Beam Shaping for Laser Material Processing – Collaborative Industry Project

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Project Information

Project Code:	I17-P-046/SIMT/17-310032
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Table of Contents

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Project Summary

Laser beam shaping is a potential technique to optimize laser-material processing applications, especially to improve the process quality and throughput manufacturing, such as depth control and edge profile control of machining.

There has been some commercial available beam shaper to manipulate the spatial profile to flat top. It serves as a module to uniformly distribute the laser energy in order to improve the beam utilization efficiency, especially in machining applications. However, the beam quality control is very much by estimation. Because the characterization tool and quantification parameter are missing. A systematic beam design approach will be essential for laser material processing applications.

This project aims to work collaboratively with Wintek Technology to come out new beam delivery system with minimal change on most industrial laser system design, to realize top-hat application. The whole process will (1) help precision engineering companies to identify and enhance their competencies in developing new and high-value laser-based products and systems. (2) help companies gain know-hows of surface quality control and processing speed improvement in material processing by the laser beam shaping technique. (3) help companies built up competencies in design, engineering, and characterization of customized laser beams. We aim to benefit them by building up their new competences in high value added optical modules and exploring new processes for product innovation. This may hence enable them to create new business opportunities.

1: Introduction

This is the project closure report to summarize the deliverables of CIP with Wintek Technology.

2: Objectives and Deliverables

To help the company to identify/enhance competencies for new high-value products by developing (1) know-how of laser beam profile effect on surface quality and speed; (2) design, prototyping and application notes of a module for laser beam customization; (3) a characterization methodology for customized beam properties.

To provide demonstrator using SIMTech laser system platform and beam shapers for a customized product needs.

Project deliverables

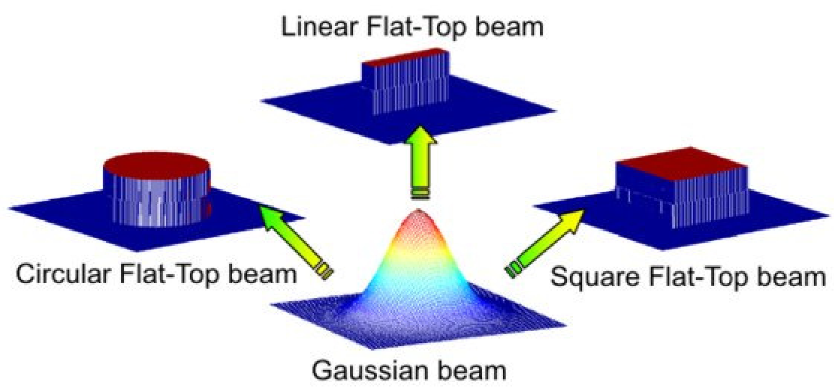
1. A workshop on Beam Shaping Methodology
   - A design course including laser principle and beam shaping principles and critical parameters.
   - A software kit to design the laser and the laser system with beam shaper.

2. Application notes on laser system with customized beam:
   - Prototype design for the beam shaper module.
   - Optimal key parameters identification.
   - Working principle of all developed characterization tools.
   - A software kit for integrated GUI of laser characterization.
   - Testing report on a specific application (by each company).

3: Workshop on Beam Shaping Methodology

3.1 Laser principle and beam shaping principle and critical parameters

The details of laser principle and beam shaping principle could be found in Appendix: Workshop Notes.



The design principle of beam shaping is fundamentally the remapping of the incoming intensity distribution – Preservation of ***wave-front uniformity*** and ***loss-less shaping***.

Different possible approaches:

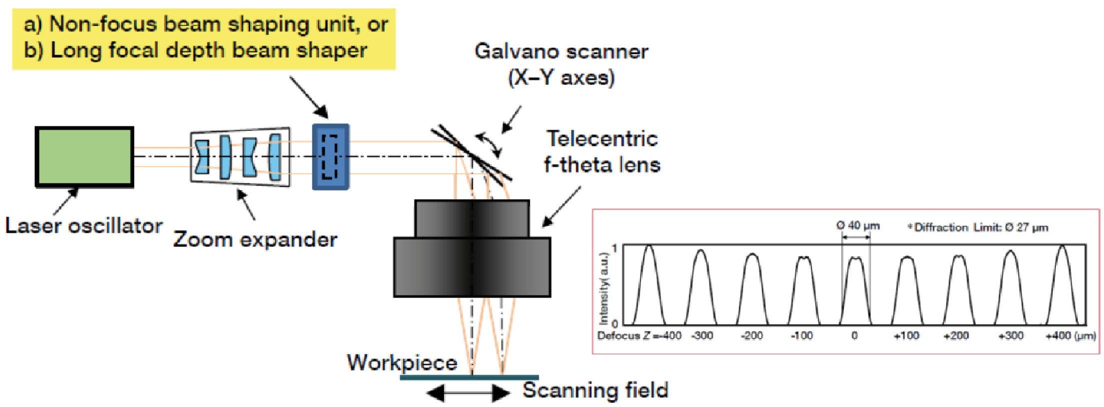
- Simple aperture masking (lossy)
- Loss-less geometric optics (refractive)
- Fourier transforms optics (diffractive)

$$\beta = \frac{2\sqrt{2\pi} r_0 Y_0}{f\lambda}$$

λ: wavelength
r_0: waist or radius of input beam
Y_0: half width of the desired output dimension
f: focal length of the focusing optics, or the working distance from the optical system to the target plane.

β<4, beam shaping will not produce acceptable results.
β>32, geometrical optics methods should be adequate.
4<β<32, diffraction effect are significant (Diffractive optical element was chosen by calculating our system design).

3.2 Laser system with beam shaper



Important to:
1. Check input laser mode quality and adjustment of beam parameters.
2. Check whether beam vignetting or optical surface distortion occur.

Wish list:
- Uniform intensity profile: typically +/-5%
- Steep transition region: typically similar to diffraction-limited spot with the same input diameter and working distance.
- High power threshold
- High efficiency >95%
- Sensitivity to X-Y displacement and input beam diameter: 5% of the input beam, in order to keep acceptable performance
- Rotation insensitive: for round shape output beam
- Sensitivity to working distance: <50% of the spot size in order to keep acceptable performance.

4: Application Notes on Laser System with Beam Shaping

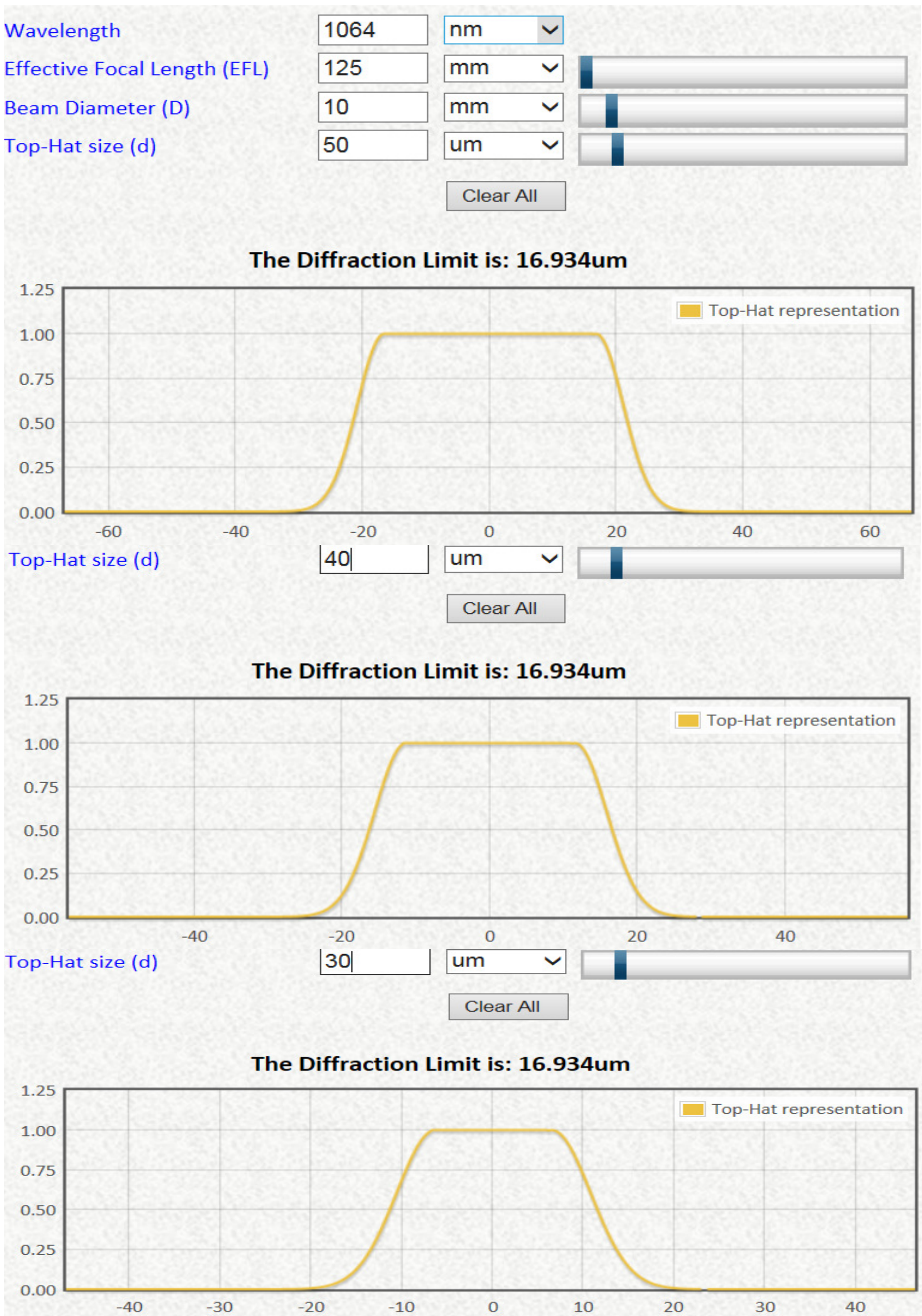
4.1 Prototype design for beam shaper module

Beam shaper module	Design requirements:
(A) Circular Flat-top Required flat-top diameter = 50um @ $1/e^2$	Wavelength = 1064nm Input beam waist diameter = 10mm f-theta lens effective focal length=227mm

4.2 Optimal key parameters identification

The key parameters during the beam shaper design includes: wavelength, effective focal length, input beam size, required shaped beam size at focus.

Pay attention (use top hat design as an example): If we fix the wavelength, focal length and input beam size, ith the deducing top-hat size at focal point close to diffraction limit, the top hat region is getting narrower while the edge (transition region) is getting less steep.



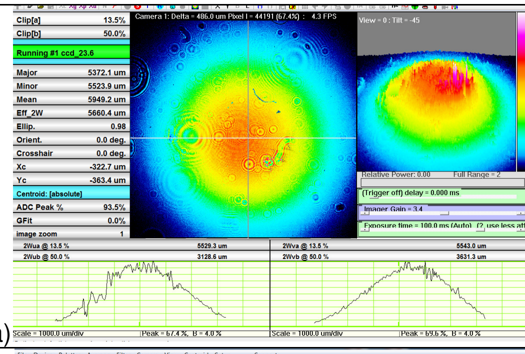
4.3 Working principle of all developed characterization methodology

Beam profiling was carried out by infrared CCD at three different conditions:

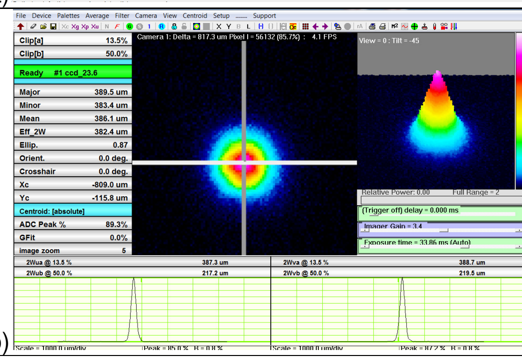
(a) Collimated Gaussian beam (beam size=10mm), exceeding the measurement range of the CCD area
(b) Focused Gaussian beam after the f-theta lens
(c) Top-hat beam near the focal point after the f-theta lens

WinCamD-UCD23 – 2/3" CCD Beam Profiler

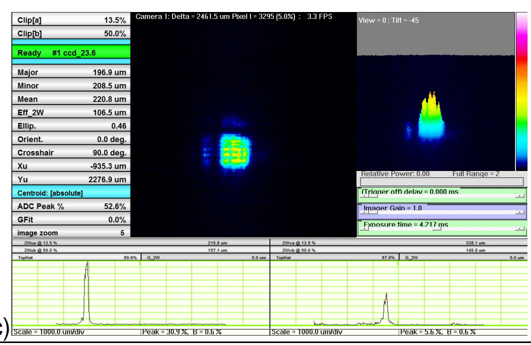
- 355 to 1150 nm, standard CCD detector
- 1360 x 1024 pixels, 8.8 x 6.6 mm active area
- 6.45 µm pixels (the beam measurement near focal point is limited by the pixel size of the CCD)



(a)



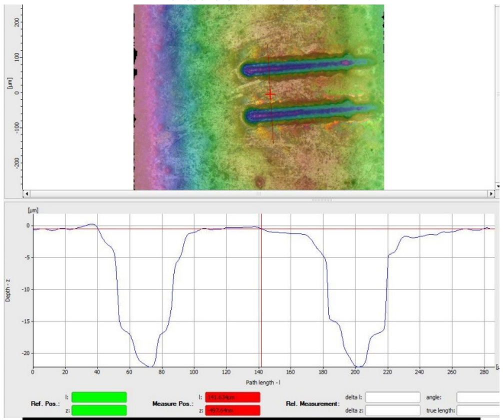
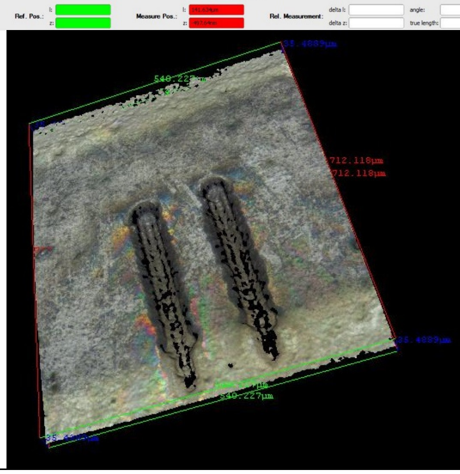
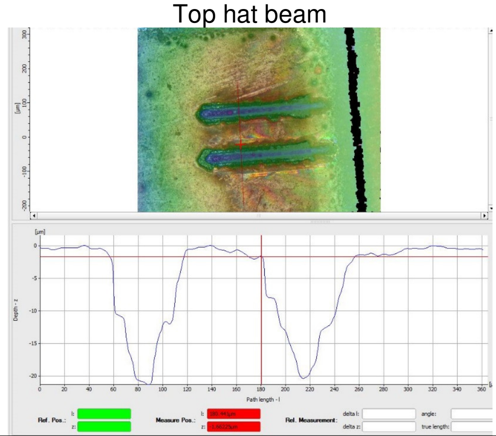
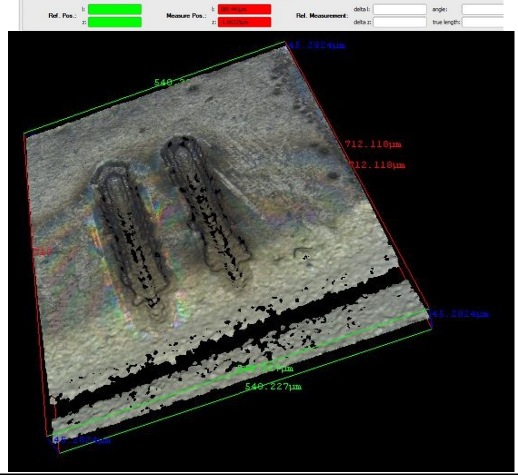
(b)



(c)

4.4 Testing results

3D measurement of laser processed parts with/without DOE element were carried out by Alicona stylus profilometer. **The comparison shows there is an obvious slide slope at about 20um away for the center in the case of Gaussian beam. The value could be further improved with diffractive beam shapers.**

Gaussion beam	Top hat beam
 	 

5: Conclusion

System instrumentation capability have been established through this project.

6: Future Plans

6.1 Technology

Methodology of beam measurement and characterization (power stability, spectral domain, time domain and spatial domain) have been transferred to company. Design methodology of a flattop laser beam shaper based on diffrative optical element has been transferred to company.

6.2 Commercialisation

The team foresees growing insterest from laser material applications on customized beam shaping, especially top-hat, beam splitter and Bessel beam. The system instrumentation and application knowhow should be estabilished, the high power design could be fabricated and tested with measurement data. Further more, laveraging on Wintek's capability in communication and electronics, IP could be filed based on laser systems with in-situ process monitoring (compliance to industry 4.0), for commercialisation.

Appendices

Workshop notes: training documents

Acknowledgments

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Singapore Institute of Manufacturing Technology (SIMTech) is a member of the Agency for Science, Technology and Research (A*STAR). The Institute has a three-pronged role to develop human, intellectual and industrial capital for the industry.