

Laser Shock Micro-Forming as an Emerging Technique for Microsystems Shaping and Adjustment

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Laser Shock Micro-Forming as an Emerging Technique for Microsystems Shaping and Adjustment

OUTLINE:

- Introduction
- Physical Principles. Simulation Model
- Simulation Results
- Experimental Setup. Sample Preparation
- Experimental Results
- Recent Alternative Approaches
- Discussion and Outlook

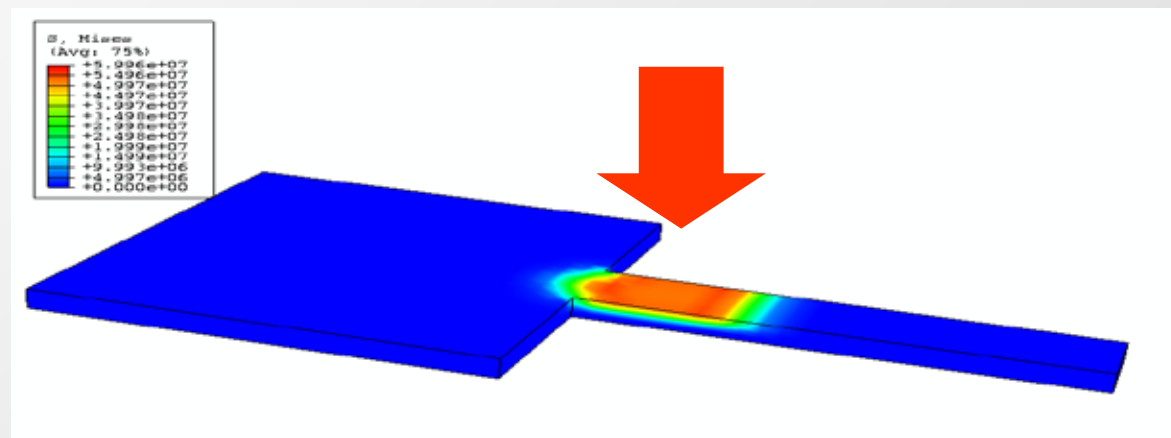
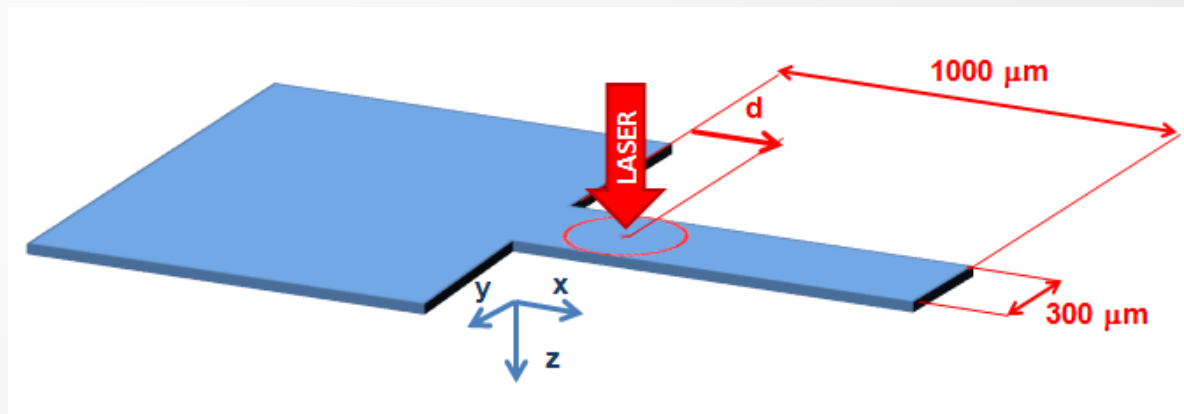
1. INTRODUCTION. MOTIVATION

- § The increasing demands in MEMS fabrication are leading to new requirements in production technology. Especially the packaging and assembly require high accuracy in positioning and high reproducibility in combination with low production costs.
- § Conventional assembly technology and mechanical adjustment methods are time consuming and expensive. Each component of the system has to be positioned and fixed. Also adjustment of the parts after joining requires additional mechanical devices that need to be accessible after joining.
- § Accurate positioning of smallest components represents an up-to-date key assignment in micro-manufacturing. It has proven to be more time and cost efficient to initially assemble the components with widened tolerances before precisely micro-adjusting them in a second step.

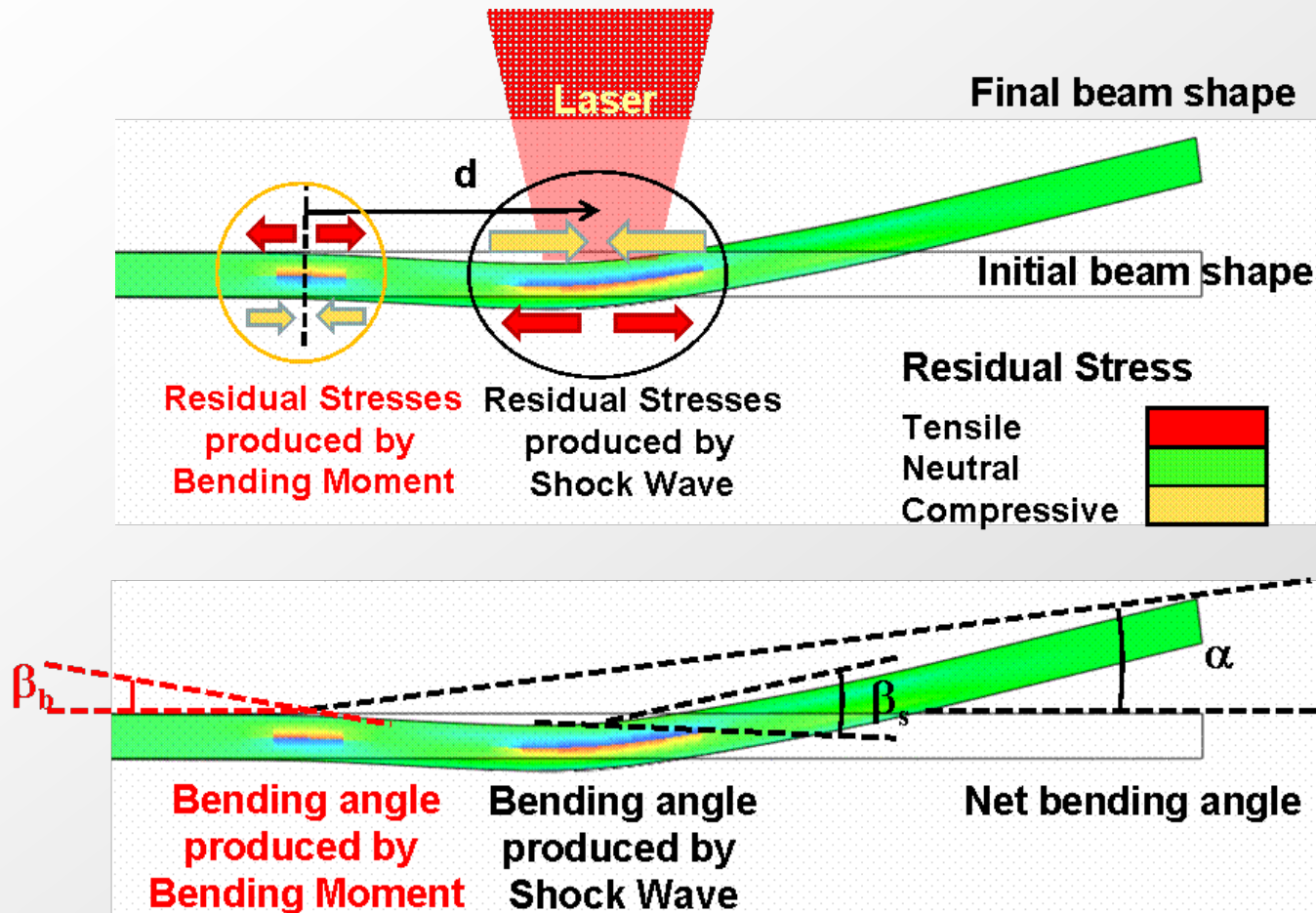
1. INTRODUCTION. PROPOSED APPROACH

- § Provided that mounted micro components are typically difficult to access and highly sensitive to mechanical forces and impacts, contact-free laser adjustment processes offer a great potential for accurate manipulation of micro devices.
- § However, long relaxation-time thermal fields developed in continuous or long-pulse laser forming of metal thin sheets are responsible for the introduction of constraint residual stresses in component assembly processes.
 - § Changes in the materials microstructure could cause changes in density and volume and create stresses
 - § Chemical reactions of the irradiated surface, e.g. oxidation could take place and lead to stressed surface layers
- § The use of ns laser pulses inducing predominantly mechanical deformation stresses provides the capability for a suitable parameter matching in laser bending of MEMS components.
- § Theoretical interaction regime description, computational process simulation results and preliminary experimental results and practical issues are presented in this work.

2. PHYSICAL PRINCIPLES



2. PHYSICAL PRINCIPLES



2. NUMERICAL SIMULATION. MODEL DESCRIPTION

PRESSURE PULSE MODEL

LSPSIM

Interface thickness

$$L(t) = \dot{Q}_0' [u_1(t) + u_2(t)] dt$$

Heating phase

$$I(t) = P(t) \frac{dL(t)}{dt} + \frac{d[E_i(t)L(t)]}{dt}$$

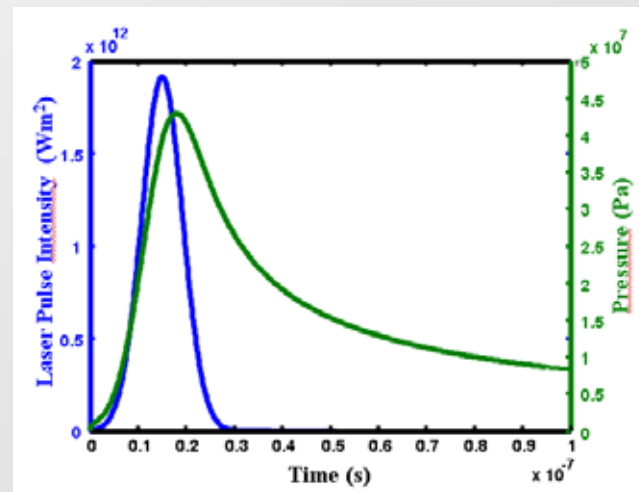
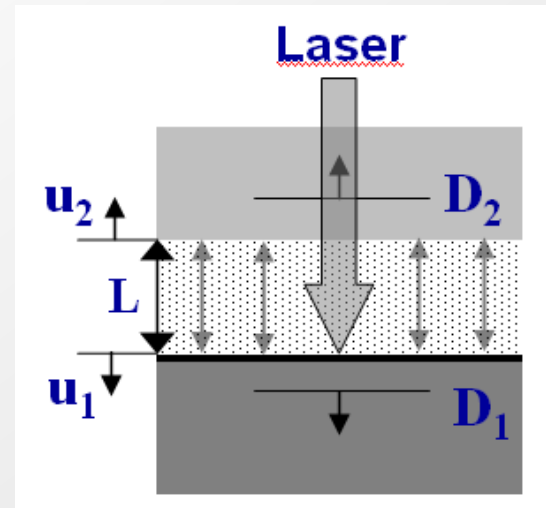
$$P(t) = \frac{2}{3} E_i(t) = \frac{2}{3} a E_i(t)$$

Shock wave relation

$$P = r_i D_i u_i$$

Solid/Liquid $D = C + S u$

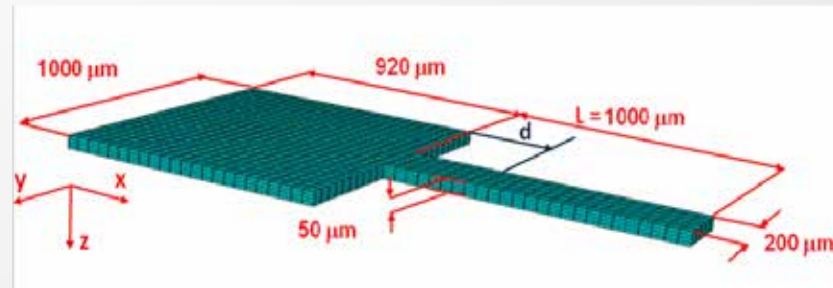
Gas $D = u = \frac{a(g+1)}{e} \frac{P}{r} \frac{\dot{Q}_0'}{\phi}^{1/2}$



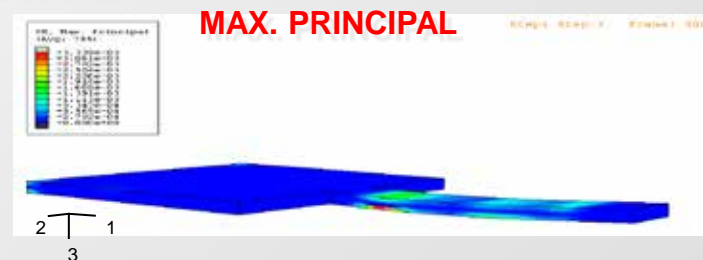
2. NUMERICAL SIMULATION. MODEL DESCRIPTION

FEM MODEL – STRESS-STRAIN ANALYSIS

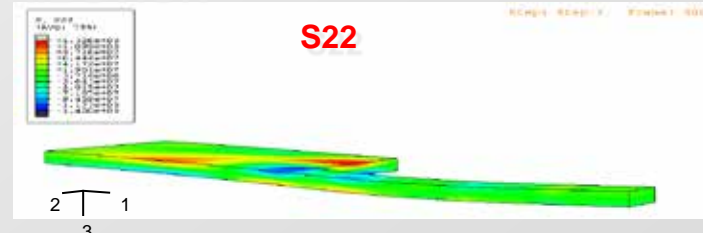
GEOMETRY AND DIMENSIONS



PLASTIC STRAIN



STRESS DISTRIBUTION



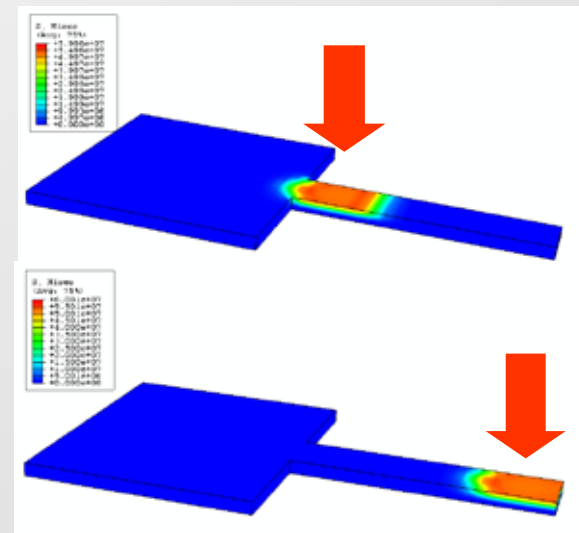
2. NUMERICAL SIMULATION. MODEL DESCRIPTION

MATERIAL PROPERTIES (AISI 304)

Target	AISI 304
Young's Modulus: E [GPa]	193
Poisson's Coefficient: ν	0.25
Density: ρ [kg/m ³]	7896
Melting Temperature: T_m [K]	1811
Test Temperature: T_0 [K]	300
Inelastic Heat Fraction: X	0.9
Johnson-Cook parameters	
A [MPa]	350
B [MPa]	275
C	0.022
n	0.36
m	1
T_r [K]	300
ϵ_0 [s ⁻¹]	1

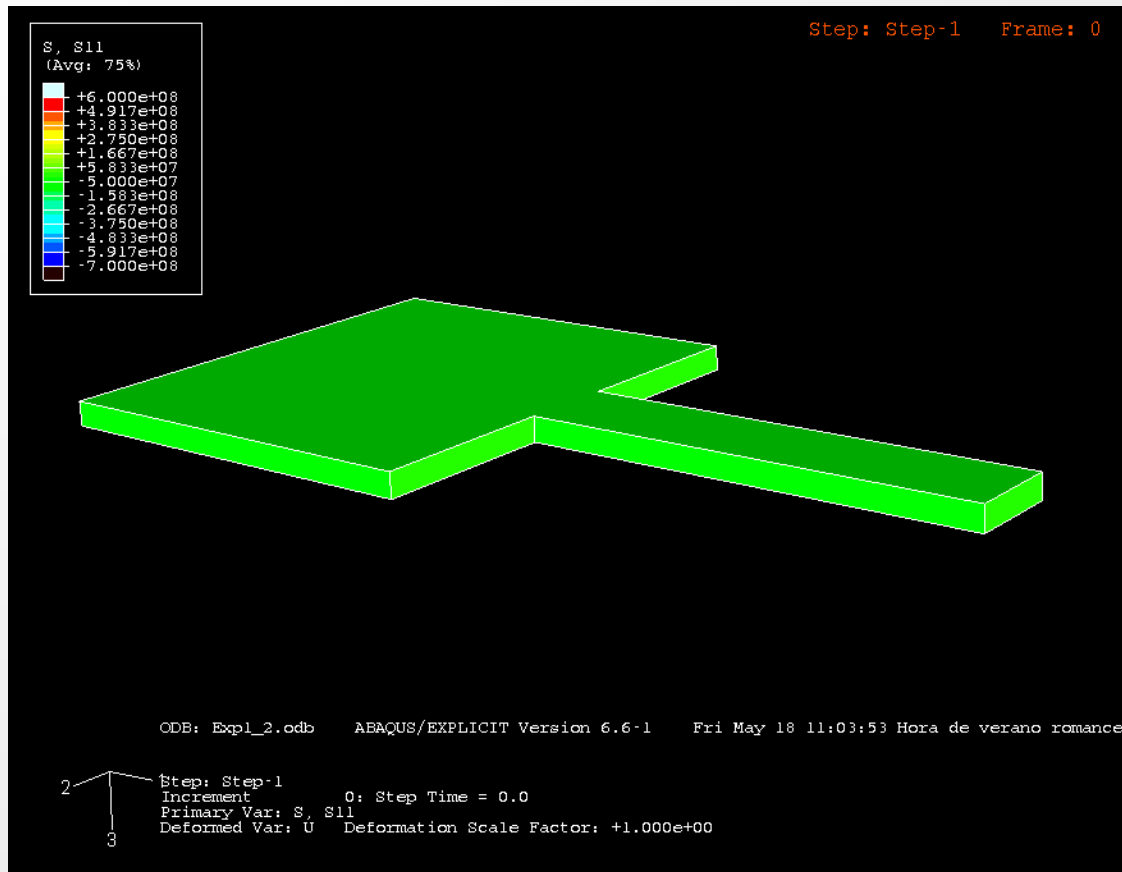
LSPSIM PARAMETERS

Nd:YAG Laser [nm]	1064
Energy per pulse [mJ]	33 - 150
Pulse length [ns]	9.4
Spot Radius [mm]	175
Confining medium	Air
Interaction parameter a	0.2



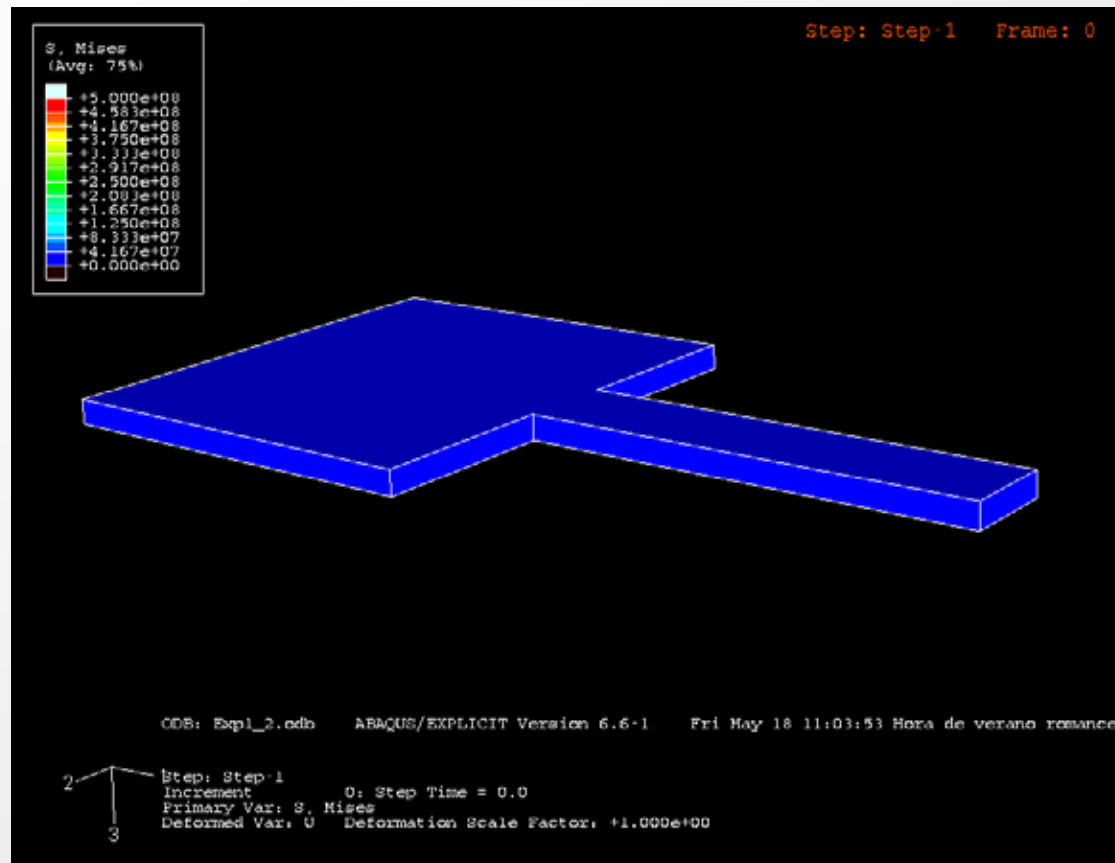
3. NUMERICAL SIMULATION RESULTS

SHOCKLAS EXPLICIT – STRESS (S11) EVOLUTION



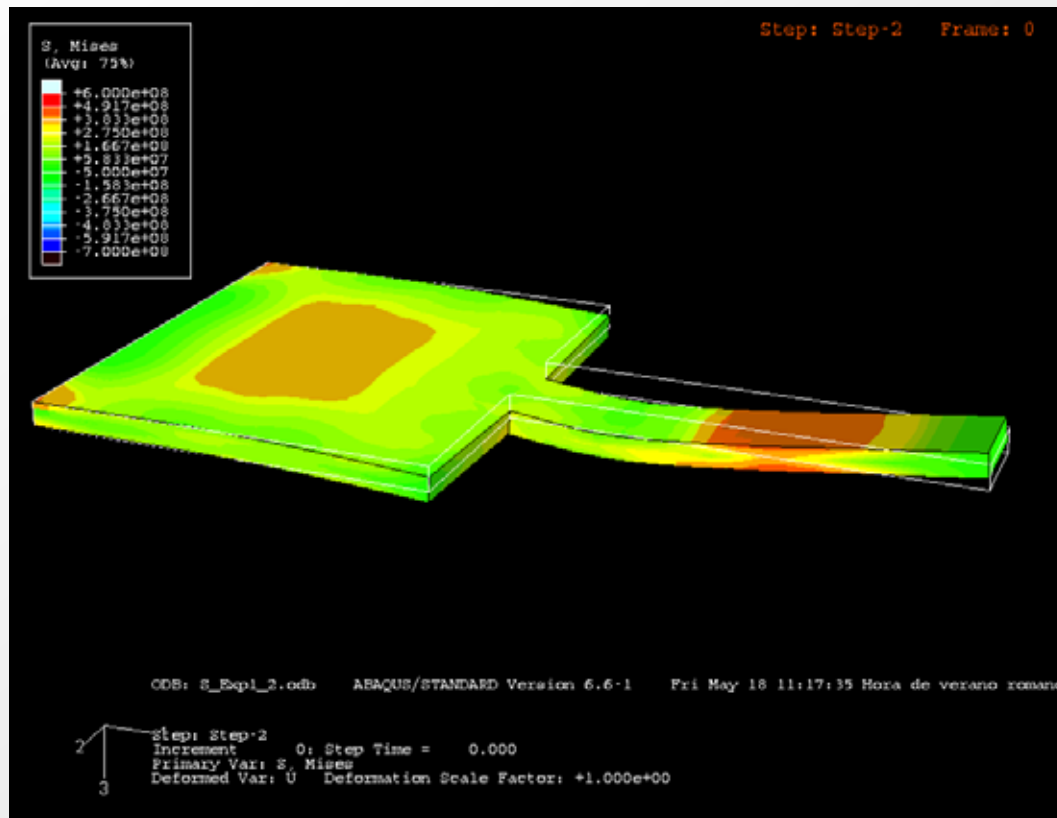
3. NUMERICAL SIMULATION RESULTS

SHOCKLAS EXPLICIT – VON MISES EVOLUTION



3. NUMERICAL SIMULATION RESULTS

SHOCKLAS STANDARD – STRESS (S11) EQUILIBRATION

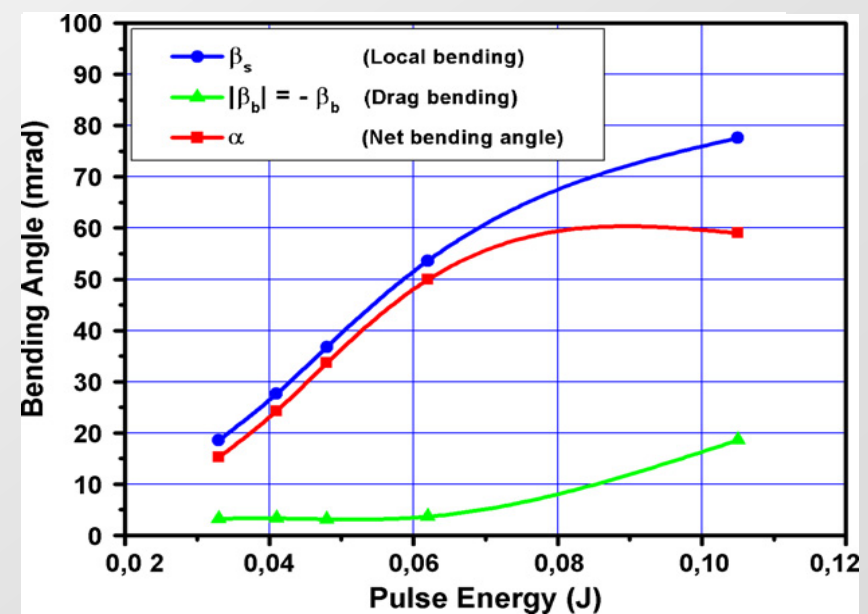
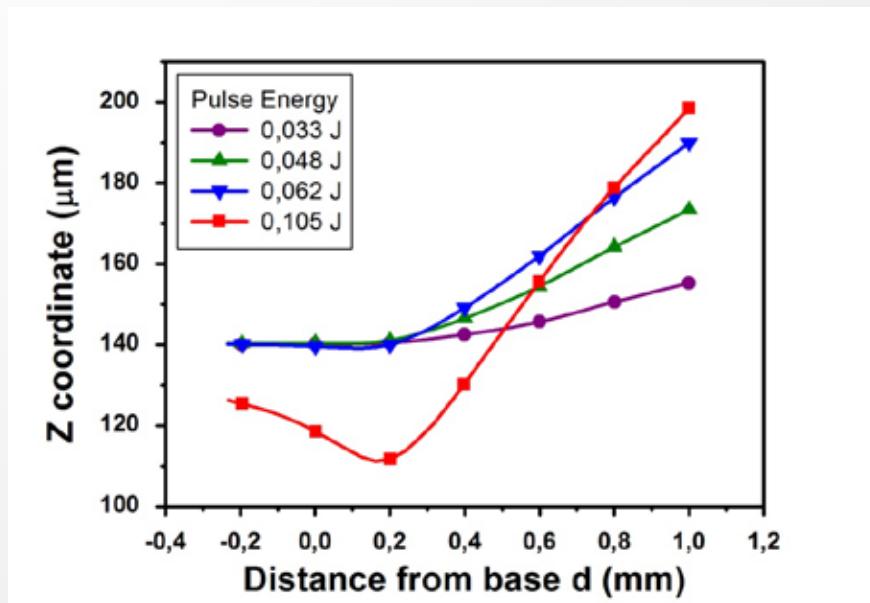


3. NUMERICAL SIMULATION RESULTS

Pulse Energy Parametrization

Nd:YAG Laser [nm]	1064
Energy per pulse [mJ]	variable
Pulse length [ns]	9.4
Spot Radius [mm]	175

Material Model	SS304
Confining medium	Air
Interaction parameter a	0.2
Spot center distance [mm]	150

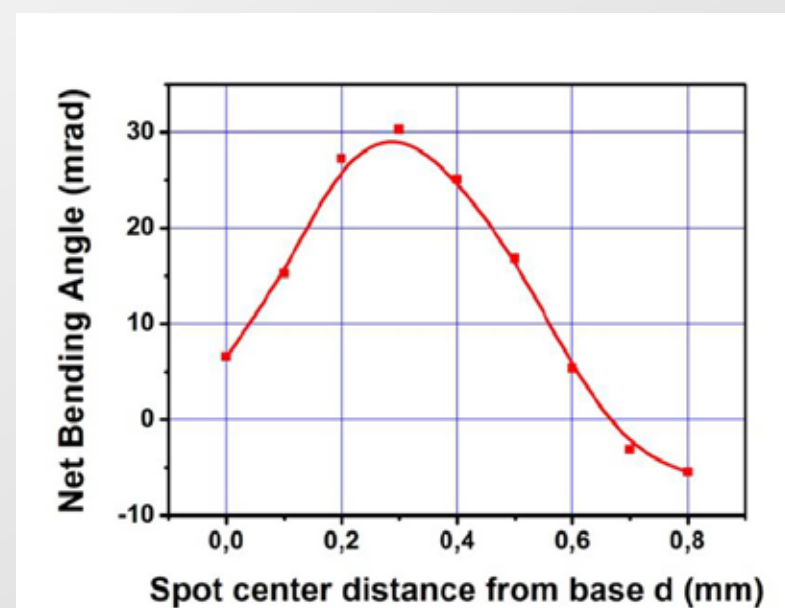
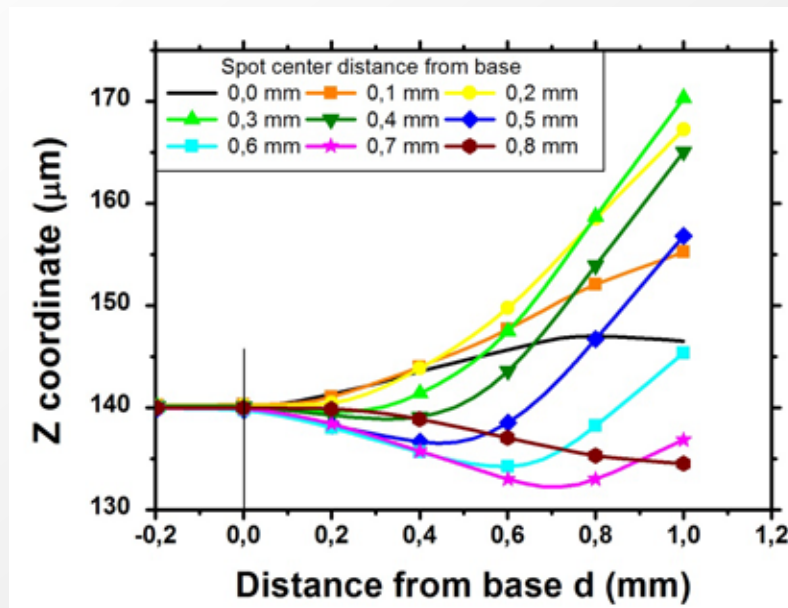


3. NUMERICAL SIMULATION RESULTS

Spot Center Distance Parametrization

Nd:YAG Laser [nm]	1064
Energy per pulse [mJ]	33
Pulse length [ns]	9.4
Spot Radius [mm]	175

Material Model	SS304
Confining medium	Air
Interaction parameter a	0.2
Spot center distance [mm]	variable

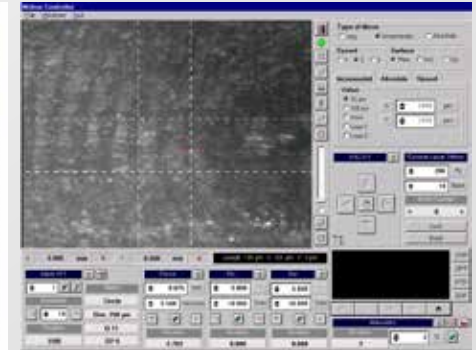
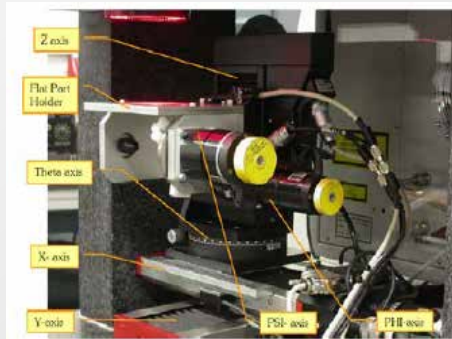


4. EXPERIMENTAL SETUP. SAMPLE PREPARATION

ML-100 LASER WORKSTATION

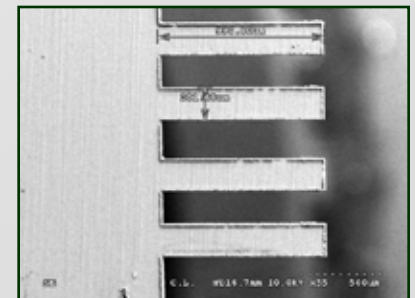


Laser media	Excimer (KrF)	DPSS 3ω
Wavelength (nm)	248	355
Pulse duration (ns)	3–7 ns	<12 ns (at 50 kHz)
Beam shape/mode	Rectangular (3.5 × 6 mm)	TEM ₀₀ ($M^2 < 1.3$)
Operating frequency	0–300 Hz	15–300 kHz
Average power (W)	0.3–5 (at 300 Hz)	5 W (at 50 kHz)



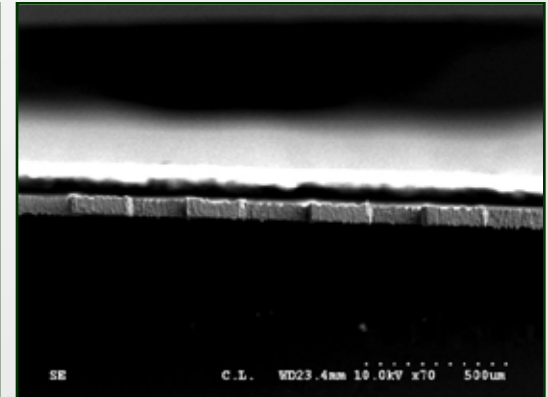
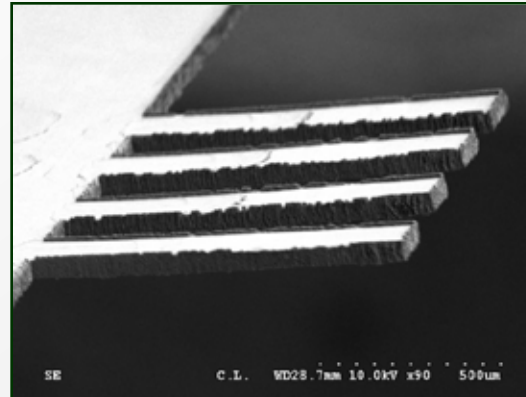
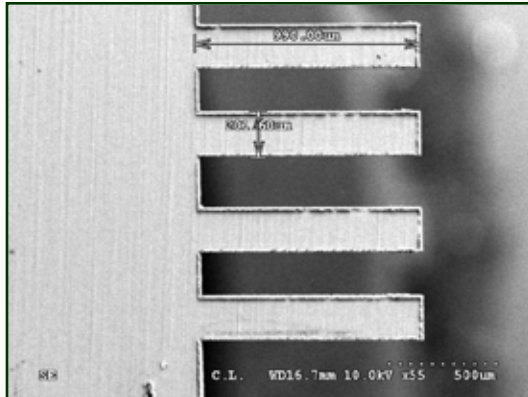
- Dual Excimer/DPSS Laser processing
- Multiaxis (6) System
- Work volume: 120*100*50 mm
- XY accuracy: 1 mm
- Global positioning accuracy: 40 mm
- CCD direct vision (x 500)

AISI 304
1000 x 200 x 50 mm

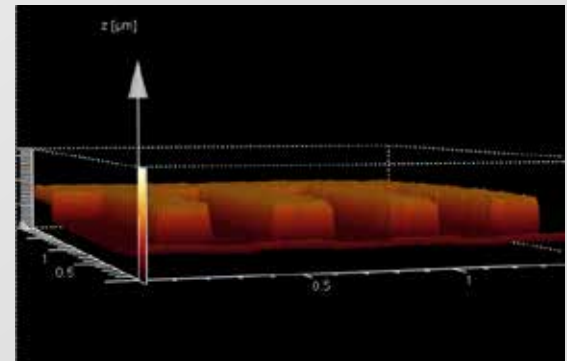
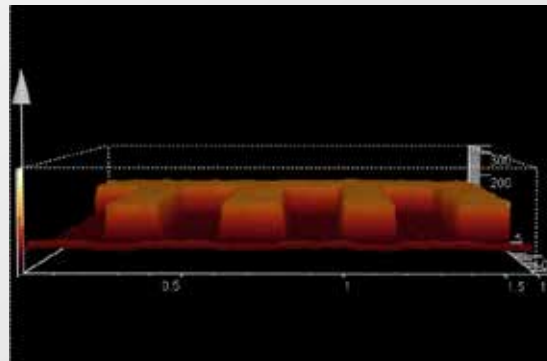
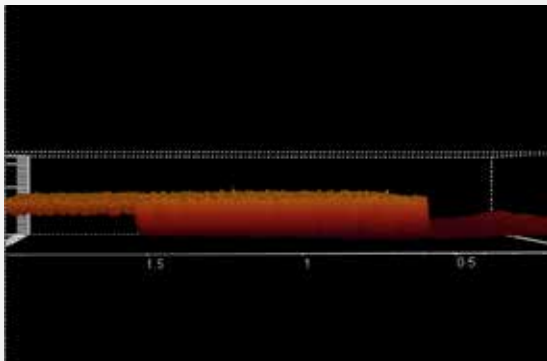


4. EXPERIMENTAL SETUP. SAMPLE PREPARATION

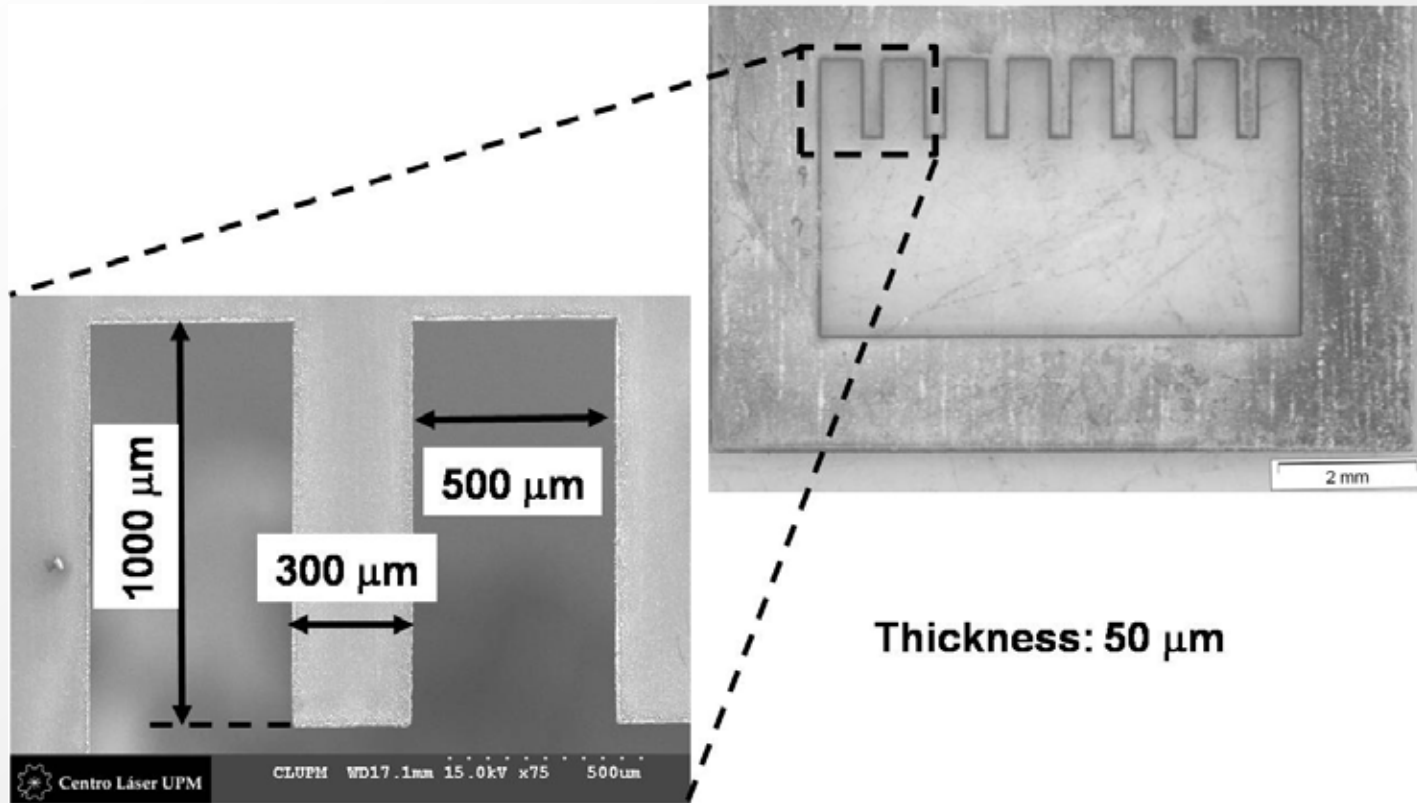
SEM IMAGES OF LASER CUT SHEET



CONFOCAL IMAGES OF LASER CUT SHEET

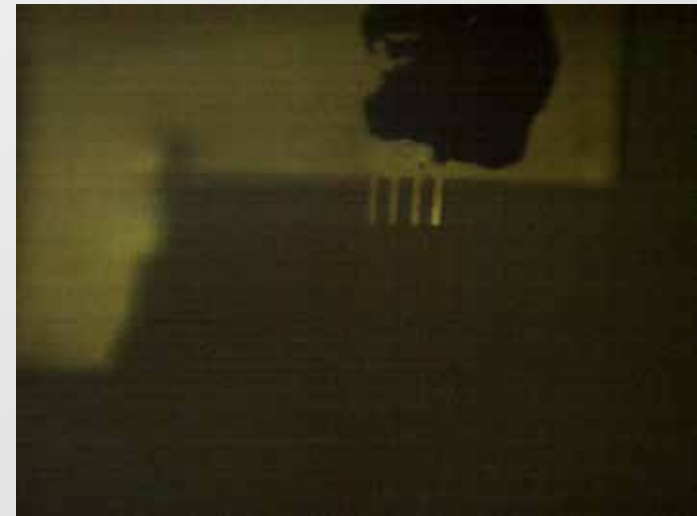
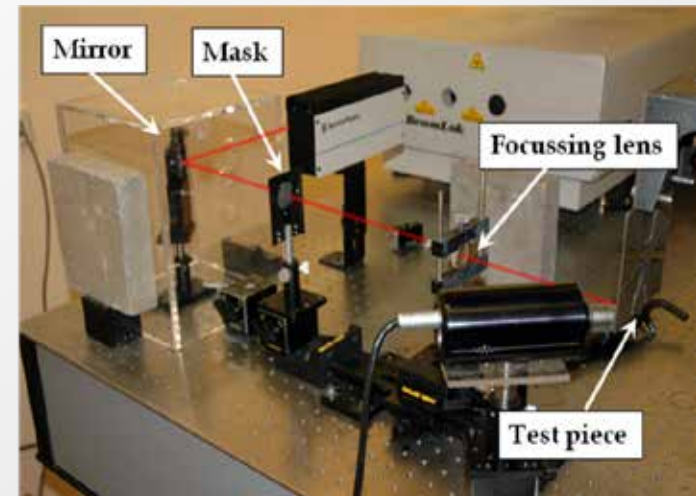


4. EXPERIMENTAL SETUP. SAMPLE PREPARATION



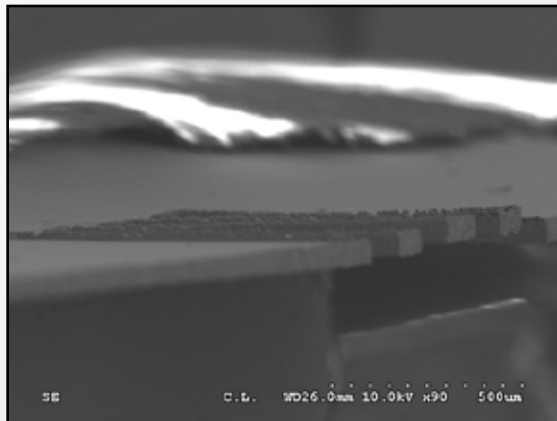
4. EXPERIMENTAL SETUP. SAMPLE IRRADIATION

Nd:YAG Laser Wavelength [nm]	1064
Energy per pulse [J]	1.651
Laser Pulse length FWHM [ns]	9
Laser Beam radius [mm]	14
Confining layer	Air
Thin sheet material	AISI 304
Thin sheet thickness [mm]	50

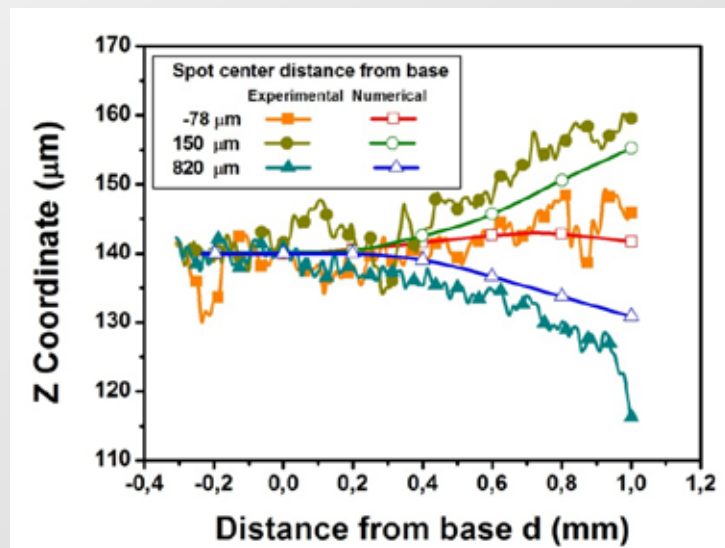
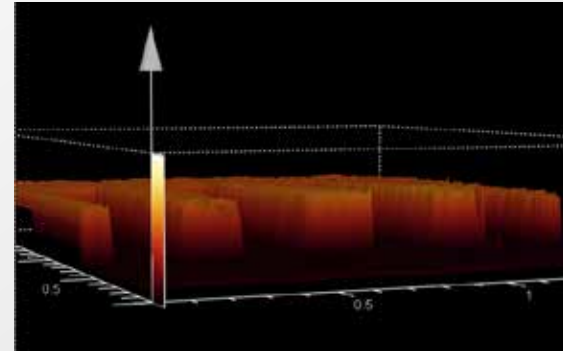


5. EXPERIMENTAL RESULTS. INFLUENCE OF SPOT CENTER DISTANCE

SEM IMAGES

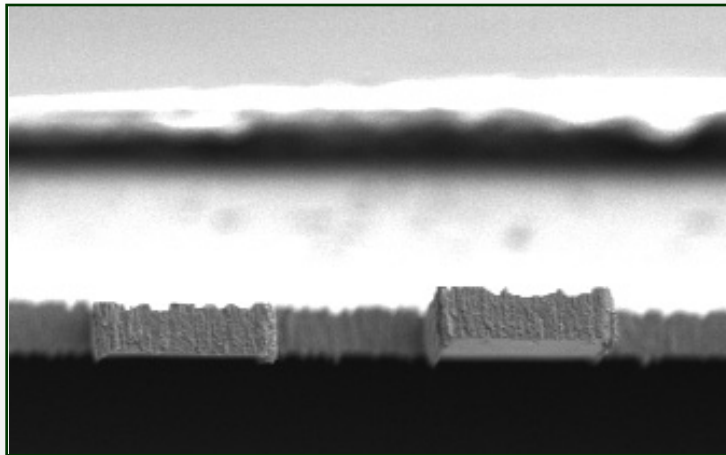
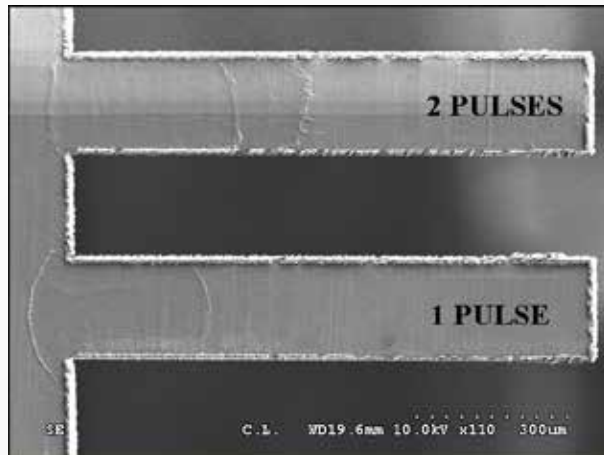


CONFOCAL MICROSCOPY

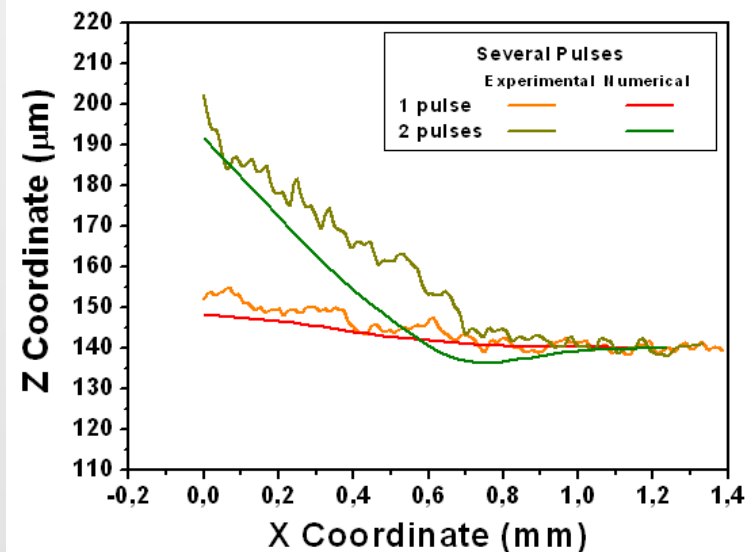
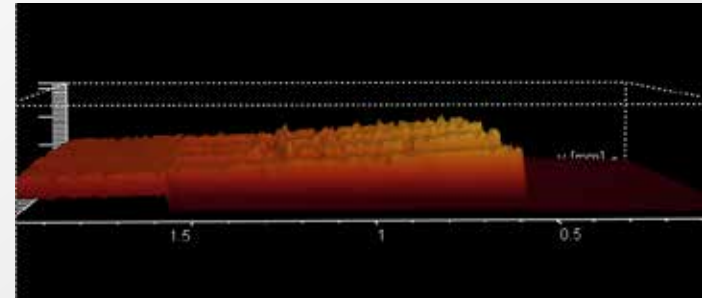


5. EXPERIMENTAL RESULTS. INFLUENCE OF NUMBER OF PULSES

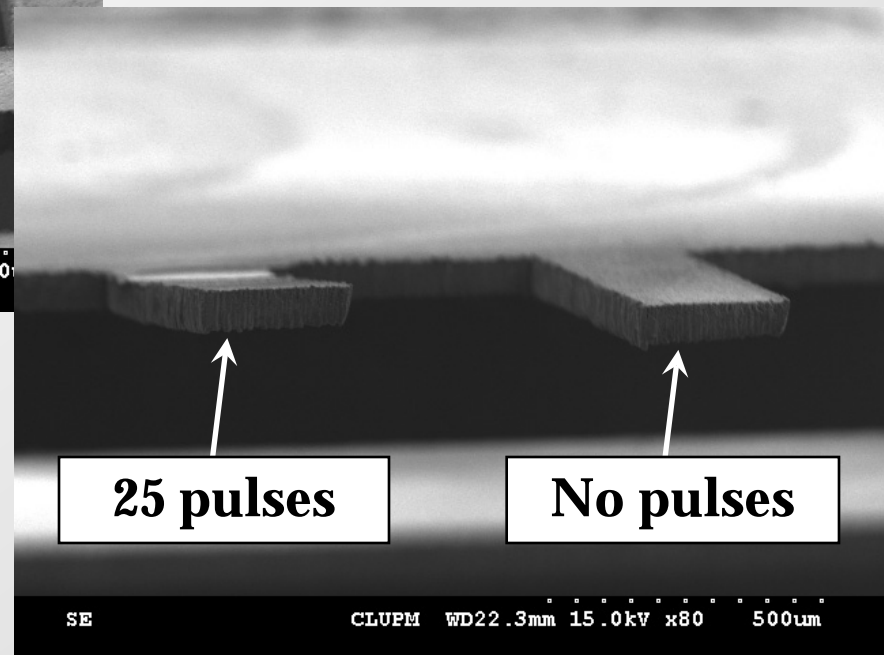
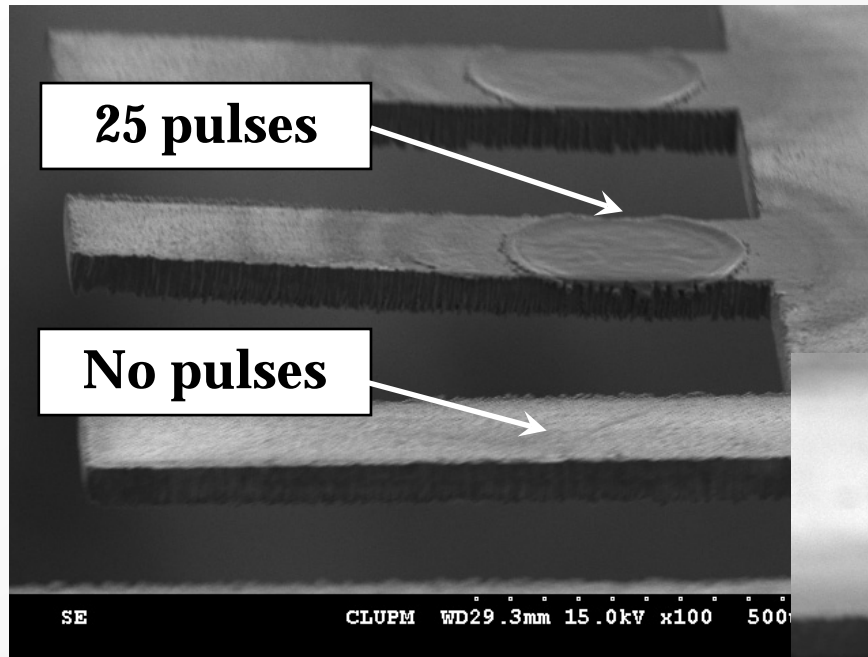
SEM IMAGES



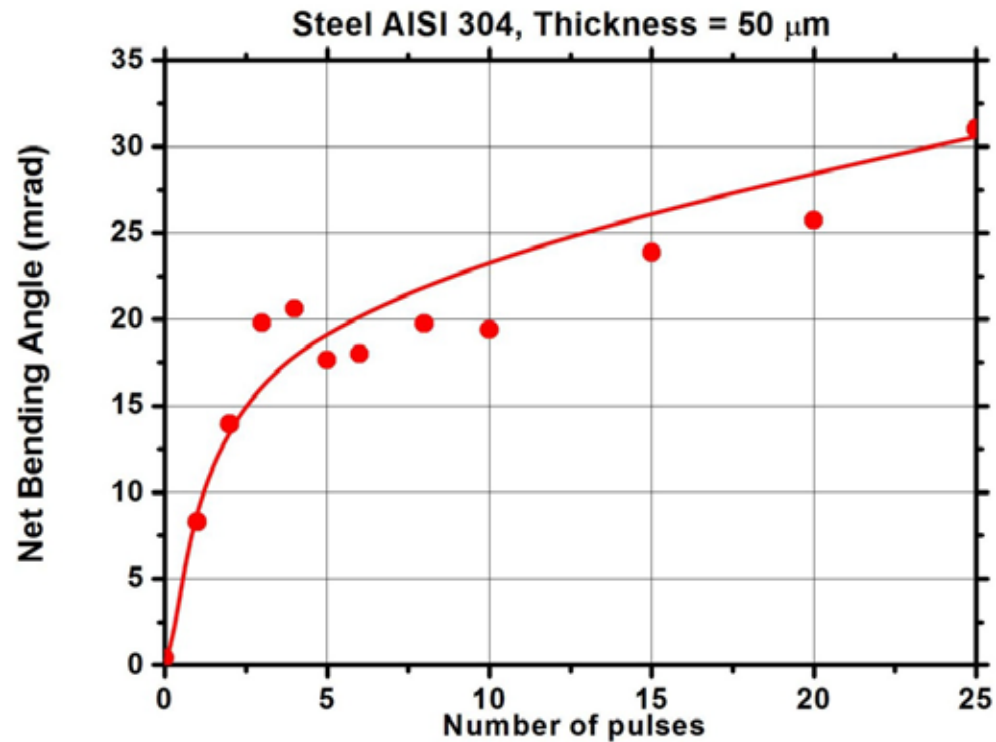
CONFOCAL MICROSCOPY



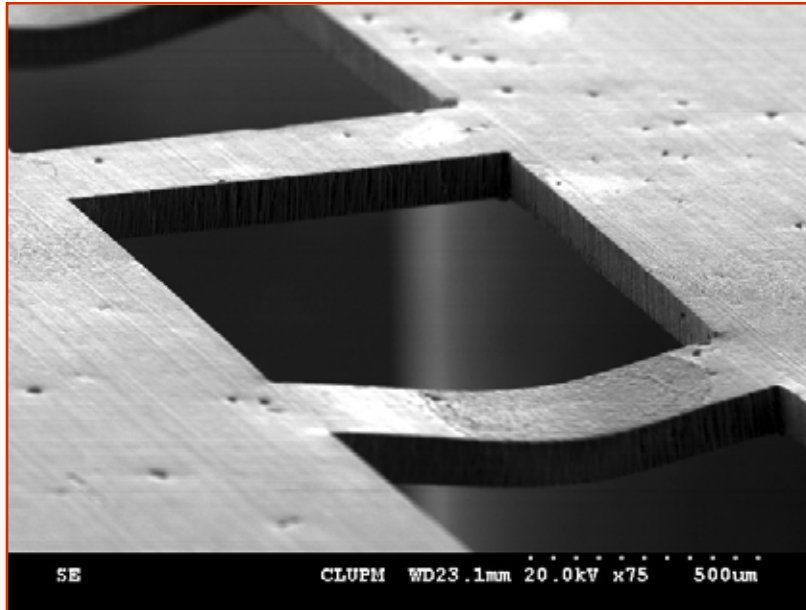
5. EXPERIMENTAL RESULTS. INFLUENCE OF NUMBER OF PULSES



5. EXPERIMENTAL RESULTS. INFLUENCE OF NUMBER OF PULSES

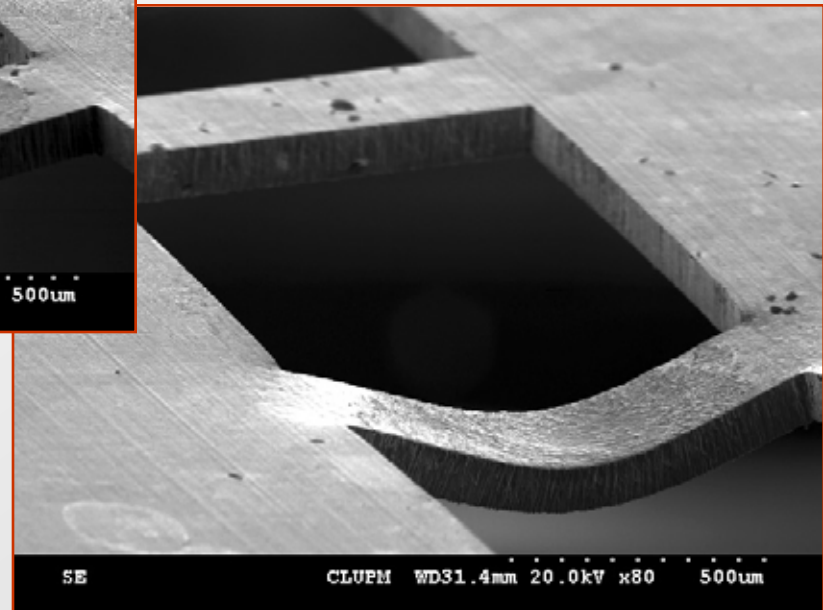


5. EXPERIMENTAL RESULTS. LAST RESULTS. CONFINED REGIME

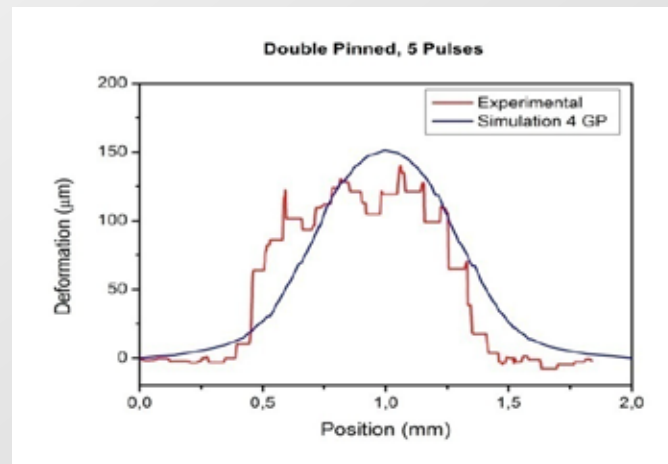
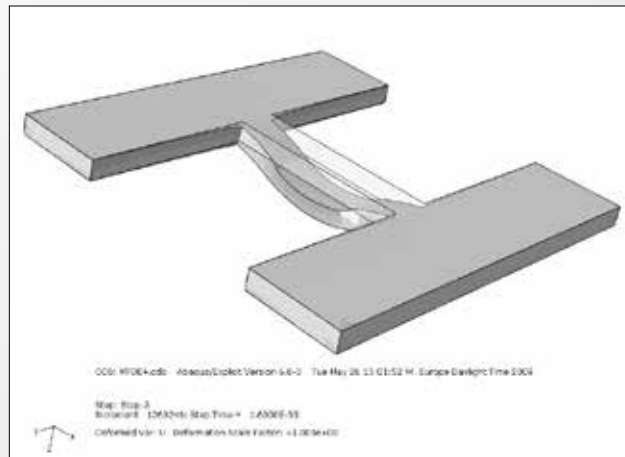
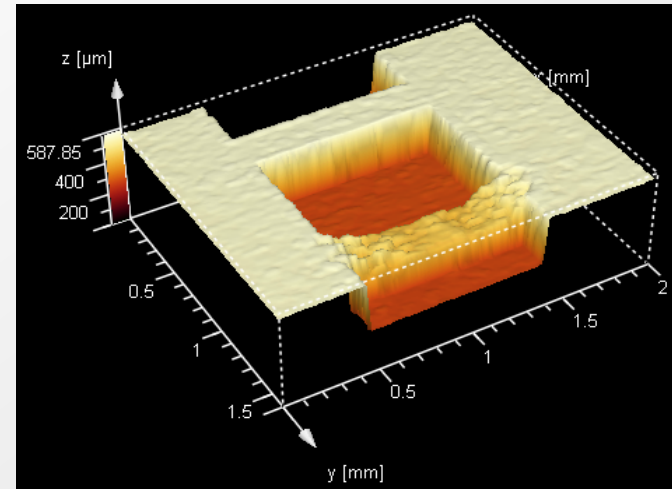
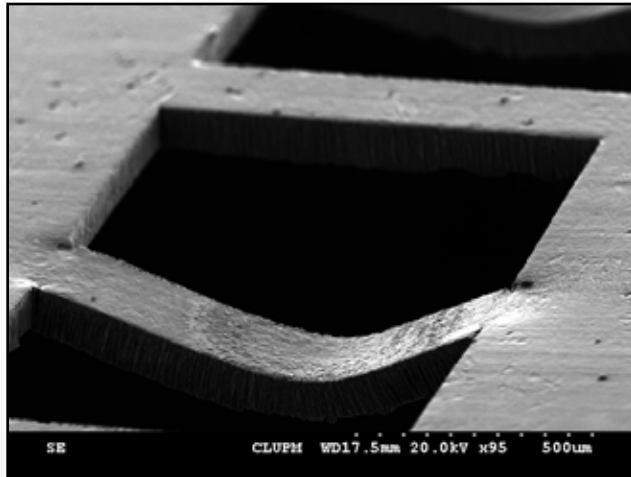


1 pulse

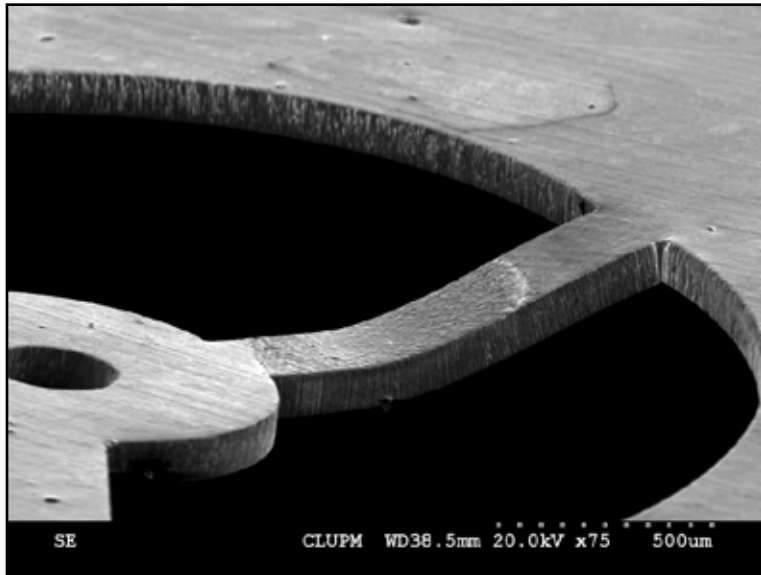
4 pulses



5. EXPERIMENTAL RESULTS. LAST RESULTS. CONFINED REGIME

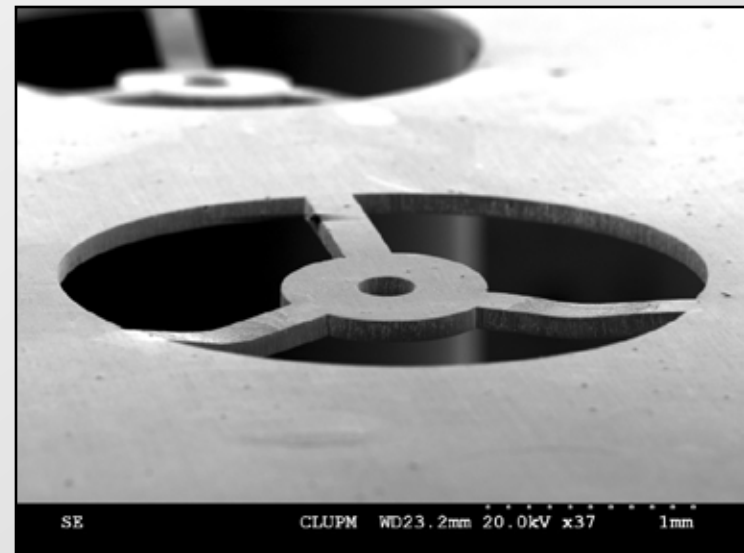
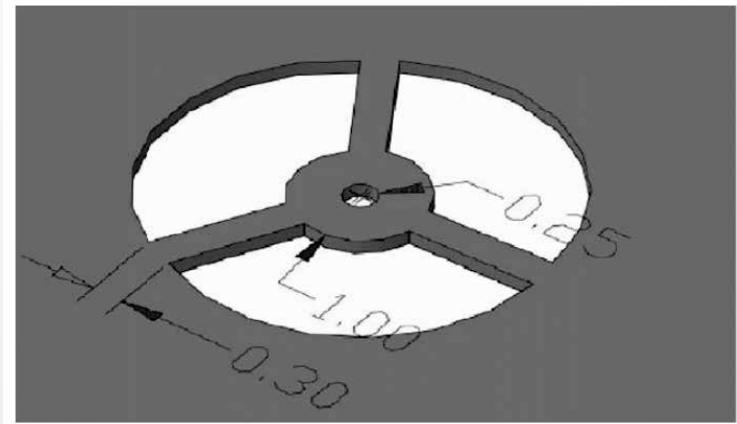


5. EXPERIMENTAL RESULTS. LAST RESULTS. CONFINED REGIME



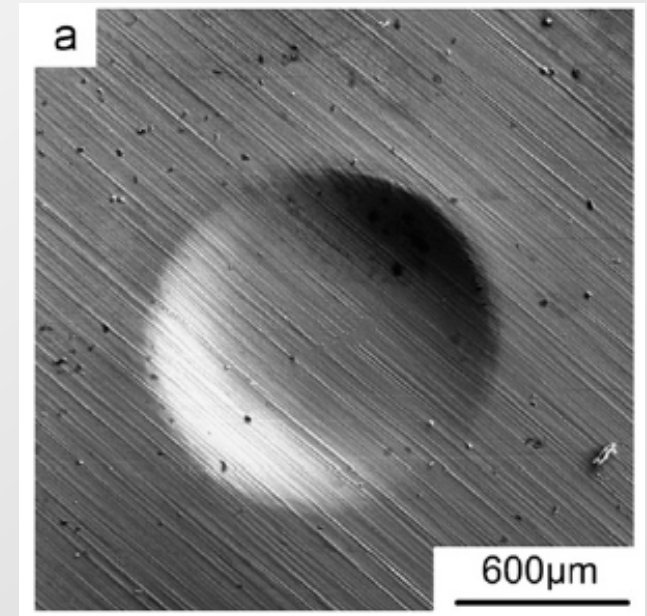
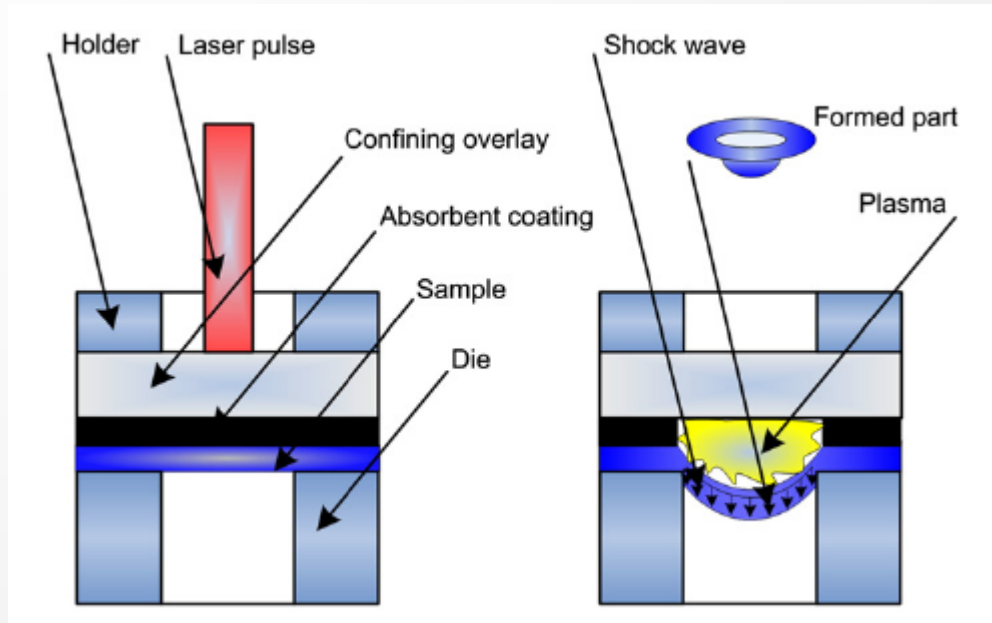
5 pulses

5 pulses in two arms



6. RECENT ALTERNATIVE APPROACHES

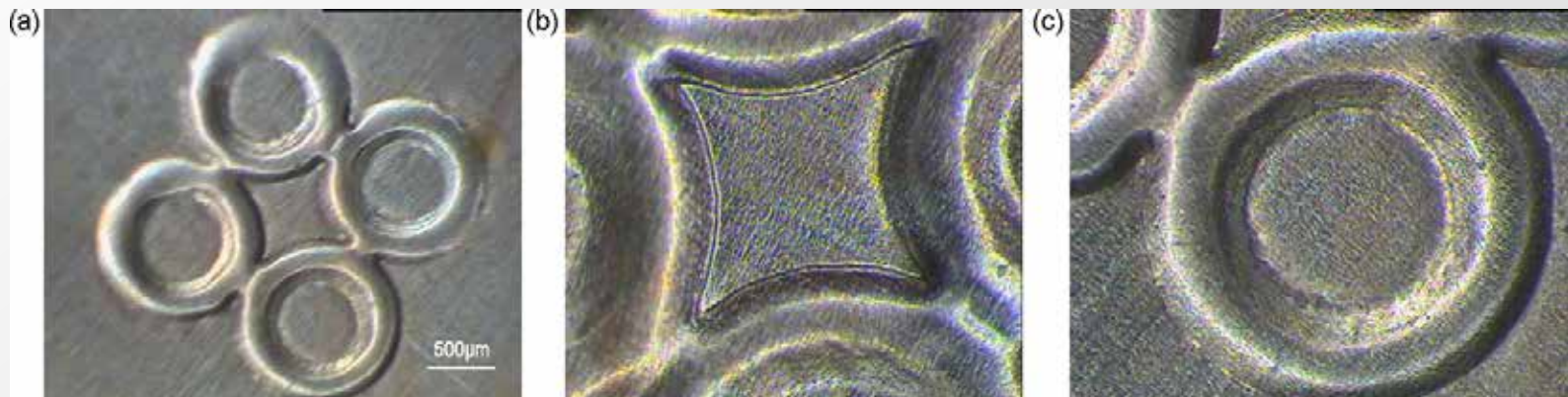
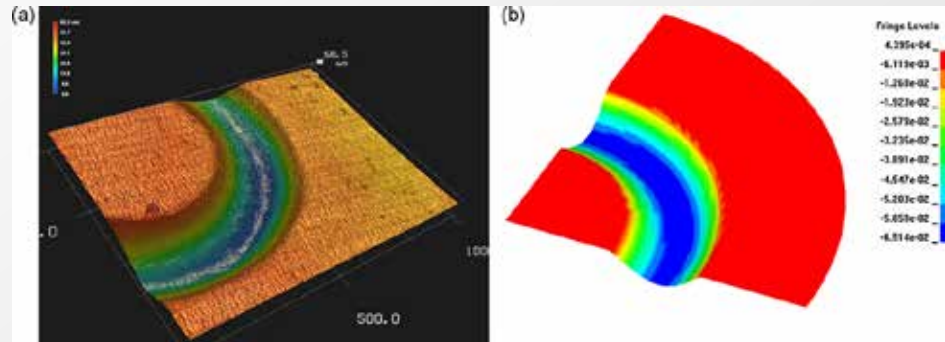
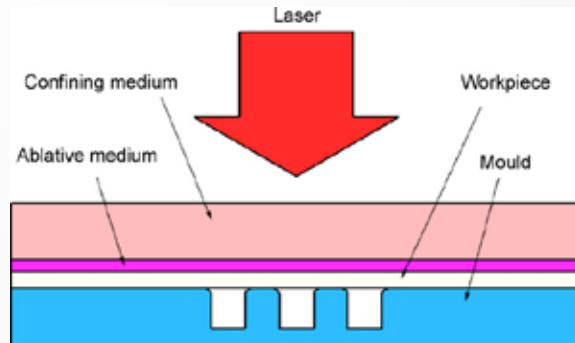
Microscale laser bulge forming:



C. ZHENG et al.: Int. J. Machine Tools & Manufacture, 50 (2010), 1048–1056

6. RECENT ALTERNATIVE APPROACHES

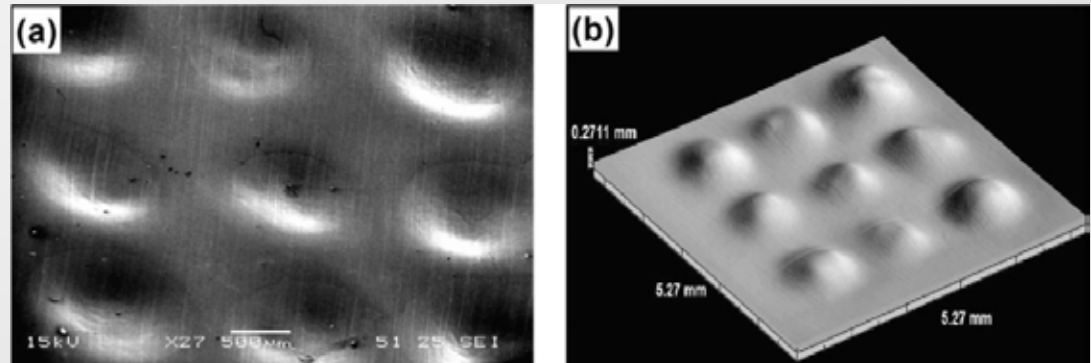
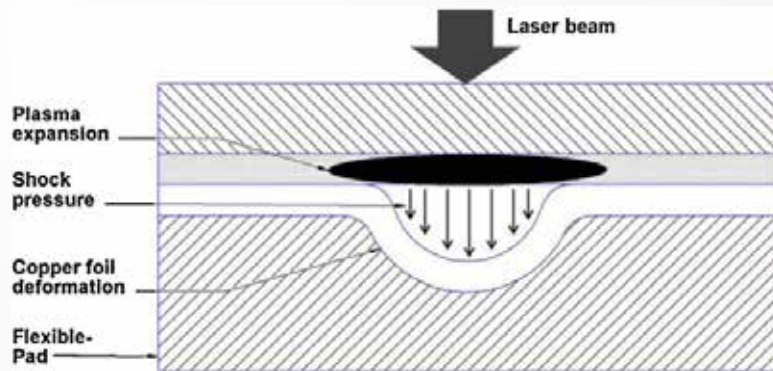
Micromould based laser shock embossing:



H. LIU et al.: Applied Surface Science, 256 (2010), 4687–4691

6. RECENT ALTERNATIVE APPROACHES

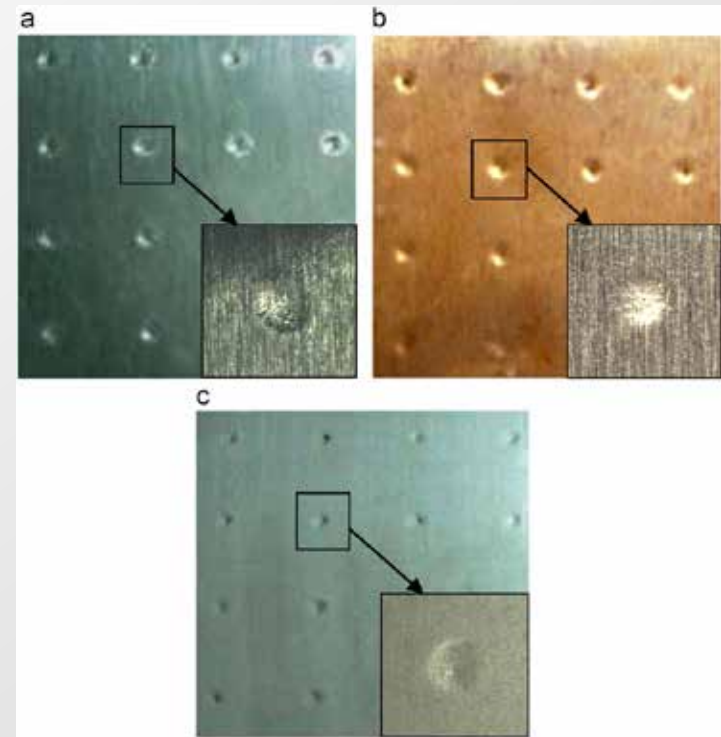
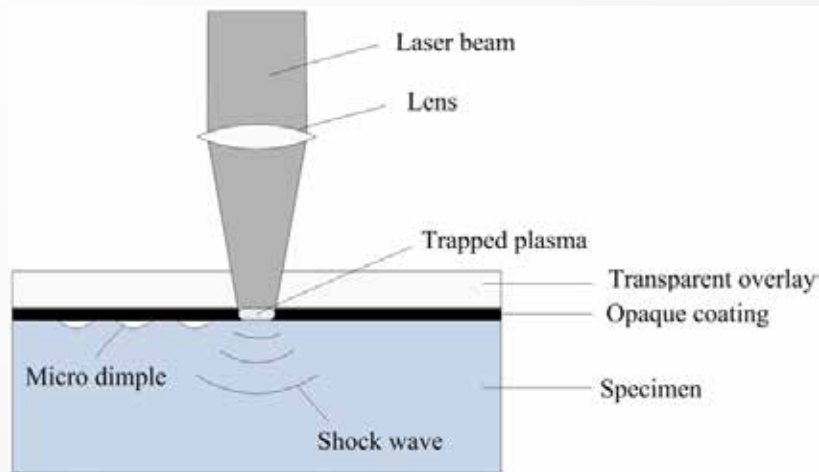
Mold-free fabrication of 3D microfeatures with laser shock:



B. NAGARAJAN et al.: Applied Surface Science, 268 (2013), 529– 534

6. RECENT ALTERNATIVE APPROACHES

Micro dimple fabrication based on laser shock processing:

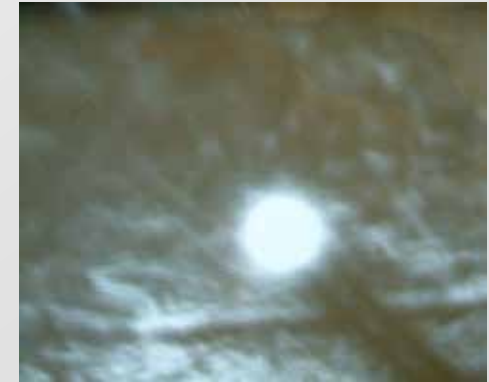
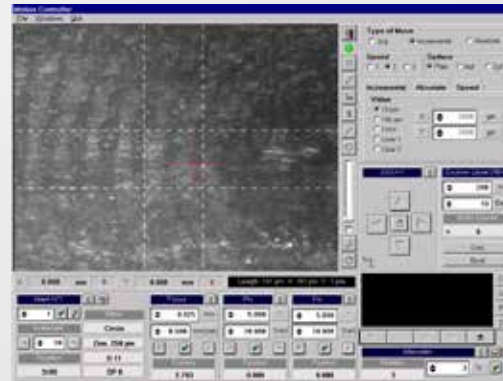
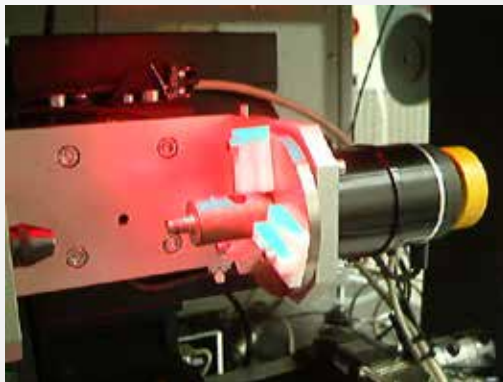
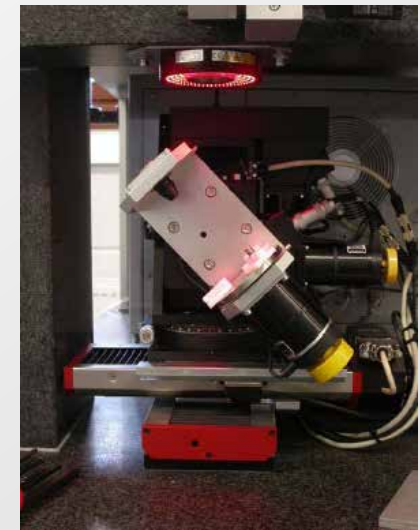
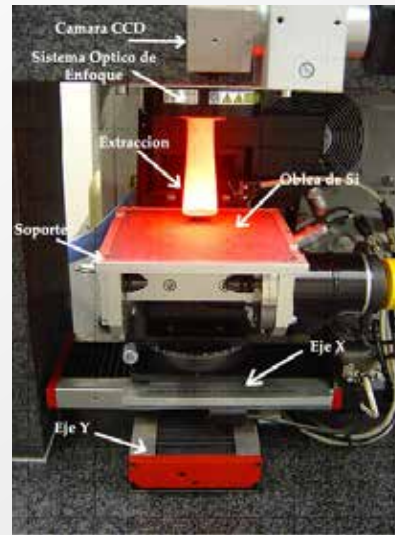
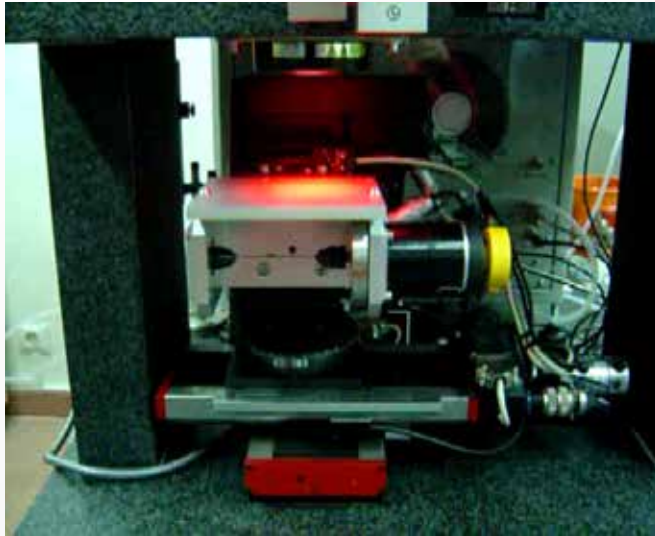


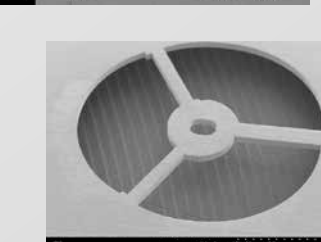
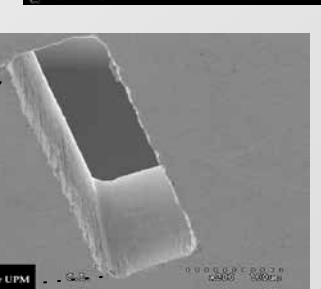
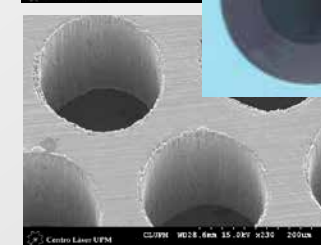
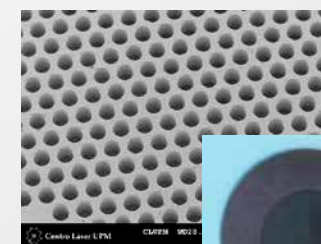
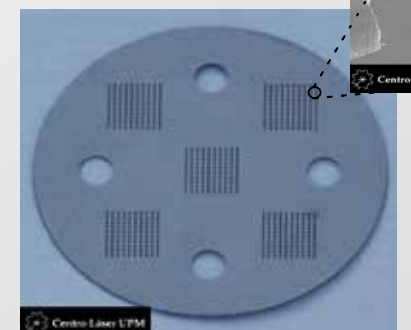
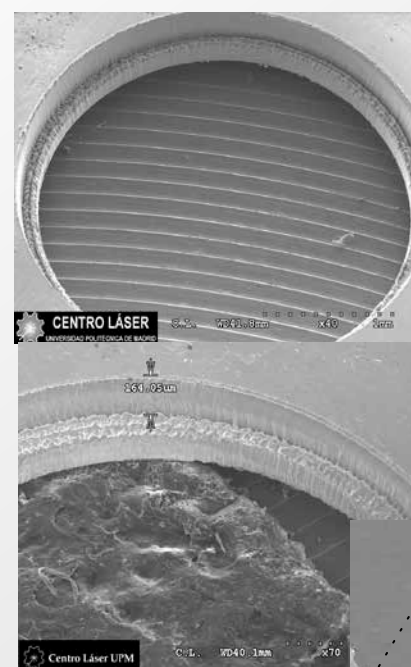
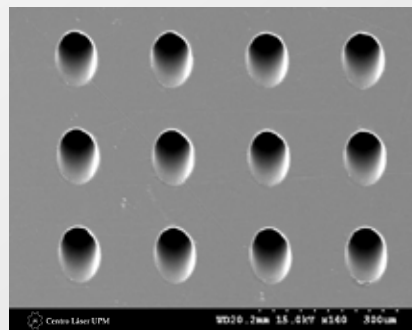
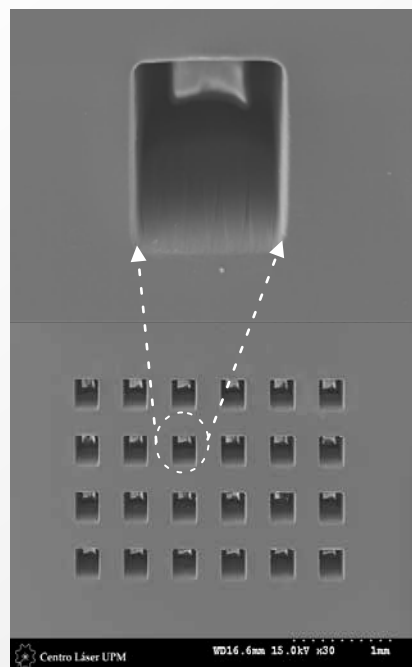
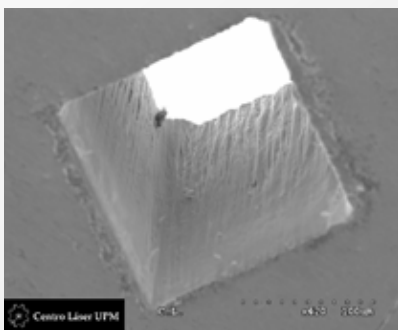
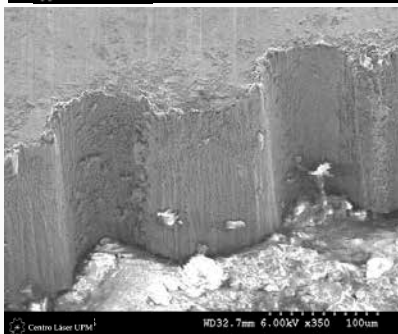
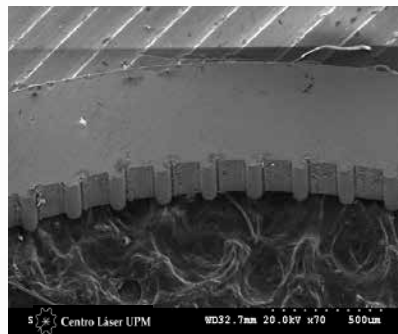
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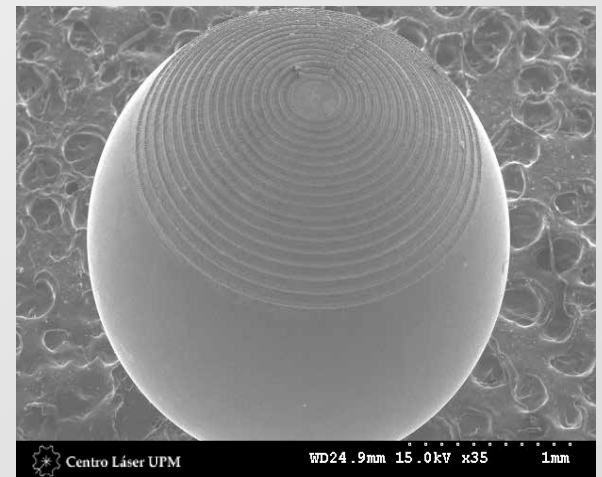
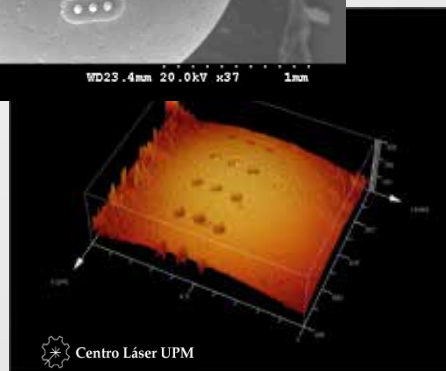
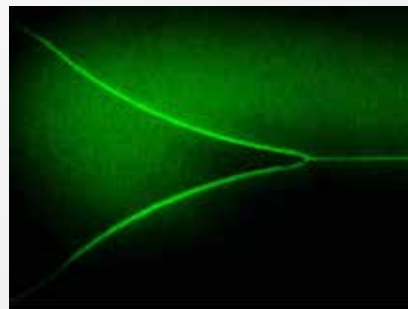
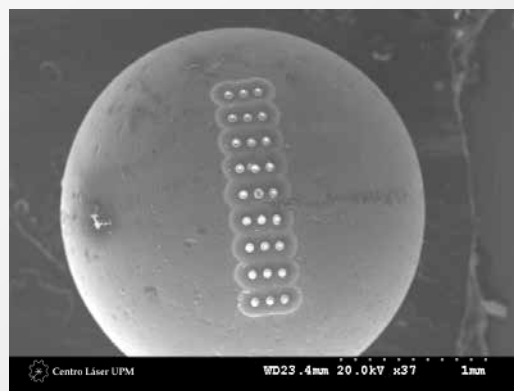
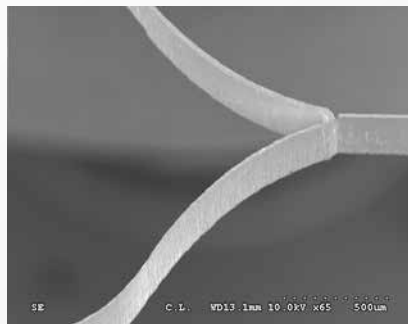
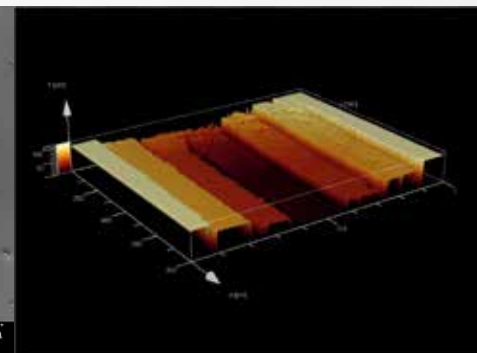
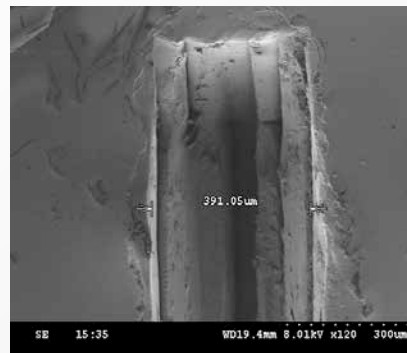
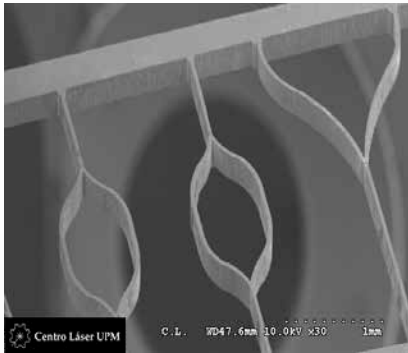
6. DISCUSSION AND OUTLOOK

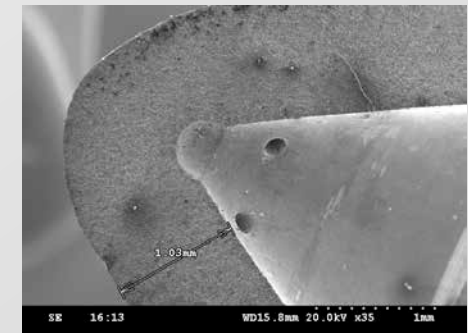
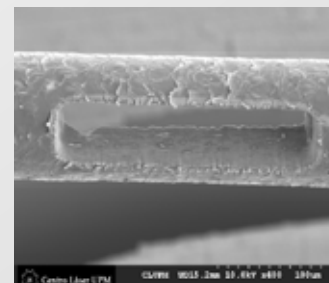
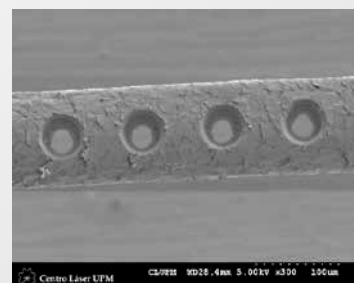
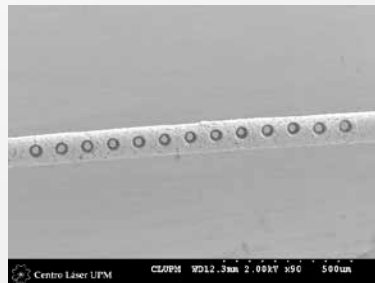
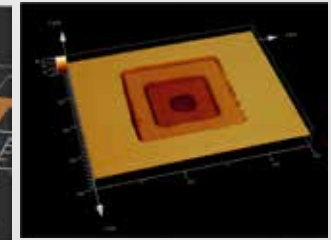
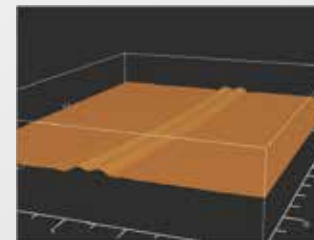
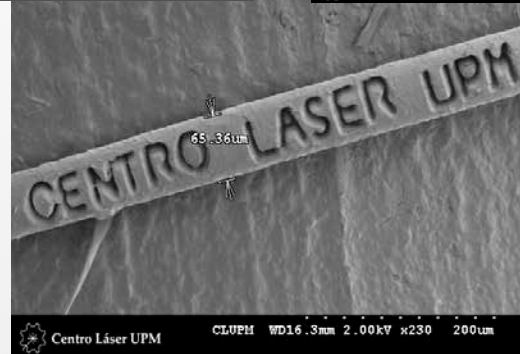
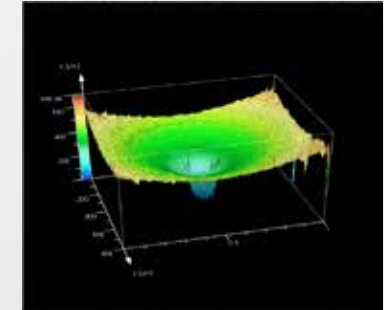
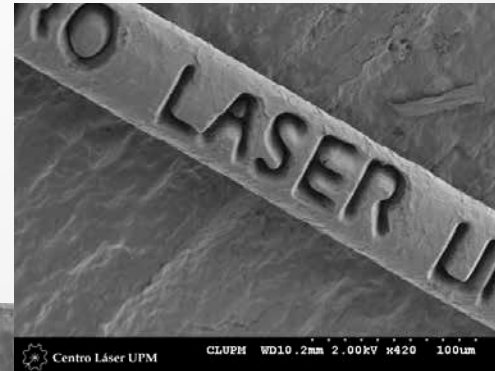
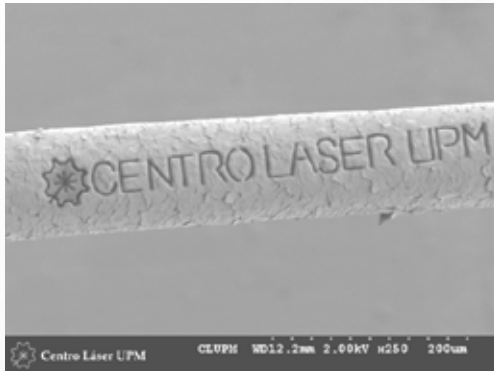
- § The suitability laser micro-bending of thin metal parts by means of ns pulsed lasers with average power in the range of several Watt has been experimentally demonstrated.
- § The micro-bending process can be developed both in free and confined environment with good tuning capability in both cases but with much more efficient results in the latter case. The numerical simulation capabilities developed by the authors allow a full predictive assessment of the bending process and final result.
- § Based on the same predictive assessment capabilities the release of residual stresses in MEMS components can be properly handled.
- § According to the authors' experience, the use of ns laser pulses in laser shock regime provides a really suitable parameter matching for the laser forming of an important range of MEMS sheet or stripe components. New alternative forming and embossing approaches based on the same principle reinforce this vision.
- § Laser shock microforming and adjustment stresses release of arbitrary geometry components is envisaged as a promising technology for MEMS development.

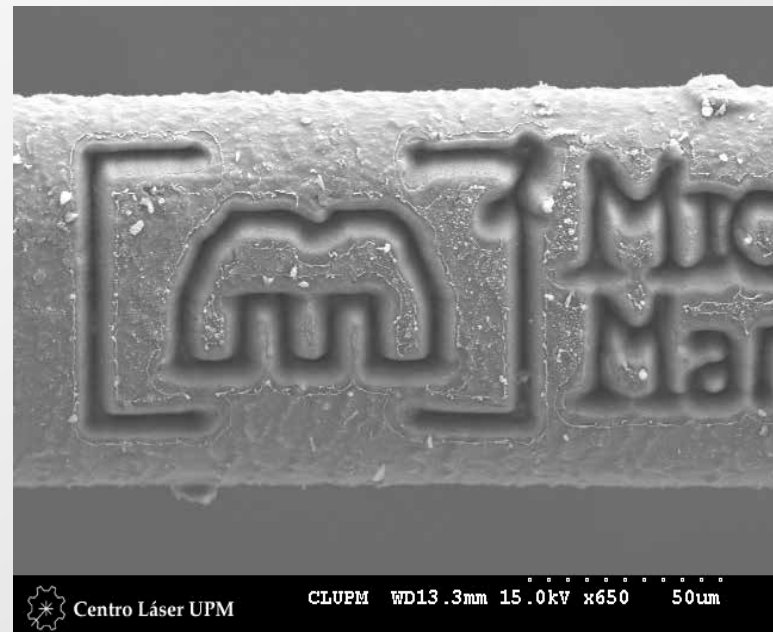
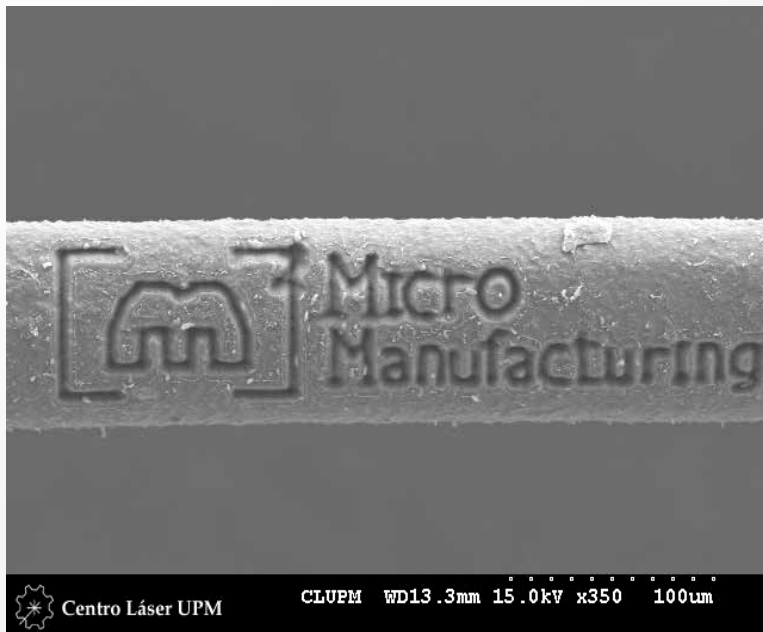
MICROMANUFACTURING EXPERIMENTAL SETUP AT CLUPM









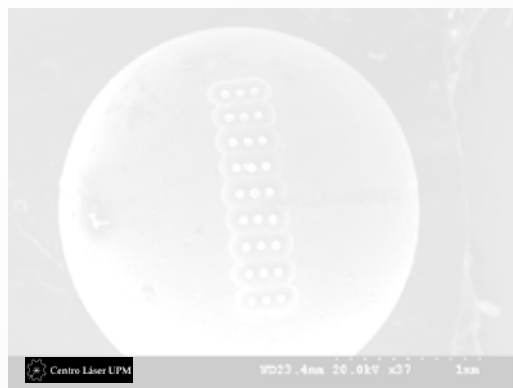


ACKNOWLEDGEMENTS

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*Thank you very much
for your attention!*

