Laser Shock Microforming of Thin Metal Sheets with Q-Switched ns Lasers

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ETS de Ingenieros Industriales, Universidad Politécnica de Madrid, SPAIN

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OUTLINE:

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

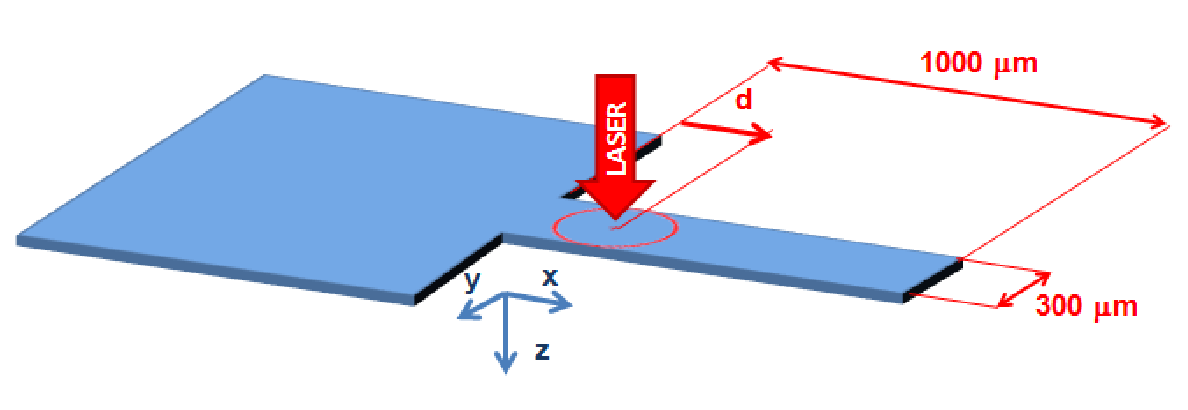
1. INTRODUCTION

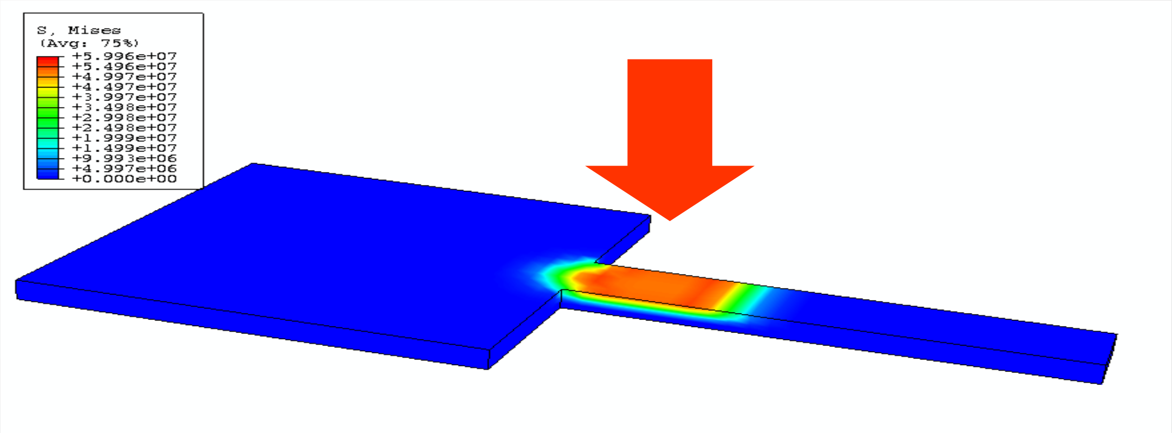
- **The increasing demands in MEMS fabrication are leading to new requirements in production technology. Especially the packaging and assembly require high accuracy in positioning and high reproducibility in combination with low production costs.**
- **Conventional assembly technology and mechanical 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.**
- **As 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.**

1. INTRODUCTION (Cont.)

- 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





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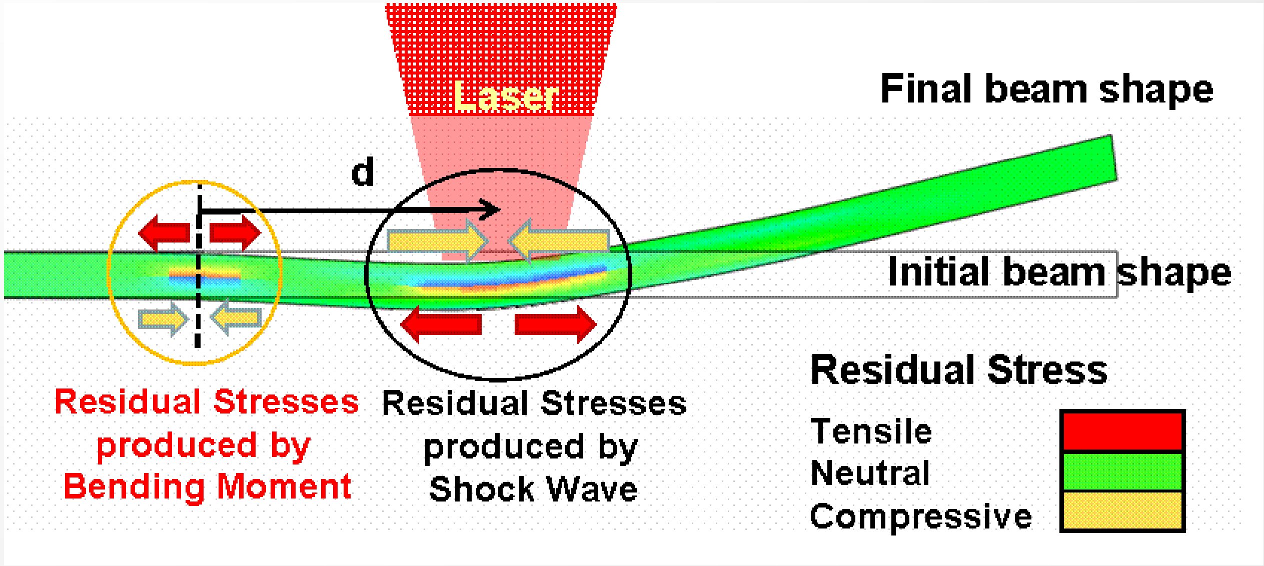
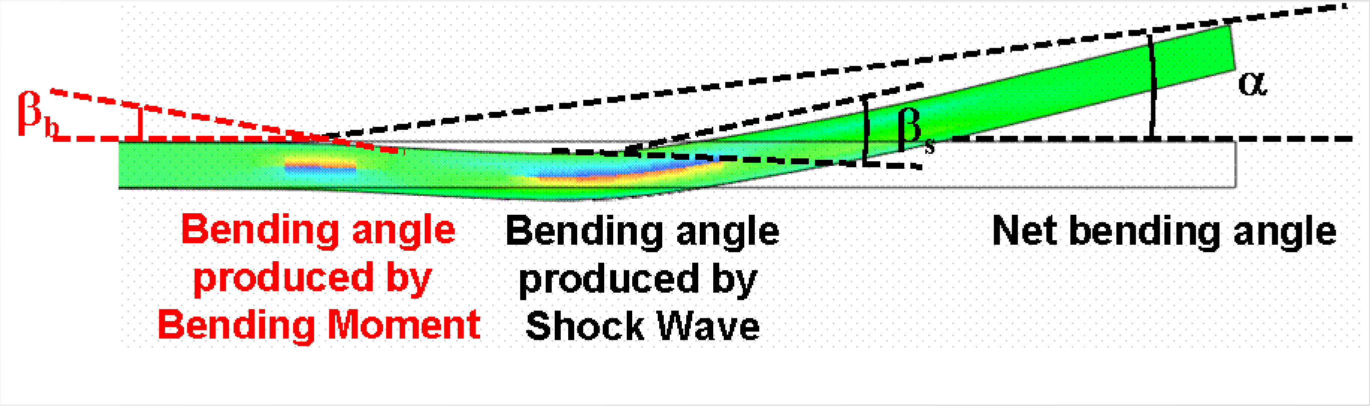




PRESSURE PULSE MODEL

LSPSIM

Interface thickness

$$L(t)=\int_0^t [u_1(t)+u_2(t)]\,dt$$

Heating phase

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

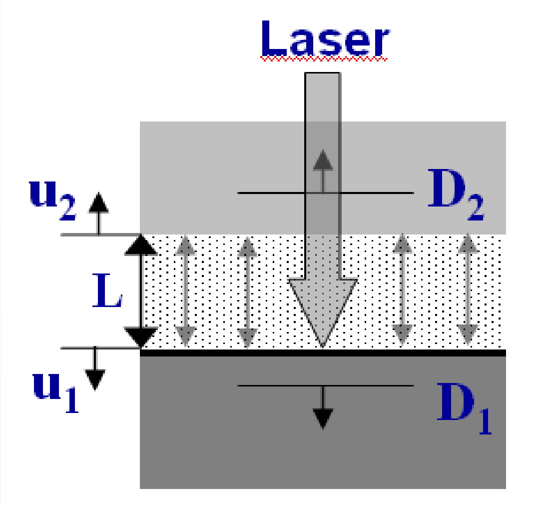
$$P(t)=\frac{2}{3}E_t(t)=\frac{2}{3}\alpha E_i(t)$$

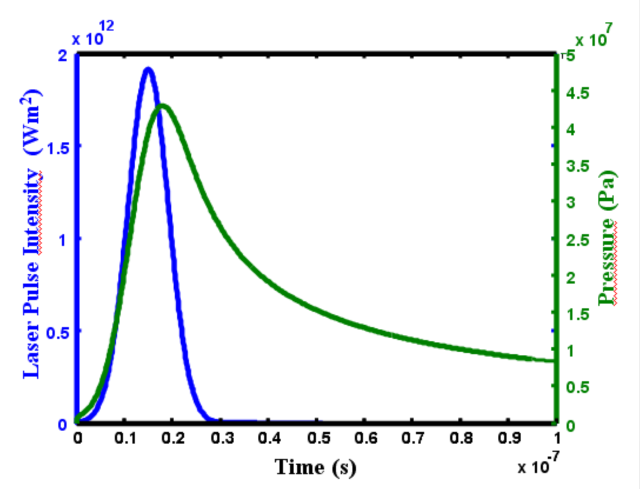
Shock wave relation

$$P=\rho_i D_i u_i$$

Solid/Liquid $D=C+Su$

Gas $D=u=\left(\frac{(\gamma+1)}{2}\frac{P}{\rho}\right)^{1/2}$

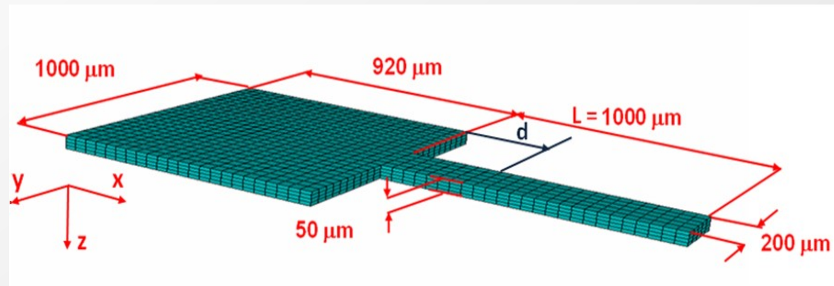




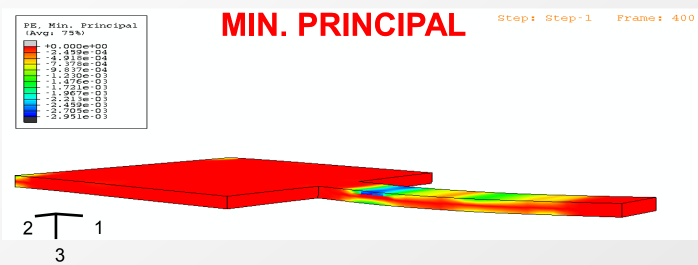
2. NUMERICAL SIMULATION. MODEL DESCRIPTION

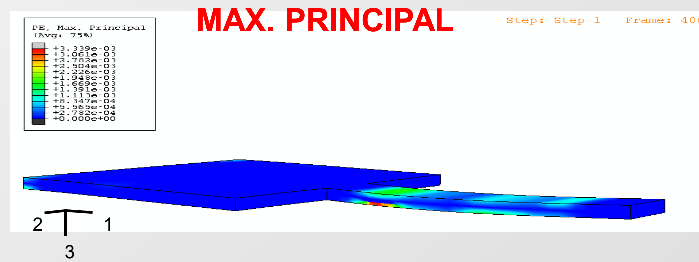
FEM MODEL – STRESS-STRAIN ANALYSIS

GEOMETRY AND DIMENSIONS

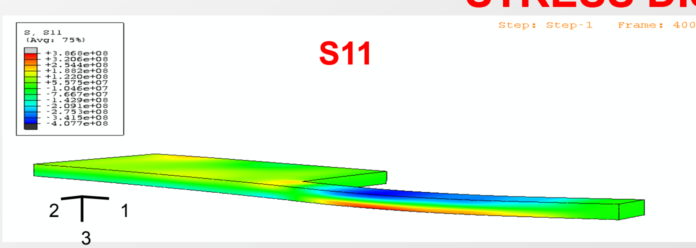


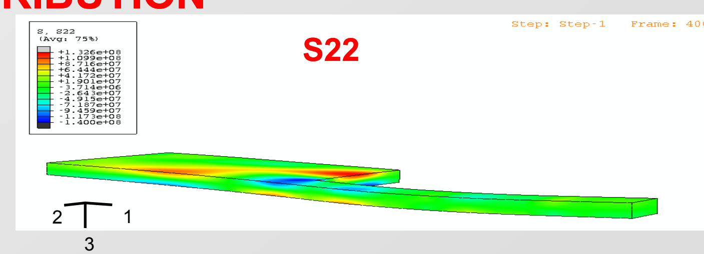
PLASTIC STRAIN





STRESS DISTRIBUTION





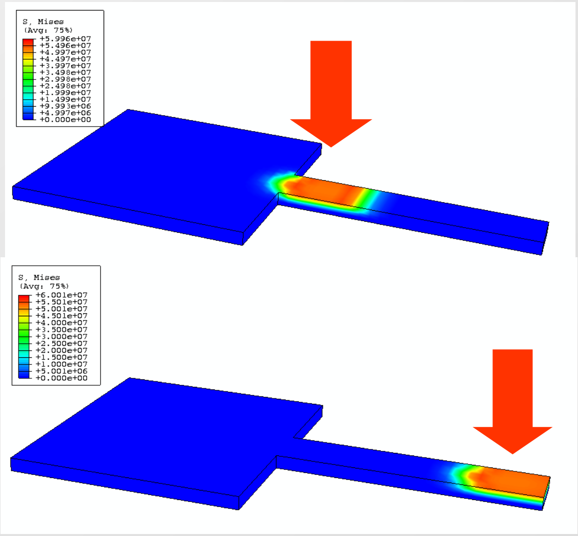
2. NUMERICAL SIMULATION. MODEL DESCRIPTION

MATERIAL PROPERTIES (AISI 304)

Target	AISI 304
Young's Modulus: E [GPa]	193
Poisson's Coeffcient: ν	0.25
Densisty: ρ [kg/m3]	7896
Melting Temperature: Tm [K]	1811
Test Temperature: T0 [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
$\dot{\varepsilon}_0$ [s^{-1}]	1

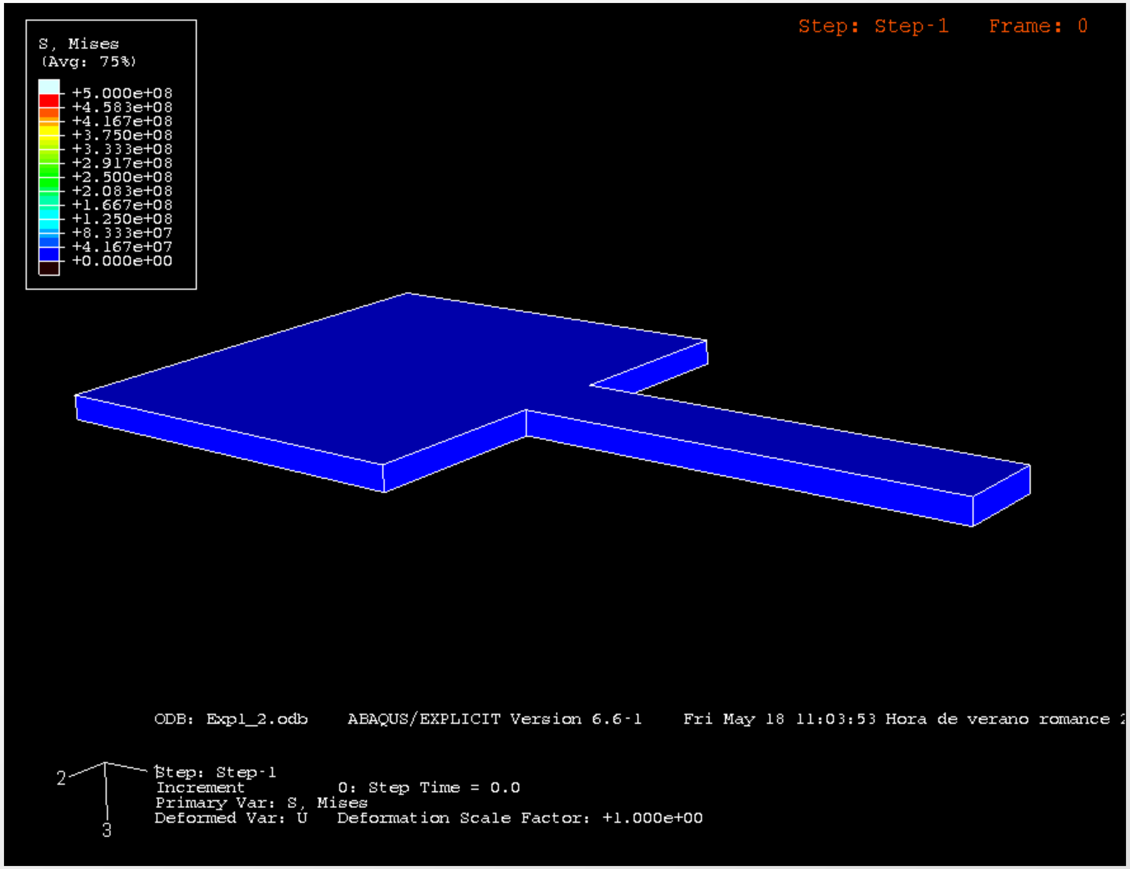
LSPSIM PARAMETERS

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



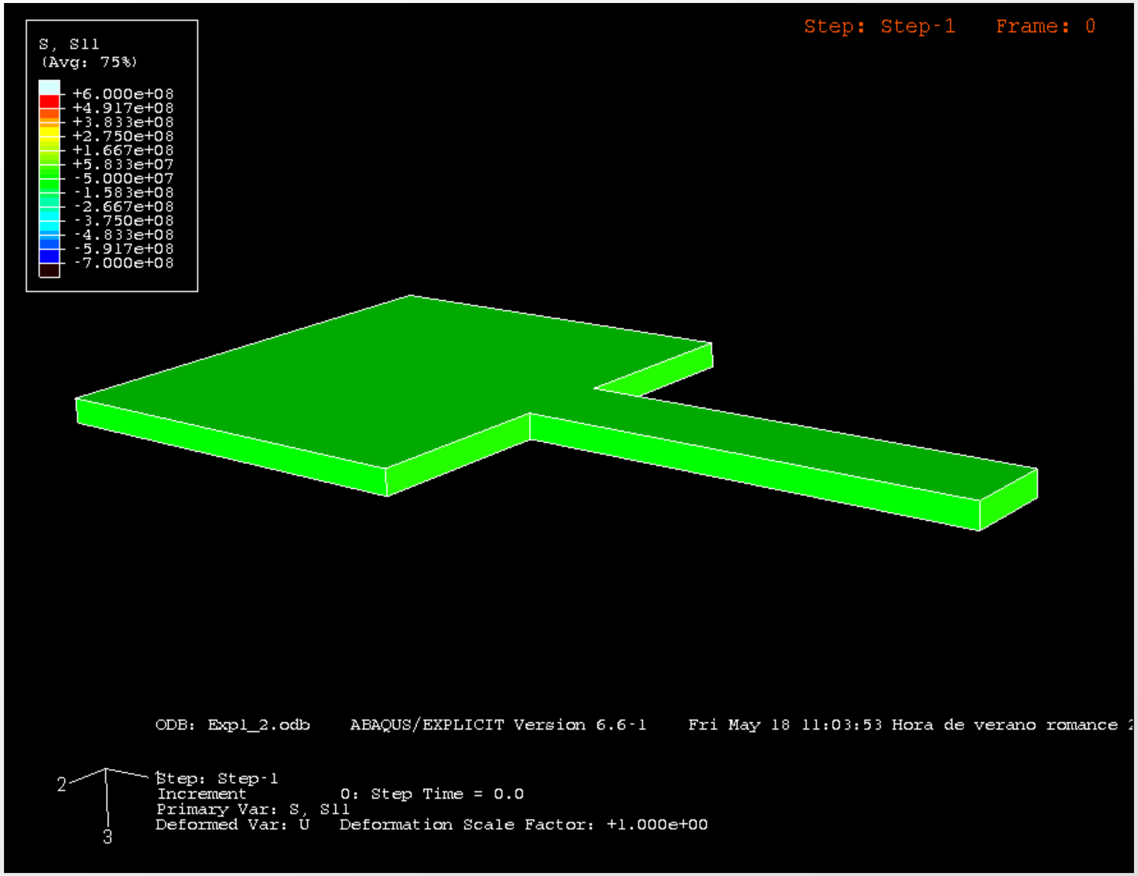
3. NUMERICAL SIMULATION RESULTS

SHOCKLAS EXPLICIT – VON MISES EVOLUTION



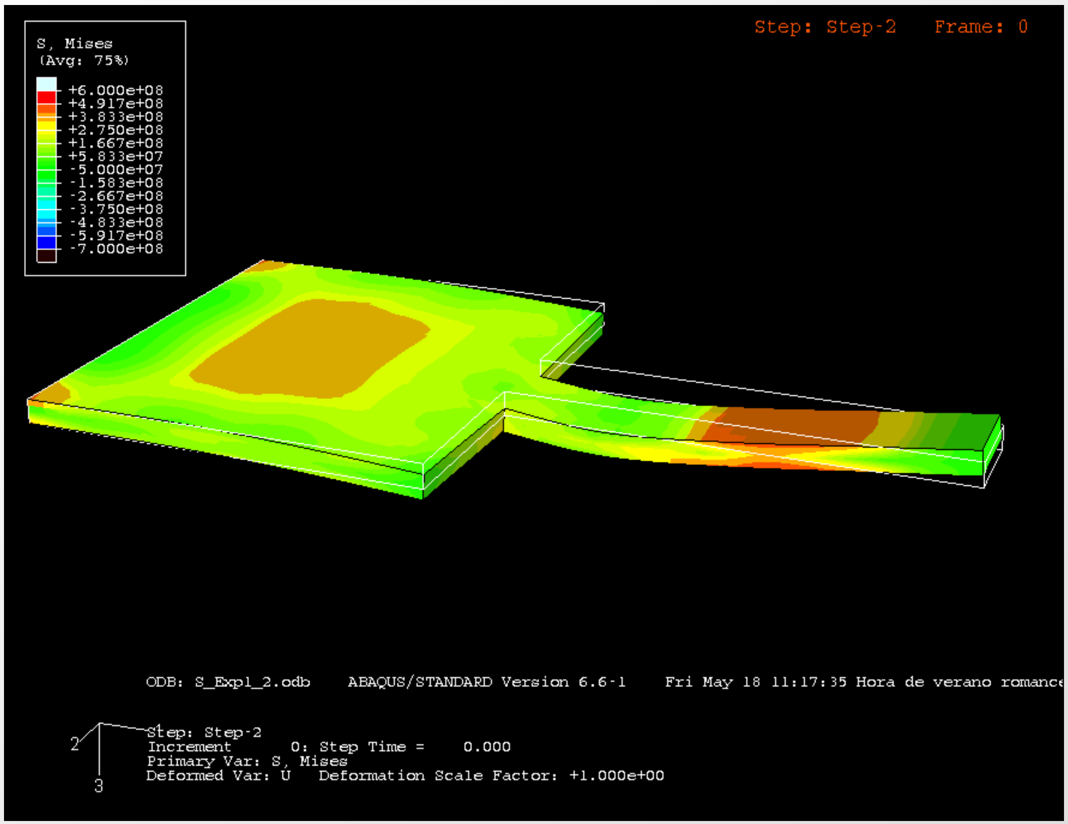
3. NUMERICAL SIMULATION RESULTS

SHOCKLAS EXPLICIT – STRESS (S11) EVOLUTION



3. NUMERICAL SIMULATION RESULTS

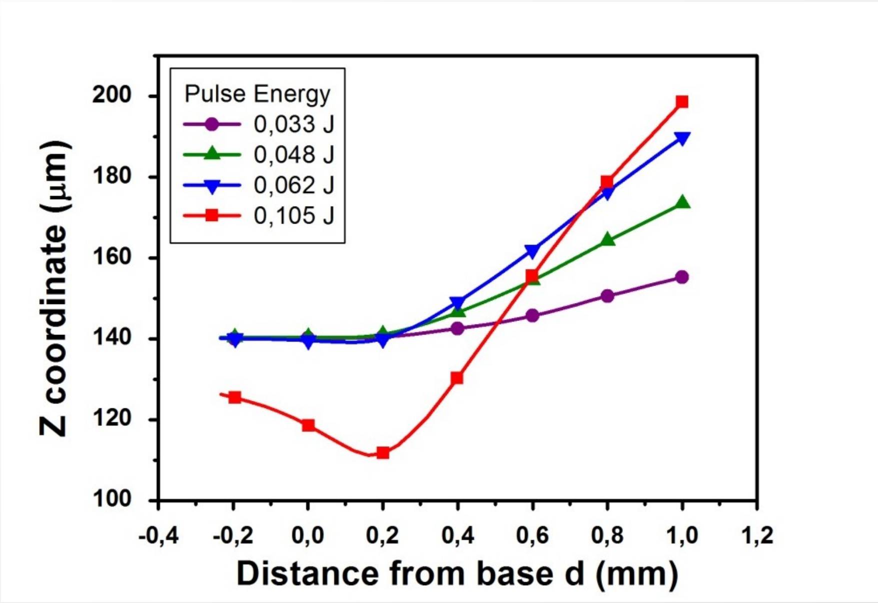
SHOCKLAS STANDARD – STRESS (S11) EQUILIBRATION

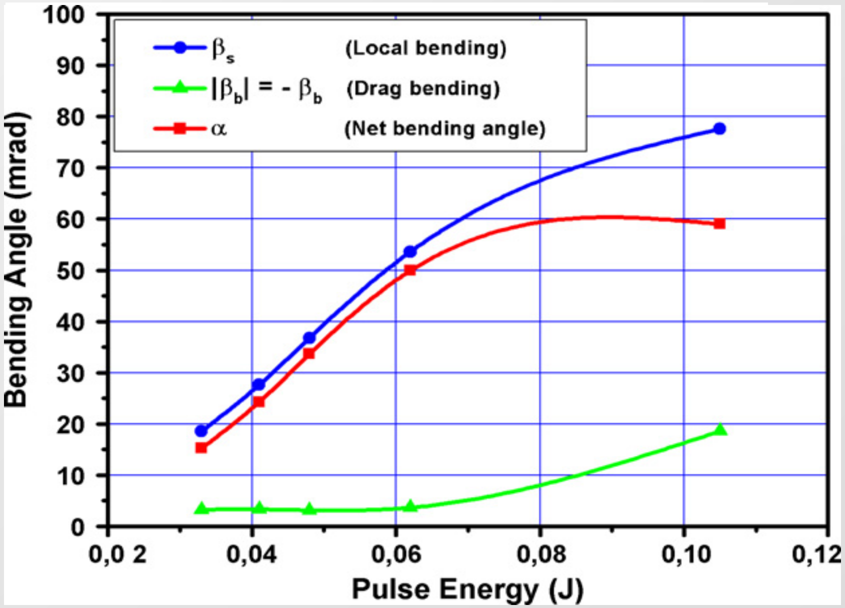


Pulse Energy Parametrization

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

Material Model	SS304
Confining medium	Air
Interaction parameter α	0.2
Spot center distance [μm]	150



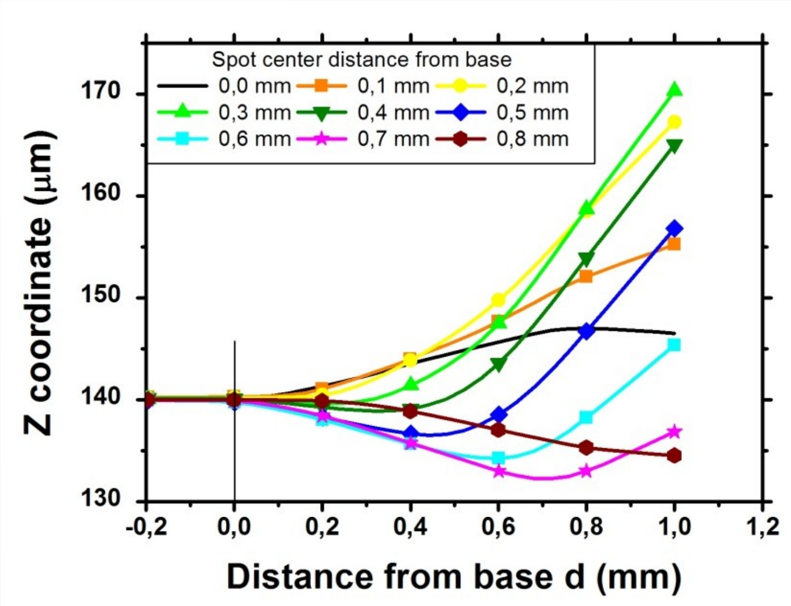


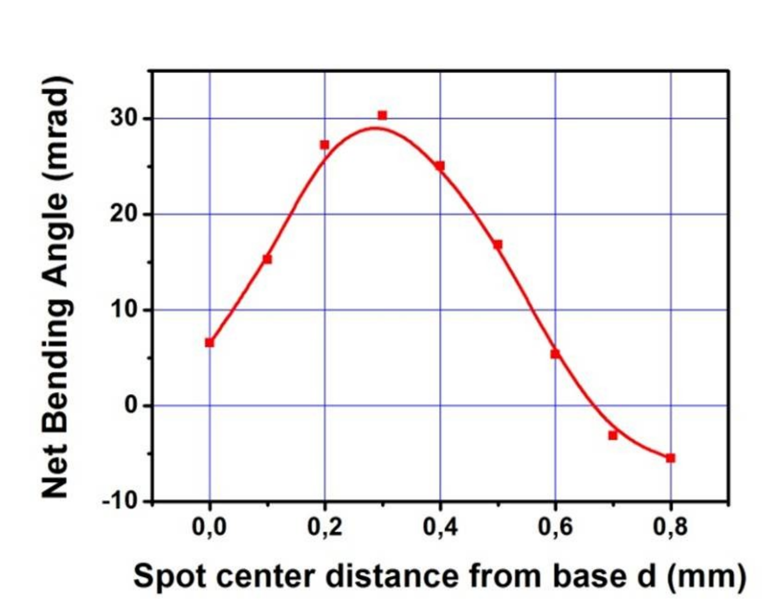
3. NUMERICAL SIMULATION RESULTS

Spot Center Distance Parametrization

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

Material Model	SS304
Confining medium	Air
Interaction parameter α	0.2
Spot center distance [μm]	variable

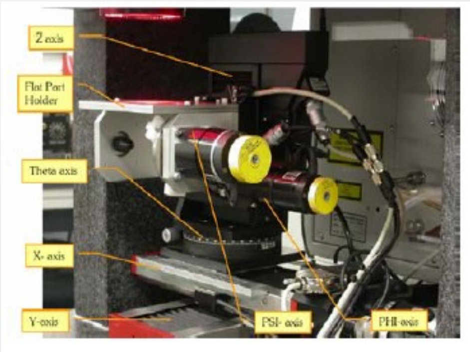


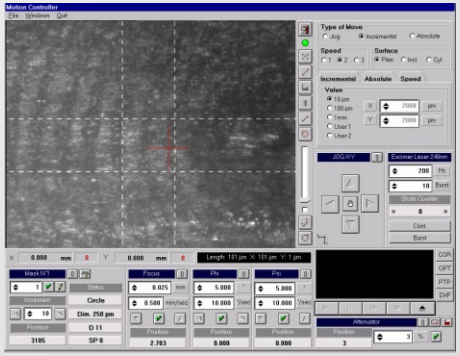


4. EXPERIMENTAL SETUP. SAMPLE PREPARATION

ML-100 LASER WORKSTATION

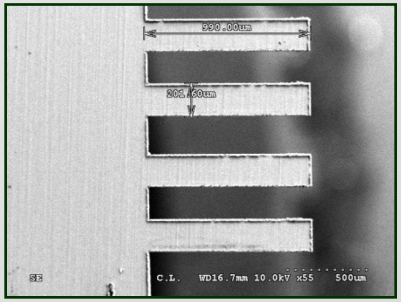
Laser media	Excimer (KrF)	DPSS 3ω
Wavelength (nm)	248	355
Pulse duration (ns)	3–7 ns	$<$12 ns (at 50 kHz)
Beam shape/mode	Rectangular (3.5 × 6 mm)	TEM_{00} ($M^2 < 1.3$)
Operating frequency	0–300 Hz	15–300 kHz
Average power (W)	0.3–5 (at 300 Hz)	5 W (at 50 kHz)





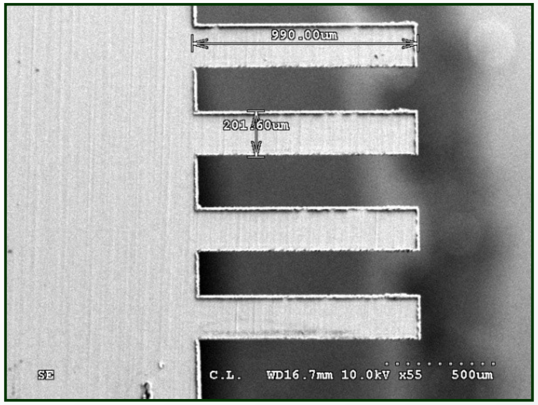
- Dual Excimer/DPSS Laser processing
- Multiaxis (6) System
- Work volume: 120*100*50 mm
- XY accuracy: 1 μm
- Global positioning accuracy: 40 μm
- CCD direct vision (x 500)

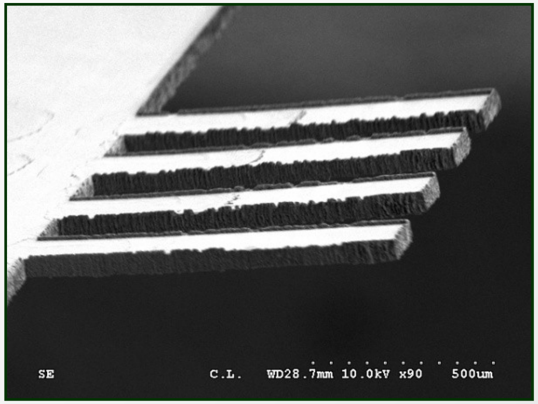
AISI 304
1000 x 200 x 50 μm

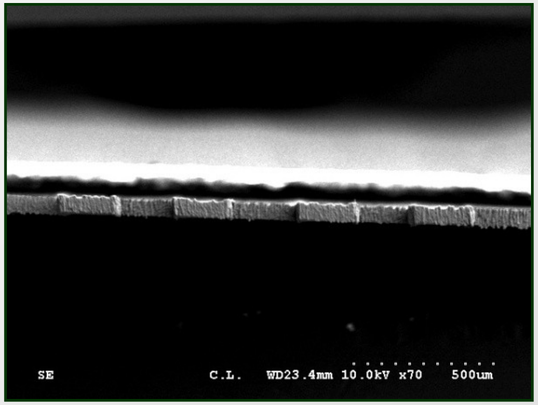


4. EXPERIMENTAL SETUP. SAMPLE PREPARATION

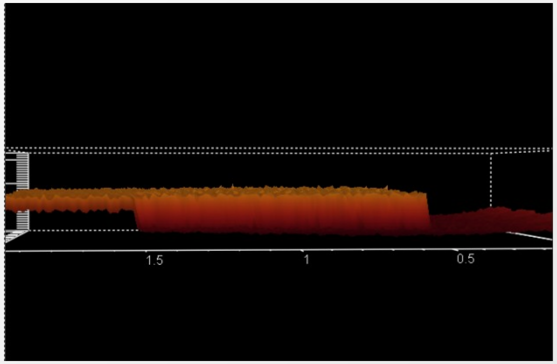
SEM IMAGES OF LASER CUT SHEET

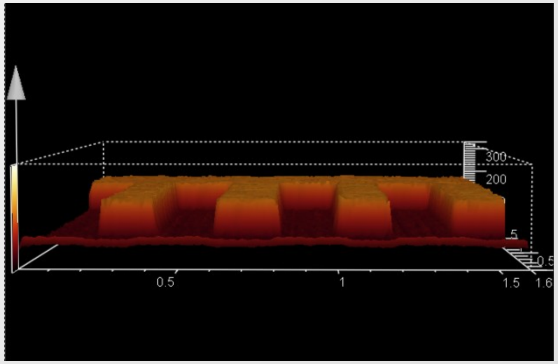


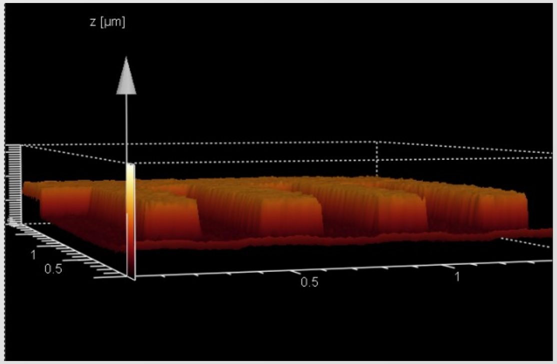




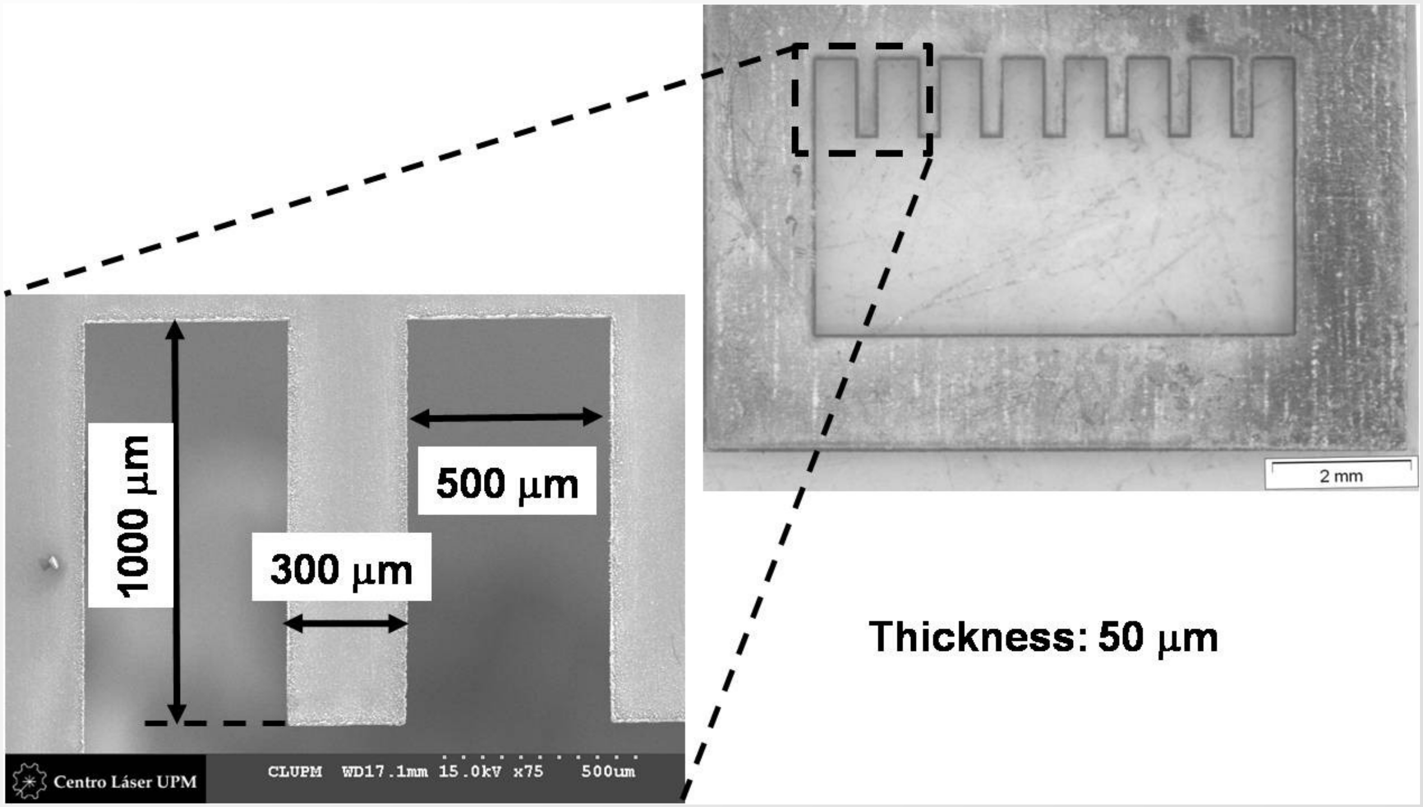
CONFOCAL IMAGES OF LASER CUT SHEET







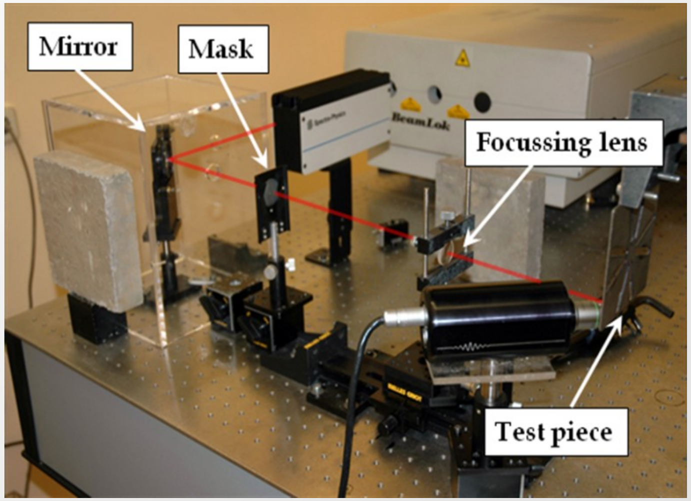
4. EXPERIMENTAL SETUP. SAMPLE PREPARATION

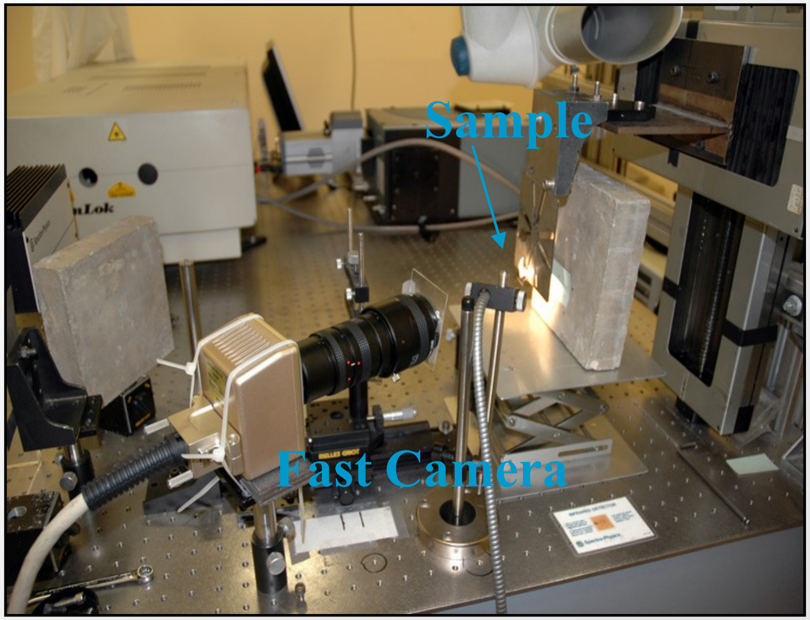


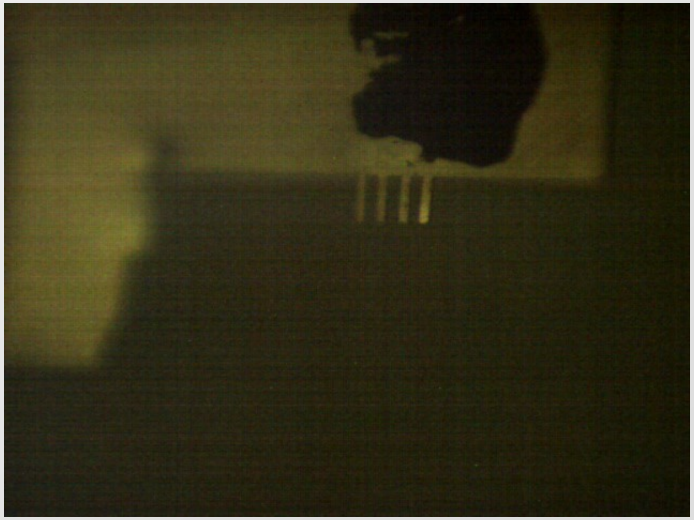
Thickness: 50 µm

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 [μm]	50

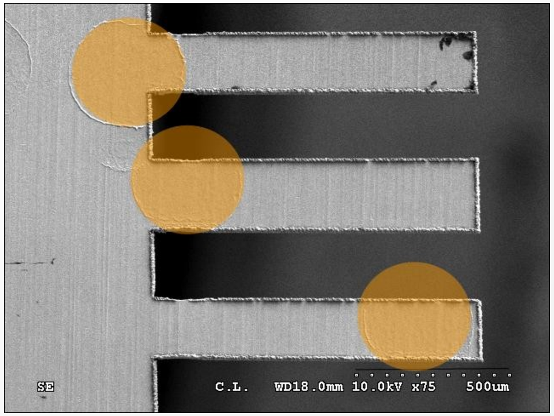


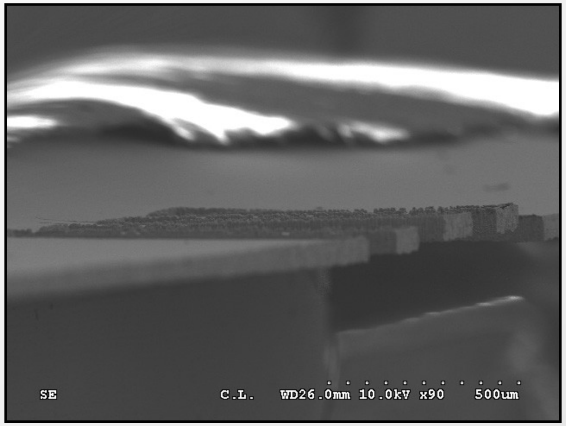




5. EXPERIMENTAL RESULTS. INFLUENCE OF SPOT CENTER DISTANCE

SEM IMAGES





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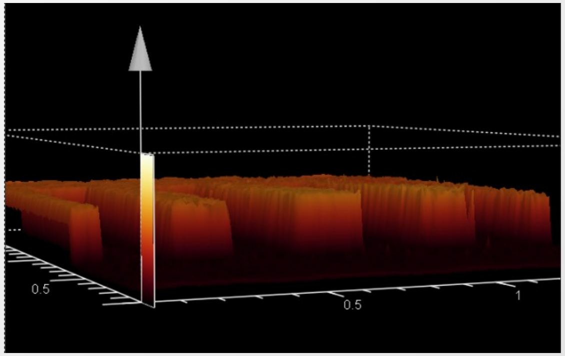
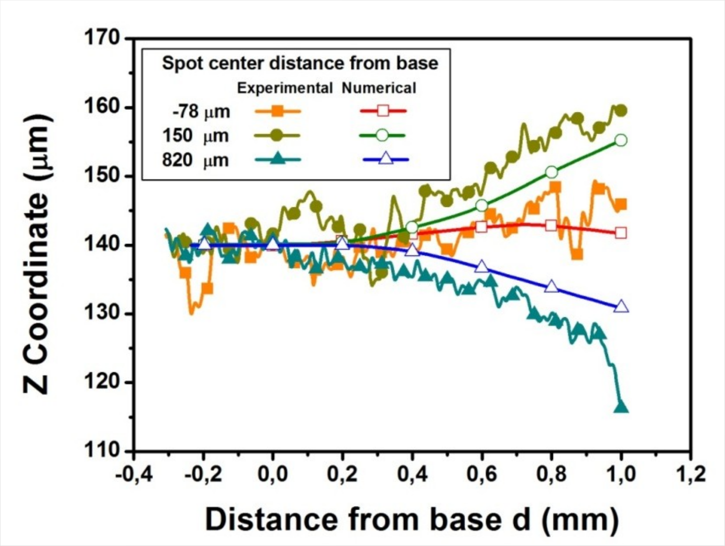
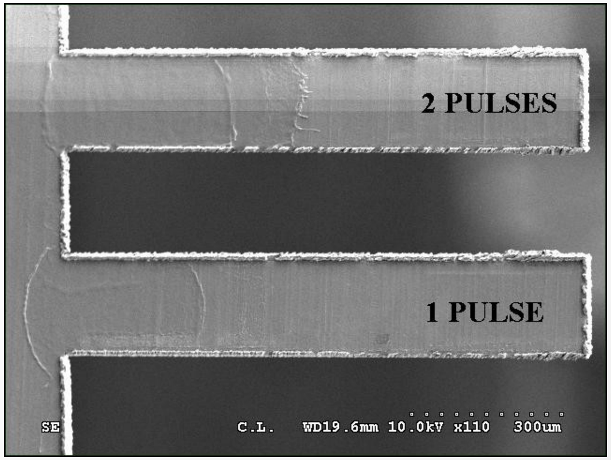
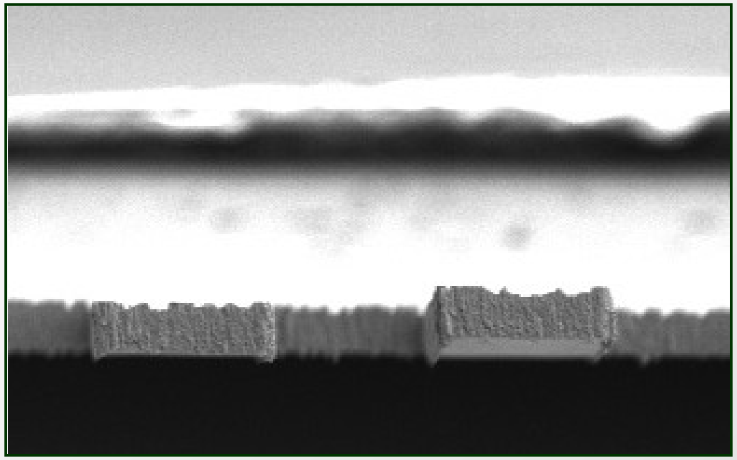




5. EXPERIMENTAL RESULTS. INFLUENCE OF NUMBER OF PULSES

SEM IMAGES





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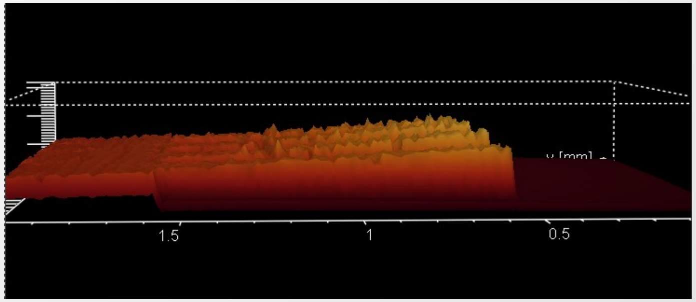
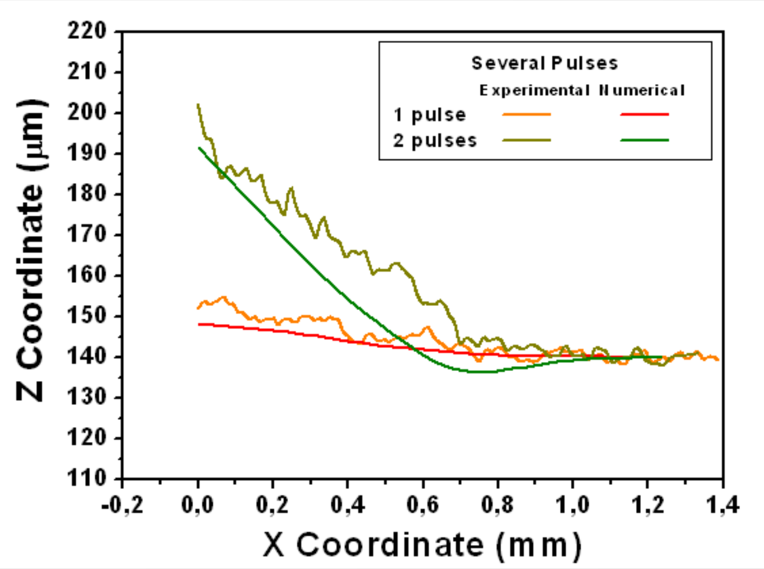
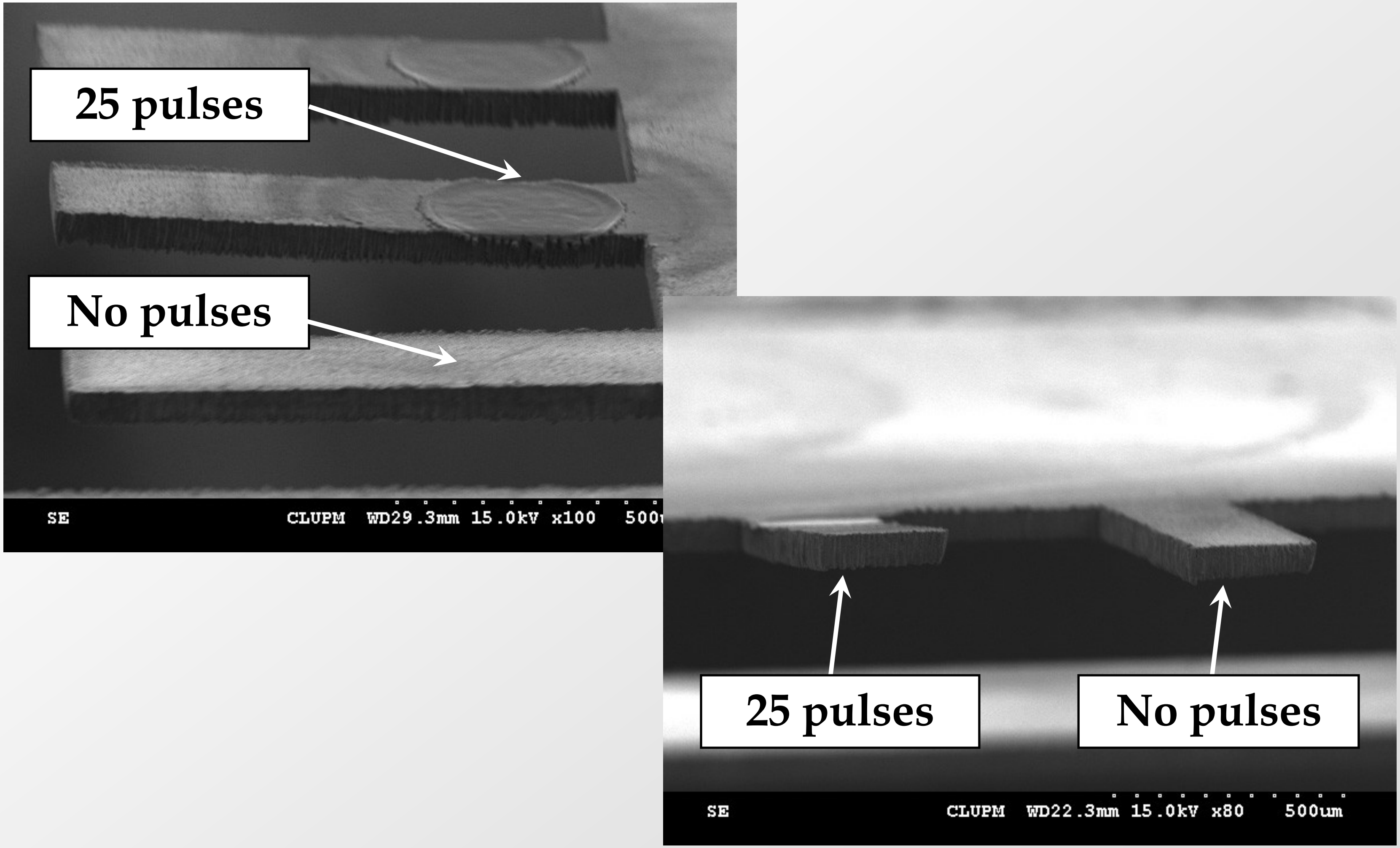
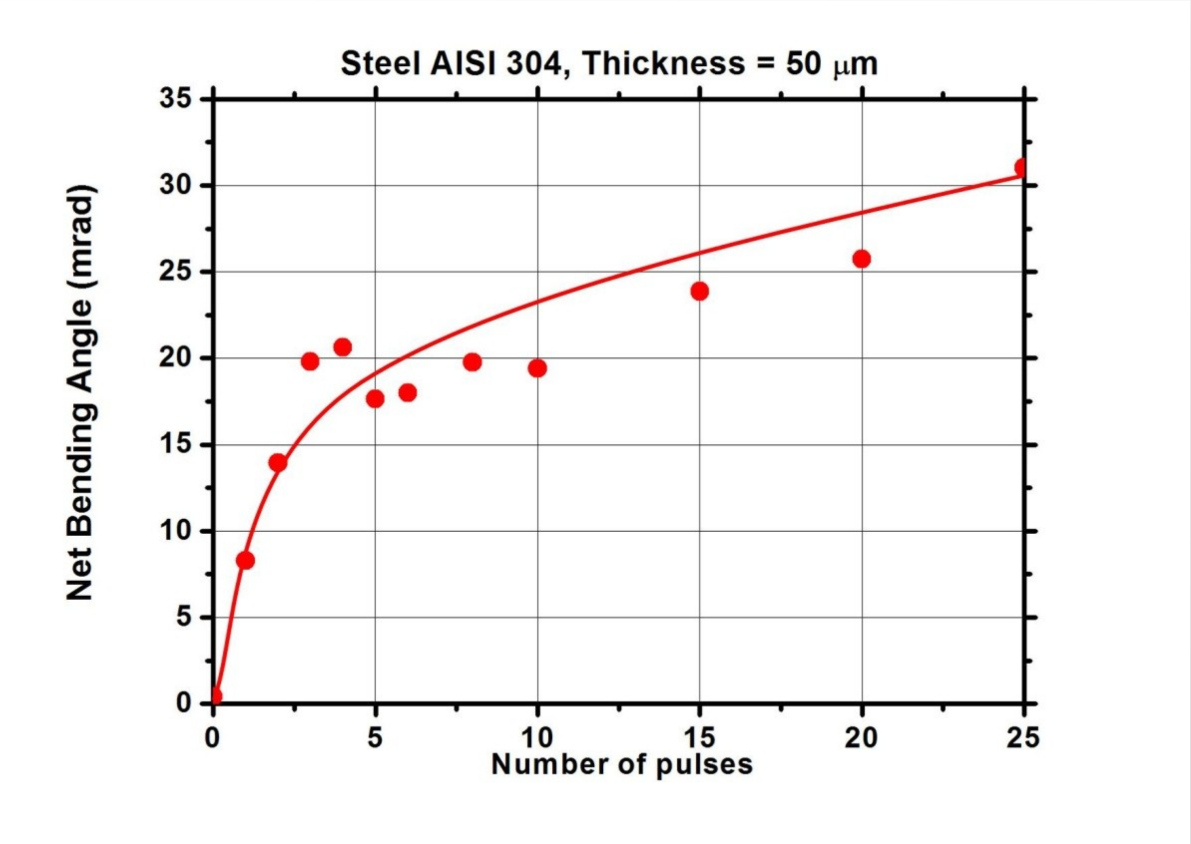




5. EXPERIMENTAL RESULTS. INFLUENCE OF NUMBER OF PULSES

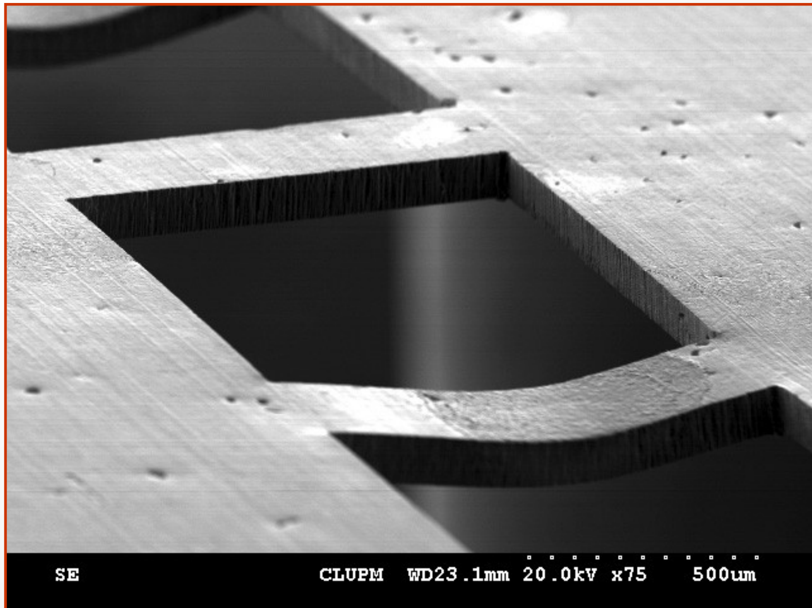


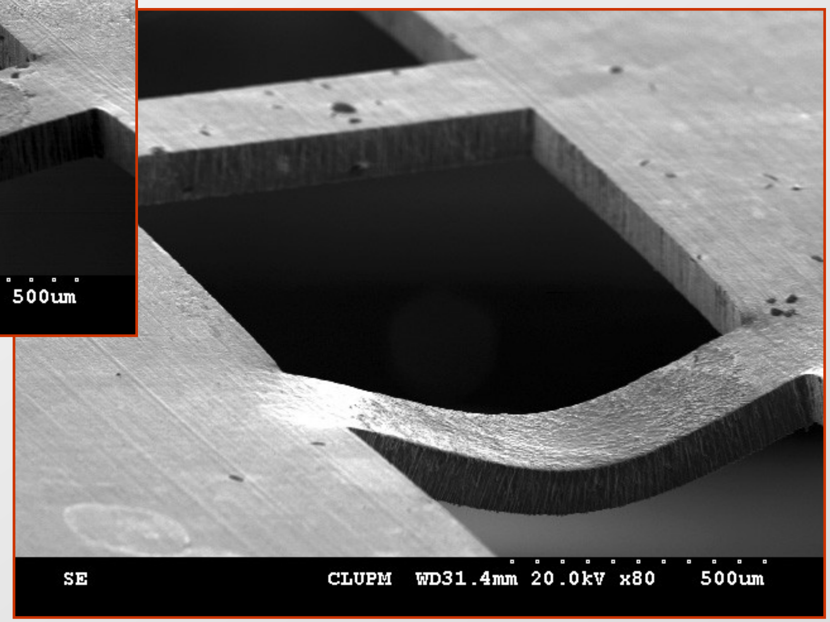
5. EXPERIMENTAL RESULTS. INFLUENCE OF NUMBER OF PULSES



5. EXPERIMENTAL RESULTS. LAST RESULTS

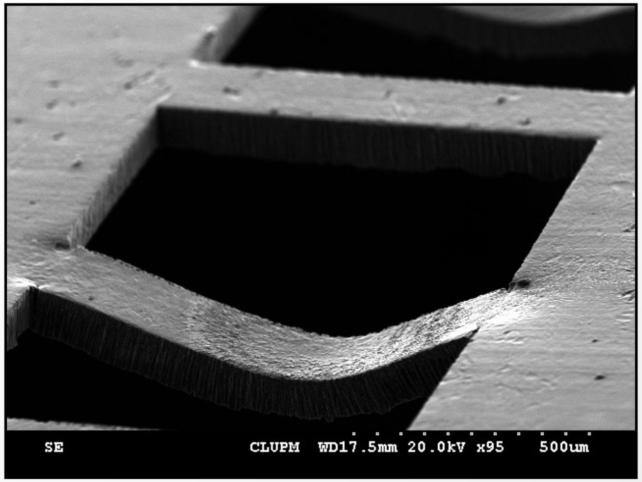
4 pulses

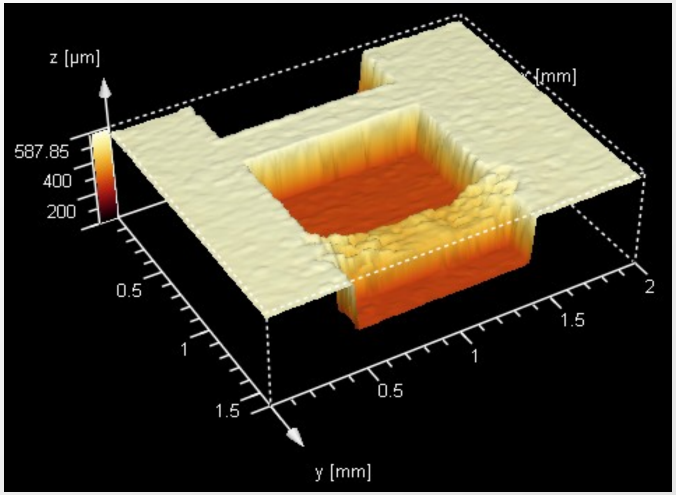


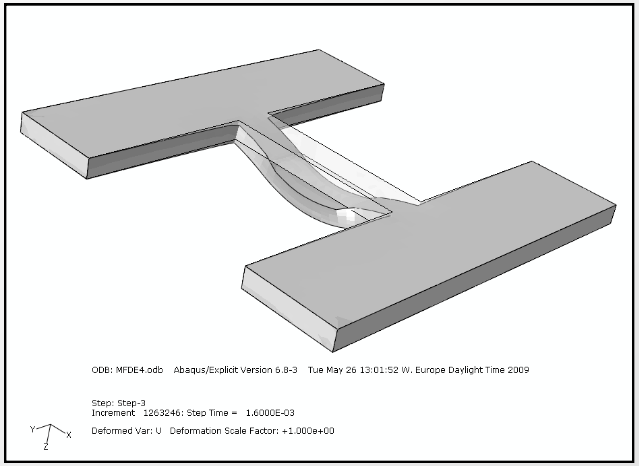


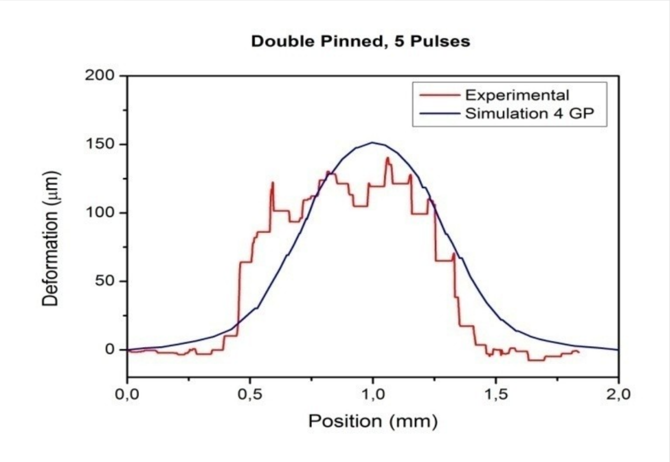
1 pulse

5. EXPERIMENTAL RESULTS. LAST RESULTS

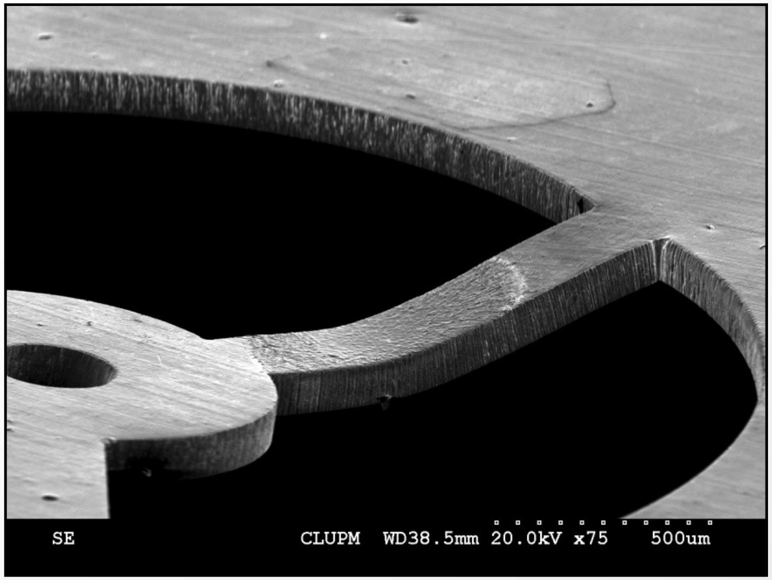


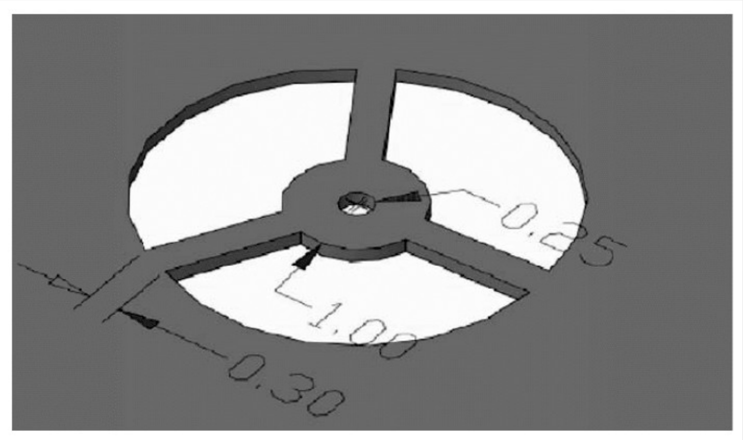






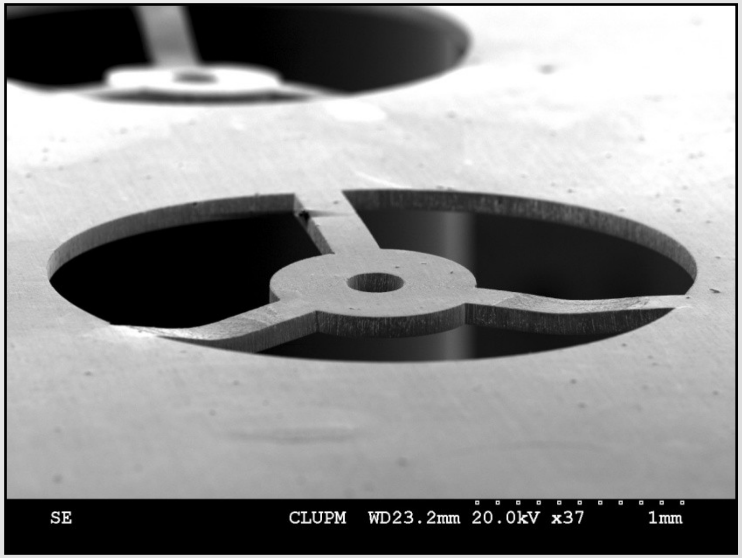
5. EXPERIMENTAL RESULTS. LAST RESULTS





5 pulses

5 pulses in two arms



6. DISCUSSION AND OUTLOOK

- The suitability laser micro-bending of thin metal strips by means of ns pulsed lasers with average power in the range of several Watt has been experimentally demonstrated.
- Numerical simulation of the process has shown as critical parameters:
  - Pulse energy
  - Spot center distance relative to pinned end
- Simulations of single-end pinned targets show the presence of two bending components.
  - Overall angular displacement from beam clamping
  - Local bending at beam incidence position
- According to the authors' experience, the use of ns laser pulses is expected to provide a really suitable parameter matching for the laser bending of an important range of MEMS sheet components
- On the basis of the developed experience, the laser microforming and adjustment stresses release of arbitrary geometry components can be envisaged

Thank you very much for your attention !

ACKNOWLEDGEMENTS

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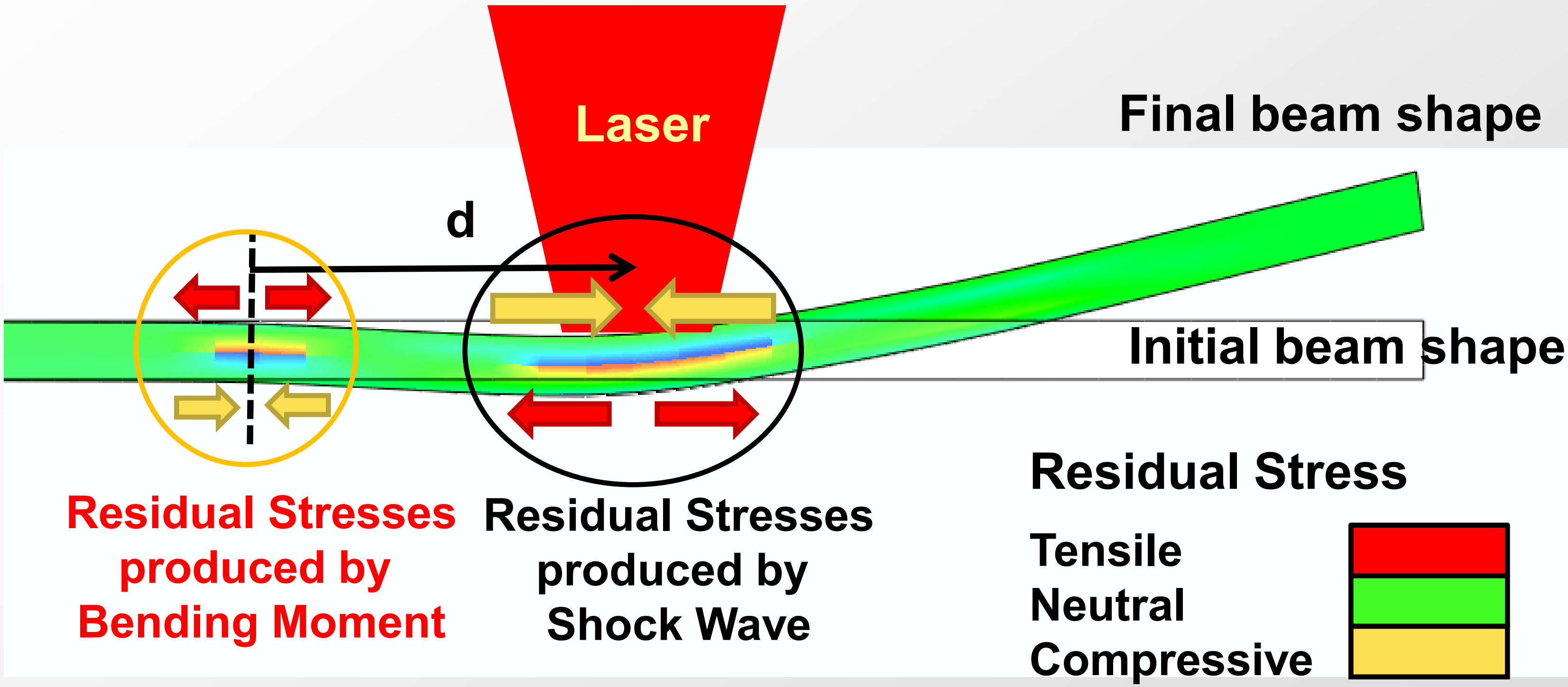
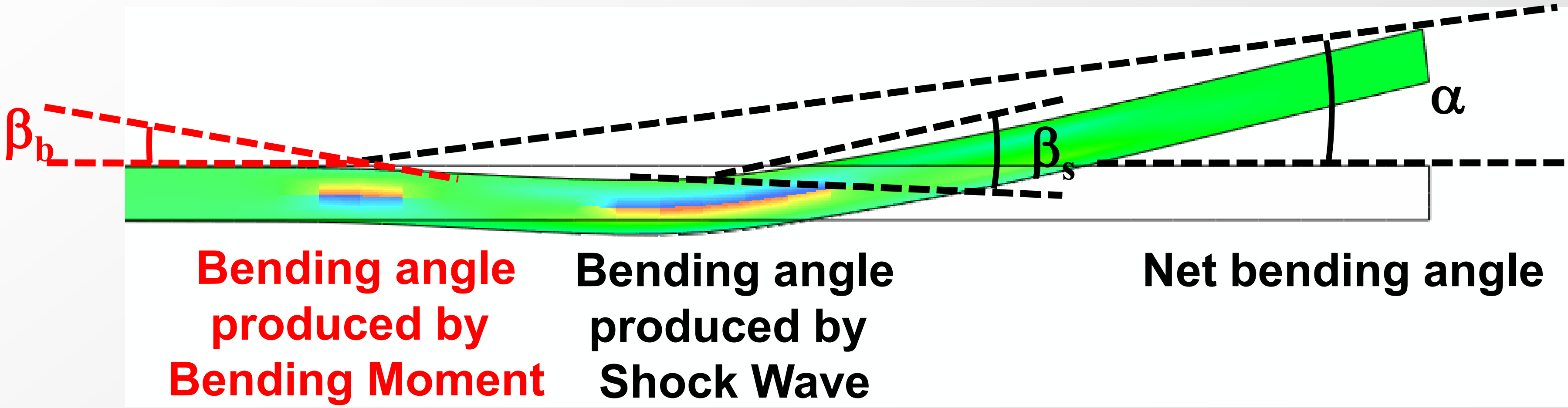

Laser
Final beam shape
d
Initial beam shape
Residual Stresses produced by Bending Moment
Residual Stresses produced by Shock Wave
Residual Stress
Tensile
Neutral
Compressive


β_b
β_s
α
Bending angle produced by Bending Moment
Bending angle produced by Shock Wave
Net bending angle