Construction of a white-light interferometer for the thickness determination of thin sample

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Introduction

White-light interferometry is an optical technique for measuring the thickness of samples which has high precision, convenience in operation, and wide application.

In my summer research project:

- I constructed a white-light interferometer and verified its accuracy by measuring a quartz sample
- The interferometer was then employed to measure the thickness of fused silica substrate of Barium borate (BBO) crystal.

Basic Principle

For the quartz, the white light will be incident on the sample at a certain angle (instead of perpendicularly), and the reflected light from the upper and lower surfaces of the sample will be received by the spectrometer

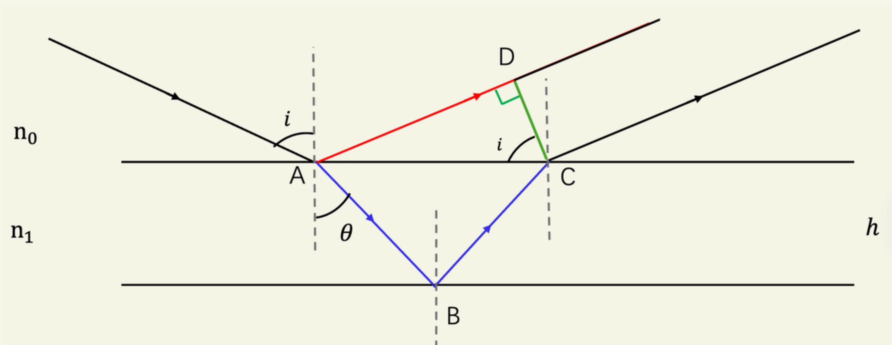

Figure 1. Thin crystal interference

The relation between the time delay and the thickness is

$$h = \frac{c\Delta t - \lambda/2}{2\sqrt{n_1^2 - n_0^2 sin^2 i}}$$

where c is the speed of light, Δt is the time delay, n_0 is the refractive index of the air, n_1 is the refractive index of the sample, $\lambda/2$ is the half-wave loss, and i is the incident angle of the light.

For the measurement of the fused silica substrate of BBO, the principle is slightly different. Since BBO is a crystal grown on the substrate, it is challenging to directly measure the thickness of each layer due to the small difference of the refractive index (1.68 approximately for BBO and 1.45 approximately for the substrate). Therefore, the interference signal arises from the reflected beams off the top and bottom surfaces. However, since the thickness of the BBO layer was known, this method could still be applied to determine the thickness of the substrate.

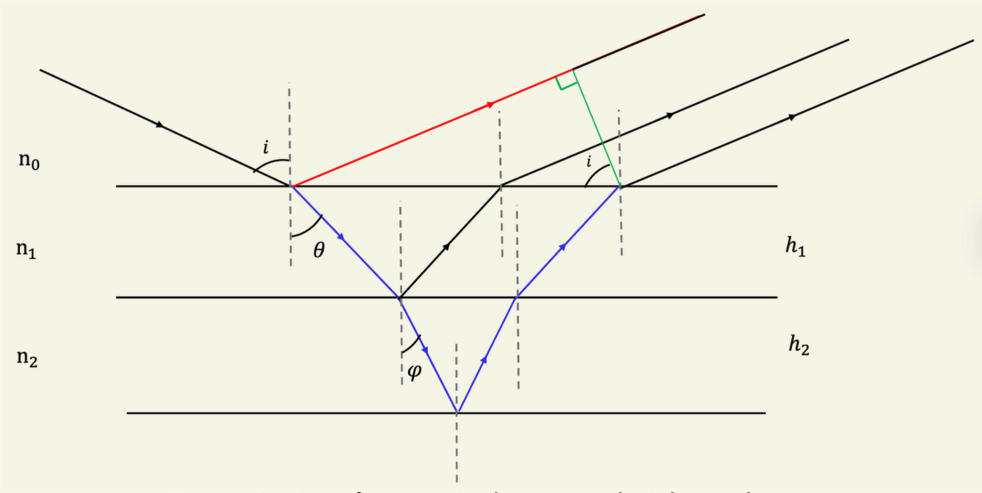

Figure 2. Interference in thin crystal with two layers

The relation between the time delay and the thickness is

$$h_2 = \frac{c\Delta t - 2h_1\sqrt{n_1^2 - n_0^2 \sin^2 i} - \lambda/2}{2\sqrt{n_2^2 - n_0^2 \sin^2 i}}$$

where h_1 is the thickness of BBO and h_2 is the thickness of the substrate.

Apparatus

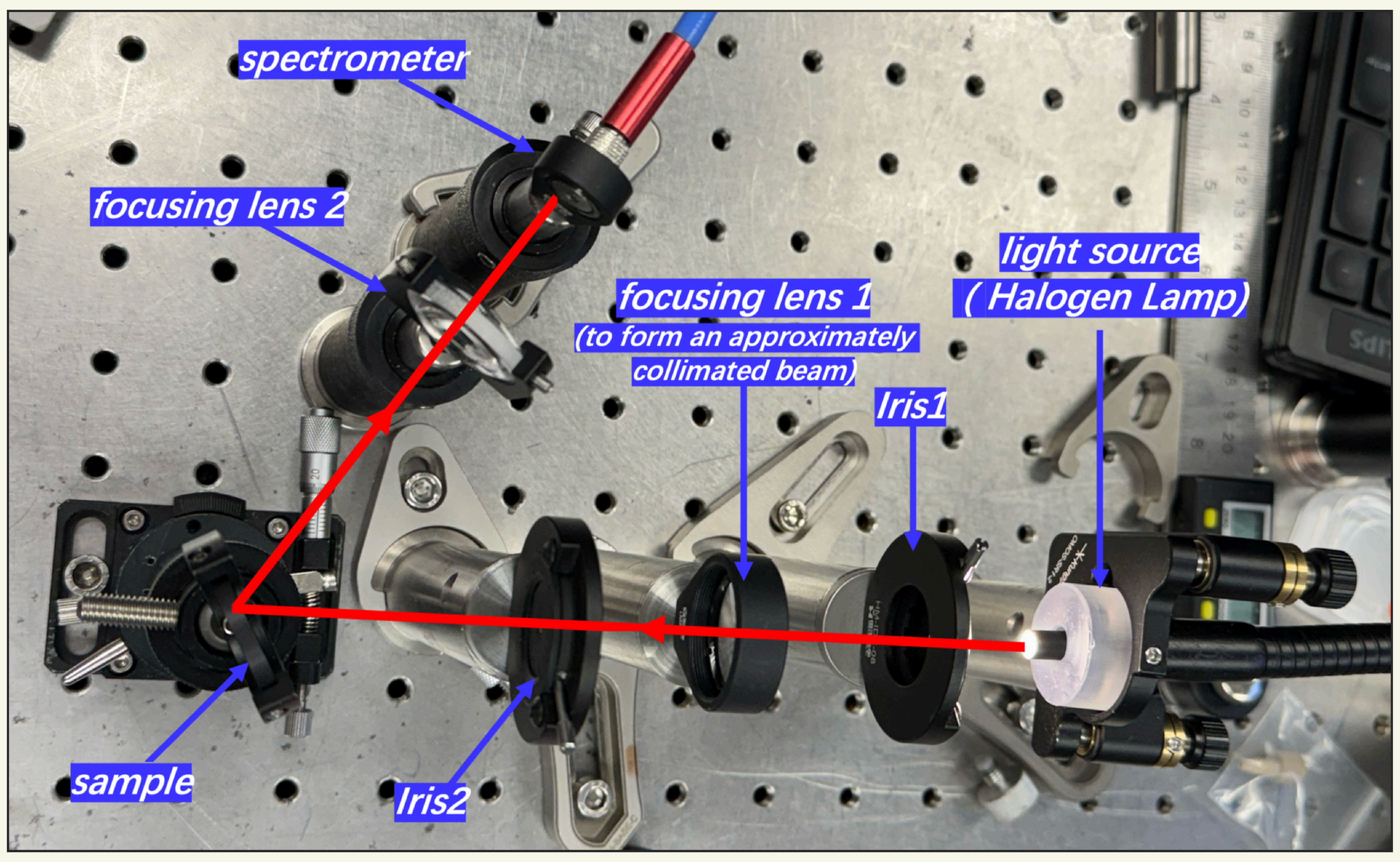

Figure 3. apparatus of the experiment (above view)

Data Processing

In this project, I use MATLAB to process the data and calculate the results.

The spectrum acquired by the spectrometer will first be converted from the wavelength domain ($S(\lambda)$) to the frequency domain ($S(f)$) by

$$S(f) = S(\lambda)\frac{-c}{f^2}$$

Where f is the frequency. Then it will be uniformly resampled, flipped, truncated, and filtered with a Gaussian function before it proceed to perform Fast Fourier Transform (FFT). From the Spectrum in time domain, we can acquire the time delay of the two interfering light beams.

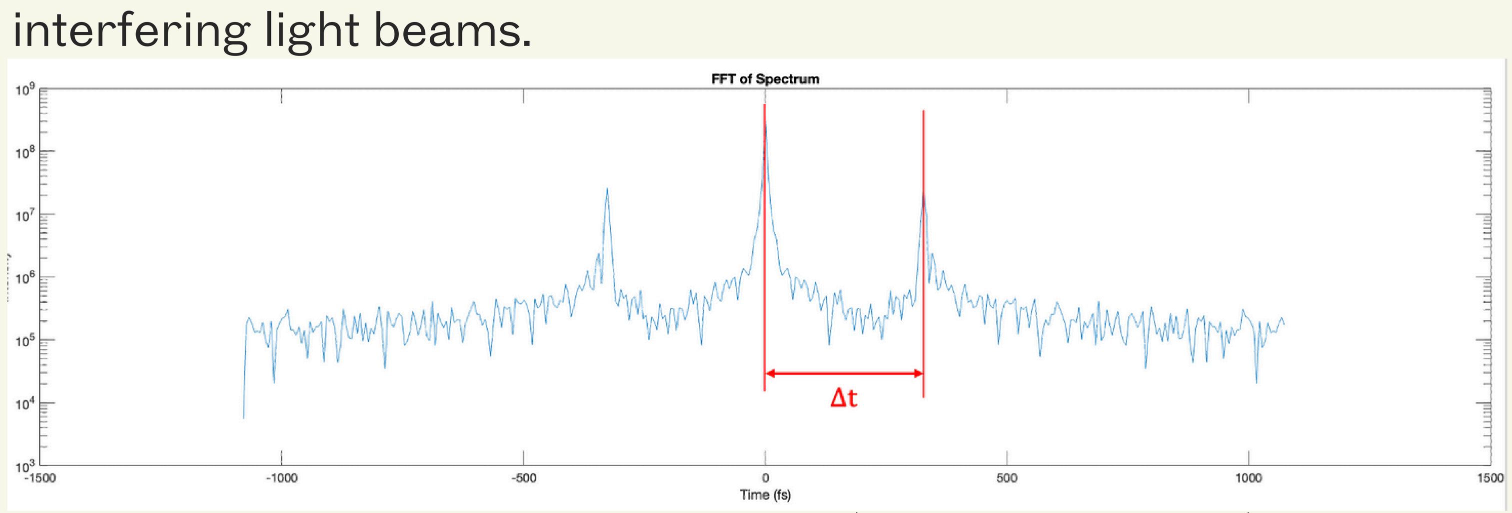

Figure 4. Time domain spectrum of the quartz (Intensity on a logarithmic scale)

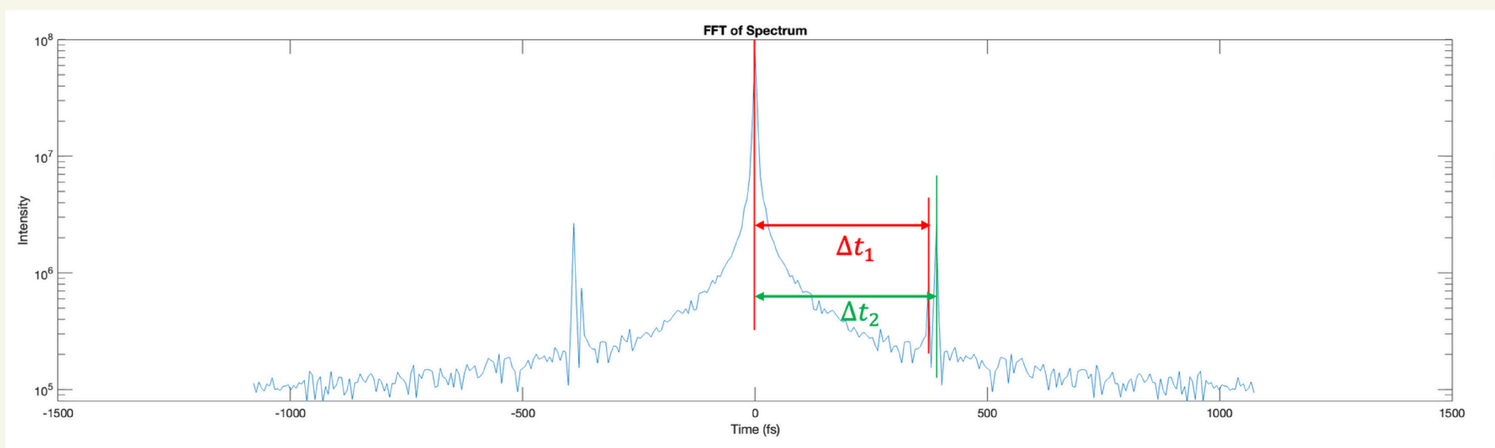

Figure 5. Time domain spectrum of the BBO sample(Intensity on a logarithmic scale)

The time-domain spectrum has two closely spaced peaks on each sides. This abnormal feature may be attributed to the unevenness of the interface between the BBO and the substrate.

Result and Discussion

- **Quartz**

Sample	Thickness with error (μm)	Thickness with error bars in percentage
Quartz	35.95±0.22	35.95μm ± 1%

- **Fused silica BBO substrate**

Sample	Thickness with error (μm)	Thickness with error bars in percentage
Fused silica (left peak)	44.41±1.73	44.41μm ± 4%
Fused silica (right peak)	48.06±2.49	48.06μm ± 6%

References

[1] Park, J., Kim, JA., Ahn, H. et al. A Review of Thickness Measurements of Thick Transparent Layers Using Optical Interferometry. Int. J. Precis. Eng. Manuf. 20, 463–477 (2019). https://doi.org/10.1007/s12541-019-00105-0

[2] Quinten, M. (2019). On the use of fast Fourier transform for optical layer thickness determination. SN Applied Sciences, 1(8), Article 823. https://doi.org/10.1007/s42452-019-0866-9