

# Frequency-Modulated, LiDAR-Based Length and Thickness Metrology Systems

February, 2020  
Page 1



## ABSTRACT

When manufacturing optics, confirming that they meet specifications is critical. Testing can cause damage to the surfaces in accurate measurements of distance and thickness, and not all optics are testable with non-contact measurement techniques. While thickness measurement methods tend to use contact systems that damage the lens and length metrology techniques use methods that have problems with surfaces that diffuse the light, Bridger Photonics provides a solution for both thickness and length applications with a Frequency Modulated Continuous Wave (FMCW) Light Detection and Ranging (LiDAR) technique. Without contact with the optic, Bridger Photonics can measure lengths of up to 2 m and thicknesses of up to 60 mm with 1  $\mu\text{m}$  precision. The FMCW LiDAR Metrology Systems provide additional benefits including three dimensional (3D) mapping with the precision and accuracy needed in laser materials processing applications and optics manufacturing.

## OPTICS MANUFACTURING

Accurate and precise measurements are critical to testing and material identification in optics manufacturing. In any application requiring extremely accurate positions of the optics, the thickness (optical and physical) of the lens needs to be known to a very small degree of uncertainty. The most demanding applications require 1 micron or better center thickness uncertainty.<sup>1</sup>

Quick and easy, non-contact measurements can be made with new metrology systems. High accuracy, three-dimensional (3D) mapping can be achieved using specific metrology systems with multiple measurement scans over the object under test.

## PROBLEMS

The most common way to measure the thickness of a lens is by physical contact with that lens. This invariably slightly damages the surface of the optic and requires evaluation of the extent of the damage. Damaged optics can cause problems in high-power laser applications. Imperfections in the lens or on the surface of the lens can cause damage centers.<sup>1</sup> These can affect the beam quality of the laser and the divergence of the laser. When the damage is too great, testing results in scrapped optics. Human error also is a source of inaccuracy when manually measuring the optics using contact methods.

Non-contact techniques such as low-coherence interferometry, optical coherence tomography, and laser radar can achieve high levels of resolution, but they have difficulties with diffusely scattering surfaces. This limits

measurements to only polished optics with these methods. Additionally, they only work for very thin or flat optics. Many manufacturers have a need for measuring thicknesses of curved lenses. These non-contact techniques are also limited to the size of the transparent material and cannot measure the optical thickness and therefore the group index. The optical thickness is related to the phase change of light in the material and is related to the physical thickness by a factor of the group index. This can be used to identify the type of material that has been processed confirming the correct blank was used. If this is not measured alongside the physical thickness, problems can arise from manufacturing or shipping the wrong lens material.

In situ measurements during laser material processing is desirable. Adding extra components to the laser setup by using a parallel measuring system, however, is costly. Being able to measure any optic easily and quickly, regardless of form or surface or material, is critical for saving manufacturers time and money.

## BRIDGER PHOTONICS' SOLUTION

Bridger Photonics has created rapid, accurate, compact, and non-contact solutions for industrial use on any type of lens. The Thickness Metrology Station (TMS) (**Figure 1**) can measure the physical thickness, optical thickness, and group index of the material, solving identification and confirmation problems. The Length Metrology System (LMS) (**Figure 2**) is designed with a compact optical probe to make integration into any system simple. It is specifically designed for laser materials processing systems.



Figure 1. Bridger Photonics' Thickness Metrology Station<sup>2</sup>



Figure 2. Bridger Photonics' SLM-IM Length Metrology System<sup>2</sup>

The laser engine in both systems utilizes Bridger Photonics' patented Frequency Modulated Continuous Wave (FMCW) LiDAR (Light Detection and Ranging) technology. The laser's output is chirped (the frequency is ramped with time). This frequency is swept over a given bandwidth (B),

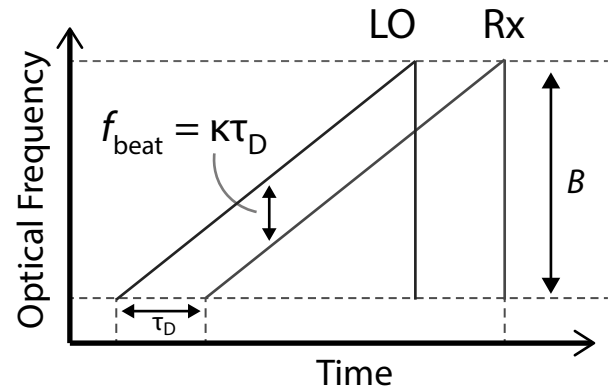


Figure 3. Frequency Ramp with Local Oscillator (LO) and Return Signal (Rx) showing time delay ( $\tau_D$ )<sup>1</sup>

seen in **Figure 3**. The light from the chirped laser is split into two portions: transmitted (Tx) and a reference (local oscillator or LO). The transmitted light is incident on the optic under test and reflects back to the detection system. The returned (Rx) frequencies are compared with the reference frequencies. The setup is shown in **Figure 4**.

Because the return signal has covered the distance to the object and returned, it will be shifted in time compared to the reference waveform as seen in **Figure 3**. The two signals are combined, and a detector measures the beat created from the frequency difference. The beat is dependent on the chirp rate ( $\kappa$ ) and the time delay ( $\tau_D$ ). The signal is then converted with a fast Fourier transform to give the full-waveform range profile (seen in **Figure 5**). The peaks show the location of each surface of the given object. The widths of the peaks ( $\Delta R$ ) are dependent upon the chirp bandwidth. From the peaks the thickness of the optic can be realized. This method allows for measurements of diffusely scattering surfaces which challenge the accuracy and resolution of other non-contact techniques.

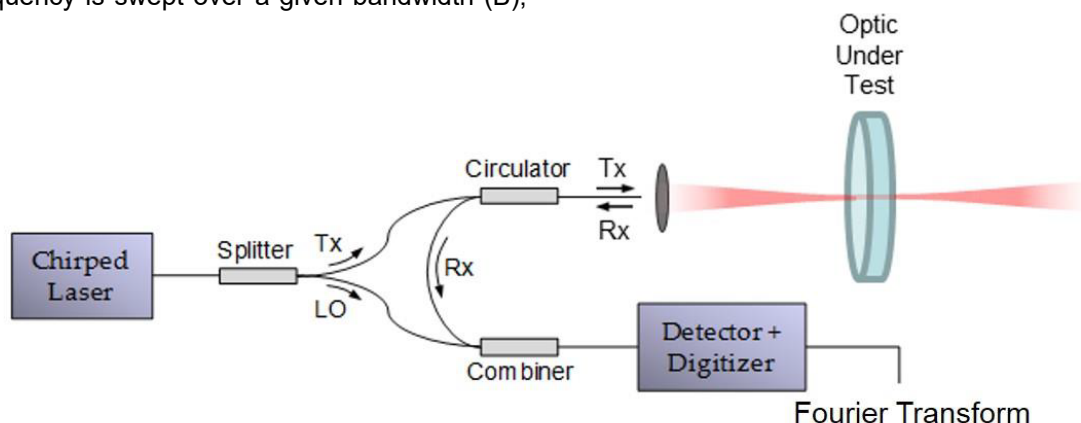
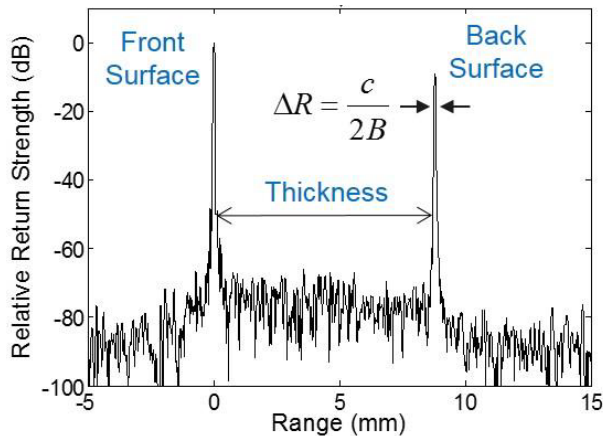


Figure 4. (FMCW) LiDAR measurement technique<sup>1</sup>



**Figure 5. Beat peaks showing thickness measurement results<sup>1</sup>**

Bridger Photonics' Thickness Metrology Station, is used mainly for applications needing precise lens measurements. This station can measure optics up to 60 mm thick (with larger custom stations possible) and up to 6 inches diameter. It can measure physical thickness, optical thickness, and group index to a precision and accuracy of less than 1  $\mu\text{m}$ . Knowing the index of refraction makes it possible to identify the material. The greatest advantage of the TMS is that it is non-contact. This ensures that the optic is not damaged, reducing scrap and evaluation time. This also eliminates errors from manual calibration and set-up as well as the other problems discussed earlier about traditional thickness measurement methods.

The Length Metrology System has been specifically designed for integration into materials processing machines. The LMS delivers the light through a compact fiber optic probe. The laser in the LMS can be co-aligned with the materials processing laser beam eliminating extra components and cost. In real time, the LMS provides feedback about the material and its distance from the machine tool.

The LMS detects obstructions in the beam path (the optic) and knows immediately when the laser has broken through the material making it ideal for detection in drilling systems. Additionally the Length Metrology System is not damaged by backscattered light from the materials processing laser beam. The LMS can provide high accuracy and precision as low as 1  $\mu\text{m}$ . It has 1 kHz measurement rate, 0 - 2 m range window, < 2 ms measurement latency (for rapid measurements), and Ethernet communication for real-time feedback. It also provides 3D mapping of the part under test using scanning measurements.

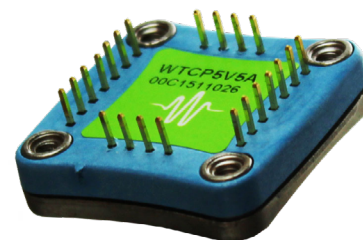
## WAVELENGTH'S ROLE

The lasers for the FMCW LiDAR need to be wavelength stabilized through precise temperature control because the group index is dependent on wavelength. Wavelength Electronics' WTCP-5V5A (**Figure 6**) provides a current limit of 1 A and voltage less than 3 V to control the temperature of the laser for both of Bridger Photonics' metrology systems. The WTCP has efficient Pulse-Width Modulation (PWM) up to  $\pm 5$  A and 5.5 VDC to the thermoelectric controller. The WTCP can produce temperature stability as low as 0.001°C. This ensures that the wavelength of the laser does not fluctuate over time, and the measurements are consistent over multiple tests.

Different lasers can have completely different thermal profiles, so the PWM tuning coefficients can be different for each one. Both the laser system and the WTCP can easily be characterized with the WTCP Evaluation Board. Once operation is understood with the evaluation board, the optimized WTCP can be seamlessly transferred to an OEM circuit board.

The WTCP also offers multiple safety features to protect the laser system. These include current and voltage limits, temperature-in-range signal, TEC voltage and current monitors, and remote enable input. The intuitive evaluation board made better system design simple and easy.

The compact WTCP is perfect for applications requiring high efficiency, low power dissipation, and high stability in space-constrained temperature control applications such as Bridger Photonics' Length Metrology System and Thickness Metrology Station.



**Figure 6. WTCP 5 A, 5 V PWM Temperature Controller**

## REFERENCES

1. M. J. Thorpe, J. K. Brasseur, P. A. Roos, "Development of a non-contact center thickness optical metrology system," Proc. of SPIE 9576, Applied Advanced Optical Metrology Solutions, 957601 (2015); <https://doi.org/10.1117/12.2190163>
2. Bridger Photonics. Bozeman, MT  
<https://www.bridgerphotonics.com/>

## USEFUL LINKS

- WTCP-5V5A [Product Page](#)
- WTCP-5V5A EVAL Board [Product Page](#)

### PRODUCT USED

WTCP-5V5A

### KEYWORDS

Metrology, industrial distance, laser, index of refraction, non-contact, frequency modulated continuous wave, part mapping, lidar, materials processing, length metrology

### REVISION HISTORY

Document Number: CS-TC02

REVISION	DATE	NOTES
A	February 2020	Initial Release