

Innovative laser processing systems

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Abstract

The number of laser applications increase year by year thanks to the ability of using and control the light energy in accurate and flexible processing systems. Nowadays lasers can produce hundreds of microjoules at frequencies of megahertz, making necessary advanced motion control at higher speeds with sub-micrometer resolutions. In parallel, R&D laser systems's end users demand flexible setups to study the applications with spot-sizes from 1 to 100 micrometers, pulse energy control, auto-alignment and even metrology capability in the same machine, increasing the hardware and software complexity.

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1. Introduction

The R&D laser systems development is covered mainly by engineering companies that integrate laser solutions. These machines have different levels of complexity depending on the application specifications:

- Spot sizes. Normally having spot sizes < 5-10 micrometers makes the focus plane correction necessary due the limitation on the Rayleigh length parameter. The correction is made motorizing one lens, but a measurement system is needed to correct the distance in real time, making the process more complex.
- Motorized spot size selection. The dimension of the spot size can be adjusted with motorized BET (Beam Expander Telescopes) but it always produces a position misalignment that needs to be corrected by hardware and/or software.
- Automatic beam positioning alignment module. For very accurate applications with processing times of hours could be mandatory to maintain the laser beam energy in a volume of few μm^3 during all the process, making necessary implementing advanced optical setups with active beam tracking and special vision-software algorithms.



Fig. 1. LS-fPRO System.

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- High accuracy positioners. The capability of the motion stages or scanners to maintain very low following errors are critical for setups with small spot sizes, as reduce the position jitter of the laser pulses on the target surface. These stages with fast response time need complex tuning to give high performance.
- Metrology capabilities that allow automatic analysis of the laser processing results, with nanometer resolution, and without any user manipulation, ensuring higher reproducibility and throughput. Depending on the parameters to analyze, confocal or interferometry technology is used and integrated into the laser machine.

To integrate all the previous capabilities into a unique laser machine with multiple lasers and wavelengths, the LS-fPRO laser system has been developed, providing a complete application laboratory for R&D users (*Figure 1*).

2. Advanced Processing system

As an example of high technology laser system, the LS-fPRO is a versatile five-axis micro-machining workstation designed for high demanding laser processing applications where nanometer resolutions and laser spot sizes down to 1 micron are required. The main heavy granite structure with passive dampers, and advanced solutions like close loop surface measurement for automatic focus correction, provides extremely high accuracy and stability even for complex trajectories. As an option, LS-fPRO integrates features that ensures a high precision laser processing, as an active beam tracking solution for analyze and reduce the beam pointing errors produced internally in the laser or by room thermal changes, as well as a confocal system for close loop metrology (*Figure 2*).

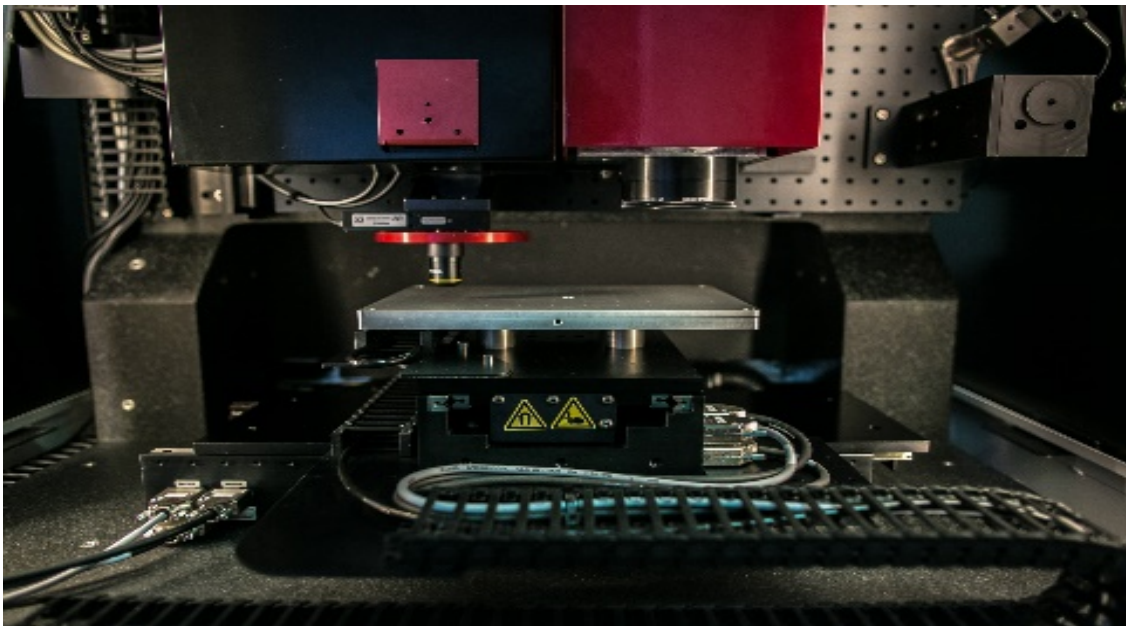


Fig. 2. LS-fPRO Processing system.

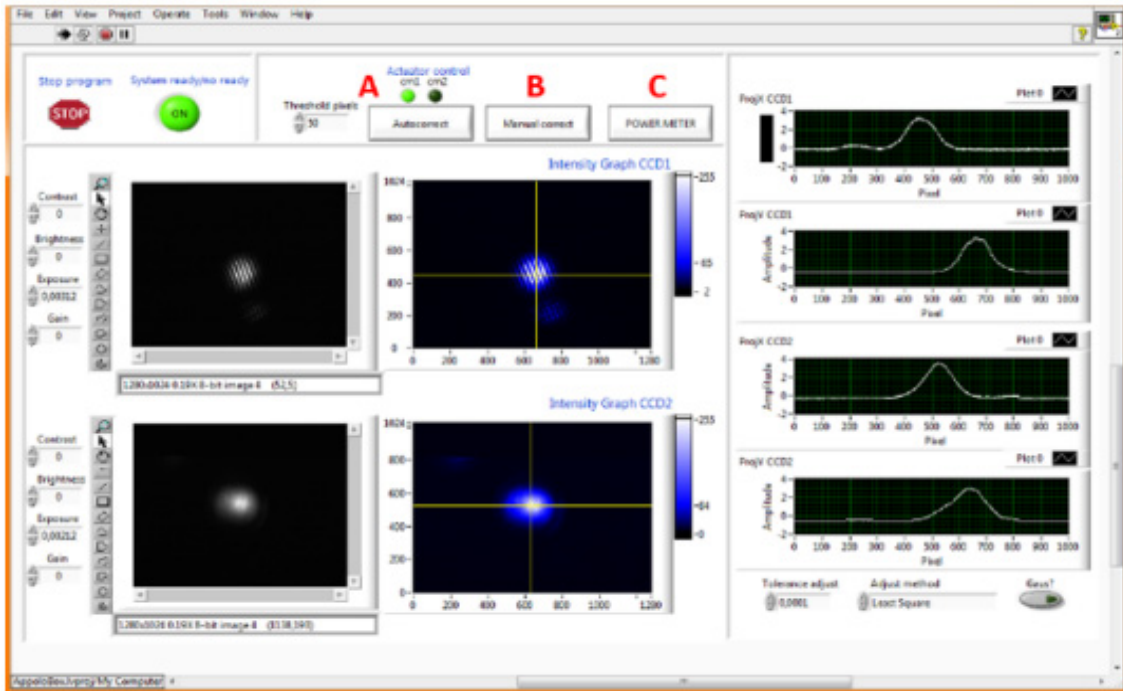
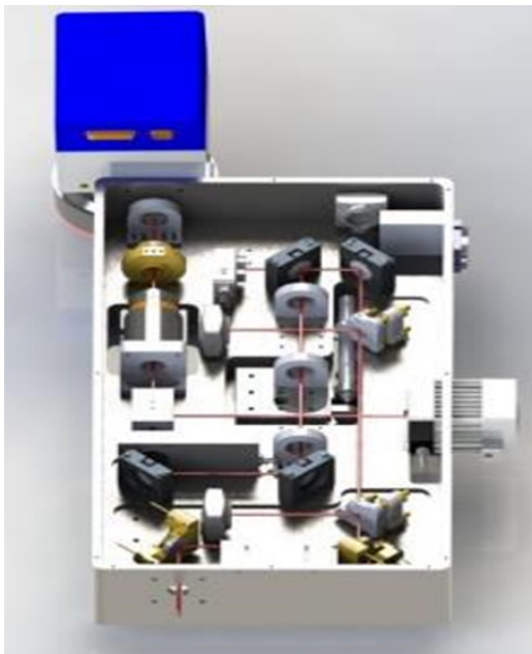


Fig. 3. Beam-pointing stabilization software.

2.1. Active beam tracking optics.

The standard beam pointing instability specifications for precision machining laser is $< 50 \mu\text{rad}$ and having into account that the laser source can be up to 3-4 meters far from the final focusing lens, this error translates to 0,2 mm XY displacements before the lens. If very accurate laser processing is needed, these errors need to be corrected. Using 2 CCD sensors and 2 motorized (piezo) mirrors, the active optical system reduces the error to $< 5 \mu\text{rad}$. This correction can be applied in open or close loop, depending on the process functionality (Figure 3).

Additionally to the beam pointing correction, the motorization of different optics permit (Figure 4 & 5):



- Energy control through motorized polarization optics.
- Beam size selection through motorized telescope.
- Divergence correction through a 1:1 telescope with motorized lens correction, providing the Z correction of the focal plane (3D processing).
- Advance polarization control of the beam (circular, lineal).
- Detection of missing pulses thanks to the synchronization of the laser gate, trigger and a fast counter. The system knows the exact number of pulses that pass through the optical setup using a fast photodiode and compare the result in close loop. As an example, this feature is very useful to ensure the correct isolation processes for thin film solar cells with low overlap processes.

Fig 4. Energy, polarization and Divergence control.

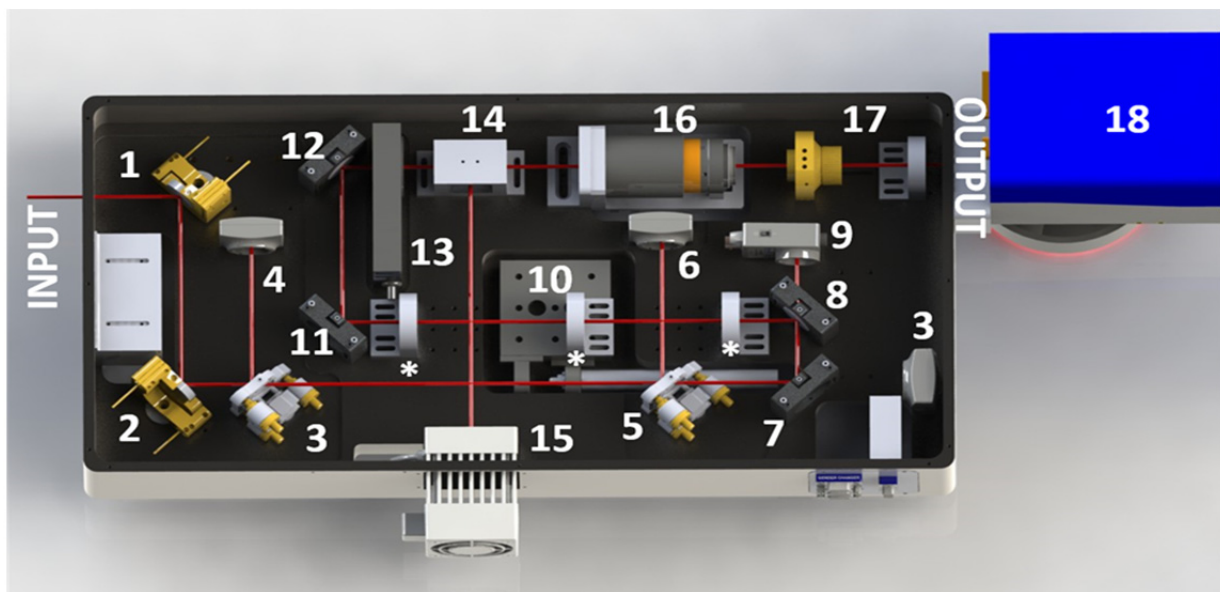


Fig. 5. Active beam tracking box solution.

2.2. Integrated metrology head sensors

An advanced sensor head with triple technology (Confocal-Interferometry-Focus Variation) is integrated into system to provide 3D analysis of the processed results (*Figure 6 & 7 and specifications on Table 1*). Depending on the surface topology (surface slope) and in the laser process itself, different technologies are more appropriate:

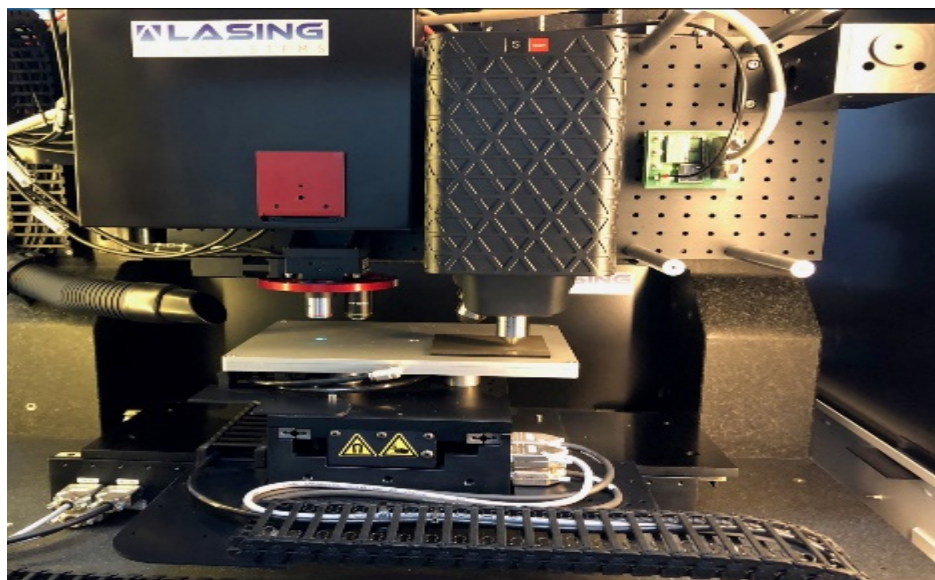


Fig. 6. Confocal-Interferometric-Focus Head inside LS-fPRO system.

Table 1. Metrology head sensor specifications integrated in LS-fPRO system

Confocal	5X	50X	100X
XY resolution (microns)	1.11	0.21	0.18
Vertical resolution (nm)	75	3	2
Maximum Slope (°)	8	42	51
Interferometry	5X	50X	100X
XY resolution (microns)	2.76	0.3	0.24
Vertical resolution (nm)	1	1	1
Maximum Slope (°)	3	21	42
Focus Variation	5X	50X	100X
XY resolution (microns)	1.11	0.21	0.18
Maximum Slope (°)	86	86	86
Min. Measurable roughness	>10 nm	>10 nm	>10 nm

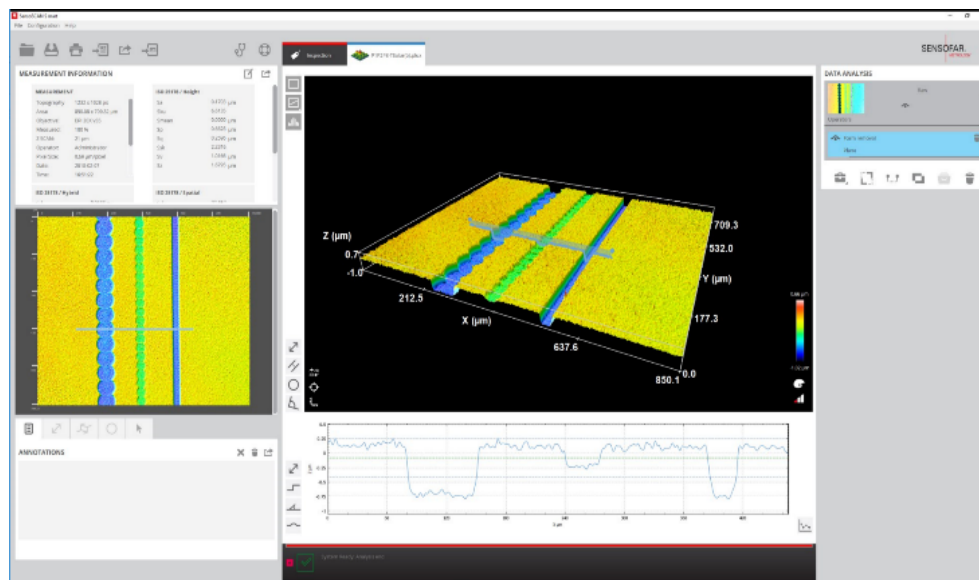


Fig. 7. Processing and metrology heads with P1-P2-P3 analysis results.

The 3D cloud data obtained from the sensor head with a pre-programmed analysis template permits to the user perform close loop iteration processes in minutes, using the same mechanical setup than the laser machining process, with the following advantages:

- Same positioning stages with nm resolution.
- No need of post-processing measurement in external systems.
- Perform automatic measurements related with the process object and trajectories dimensions.
- Less time consuming.
- Increased measurement reliability.
- Automatic report generation for quality control.

3. Conclusion

High accurate laser processing applications can't permit beam misalignments in the optical setup, as it produces inadmissible positioning errors that can invalidate the process. To solve this issue, advanced setups need to be implemented with active beam tracking and correction, increasing the quality results and process performance. Integrating these solutions, the beam pointing error produced by the laser and the mechanical thermal effects could be decreased up to 10 times. In parallel, advanced metrology sensors can be integrated to perform automatic analysis of the process results, including close loop options to increase the reproducibility of the process.

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