

Contents

I	Optical Coherence Tomography	6
1	Time Domain OCT	7
1.1	Theory	7
1.1.1	Michelson Interferometer	7
1.1.2	Optical interferometry with coherent light	9
1.1.3	Low-coherence interferometry	9
1.1.4	Low coherence interferometry with multilayer structures	10
1.1.5	Detector signal	12
1.2	Reflectivity Sensitivity	12
1.2.1	Effective reflectivity vs interface reflectivity	13
1.2.2	Signal to noise ratio	13
1.2.3	Noise sources	13
1.2.3.1	Shot noise	13
1.2.3.2	Relative intensity noise	13
1.2.3.3	Thermal noise	14
1.2.4	Sensitivity optimization	14
2	Fourier Domain OCT	15
2.1	Overview of fourier domain OCT	15
2.2	Frequency domain OCT	17
2.2.1	FD OCT image reconstruction	19
2.2.1.1	DC level removal	19
2.2.1.2	Image in clean area	19
2.2.1.3	Autointerference supression double spectrum	19

<i>CONTENTS</i>	2
2.2.1.4 Differential Fourier domain method	19
2.2.1.5 Heterodyne complex FDOCT	19
2.2.1.6 Quadrature Fourier domain method	20
2.2.1.7 Triple spectrum complete reconstruction	20
2.2.1.8 Hibert transform	20
2.2.2 Spectral resolution effects	20
2.3 Processing	20
3 Spectral Radar	23
3.1 Spectrometer	23
4 Swept Source	25
4.1 Light Source	25
4.2 Detection and Digitalization	25
4.3 Signal Processing	25
4.4 Probe	25
5 Signal Processing	26
6 Applications	27
6.1 Materials and Methods	28
6.2 Results	29
7 Dental fiber-reinforced composite analisis	31
7.1 abstract	31
7.2 Intro	31
7.3 Experimental details	32
7.4 Fiber reinforced composite studies	34
7.5 Conclusions	36
8 Clinical use of optical coherence tomography to evaluate the integrity of dental restorations	
8.1 abstract	37
8.2 Introduction	37
8.3 Material and Methods	39

8.4	Results	42
8.5	Discussion	46
8.6	Conclusion	49

II Optics on chip 51

8.7	Broad picture	52
8.8	Slab waveguide	52
8.9	Dispersion in Silicon	55
8.10	Rectangular waveguide	55
8.10.1	fem	55
8.11	Bending radius	55
8.12	Ring resonators	56
8.13	Coupling light to the chip	56
8.14	Active components	57
8.14.1	Thermo optic effect	57
8.14.2	Eletrooptic effect	57
8.14.3	Effect χ^3	57
8.14.4	Plasma dispersion	57
8.15	Light sources	57
8.16	Detectors	57
8.17	Fabrication Techniques	58
8.17.1	Fabrication difficulties discussion	58

9 Diffraction Grating Spectrometers 59

9.1	alternatives	59
9.2	Kirchhoff's diffraction theory	59
9.3	Diffraction grating	60
9.3.1	Free spectral range	65
9.4	Planar devices	66
9.5	Spectrometer Architectures	66
9.5.1	Czerny-Turner	67
9.5.2	Rowland	68

9.5.3	Arrayed Waveguide Grating (AWG)	69
9.6	Grating illuminated by a Gaussian Beam	70
9.7	Size	72
9.8	Spectral defects	72
9.8.1	Rowland Ghosts	72
9.8.2	Lyman Ghosts	72
9.9	Aberrations	72
9.9.1	Aberration free conditions	73
9.9.2	One point stigmatic correction	74
9.9.3	Two points stigmatic correction	75
9.10	Blazing and Groove size	75
9.11	Rayleigh-Huygens model	75
9.12	Comparisons of simulationas and analitic solution	76
9.13	Simulation of Spectral defects and aberrations using Rayleigh-Huygens model	76
9.14	implementation	76
9.14.1	Design	77
9.14.2	Operating wavelength	77
9.14.3	Dispersion	77
9.14.4	Grating size	77
9.14.5	Diffraction order and input, output angles	78
9.14.6	Number of grooves	78
9.14.7	Linear Dipersion	78
9.14.8	input and output angle	79
9.14.9	Output waveguide positioning	80
9.14.10	Fabrication	80
9.14.11	Testing	81
10	Ring enhanced spectrometer	83
10.1	Device Theory	83
10.1.1	Crosstalk	84
10.2	Design	84
10.3	Fabrication	85

<i>CONTENTS</i>	5
10.4 Testing	85
10.5 Increasing Channel Density	86
10.6 Device Comparison	88
10.7 Effect of transmission spectrum lineshape	88
10.8 Numerical calculation	91
10.9 Approximations	91

Part I

Optical Coherence Tomography

Chapter 1

Time Domain OCT

[?][?][?]

1.1 Theory

In OCT, the kind of interferometry used is the low-coherence type. In this section, we are going to describe how low-coherence interferometry is used to measure the distance of an object with more than one reflecting surface.

1.1.1 Michelson Interferometer

Consider the interferometer shown in figure 1.1.1. To simplify the analysis, ignore the light polarization and dispersion effects. A light source emits a radiation whose electric field shines upon a beamsplitter described by $E_0(t)$. This light is divided and a fraction D of its power is directed

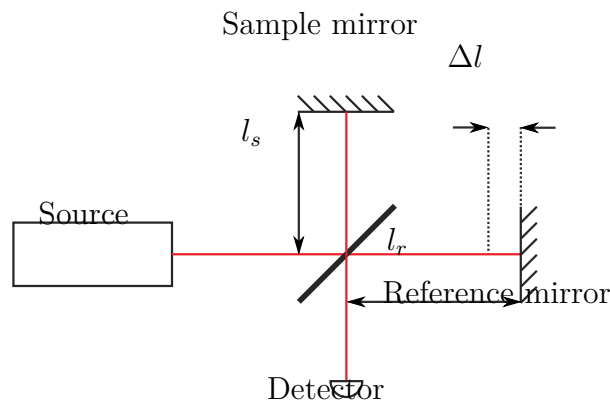


Figure 1.1.1: Michelson interferometer

to mirror S with reflectivity R_s . The light is reflected and returns to the beam splitter, where a fraction $(1 - D)$ of its power goes to the detector. Similarly, in the other interferometer arm, $(1 - D)$ of the light emitted by the light source is redirected to the mirror R_r , which is reflected and returns to the beamsplitter, where a fraction D of this light is redirected back to the detector. The electric field at the detector can be described by

$$E_s = \sqrt{K_0} E_0 (t - \tau_a) + \sqrt{K_r} E_0 (t - \tau_r), \quad (1.1.1)$$

where $K_i = R_i D (1 - D)$ is the light power fraction that is shined to the detector and τ_i is the time the light takes to go from the beamsplitter to the mirror i and back.

The relationship between the output light intensity $\langle I \rangle$ and the mean electric field is:

$$\langle I \rangle = \left\langle \frac{|E(t)|^2}{2\eta_0} \right\rangle, \quad (1.1.2)$$

where $\eta_0 = \sqrt{\frac{\mu_0}{\epsilon_0}}$ is the free space impedance. Using 1.1.1 and 1.1.2, we get the intensity at the detector as been

$$\langle I \rangle = \langle I_{DC} \rangle + \sqrt{K_s K_r} \Re(\Gamma(\tau_{s,a})) \quad (1.1.3)$$

where $\tau_{r,s} = \tau_s - \tau_r$. We define the autocorrelation function for beam electric field as

$$\Gamma(\tau) = \frac{E(t - \tau) E^*(t)}{\eta_0}$$

and

$$\langle I_{DC} \rangle = \sum_j K_j \langle I_0 \rangle,$$

where $\langle I_0 \rangle = \left\langle \frac{|E_0(t)|^2}{2\eta_0} \right\rangle$ is the mean light intensity that leaves the source, which in this case is constant. More specifically, it is of interest that the light source should be stationary in the wide sense, which means

1. $\langle E(t) \rangle$ is independent of t .
2. $\langle E(t_1) E^*(t_2) \rangle$ depends only on $\tau = t_2 - t_1$.

1.1.2 Optical interferometry with coherent light

If the light is perfectly coherent (i.e. monochromatic), then its electric field can be described as $E(t) = E_0 e^{-i2\pi\nu t}$ where ν is the optical frequency and E_0 is the field amplitude. Replacing $E(t) = E_0 e^{-i2\pi\nu t}$ in equation and using, we get