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Industrial scale riblets manufacturing with a high energy femtosecond laser and a Multi-Plane Light Conversion beam-shaper

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Abstract

Riblets manufacturing lead to the reduction of flight fuel consumption by 2-3%. However, achieving the necessary high precision in texturing and high processing speed to engrave large surfaces is challenging. To overcome this challenge, an innovative combination of high repetition rate (40MHz) and high-energy (3 mJ) femtosecond laser with an optimal beam management has been developed. The beam-shaper based on Multi-Plane Light Conversion (MPLC) technology enables beam division and square top-hat generation, resulting in a high level of homogeneity of spots. The change from Gaussian to square top-hat improves the process speed by 10. Combined with beam-splitting a 90 times speed increase is demonstrated.
In this study, we present texturing tests that demonstrate the efficacy of this new technique. This breakthrough combination of laser and beam-shaping has the potential to revolutionize the aerospace industry by enabling the production of high-quality riblets at a faster rate and with greater precision.

Keywords: Laser; Additive Manufacturing; powder; Nickel; 3D-Printing; beam shaping; MPLC; cracking; porosity

1. Introduction: Riblets

Riblets are surface grooves inspired by shark skin, reducing fluid drag by disrupting the boundary layer of turbulent flows. Aligned with the flow, they offer significant performance gains in aeronautics, the marine industry, and other fields. They reduce braking forces and aircraft fuel consumption. However, their optimum design depends on factors such as flow velocity and surface geometry, requiring study and testing for each specific application.

The current processes available for texturing of painting and riblets generation pose their respective challenges and limitations. Texturing of painting through a mold is one approach, but the durability of the mold is relatively low, leading to potential issues in maintaining consistent and high-quality texturing over time.

On the other hand, 3D printing offers great versatility, but its main drawback is the slow processing speed, which hinders its efficiency for large-scale production and time-sensitive applications.

For riblets generation with USP (Ultra-Short Pulse) laser technology, specific challenges need to be addressed. Achieving high precision on metallic surfaces is a critical requirement, and the process must ensure meticulous control to avoid any surface imperfections. Additionally, the capability for large area processing is essential to make riblets viable for various applications and industries.

Another challenge lies in implementing a high-power laser for riblets generation. A robust and efficient laser system is necessary to maintain consistent and reliable performance while delivering the required power for effective riblet creation on surfaces.

Innovations and advancements in laser technology and processing techniques are essential to overcome these challenges. Finding solutions to achieve high precision, large area processing, and the integration of high-power lasers will significantly enhance the applicability and efficiency of riblets generation processes. Overcoming these hurdles will open new possibilities for practical and widespread use of riblet surfaces, benefiting various sectors like aviation, automotive, and marine industries, where reduced drag and improved aerodynamics are highly desirable.

2. Solution provides by MPLC technology

2.1. Multi-Plane Light Conversion

Multi-Plane Light Conversion (MPLC) is a technique that allows performing any unitary spatial transform. Theoretically, it enables the lossless conversion of any set of N orthogonal spatial modes into any other set of N orthogonal modes through a succession of transverse phase profiles separated by free-space propagation serving as a fractional Fourier transform operation. The principle of the MPLC is shown schematically in Figure 1.

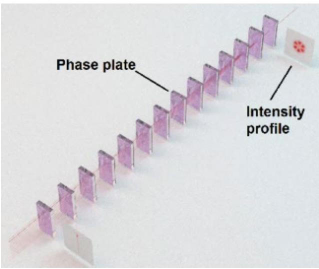


Fig. 1. Principle of MPLC

Historically, MPLC was implemented using a multi-pass cavity, in which the successive phase profiles are all manufactured on a single reflective phase plate (see Figure 2). The cavity is formed by a mirror and the reflective phase plate and performs the successive phase profiles.

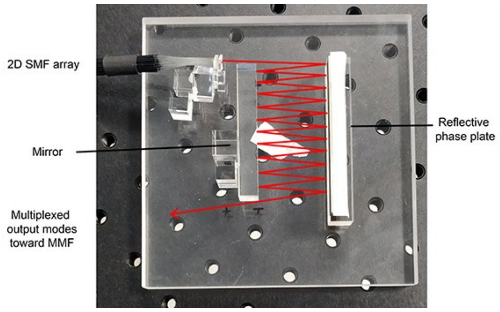


Fig. 2. Picture of a MPLC with fibered inputs. The beam path is shown in red.

MPLC technology enables complex beam shapes with a high control over amplitude and phase. The free-space reflective design allows for high beam shaping quality whilst conserving the property of the laser, such as the depth of field, which is not usually achievable through other beam shaping methods. Moreover, MPLC technology may be adapted to a wide range of wavelengths from visible to IR. Therefore, MPLC technology is well adapted to laser processing.

Amplitude, Cailabs, Onera and Alphanov are working in partnership on a project called “Chasseur”. The goal is to create an industrial, reliable, precise, and efficient solution for manufacturing these riblets using beam shaping technology.

2.2. Integration system

In this paper we discussed the results obtained with a set-up typical of an industrial implementation as detailed further. The assembly consists of an Amplitude Tangor 300 laser with a wavelength of 1030nm. It provides 300 fs pulses at 10W power into a beam expander and then into the beam shaping module. The beam shaping module based on patented Multi-Plane Light Conversion (MPLC) technology. Fully reflective, the module is designed to withstand high-energy femtosecond laser pulses with remarkable stability. Here it is configured to produce high-quality, square 15µm Top-Hat shaping for fast and efficient texturing of large areas. A 14mm galvo-scanner and a 150mm F-Theta lens complete the set-up. The aim is to generate fast, conformal riblets on AU4G aluminium.

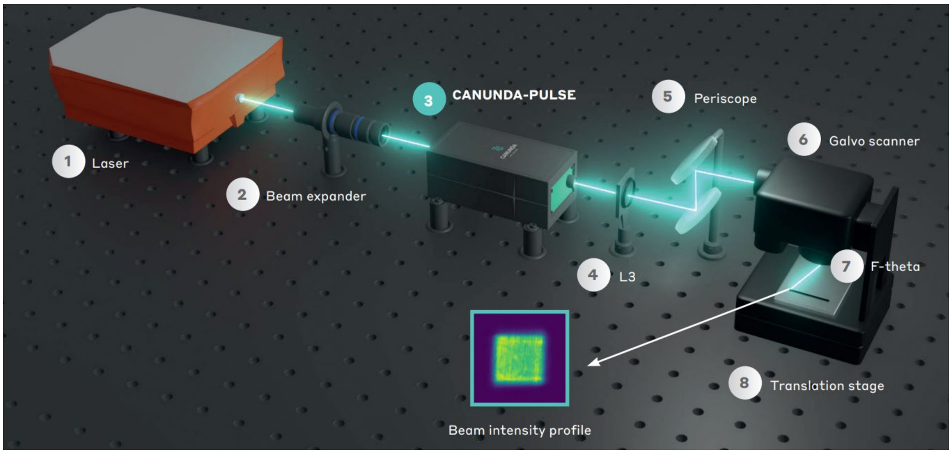


Fig. 3. Integration system

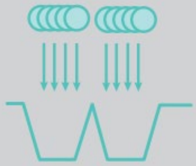
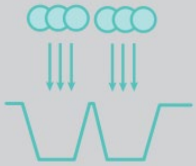
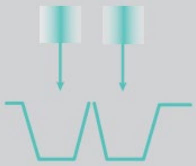
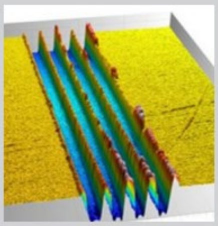
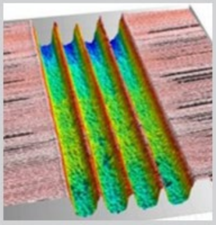
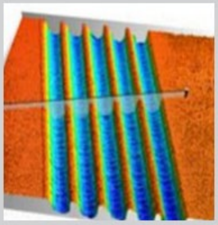
3. Results obtained with Amplitude.

To determine the relevance of the formatting solution with the system, we decided to compare the results (see Table 1) with those obtained without formatting.

In the first case, a 7µm diameter Gaussian beam allowed us to produce riblets with 13 lateral passes and 37 longitudinal passes. The apex angle obtained is 35° and the riblets are compliant. The ablated area is 201µm². On the other hand, the process time is 0.5s which is quite long.

In the second case, a 15µm diameter Gaussian beam allowed us to reduce the number of lateral passes to 10 and the number of longitudinal passes to 34 in order to reduce the manufacturing time. According to the theory, the process time down to 0.3s but the apex angle is 74° and the riblets are not conformal. The ablated area is 571µm².

Table 1. Comparative table of solutions

With a Gaussian beam		with a square Top-Hat beam
Beam size: 7 µm Number of lateral passes: 13 Number of longitudinal passes = 37	Beam size: 15 µm Number of lateral passes: 10 Number of longitudinal passes = 34	Beam size: 15 µm Number of lateral passes: 1 Number of longitudinal passes = 21
		
 Confocal Apex angle = 35° COMPLIANT	 Confocal Apex angle = 74° NON-COMPLIANT	 Confocal Apex angle = 35° COMPLIANT
0.5 s	0.3 s	0.03 s

Finally, the square top-hat beam generated by the MPLC shaping technology made it possible to perform a single lateral pass and 21 longitudinal passes. The apex angle obtained is the same as that obtained in the 1st case, i.e. 35° and the riblets are compliant. The ablated area is 335µm². Processing time is considerably reduced to 0.03s, 17 times less.

4. Conclusion

The collaboration between Cailabs and Amplitude has showcased an exciting use-case of surface texturing, employing a square top-hat beam to generate riblets on aluminum Au4G. The resulting riblets demonstrated a compliant 3D structure, marking a significant advancement in surface texturing technology. One notable achievement was the remarkable increase in process speed, which is 17 times shorter compared to the traditional Gaussian beam method. This substantial improvement in efficiency enhances the viability of riblet generation for large-scale industrial applications, bringing new possibilities to industries seeking aerodynamic improvements and drag reduction.

Building on this success, the joint effort aims to push the boundaries even further with ongoing developments in the coming months. By combining beam shaping and splitting techniques, achieving a process speed increase of over x100 is targeted. Additionally, the ongoing developments include the generation of HLFC (Hybrid Laminar Flow Control) structures. The combination of riblets and HLFC holds the promise of delivering remarkable aerodynamic performance improvements in various applications, such as aviation and aerospace.

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