Coherence Length Measurement System Product Requirements Document

ASML / Tao Chen

Faculty Advisor: Professor Thomas Brown

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Lei Ding (Customer Liaison)
Maxwell Wolfson (Project Coordinator)

Document Number 00005

Revisions Level	Date
E	12-15-2017

Authentication Block

Rev	Description	Date	Authorization
A	Initial PRD	10-18-2017	All
B	Updated Specifications	11-10-2017	All
	Incorporated Potential Design		
C	Updated Specifications	11-27-2017	All
	Updated Potential Design 1		
	Incorporated Potential Design 2		
D	Updated Specifications	12-08-2017	All
	Incorporated Resources Needed		
	Incorporated Spring Timeline		
E	Updated Specifications	12-15-2017	All
	Edited Timeline		
	Added System Block Diagram		
	Added Appendix		

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Statement of Advisors:

The Coherence Length Measurement System is a customer driven product. As such its design inputs are derived from the direction of our customer, Tao Chen. Additional guidance and assistance are provided by our faculty advisor, Professor Thomas Brown.

This product requirement document has been approved by our customer as of 12/15/17. Email certification of his review can be found in the appendix.

Vision:

The product is a coherence length measurement system with the purpose of accurately measuring the coherence length of light sources consisting of one or more spectral peaks. The goal of this project is to develop and assemble a prototype that will fulfill this purpose.

Environment:

As a device intended for performance examination, it needs to operate in the following environment:

Temperature

15-35 °C – operation range

Relative Humidity

Non-condensing

Vibration

Upon an optical table with a vibration isolation pad in a lab setting

Regulatory Issues:

Open beam needs to be completely covered in a light tight enclosure.

Fitness for use:

The system will:

Measure the coherence length of light sources directly, since measuring by the spectrum will not give accurate results regarding low visibility resurgent peaks.

Be able to measure coherence length of sources over a wavelength range of 500-900nm

Possess the ability to measure the coherence length up to 500mm starting from the point of equal path length.

Measure visibility at increments of 0.01mm of optical path length difference.

Possess a visibility level less than 0.01

Make use of a FC/PC single mode fiber connector to introduce the light into the system

Report the raw plot data of the coherence visibility curve over the entire scan length

Specifications		
Laser Sources		
Power	=	1-20 mW
Operation Mode	=	Continuous-wave
Minimum Coherence Length	=	0.5 mm

It is desirable that:

The cost of the system is < 5000 USD for all components

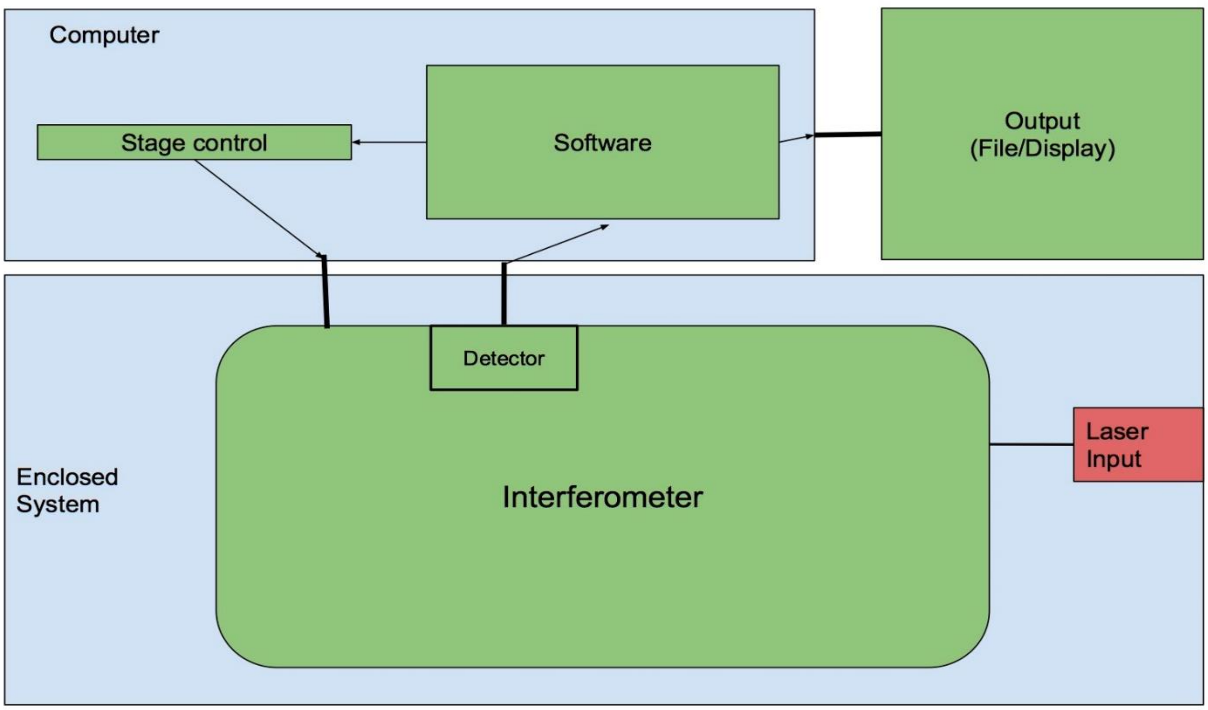
The volume of the system be less than 1000mm x 1000mm x 500mm

Have an operation time that is less than 30 minutes

Project Scope:

System Block Diagram:

Green boxes are our responsibilities.



We are responsible for:

Designing and building a functioning prototype of the system in a lab setting.

Writing and developing software to analyze information from the prototype and report raw visibility plot data.

We are not responsible for:

System vibration compensation outside of a lab setting

Proposed Interferometer Designs:

Method 1: Modified Michelson Interferometer Utilizing a Stepped Mirror[1]

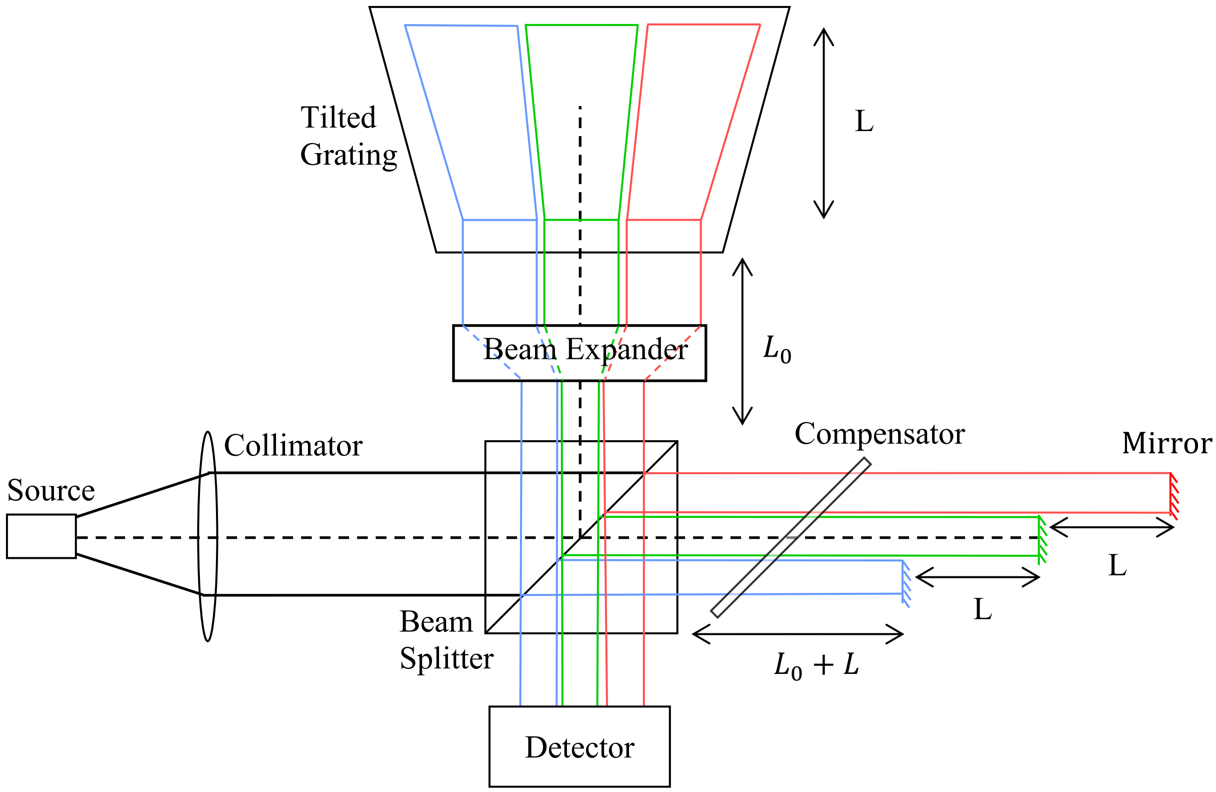


Figure 1. Setup diagram. Different colors do not represent different wavelengths. They are used to label different paths from different mirrors.

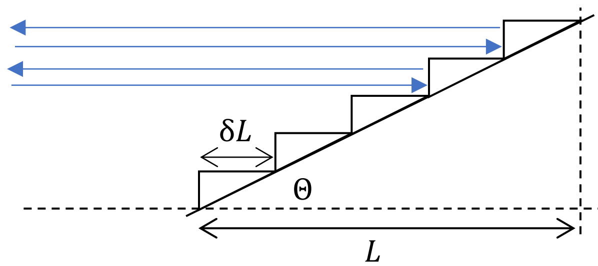


Figure 2. Diagram depicting grating as a step mirror

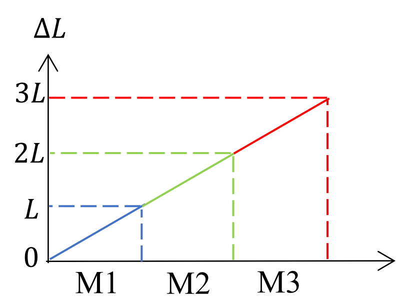


Figure 3. Path difference against mirror used.

[1] Reference: Vladimyros Devrelis, Martin O'Connor, and Jesper Munch, "Coherence length of single laser pulses as measured by CCD interferometry," Appl. Opt. 34, 5386-5389 (1995)

<table>
<tr><th colspan="2">Overview of Method</th></tr>
<tr><td colspan="2">Replaces the mirror in the measurement arm of the traditional Michelson Interferometer with a blazed diffraction grating at the complementary angle of the Littrow configuration.
This orientation of the grating makes use of the 90° blazed grating shape, in order to have the incident light reflect back at various different optical path lengths. In this way, the grating functions as a “staircase” of flat mirrors.
Adds additional reference mirrors to the reference arm of the interferometer in a tiered structure. This allows for an extension of the system’s measurement range by slicing the grating into narrow regions that sample different optical path lengths.</td></tr>
<tr><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td>Can quickly measure the complete coherence function.
Does not have any moving components</td><td>If a custom grating is required, this method could become expensive.</td></tr>
</table>

Component Analysis			
Component	**Key Specifications**	**Price**	**Link**
Fiber Optic Collimator	• Aperture Size = 4 mm • Wavelength Range = 190-1250 nm	$ 195	https://www.edmundoptics.com/optics/optical-lenses/specialty-lenses/4mm-aperture-uvvis-fiber-optic-collimator-fc/
Beam Expander	TBD (Possibly fabricated from individually purchased components)	?	N/A
Diffraction Grating	• Dimensions = 25 mm x 50 mm x 9.5 mm • Grooves/mm = 300 • Blaze Angle = 26.5 Degrees	$ 304	https://www.thorlabs.com/thorproduct.cfm?partnumber=GR2550-30035
Flat Mirrors	• Dimensions = 12.5 mm x 12.5 mm • Coating = Protected Silver • $\boldsymbol{R_{avg}}$ > 98% at 450-2000 nm ○ Note: Provided reflectivity curve has R>90% for 400 nm	$ 75 per mirror	https://www.edmundoptics.com/optics/optical-mirrors/flat-mirrors/12.5mm-square-silver-coated-lambda10-mirror/
Detector	TBD	?	N/A

Beam Splitter Plate (Designed for 45° AOI)	• Dimensions = 25 x 36 mm • Reflection = 50 ± 12 % • Thickness = 1 mm • Wavelength Range = 350-1100 nm	$ 289	https://www.thorlabs.com/thorproduct.cfm?partnumber=BSW26R
Compensator Plate (Designed for 45° AOI)	• Dimensions = 25 x 36 mm • Thickness= 1 mm • Wavelength Range = 350-1100 nm	$ 116	https://www.thorlabs.com/thorproduct.cfm?partnumber=BCP42R

Method 2: Michelson Interferometer utilizing corner cubes and a translation stage.

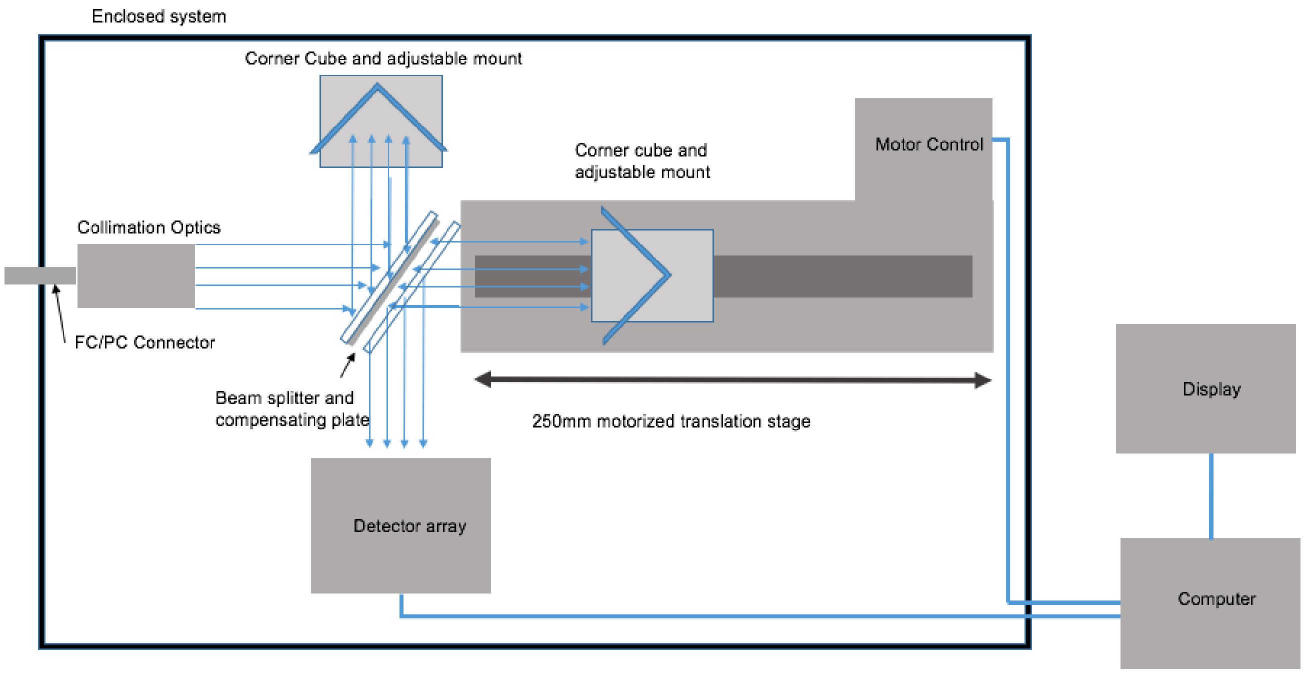


Figure 1. Setup diagram. This system utilizes a Michelson interferometer setup. Light from a laser is introduced to the system via a single mode fiber. One arm holds a motorized translation stage with a minimum of a 250 mm travel length controlled by a microcontroller or PC. The reference arm can hold a corner cube mirror as to ease calibration.

<table>
<tr><th colspan="2">Overview of Method</th></tr>
<tr><td colspan="2">Replaces the flat mirrors used in a traditional Michelson Interferometer with hollowed corner cubes. Corner cubes are valuable because any arbitrary rotation of the cube about its corner point occurring during motion, does not affect the fringes.
Measurement corner cube will be moved by a translation stage, in order to capture information about the coherence length over the entire 500 mm range.</td></tr>
<tr><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td>Involves less optical components.</td><td>Utilizes moving components.
Cost currently exceeds budget.</td></tr>
</table>

Component Analysis			
Component	**Key Specifications**	**Price**	**Link**
Fiber Optic Collimator	• Aperture Size = 4 mm • Wavelength Range = 190-1250 nm	$ 195	https://www.edmundoptics.com/optics/optical-lenses/specialty-lenses/4mm-aperture-uvvis-fiber-optic-collimator-fc/
Translation Stage	• Travel Range = 300 mm • Maximum Horizontal Velocity = 50 mm/s • Minimal Achievable Incremental Movement along Optical Axis = 0.1 µm • Minimal Repeatable Incremental Movement along Optical Axis = 4 µm	$ 3,027	https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=7652&pn=LTS300/M
Hollow Corner Cube Mirrors	• Wavelength Range = 450-10,000 nm • Parallelism = 5 arc second • Aperture = 25.4 mm	$ 849 per cube	https://www.newport.com/p/UBBR1-5S
Detector	TBD	?	N/A
Beam Splitter Plate (Designed for 45° AOI)	• Dimensions = 25 x 36 mm • Reflection = 50 ± 12 %	$ 289	https://www.thorlabs.com/thorproduct.cfm?partnumber=BSW26R

	• Thickness = 1 mm		
	• Wavelength Range = 350-1100 nm		
Compensator Plate (Designed for 45° AOI)	• Dimensions = 25 x 36 mm	$ 116	https://www.thorlabs.com/thorproduct.cfm?partnumber=BCP42R
	• Thickness= 1 mm		
	• Wavelength Range = 350-1100 nm		

Resources Needed:

The following individuals will be used as advisors for our team:

- Professor Thomas Brown for general system help
- A graduate student possibly provided by Professor Fienup to assist with FRED

The following software will be used in the design process:

- FRED for computer modeling of the propagation of light through the system
    - Possible Backup: FDTD Software
- Python or MATLAB for data analysis

Timeline	
Fall Semester (Prior to Semester End)	
December	• Continued investigation of possible detectors • Begin investigation into using FRED • Finalized PRD
Spring Semester Timeline	

January	• Start working in lab:
	    o Setup interferometer
	    o Begin preliminary tests
	• Identify and order items with long delivery times

February	• Continue testing • Selection of best method to pursue • Complete BOM • Order all parts
March	• Start writing software (Python) • Assemble prototype
April	• Test prototype

Appendix:

This appendix section contains the email certification that our PRD has been approved by our customer Tao Chen. The questions provided by our customer will be investigated over winter break and firmly answered during our testing in the spring semester.

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From: Tao Chen - TACH
Sent: Friday, December 15, 2017 2:50 PM
To: Lei Ding
Subject: RE: PRD Approval

Hi, Lei,

I reviewed the PRD file and I think it's well written document. I approve it for your team's submission today.

However, I do have some questions about these 2 proposed solutions:

1. For both method, Fiber Optic Collimator has Aperture Size = 4 mm. Is this big enough for you to get good interference fringe? How much aberration will this collimator introduce to beam and what's the impact of the aberration to the coherence length measurement?
2. Beam Splitter Plate has reflection = 50 ± 12 %. If it's not 50% split ratio, for example 60%, how much this will affect the coherence contrast measurement? Can this be calibrated out?
3. You proposed 2 solutions, which one is selected by your team as final solution?

Thanks,

Tao