

## **Multiaxis Flexible Cell for Laser Precision Machining – Design and Applications**

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**Abstract.** Laser micromachining techniques are among the most emerging and promising fabrication processes in strategic industrial fields, targeting important applications, such as MEMS, fluidic devices, advanced sensors, biomedical devices and instruments etc. Suitable tools for materials processing are needed, especially for developing tasks in different kind of materials and geometries around the micron, since this dimensional range emerged at the crossroad of nanotechnologies and conventional fabrication techniques. CLUPM team has designed and integrated, in cooperation with different laser systems and laser sources suppliers, the prototype of a 3D laser micro-processing system, ML-100, presently devoted to characterization and development of different laser micro-processes. This paper briefly describes the design and notable applications of this multi-axis laser micromachining cell based on the main concept of flexibility. This system integrates an advanced 6-axis positioning system and two UV laser sources, excimer and Diode Pumped Solid State (DPSS), working in nanoseconds pulse regime for precision 3D micro-machining of complex parts. Advanced materials (including composites) were machined at a dimensional range of microns for the processed zones. The main issues overcome by the authors in generation of 2D/3D structures by high intensity laser pulses with direct incidence are briefly described. Several examples of the applications achieved with this system, including micro-nano photonics and fluidics applications, processing of semiconductor sensors, organic materials for biomedical devices and metallic materials for important industrial sectors are presented.

**Keywords:** Flexible Cell, Manufacturing systems, Laser Micromachining, Laser Ablation, UV Lasers, Sensors, Medical applications, MEMS, Advanced Materials

### **1. Introduction**

Suitable tools for materials processing are needed, especially for developing tasks in different kind of materials and geometries around the micron, since this dimensional range emerged at the crossroad of nanotechnologies and conventional fabrication techniques. Laser systems have been widely applied in the last decades in semiconductor industry in microfabrication process development. The current availability of new excimer and Diode Pumped Solid State (DPSS) lasers are broadening the applications fields of laser microprocessing [1]. Nowadays micro-electro-mechanical systems (MEMS) [2], fluidic devices, advanced sensors and biomedical devices and instruments are among the most promising developments of this technology.

An important issue is to define properly the concept of laser micromachining. A potential definition, with functional character not limited to applications derived directly from ablation processes could be: “Micromachining means cutting, welding, soldering, selective ablation, forming, patterning, etc, with dimensional details in the order of 1  $\mu\text{m}$ ”.

In this sense, and considering the previous experience in laser microprocessing and the kind of processes using lasers for precision applications in biomedicine, semiconductor industry, sensors fabrication, etc., some fundamental facts must be considered in advance. Laser micromachining is intended mainly for material modification near the surface, or for processing with high aspect ratios (contrary to macromachining

applications in which bulk processes and material removal are the main target). Additionally, and despite the fact that the majority of present applications are strictly 2D (planar or cylindrical), or are intended to process planar areas of 3D objects, an increasing interest in fully 3D applications is developing, generally generating serious mechanical problems. These facts imply non-trivial questions at the time of systems' definition and design. In particular, the characteristics of the positioning systems and the related solutions are of great transcendence, because simple scaled solutions taken from macroprocessing systems are not allowed.

The Laser Centre belonging to the Polytechnical University of Madrid (CLUPM) has designed and integrated, in cooperation with different laser systems and laser sources suppliers, the prototype of a 3D laser microprocessing cell, ML-100 (Fig. 1), presently devoted to the characterization and development of different laser micro-processes [3].

Nanoseconds laser pulses present an excellent tool for precision ablation of thin films of special materials [4-6]. CLUPM also offers the capacity in simulation, fabrication and characterization of materials, photonic, biophotonic and fluidic structures and devices in the framework of micro-nano technology [7-9]. Spectacular results were obtained in manufacturing of various sensors, as well as in special applications, e.g. microstructural modifications produced by nanosecond ultraviolet ablation in neodymium doped lithium niobate crystals [10].

The features of the laser ablation process are mainly given by the short pulse (nanoseconds) laser regime, but the interaction with a certain material is crucial, determining also the quality of the machined parts [11]. Different process developments in CLUPM, ranging from pure planar applications to fully 3D parts machining are also presented in this paper.

The applicability of long pulse lasers in forming is limited for MEMS manufacturing due to the long relaxation time of the thermal fields responsible for the forming phenomena. The use of nanosecond laser pulses provides a suitable parameter matching the laser non-thermal micro-forming (i.e. by laser shock processing), of an important range of sheet components used mainly in MEMS [12].

## 2. Laser Micro-Machining Flexible Cell

The main features and potential applications of ML 100 3D laser micromachining 6-axis workstation is based on the main concept of geometrical flexibility (Fig. 1). This system integrates two UV laser sources, excimer and DPSS working in ns-pulse regime (Table 1), and an advanced 6-axis positioning system for complex parts machining (Fig. 1b).

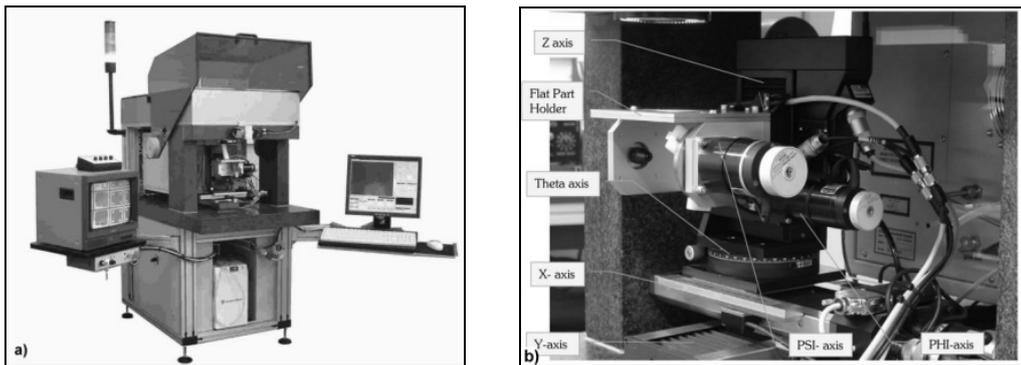


Fig. 1: ML-100 UV laser micromachining workstation at CLUPM): a) General view. b) Multiaxis positioning system.

The system also integrates other important features, such as a nozzle for extracting process fumes, a vacuum chuck for planar parts holding, a clamping system for axi-symmetrical work pieces, and a TTL system (x500 magnification) for process viewing and in-situ measurements, if properly calibrated. The software includes teach-in options, reticle projection for in-situ spatial calibration, special trepanning options, and other personalized features in order to improve, via software, the mechanical yield of the system.

### 2.1. Positioning Systems

The 6-axis part positioning system mounted on ML-100 specially designed for 3-D processing is presented in Fig. 1b. Main part motion is assured by the X,Y stages, which are servomotor driven stages with

linear position encoder (resolution of 0.1  $\mu\text{m}$  in each axis). Overall precision in the XY working area (100 x 100 mm) is about 1 $\mu\text{m}$ . The Z-axis is used to bring the part to the laser focus.

Rotary axes are included for full 3D spatial control. A low profile Theta trim allows squaring of parts relative to X, Y stages. Phi axis allows parts to be tilted (max. 90°) and Psi axis, in fact a part lathe, is used to mount objects with rotational symmetry. The Sphere of Confusion for the whole system is 50  $\mu\text{m}$ .

## 2.2. Laser Systems and Optical Paths

The ML-100 laser workstation designed by CLUPM combines two different UV laser sources: a Nd:YVO4 (Spectra Physics HIPPO) emitting pulsed UV radiation at 355 nm for focal point processing and an excimer laser (ATL Laser Technik SP300i) emitting pulsed UV radiation at 248 nm (KrF) for mask projection processing (Table 1).

For only IR irradiation, a simplified experimental set up with a Nd:YAG laser source (Spectra Physics NAVIGATOR) emitting pulsed IR radiation at 1064 nm for focal point processing mounted over an XY positioning system is used.

TABLE 1. Characteristics of the UV laser sources integrated in ML-100 system.

Laser Media	Excimer (KrF)	DPSS 3 $\omega$
Wavelength (nm)	248	355
Pulse Duration (ns)	3-7 ns	< 12 ns (@ 50 kHz)
Beam shape/mode	Rectangular (3.5 x 6 mm)	TEM <sub>00</sub> (M <sup>2</sup> < 1.3)
Operating frequency	0-300 Hz	15 – 300 kHz
Average power (W)	0.3-5 (@ 300 Hz)	5 W (@ 50 kHz)

The excimer laser emits a beam of approximately 4x6 mm that is directed to the mask and lens, via the energy controller, through two steering mirrors (Fig. 2a). A three element process lens images the mask onto the part, via a dichroic mirror, at nominal 10:1 demagnification.

The DPSS 355 nm laser source is steered in the insertion mirror (Fig. 2b), which is placed in the excimer beam path whenever Nd:YVO4 processing is required. The process lens gives a 10x demagnified image of the virtual point source formed by a lens in the middle of the beam path.

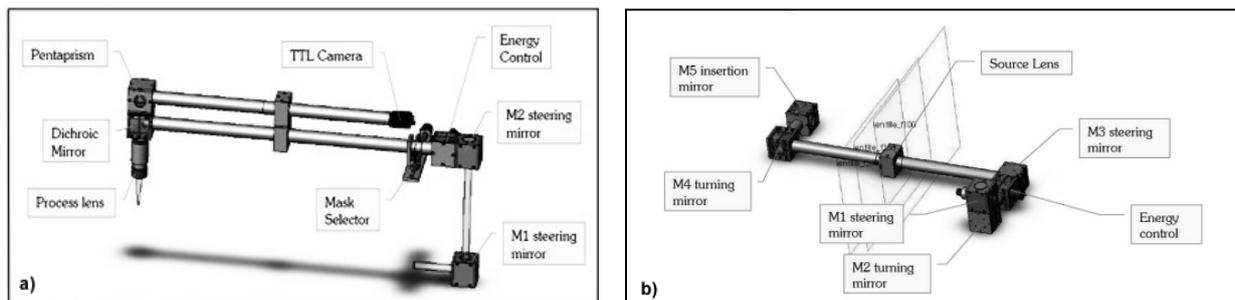


Fig. 2: ML-100 micromachining workstation at CLUPM: a) Excimer laser path. b) DPSS laser path.

An important feature is the possibility of external energy control using an attenuator in the beam path (Fig. 2a,b). In most laser microprocessing applications, very low power densities are required in order to avoid material or substrate damage, and usually the energy control integrated in the commercial laser sources don't give good result for laser energy fine tuning.

## 2.3. Measurement and Imaging

Confocal Laser Scanning Microscopy (CLSM) has been used for characterization of the ablation curves, ablation-profile measurements and morphological characterization. Measurements presented in this article have been made using a CLS Microscope make Leica ICM 1000.

The equipment operational wavelength (635 nm), together with the objective numerical aperture and pinhole diameter gives the final resolution in axial direction.

The expected accuracy in step measurements is about 50 nm that corresponds to theoretical calculations according to the objective specifications; however, global accuracy in Z measurements is strongly dependent on the optical reflectivity of the sample. Higher reflectivity gives better step measurement accuracy, so the previous value must be considered a reasonable approach when considering the optical behavior of the studied materials.

### 3. Laser Based Optics, Micro-Nano Photonics and Fluidics Applications

This field of investigation mainly includes design and simulation of photonic structures, micro-fabrication of photonic and biophotonic devices, and optical characterization of photonic and biophotonic devices. The fabrication of photonic structures by means of laser micro-machining techniques offers advantages such as cost reduction, capability of processing of a great diversity of materials, and of complex geometries.

Among the variety of materials, polymeric materials are remarkable when are processed by UV lasers in the ns, ps or fs regime for direct scribing ablation processes. Particularly in the micro-nano fabrication field, CLUPM has developed optical lithography deep UV (DUV) by means of mask projection and excimer laser.

CLUPM has a broad experience in developing preparation of thin layers of polymeric materials for use in fluidic, photonic and biophotonic devices, such as such as PDMS Sylgard (Dow Corning) and a photoresist SU8 (Microchem).

Laser assisted cleaving of photonic devices is of particular interest to avoid the polishing process of photonic chips, which is normally costly and time consuming.

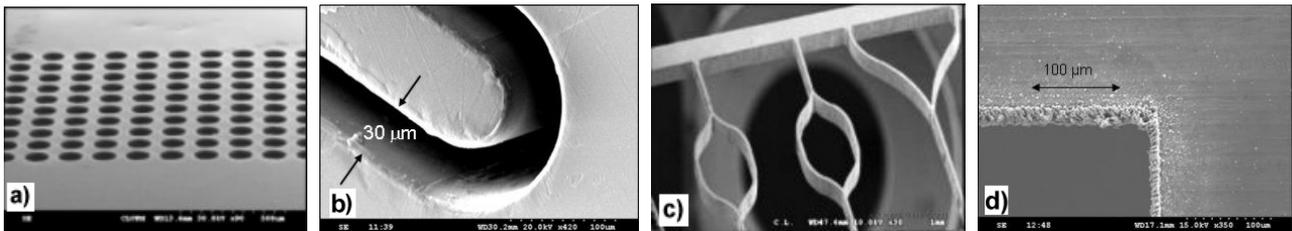


Fig. 3: Precision microfabrication at CLUPM: *a)* Lattice of micro-holes made in polymeric material. *b)* Polycarbonate cutting, 1mm thickness. *c)* Metal mask for projection photolithography. *d)* Stainless Steel using DPSS, 50  $\mu$  thickness.

### 4. 2D, 2D+1/2 and 3D Micro-Machining

Although laser micromachining processes in planar geometry have a long tradition, four results at CLUPM showing the potential of ML 100 system integrating both excimer and DPSS laser sources are presented in Fig. 3. With the same machine it is possible to process polymers (Fig. 3a,b) with high quality characteristics of the excimer irradiation of 248 nm, and metallic materials with DPSS of 355 nm (Fig. 3c,d).

In case of macro-machining systems it is a common task to process pieces (both planar and axis-symmetric) in 2D+1/2 geometry. The factor 1/2 makes reference at a possible reorientation of the tool (using a rotary axis for colatitude control) with respect to a characteristic plane (Fig. 4a).

In Fig. 4b,c, the excimer laser with hybrid mask projection technique was used for machining and surface texturing of a glass sphere, namely drilling 75  $\mu$ m blind holes on the sphere surface - a good example of the fully 3D micro-machining capability.

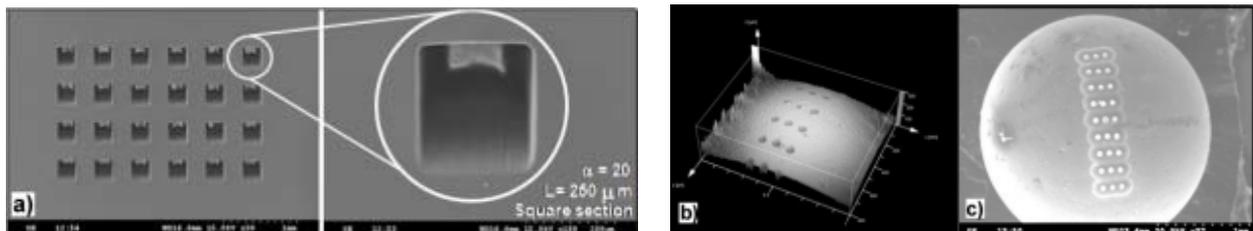


Fig. 4: Micromachining at CLUPM: *a)* 2D+1/2 application: square section channel fabrication with colatitude control in polycarbonate (1 mm thickness). *b),c)* Surface texturing - small blind holes (75  $\mu$ m in diameter generated at 248 nm onto an spherical surface of 2.5 mm in diameter): *b)* Confocal microscopy 3D reconstruction. *c)* SEM image.

## 5. Conclusion

A prototype of a fully 3D flexible laser micromachining system has been designed and presently is completely operative in order to give a potential answer to the increasing demand in different strategic sectors for 2D, 2D + $\frac{1}{2}$  and 3D process development in the micron range.

As has been shown in this work, integration of excimer and DPSS UV laser in the same system has demonstrated to be an added value for this kind of equipment. Complex geometries (concerning the workpiece and the pattern to be processed) have been obtained in different materials with appropriate quality for the related applications.

Additionally, the integration of standard robotics control functions such as teaching for spatial repositioning, or TTL view for process control appears as valuable tools for complex tasks development from the point of view of in situ control and analysis.

## 6. Acknowledgements

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## 7. References

- [1] M.C. Gower. Industrial applications of laser micromachining. *Opt. Express*. 2000, 7 (2): 57-67.
- [2] A.S. Holmes. Laser processes for MEMS manufacture, *Proc. of 2<sup>nd</sup> International Symposium on Laser Precision Microfabrication 2001*. Singapore, May 2001. Pub. in *RIKEN Review*. 2002, 43: 63-70.
- [3] J.L. Ocaña, M. Holgado, M. Morales, C.L. Molpeceres, S. Lauzurica, and J.J. García-Ballesteros. 3D Laser Micromachining Applications Development on a Dual ns Laser Based Processing System. *Anales de Ingeniería Mecánica*. 2008: 471-477.
- [4] C. Molpeceres, S. Lauzurica, J.L. Ocaña, J.J. Gandía, L. Urbina, and J. Cárabe. Microprocessing of ITO and a-Si thin films using ns laser sources. *J. Micromech. Microeng.* 2005, 15: 1271-1278.
- [5] J.L. Ocaña, C.L. Molpeceres, S. Lauzurica, J.J. García-Ballesteros, S. Fernández, G. Guadaño, and F. Avendaño. Avances en la fabricación de células y módulos fotovoltaicos de silicio en capa fina mediante láser. *Anales de Ingeniería Mecánica*. 2008, 16: 295-300.
- [6] J.L. Ocaña, M. Holgado, M. Morales, C.L. Molpeceres, S. Lauzurica, J.J. García-Ballesteros, M. Colina., and M.I. Sanchez. Optical characterization of the heat-affected zone in laser patterning of thin a-Si:H. *Proc. of SPIE*. Feb. 2009, pp. 72020R- 72020R10.
- [7] F.J. Aparicio, M. Holgado, I. Blaszczyk-Lezak, A. Borrás, A. Griol, C. A. Barrios, R. Casquel, F. J. Sanza, H. Sohlström, M. Antelius, A. R. González-Elipé, and A. Barranco. Transparent nanometric organic luminescent films as UV active components in photonic structures. *Advanced Materials*. 2011, 23 (6): 761-765.
- [8] M. Holgado, M.F. Laguna, C. Angulo, D. Lopez-Romero, and R. Casquel. High aspect-ratio SU-8 resist nanopillar lattice by e-beam direct writing and its application for liquid trapping. *Microelectronic Engineering*. 2009: pp. 663-667.
- [9] R. Casquel, M. Holgado, J.J. García-Ballesteros, K. Zinoviev, C. Fernández-Sánchez, F.J. Sanza, C. Molpeceres, M.F. Laguna, A. Llobera, J.L. Ocaña, and C. Domínguez. UV laser-induced high resolution cleaving of Si wafers for micro-nano devices and polymeric waveguide characterization. *Applied Surface Science*. 2010, in press, doi:10.1016/j.apsusc.2010.11.021.
- [10] J.L. Ocaña, C.L. Molpeceres, S. Lauzurica, A. Ródenas, D. Jaque, F. Agulló-Rueda, and G.A. Torchia. Ultraviolet Nanosecond Laser-Assisted Micro-Modifications in Lithium Niobate Monitored by Nd 3+ Luminescence. *Appl Comput Harmon A*. 2007, 7: 87-90.
- [11] J.L. Ocaña, M. Morales, C.L. Molpeceres, S. Lauzurica, and J.J. García-Ballesteros. Advanced 3D micromachining techniques using UV laser sources. *Microelectron Eng.* 2007, 84: 1337-1340.
- [12] J.L. Ocaña, M. Morales, C.L. Molpeceres, JA Porro, O. Garcia, and J.J. García-Ballesteros. Short pulse laser microforming of thin metal sheets for MEMS manufacturing. *Appl Surf Sci*. 2007, 254: 997-1001.