

Content

List of figures	v
List of tables	XI
Formula symbols	XIII
Abbreviations	XVII
1 Introduction	1
1.1 Motivation and practical relevance	1
1.2 Research approach	4
1.3 Structure of the work	4
2 Fundamentals	7
2.1 Electromagnetic radiation	7
2.1.1 Polarisation	9
2.1.2 Intensity of an electromagnetic wave	10
2.1.3 Absorption, reflection, refraction and scattering	11
2.1.4 Optical fibres and modes	15
2.1.5 Interaction of optical radiation with water	17
2.2 Water jet guided laser micro machining	22
2.2.1 Laser water jet generation and behaviour	22
2.2.2 Laser water jet technology and process parameters	24
2.2.3 Water jet guided laser drilling and cutting	26
2.2.4 Water jet guided laser structuring	29
2.3 State of the art micro machining in mould production	31
2.3.1 Micro machining for micro mould production	31
2.3.2 Laser water jet guided micro machining	32
2.4 State of the art process monitoring for laser machining	33
2.4.1 Requirements on laser process monitoring	33
2.4.2 Possibilities and restrictions for laser process monitoring	34
2.4.3 Application assessment for water jet guided laser process monitoring	41
2.5 Low coherence interferometry	43
2.5.1 Interferometry and coherence	43
2.5.2 Spectral-domain low coherence interferometry	47
2.5.3 Signal formation in Fourier domain	48
3 Task and scientific objectives	51
3.1 Innovation capacity beyond state of the art	51
3.2 Relevant process parameters for low coherence interferometry	51
3.2.1 Categorisation and weighting of expected process influences	52
3.2.2 Criteria for the validity of the in-line measurement capability of the sensor	55

3.3	Derivation of research needs	55
3.4	Interim conclusion and further scientific investigation	57
4	Description of the system influences for coherence in the water jet.....	61
4.1	Architecture of the optical system model.....	61
4.2	Modelling of the signal processing workflow in the application context	75
4.3	Influence of mode field diameter and dispersion on coherence within the water jet.....	79
4.4	System influence analysis and interim conclusion on interferometric measurement within the water jet.....	84
5	Development of an inline process monitoring for laser water jet machining	85
5.1	Derivation of system parameters based on process requirements and simulation results	85
5.2	Development of measures to enable and maintain coherence within the water jet.....	89
5.3	Optical design of an optimised inline low coherence interferometry sensor system.....	90
5.4	Mechanical set-up and implementation of the sensor system	95
6	Set-up and implementation of the sensor system.....	101
6.1	Demonstrator set up at laboratory level.....	101
6.2	Transfer and integration into the laser machining plant.....	104
7	Characterisation and validation of the sensor system.....	109
7.1	Validation criteria and process influences	109
7.2	Measurement methodology for system characterisation	110
7.2.1	Sensitivity measurement	110
7.2.2	Linearity measurement.....	112
7.2.3	Measurement range characterisation	112
7.2.4	Characterisation of axial resolution	113
7.3	In-line validation of the measurement system	114
7.3.1	In-line sensor sensitivity	114
7.3.2	In-line sensor linearity	115
7.3.3	Axial measurement range and penetration depth.....	116
7.3.4	Uncertainty of depth measurements	117
7.4	Validation of the sensor system in comparison with the physically modelled system influences.....	118
7.5	Validation of the sensor system during the structuring process with the laser water jet.....	119
7.5.1	Validation measurements during the laser structuring process of high aspect ratio structures	120

7.5.2	Development of a measurement strategy to prevent process influences from the structuring process.....	122
8	Resume and prospects	123
8.1	Resume.....	123
8.2	Prospects	124
Bibliography.....		127
References		127
Student theses.....		141
Annex		143
A.1	Datasheet – Superlum SLD-331-HP3	143
A.2	Datasheet – Thorlabs V800A	144
A.3	Datasheet – DALSA S3-24-01K40	146
A.4	Datasheet – Wasatch Photonics WP-HD1800/ 840-35X45.....	148
A.5	Datasheet – Tafelmeier Laser Mirror 532 nm (general)	150
A.6	Datasheet – Tafelmeier Laser Mirror 532 nm (detail).....	150