

Contents

1	Introduction	1
1.1	Thermonuclear fusion	1
1.2	Light-based diagnostic systems in fusion	2
1.3	Aim and structure of the thesis	5
2	Diagnostic mirrors in thermonuclear fusion	7
2.1	JET	7
2.2	ITER	9
2.2.1	The core CXRS and BES diagnostic systems of ITER	10
2.3	Fusion power plant	12
2.3.1	Feasibility and necessity of diagnostic mirrors in DEMO	13
3	Environmental conditions of the mirrors	15
3.1	Vacuum compatibility	16
3.1.1	Limitations on material choice and material condition	16
3.1.2	Impact on general design	17
3.2	Thermal environment	17
3.2.1	Machine temperature	17
3.2.2	Surface heat loads	18
3.3	Nuclear environment	19
3.3.1	Limitations on material choice	21
3.3.2	Volumetric heat loads by radiation	21
3.3.3	Design for the nuclear environment	22
3.4	Electromagnetic environment	23
3.5	Fluid ingression events	25
3.6	Mirror surface contamination	26
3.7	System lifetime and maintenance	27
4	Mirror design state of the art	28
4.1	Mirror mechanical design	28
4.2	Mirror surface treatment	34
4.3	Conclusion on environmental conditions and state of the art	37
5	Principal considerations on mirror design in fusion reactors	38
5.1	Mirror substrate material selection	38
5.2	Adjustment during assembly	42
5.2.1	Adapting the interface	43

5.2.2	Flexible hinges	45
5.2.3	Extended shaped contact	46
5.2.4	Pre-loaded small contacts	47
5.2.5	Conclusions on adjustment mechanisms	49
5.3	Thermal design	50
5.3.1	Conclusions thermal design	53
5.4	Conclusions on principal design considerations	53
6	Concept design for ITER core CXRS secondary mirrors	54
6.1	ITER UPP#3 layout	54
6.2	Baseline design fixed mirrors	57
6.2.1	Stainless steel substrate	59
6.2.2	Interface for mirror positioning and mounting	60
6.2.3	Mirror thermal control	63
6.2.4	Remote handling mirror exchange	64
6.3	Design of two-axis adjustable mirror	66
6.4	Thermo-mechanical simulation of Mirror 2	68
6.4.1	FEM model and boundary conditions	69
6.4.2	Temperature progression and distribution	73
6.4.3	Mechanical stresses	74
6.4.4	Mirror surface shape	75
6.4.5	Conclusion from FEM modelling	79
7	Prototypes and testing	81
7.1	Interface prototype	81
7.1.1	Testing and results	83
7.1.2	Conclusions on interface prototype	84
7.2	Mirror substrate prototype	84
7.2.1	Determination of weld method and parameters	84
7.2.2	Mirror substrate diffusion bonding	87
7.2.3	Conclusions substrate prototype	90
7.3	Dielectric mirror coating on stainless steel substrate	90
7.3.1	Manufacturing and initial characterisation of the mirrors	90
7.3.2	Long-term thermal testing	92
7.3.3	Blister formation and flaking	96
7.3.4	Exposure to water vapour	97
7.3.5	Reflectivity measurements at elevated temperature	98
7.3.6	Composition of the coating	99
7.3.7	Conclusions on dielectric mirror coating	100
8	Summary and discussion	101
	Bibliography	103
	List of symbols	113
	List of abbreviations	115

Appendices	117
A Fitting of optical tolerances	117
A.1 ANSYS APDL script for tolerance fitting	118
A.2 Achieved fitting accuracy	120
B M2 welded prototype drawings	121