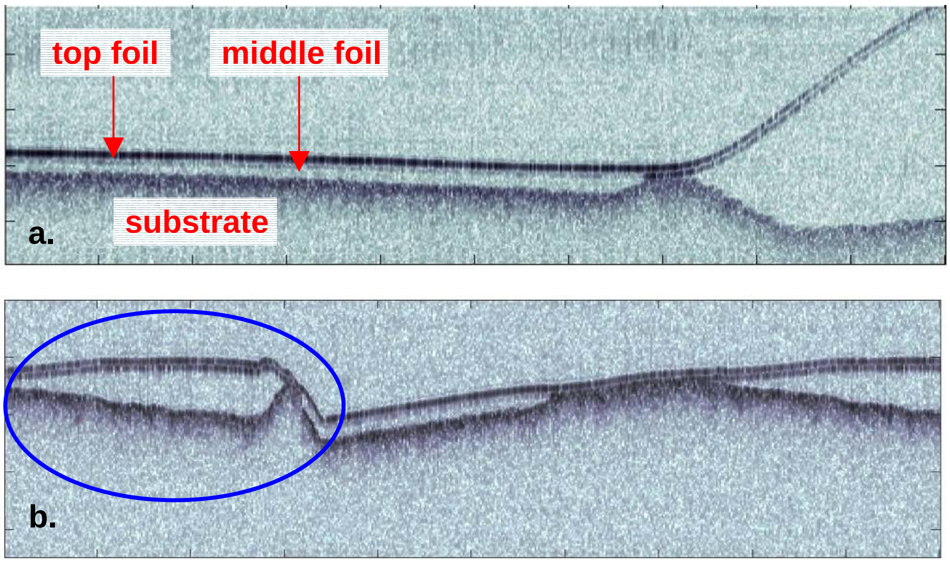


Fig 8. Cross-sections of the laminate foil. a.) Ideal case with well connected layers in the outer region (left side) and delamination of the top foil in the active region of the membrane (right side). b.) delaminations outside the active region marked with blue ellipse causing leakage of the membrane.

WP	WP Leader	WP Title
6	FHW	Field measurements and final evaluation

Participating partners: AP2K(2), PKT(1.5), MRT (1), SMP(0.5), UAR(2), FHW(5)

Description/Summary for whole project duration

There were three main tasks within this WP. The first one was dedicated to field measurements outside the laboratory directly at a production site. These activities have been performed at the site of partner PKT, as shown in the photograph below.

Figure 9: OCT-system (consisting of scanner head, evaluation unit, light source unit and PC) installed at the site of partner PKT (background: injection moulding machines)

For this purpose the device has been transferred by partner UAR to the production site of partner PKT and used for problems posed in the production of injection moulded polymer parts. By performing the individual tasks, like the evaluation of shrinkage in nose-pieces for glasses or rotor components, it could be proven, that the system is definitively capable of functioning in an industrial environment and can provide essential information in the production process: moulds have been adjusted according to the measurement results with an improvement of the subsequently produced polymer pieces to fulfil the set product tolerances.

The second task has been devoted to the evaluation of selected samples from the industry supporter group: with the help of specific dissemination activities within WP7, a total of 22 members for the industry supporter group has been acquired. The list of the members is given below:

Company	Type	Industrial sector	Main interest in OCT
Micronit Microfluidics B.V.	SME	Plastics processing	Evaluation of microfluidic devices
Sovrin Plastics LTD	SME	Plastics Processing	Inspection of micro-moulded plastics parts
Greiner Extrusionstechnik GmbH	Other	Plastics processing	Evaluation of extruded polymers
Neutrik AG	Other	Plastic processing	Inspection of high precision sockets
SPT Roth Ltd.	SME	Microceramics	Inspection of micro-ceramic parts
Fischer Advanced Composite Components AG	Other	Aerospace	Characterisation of fibre compound materials
Fritz Egger GmbH & Co Spanplattenwerk	Other	Wood	Evaluation of protective coatings on wooden panels
Gebauer&Griller Kabelwerke GesmbH	SME	Plastics, metal	Characterisation of plastics isolation of flat electronic cables
Eurofoam GmbH	Other	Plastic foams	Characterisation of cell structure
Eurocopter Deutschland GmbH	Other	Aerospace	Characterisation of fibre compound materials (rotor blades)
EVG Group E.Thallner GmbH	Other	Semiconductor	Evaluation of interface between bonded wafers
Isovolta AG	Other	Compound materials	Characterisation of fibre compound materials
Softsolution GmbH	SME	Development and Consulting	Detection of precipitates in glass window panes
Tigerwerk Lack- u. Farbenfabrik GmbH &Co.KG.	Other	Paints and coatings	Thickness determination of powder coating of wood
E+E Elektronik Ges.m.b.H.	Other	Electronic sensors	Characterisation of bonded glass substrates
NEOS SURGERY S.L.	SME	Medical engineering	Inspection of micro-plastics parts for surgical applications
SBI Produktion GmbH	SME	Plastics processing	Inspection of multi-layer foils
Landhof GesmbH & Co KG	Other	Food Industry	Inspection of multi-layer foils for food-packaging
Borealis GmbH	Other	Chemistry, Polymers	Characterisation of polymer foam grains
Micromotion GmbH	SME	Micromechanics	Characterisation of micro-/miniature moulds and parts

Teufelberger Ges.m.b.H	Other	Ropes	Inspection of bonded polymer surfaces
Concept Laser GmbH	Other	Laser-machining	Surface topography of laser sintered materials

An example for the results obtained from the investigated samples can be seen in fig. 10. A co-extruded polymer panel shows turbulences, leading to an inclusion of the inner material within the outer coating layer.

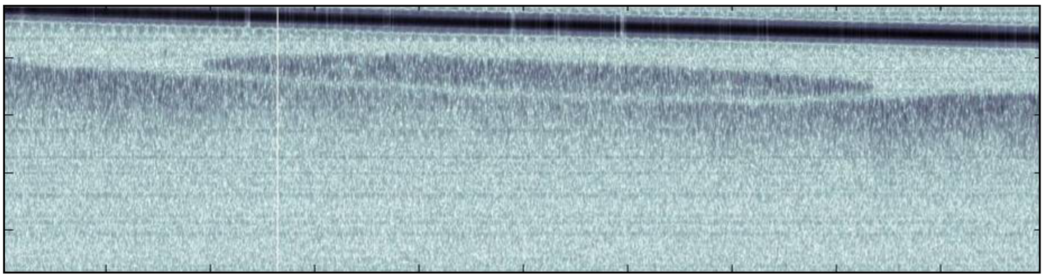


Fig.10**:** OCT cross section image (350x2500µm) of a co-extruded panel showing a turbulence at the interface.

Summarising, the table below gives the most promising results obtained with OCT compared to the results obtained with CT.

Company	Measurement Task	OCT results	CT results
Isovolta	delaminations	good	none
E+E Elektronik	layer thickness	good	not able
Concept	surface roughness	good	not able
Borealis	particle distribution	good	good
Borealis	fibre distribution	limited	good
Borealis	pore distribution	good	limited
Eurofoam	pore size	good	none
Teufelberger	defects in welds	good	good
SBI	layer thickness	good	not able
Landhof	multilayer thickness	good	not able
Tiger Coatings	gas bubbles	good	None
Egger	multilayer material	good	limited

As a third point, a final assessment of the project's measurement results has been performed by partner FHW and issued as deliverable D6.3. OCT represents a very promising method for evaluation/testing of topographies, thin structures and turbid materials and is especially effective in near surface regions: compared to CT, OCT can be regarded as a complementary method providing high resolution in reflection geometry, whereas CT delivers whole volume data of even very big samples, at the cost of lower obtainable resolution and decreased material contrast (especially important for polymer pieces).

Summarising, OCT is a novel method for non-contact evaluation of standard and micro-parts and devices, suitable for the in process control of materials processing, with respect to the measurement/detection of geometry, topography, cracks and defects, strain fields, inhomogeneities and anisotropies. The advantage with respect to other imaging techniques like ultrasound lies in the fact, that cross-sectional tomograms with high resolutions can be achieved in a contact-free and non-invasive way.

Industrial applications include inspection/characterisation of (not solely):

- Injection moulded high precision polymer workpieces
- Micro-Injection moulded work-pieces
- Glass-fibre re-enforced polymer matrix composites
- Painting or plastification of workpieces
- Extruded polymer workpieces
- Protective coatings (also with embedded functional components)
- Ceramics
- Semiconductors
- Microsystem devices
- Layered structures, e.g photoresist moulds for micro-system technology

Deliverables
The deliverables D6.1-D6.3 have been issued in months 24 and 27.

WP	WP leader	WP Title
7	HIQ	Exploitation, dissemination, IPR

Participating partners: HIQ (1), IOP (1), UAR (1), FHW (3), UOB (0.5)

Description/Summary for whole project duration

This WP has been dedicated to the dissemination of the project's results and the definition of the exploitable routes for the consortium. In detail:

<u>Dissemination:</u>

Since the OCT-principle is not widely known, a variety of dissemination activities has been performed by the consortium for experts and possible future users outside the biomedical sector. The activities were chosen to cover a broad spectrum of audience:

- Project Homepage for general information
- Technical / scientific articles for the expert audience
- Trade fair presentations incl. handouts of application notes
- Presentations at conferences (Measurement technology as well as applications)
- Presentations in seminars for end-users interested in non-destructive testing, measurement technology and also in European projects (e.g. CRAFT programme for SMEs)
- Newspaper and magazine articles for the broader public
- Email information to possible end-users of the new technology
- Guided tours for students and pupils to awake interest in technical topics

A list summarising all dissemination activities can be found in deliverable D7.3 (final exploitation and dissemination plan, FHW).

Dissemination activities will be further pursued by the individual partners also after project's end to address additional interested users and to increase the knowledge of experts and public audience.

Exploitation:

There are three major exploitation routes for the results obtained in the course of the project which can be summarised as follows:

1.)
The partners acting as technology providers could upgrade their product portfolio for the commercialisation of the developed devices. Beside the main outcome of the project each partner is also able to use individual components and additional "side-"results which have been generated during the project, e.g. the newly developed ultra compact fs-pulse laser which can be also used for THz-generation and regenerative amplifier seeding.

2.)
The partners acting as technology users could directly test the novel device and took immediate profit already during the project by:

- proper characterisation / evaluation of their products,
- faster investigation without the need of sample preparation,
- reduced time for development of new processes (e.g. determination of proper parameters for injection moulding process) and
- documentation of product quality (internal and for reference purposes with respect to their customers)

3.)
The research institutions could increase their scientific and technical expertise / reputation and will use the newly gained Know-How (after consultation with the SME partners and in accordance with the nondisclosure agreement of the consortium) for new research and industrial projects and by disseminating the project's results for the public and expert audience.

Deliverables Issued
A preliminary exploitation and dissemination plan (deliverable D7.2, FHW) has been issued in month 12. The final exploitation and dissemination plan (deliverable D7.3, FHW) as well as the public version of the final report in condensed form (D7.4, UAR) have been issued in month 27. The project homepage (D7.1) has been updated (summary of the project, new results, publications).

WP	WP Leader	WP Title
8	UAR	Project Management

Participating partners: HIQ (1), IOP (0.5), AP2K (0.5), PKT (0.5), MRT (0.5), SMP (0.5), UAR (3), FHW (0.5), UOB (0.5)

Description/Summary for whole project duration

Project coordination and management activities were performed throughout the whole project. A management consortium committee (MCC) has been formed with one site manager per partner (see minutes of kick-off meeting). Project management information has been distributed to all partners (D8.1). A ftp-server has been set up for all partners (login via website) to share documents between partners and provide access to forms and project documentations. Summarising, full management consortium committee (MCC) meeting have been held at the sites of partner UAR, UOB, HIQ, IOP and FHW (final meeting). Information on the required intermediate/final reports, financial forms and audit certificates, including model audit forms, has been distributed. Financial reports and management information have been collected from all partners every 3 months by the coordinator. At month 27, the final report (D8.5) has been issued, showing all objectives of the project have been fulfilled.

Deliverables Issued

The deliverables D8.1-D8.5 have been issued in months 1, 6, 12, 18 and 27.

2.2 Comparison of Planned Activities vs. Actual Work Achieved

Table 2.1: Technical and coordination deliverables for months 1-27

Deliverable	WP	Month	Description	Responsible partner	Delivered ?
D8.1	8	1	Project Coordination information for partners (deliverable type: documents)	UAR	yes
D7.1	7	3-27	Project presentation / public project webpage: http://www.ipc-oct.com (type: homepage)	UAR	yes
D1.1	1	4	Synthesis report on specific requirements of technology users for new imaging method (type: report)	UAR	yes
D8.2	8	6	First progress report (type: report)	UAR	yes
D2.1	2	8	Report on suitable PCFs (type : report)	UOB	yes
D2.2	2	12	First prototype of broadband light source (type: prototype)	HIQ	yes
D3.1	3	12	Protoptype industrial OCT-scanner with conventional light source (type: prototype)	IOP	yes
D4.1	4	12	First report on the comparative study of OCT with alternative methods (type: report)	FHW	yes
D7.1	7	12	Preliminary Technology Implementation Plan / plan for using and disseminating knowledge (type: report)	FHW	yes
D8.3	8	12	Second progress report, first cost statement and midterm report (type: report)	UAR	yes
D2.3	2	15	Attached light source prototype to OCT scanner	UAR	yes
D3.2	3	17	Report on test/performance of new broadband light source with industrial OCT prototype	UAR	yes
D8.4	8	18	Third progress report (type: report)	UAR	yes
D2.4	2	20	Report on system optimisation	UOB	yes
D3.3	3	21	Report on OCT-scanner optimisations	IOP	yes

D3.4	3	21	Final report on evaluation of OCT scanner with new broadband source	UAR	yes
D4.2	4	22	Evaluation results of the comparative study on materials	FHW	yes
D5.1	5	22	Report on inspection/evaluation of micro-/miniature parts	UAR	yes
D6.1	6	27	Report on field measurements and results	UAR	yes
D6.2	6	27	Report on results from industry supporter group	FHW	yes
D6.3	6	27	Final assessment of results	FHW	yes
D7.3	7	27	Plan for dissemination and exploitation	FHW	yes
D7.4	7	27	Public version of the final report in condensed form	UAR	yes
D8.5	8	27	Fourth progress report, final cost statement and final report	UAR	yes

Table 2.2:
Progress towards milestones 1-4. Measurable technical objectives at project's end

Objective	WP	Mile-stone	Achievement	Notes
Definition of technology user's requirements	1	1	Test structures and product samples, deduced requirements of technology users	Enquiry of utmost requirements (best case) and matching of specifications according technical feasibilty
Development of pulsed laser source	2	1	Set-up of prototype system. A compact Ti:sapph laser with ~50fs pulses has been developed for the use with PCFs	Operating wavelengths at 800 nm and alternatively also at 1 µm have been tested
Development of PCFs	2	1	Identification and fabrication of different fibre structures suitable for supercontinuum generation at 800 nm. Supercontinuum of up to 200 nm FWHM has been achieved with above mentioned fs-pulse laser and newly developed tapered PCFs.	
Development of industrial OCT scanner	3	2	Design and set-up of OCT prototype with conventional light sources	Scanner has possibilities to measure even at two center wavelengths (800 nm and 1300 nm). Evaluation of possibility for cross-polarisation detection (flow pattern visualisation) and lateral scanning (galvano-mirror)
Combination of light source with OCT scanner	2,3	3	The light source has been combined with the OCT scanner to form the novel high resolution system.	The final evaluation has shown that a depth resolution down to 4 µm in typical materials has been reached and surpasses the targeted value of 5µm by 20%.
Application on end-user's sample structures	4,5,6	4	Measurement series on the sample structures of the end-users (including micro-, miniature parts) have been succesfully performed	Samples from the project partners as well as from the members of the industry supporter group have been evaluated
Evaluation of OCT	4	4	Comparison and evaluation of OCT with alternative measurement methods	Comparative results with CT, AFM, micrographs, synchrotron phase-CT, white light interferometry.
Field measurements	6	4	Field measurements at the production site of partner PKT have been successfully performed	Industrial parts directly from production measured
Final assessment of results	6	4	Compilation and final evaluation of OCT performance for the individual industrial applications	
Exploitation and Usage of knowledge	7	4	Dissemination and exploitation activites: homepage, project sheet, publication in scientific journals and at conferences achieved. Individual components as commercialisable product identified and shown on exhibitions and trade fairs.	Acquisition of 14 new members for the industry supporter group (total of 22 members).

2.3 Summary of Technical Activities for Months 1-27

- Definition of technology user's requirements
- Determination of parameters of OCT scanner
- Fabrication of test samples and products
- Development of compact pulsed laser source (fs-pulse laser)
- Determination and fabrication of suitable PCFs for laser source at 800 nm band
- Combination and optimisation of PCFs with pulse laser: 130 nm broad supercontinuum @ 800 nm achieved
- Optimisation of compact pulsed laser source (fs-pulse laser), investigation on long term laser stability
- Fabrication of new FC/APC-connectorised PCFs with tapers

- Combination of tapered PCF and optimisation with pulse laser: almost 200 nm broad supercontinuum @ 800 nm achieved
- Development of industrial OCT-prototype with conventional light sources
- Measurements on test structures with industrial OCT-scanner.
- Design and evaluation of OCT extension optics (galvano scanner, cross-polarisation for birefringence measurements)
- Combination of light source and OCT scanner to form new system with high resolution
- Optimisation of industrial OCT-prototype
- Adapted fabrication of test samples and products
- Measurements on test structures with novel OCT scanner (esp.: micro/miniature parts)
- Comparative measurement study OCT vs. CT, AFM and micrographs (test samples from end-users and industry supporter group)
- Field measurements with new system at industrial production site (partner PKT)
- Acquisition of new members for industry supporter group, future end-users
- Final evaluation of measurement results on samples of end-users and industry supporter group members
- Setup of final dissemination and exploitation plan

2.4 Planned Technical Activities after Project's End – Ongoing co-operations

As discussed and agreed during the final meeting, the individual partners are willing to technically cooperate after the end of the project, beside the obligatory activities laid out in the final exploitation plan (see D7.3). Among these additionally planned activities are:

- Further adjustments of the scanner system to the light source (performed at the site of IOP together with HIQ)
- Development of new PCFs for parallel signal transfer in OCT-Scanners (UOB, IOP)
- Further development and cooperation on sidewall reconstruction measurement procedure and software (AP2K, MRT, UAR)
- CT and specialised OCT measurements for newly arising problems (FHW, UAR, end-users)
- Extension of co-operation to new fields, e.g. THz imaging (AP2K, UAR, HIQ)

3.0 Glossary

AFM	atomic force microscopy
CT	computer tomography
DSP	Digital Signal Processor
fs	femtosecond
MCC	management consortium committee
MTTF	mean time to failure
NDT	nondestructive testing
PCF	photonic crystal fibre
OCT	optical coherence tomography
THz	Terahertz