Contents

Nomenclature

Latin letters

variable	meaning	unit
A	area	m^2
w	width	m
c	concentration	wt.%
d	diameter	m
G	Gibbs free enthalpy	J
h	height	m
l	length	m
m	mass	kg
p	pressure	Pa
r	radius	m
Re	Reynolds-number	
t	time	s
V	volume	m^3

Greek letters

variable	meaning	unit
α	absorption coefficient	1/m
γ	surface tension	$^{N}/_{m}$
η	dynamic viscosity	$^{Ns}/_{m^2}$
θ	contact angle	°, rad
κ	curvature	$^{1}/_{m}$
λ	wave length	m
ν	kinematic viscosity	$^{m^2}/_{s}$
ρ	specific gravity	$^{kg}/_{m^3}$

Indices

index	meaning
lg	liquid-gas
sg	solid-gas
sl	solid-liquid
la	liquid-ambient

Abbreviations

abbreviation	meaning
2D	2-dimensional
AF	amorphous fluoropolymer
DFR	dry film resist
DI	deionized ultra-pure water
DRIE	Deep reactive ion etching
ICP	Inductive coupled plasma
MEMS	Micro-electro-mechanical system
PDMS	Polydimethylsiloxan
PEB	Post Exposure Bake
PMMA	Polymethylmethacrylat
UV-Vis	ultraviolet to visible wavelengths

1 Introduction

1.1 Motivation

Optical biopsy Multimode as key technology (include other modalities)

The presented work builds on the concept of a two layer, MEMS based silicon optical bench [1] that combines white light microscopy with OCT on a single integrated silicon microbench. In contrast to other approaches [2], the combination of white light microscopy with OCT is realized without the need of a coherent fiber bundle. With this design, the inherent drawbacks of such fiber bundles can be avoided, which are, for example, low light troughput, multi-modal coupling and poor resolution for a given field of view as stated in [3]. Furthermore, with the two level approach we can implement modalities with different requirements regarding the numerical aperture of the optical system as it is the case for white light microscopy and OCT.

One of the main challenges of multimodal endoscopy is the overlay of the different acquired images. If the different optical axes are not collinear, the fields will be shifted and tilted due to parallax error, which gains importance at the small working distances common in endoscopy. This problem can be addressed by merging the different modalities in a common beam path.

The next challenge lies in the size: The external diameter of an endoscope constrains its field of application. For example, in cystoscopy (endoscopy of the urinary bladder), probes with small diameter (under 5 mm) reduce the pain and trauma to urethra.

However, their implementation comes with optical, mechanical and computational challenges, which are described in the next pages.

1.2 State of the Art

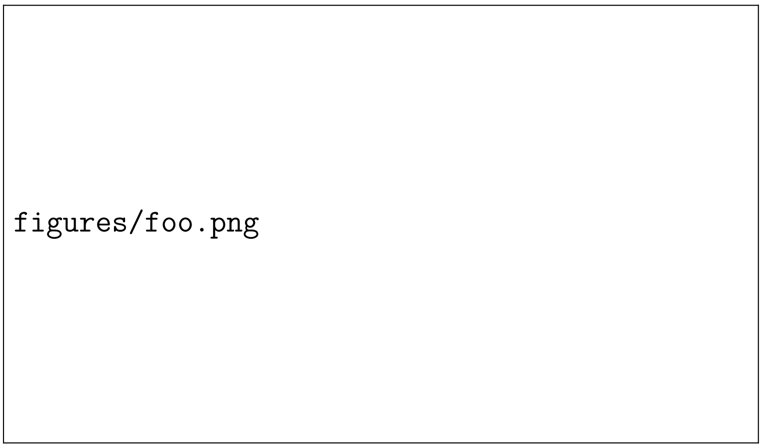

Figure 1.1: Simon bench, Tobias Scanner, Seibel scanner

1.3 Results of this thesis

2 Design & Simulation

The aim of this work is to design and test a miniaturized OCT microscope as a component of a multi-modal probe. As described in Chapter 1, this probe consist of two spectrally-separated optical paths that run partially in parallel through a micro-optical bench system. This approach allows independent tuning of the optical parameters of the two imaging modalities – such as the NA or depth of field – while still providing a geometrical overlap of the two acquired images. As OCT is a scanned-point imaging technique, a 2D scanning mechanism is integrated into the probe to reconstruct 3D volumes of the sample tissue.

2.1 Design Requirements

The OCT microscope should fulfill the following requirements:

Mechanical Requirements

- The scanner, electrical connections and optics should fit in a $1\,\mathrm{mm} \times 1\,\mathrm{mm}$ channel. Its length should be minimized.
- The field of view should be maximized for a 2 mm objective lens.
- The scanning speed should be adequate for the reduced sampling rates characteristic of OCT ($\sim 100\,\mathrm{kHz}$).

Optical Requirements

- The microscopy and OCT imaging fields should be coaxial to avoid parallax errors.
- The OCT field should be telecentric to maximize the collection of backscattered light upon normal incidence to the tissue.
- The lateral resolution and depth of field should be adequate for OCT.
- The backreflections inside the probe should be minimized.

2.2 Design overview

The main challenge of this work is to design a scanning mechanism compact enough to be placed in a thin, buried channel of a multimodal probe. Although it is theoretically possible to keep a scanner at the proximal end of the endoscope and use a coherent fiber bundle (CFB) as a relay, there are inherent drawbacks of this method, such as low light throughput, cross-talk and mechanical rigidity.

Another challenging requirement is the superposition of the images acquired by the different modalities. If the optical axes are not coaxial, the fields will be shifted and tilted due to parallax error — which gains importance at the small working distances common in endoscopy.

To overcome these problems, and taking into account the above-mentioned requirements, we propose a design comprising a resonant fiber scanner followed by a beam splitter, as illustrated in Figure 2.1.

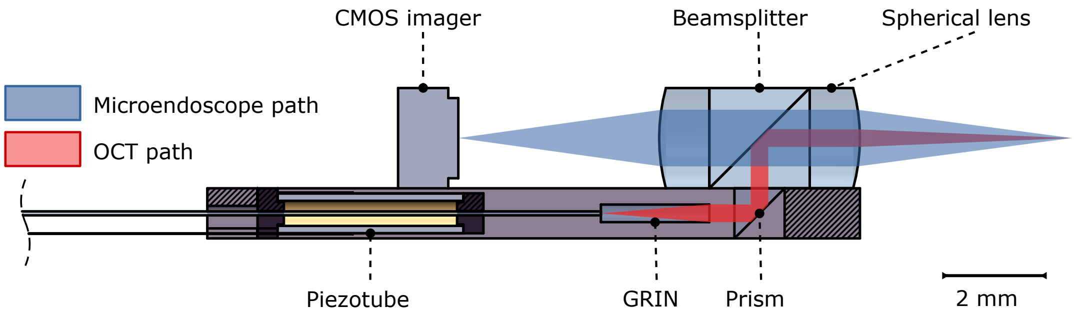

Figure 2.1: Bimodal probe cross section showing main components and optical paths.

The implementation uses a piezo tube actuator which drives a bending beam into a resonant oscillation. This bending beam is composed of an optical fiber with a GRIN lens glued to its tip which, due to the oscillation of the fiber, radially scans a collimated laser beam. An objective lens then transforms this angular displacement into translation, as explained in Chapter **??**. In order to merge the OCT field with the white light image, both fields are combined using a dichroic beam splitter.

There are many reasons why this design is preferred over other scanning topologies. First, the narrow dimensions of the piezo tube allow a compact implementation. Also, the field of view that can be achieved with this scanner is not limited to the amplitude of the vibration — instead, to the maximum angular deflection. As we need a telecentric system, a *4f* microscope could have been implemented instead of a Fourier plane scanner, but at the cost of duplicating the length of the optical system. Finally, by gluing the GRIN lens to the tip of the fiber, its resonance frequency is greatly reduced, allowing a denser sampling.

The rest of this chapter shows the design and development of the OCT imaging path for the multimodal probe. However, in order to independently test the behavior of the OCT scanner and optics, a single modality probe was fabricated as a demonstrator. Therefore, for completeness, both multi-mode and single-mode optical systems are explained.

2.2.1 Optical Design

Selection of Components

figures/foo.png

Figure 2.2: Fourier plane scanner indicating beam diameters, focal lengths and NAs

Equations for NA, focal lengths, telecentricity
Reasons for choosing each component

ZEMAX Simulation

Table with results

Minimization of backreflections

Origin of backreflections
ARC
Tilted surfaces
Position of lenses

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Figure 2.3: Layout

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Figure 2.4: Spot through focus / Field aberrations

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Figure 2.5: Implemented 1 mode probe

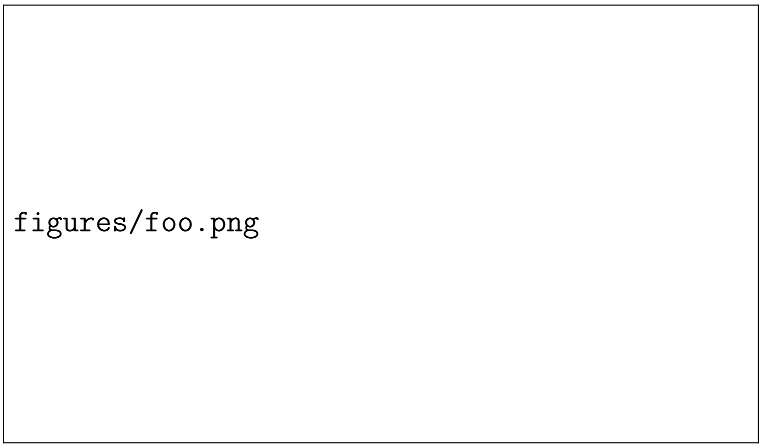

Figure 2.6: Backreflections in probe

2.2.2 Mechanical Design

Design of the spiral scanning resonant beam

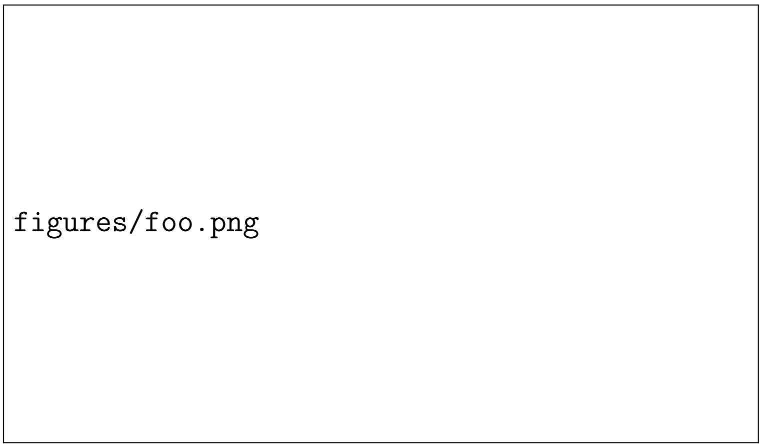

Figure 2.7: Radiant source with component sizes / Movement of spot in deltaT inside spiral

Analytical calculations (res freq, bending line, max radius)
Fsampling VS FOV -> Fres, Lfiber -> +Weight, -diameter

COMSOL simulation

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Figure 2.8: COMSOL bending line at different voltages -> Single radiant point

2.2.3 Desired Design

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Figure 2.9: Bimodal Probe CAD render with annotations

References

Note of Thanks

Lastly, I wish to express my gratitude to those many people, who helped me in the last six months, for their contribution to success of this Master Thesis.

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