Chocs produits par laser
Une question de plasma avant tout ?

Laurent Berthe
Laurent Videau

@:laurent.berthe@ensam.eu
M:+33 6 87 29 45 88

GDR Emili - Palaiseau - October 26, 2021
Shock produced by laser in water confinement regime

Parameters

- Pulse Duration: 1-100ns (shape)
- $\lambda$: 1.064 nm
- Spot diameter: <mm
- $>\text{Power density}: 1-10 \text{ TW/cm}^2$
- $>\text{Pressure}: 100 \text{ GPa}$
- $>\text{Repetition rate}: <1\text{H}$
Shock produced by laser in water confinement regime

Parameters for applications

- Pulse Duration: 8-25 ns
- \( \lambda \): 0.532 - 1.064 nm
- Spot diameter: mm
- > Power density: 1-10 GW/cm\(^2\)
- > Pressure: 1-8 GPa
- > Repetition rate: 1-...1 KHz
Why confined regime?

**Avantages**

- Pression x4 higher than in direct regime
- Loading x2 longer than pulse laser
- Easy to apply and renew
- Cheap

**Limitation**

- Protective layer/ablator layer
- Breakdown plasma in confined material layer
- No use in MRO process conditions

**Effect of water and paint coatings on laserirradiated targets**

Jay A. Fox

Citation: Appl. Phys. Lett. 24, 461 (1974); doi: 10.1063/1.1655012
View online: [http://dx.doi.org/10.1063/1.1655012](http://dx.doi.org/10.1063/1.1655012)
View Table of Contents: [http://apl.aip.org/resource/1/APPLAB/v24/i10](http://apl.aip.org/resource/1/APPLAB/v24/i10)
Published by the American Institute of Physics.
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**Shocked by Laser**

- **Laser/Technology**
- **Laser Propulsion**
- **No Destructive Technique**
- **Material Under Shock**
- **Adhesion**
- **Extreme Conditions**
- **Plasma Damaging**
- **Urology**
- **Laser Shock**
- **Aeronautic Laser Interaction**
- **Interface Mechanical Testing**
- **Space Disassembling**
- **Laser Shot Peening**
- **Defense Hyper Velocity Impact**
- **Adhesion Test**

**High strain rate**
- 50 researchers
- 15 Labs
- Co-CNRS 910

**1 Res.**
- 3 Res. Composite/Polymer
- 3 Res. SHM
- 5 Res. Metallurgist
- 1 Res. Modeling

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**Principle Why? Scope**
Plasma generation

Key Phenomena

- Laser absorption in sub-critical plasma
- Conduction in ablation front
- Conduction at Plasma/water interface
Plasma generation

Key Phenomena

- Laser absorption in sub-critical plasma
- Conduction in ablation front
- Conduction at Plasma/water interface
Laser Collisionnallo Absorption by Inverse Bremstrahlung

Key Phenomena

- \( n_c (cm^{-3}) = \frac{10^{21}}{\lambda^2} \)
- \( ZL\lambda^2 \)
- \( A_{bi} = 1 - e^{\frac{T_e^{3/2}}{455}} \)

Effect

- Best efficiency at short wavelength
- Dependant to gradient (Pulse duration, Power density)
Absorption - 532 nm - 10 ns : 100 %

- Al
- Fe
- Mo
- Ti
- Cu

Reflectivity (%) vs Incident Power density (GW/cm²)
Plasma Fabbro’s model

Hypothesis

- Total absorption
- Perfect Gas
- $\alpha$ adjustable parameters given part of laser energy for pressure rise
- Adiabatic cooling

Physical study of laserproduced plasma in confined geometry

R. Fabbro, J. Fournier, P. Ballard, D. Devaux, and J. Virmont

Citation: J. Appl. Phys. 68, 775 (1990); doi: 10.1063/1.346783

View online: http://dx.doi.org/10.1063/1.346783

View Table of Contents: http://jap.aip.org/resource/1/JAPIAU/v68/i2

Published by the American Institute of Physics.
Plasma pressure - 10 ns

Key Phenomena

\[ n_c \left( cm^{-3} \right) = \frac{10^{21}}{\lambda^2} \frac{ZL}{\lambda^2} T_e^{3/2} \]

Effect

- Higher pressure at shorter wavelength
- Plasma Breakdown in water
- Good agreement with modeling but...Adjustable parameter \( \alpha \)
Free velocity by Doppler Velocimetry
Modeling
- Analytical modeling from Fabbro

ESTHER (From CEA)
- 1D Hydrodynamic
- Helmotz/tracing
- EOS/law from Solid to plasma
- Shock wave/damage

on Abaqus
- 3D Hydro
- Shock wave propagation
- Damaging

LsDyna
- 3D Hydro
- Shock wave propagation
- Damaging

Plasma
- Pressure/thermal profile
- Microscopic parameter
- Ablated thickness

Shock wave
- Attenuation
- Interaction multi-interface
- Damage (size/location)
- Stack of multimaterial

Exp/Modeling
- Free surface Velocity
- Material transformation (phase/damage)
Laser induced plasma characterization in direct and water confined regimes: new advances in experimental studies and numerical modelling

Marine Scius-Bertrand, Laurent Videau, Alexandre Rondepiere, Emilien Lescoute, Yann Rouchaussé, Jan Kaufman, Danijela Rostohar, Jan Brajer and Laurent Berthe

- Hephaistos facility
- 532nm, 10 ns

Velocity profile

![Velocity profile graph]
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- Hephaistos facility
- 532nm, 10 ns

Velocity profile

Pressure Profile

Normalized pressure profile
Laser induced plasma characterization in direct and water confined regimes: new advances in experimental studies and numerical modelling

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- Hilase, GCLT (CEA)
- Top Hat
- 1064nm, 10 ns, 20 ns, 40ns

Pressure profile

Extraction
- As input for simulation
- Plasma parameter
### Plasma Parameters

<table>
<thead>
<tr>
<th>Laser parameter</th>
<th>$\lambda = 523$ nm $-\Delta T = 7$ ns</th>
<th>$\lambda = 1029$ nm $-\Delta T = 10$ ns</th>
<th>$\lambda = 1053$ nm $-\Delta T = 10$ ns</th>
<th>$\lambda = 1053$ nm $-\Delta T = 20$ ns</th>
<th>$\lambda = 1053$ nm $-\Delta T = 40$ ns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breakdown threshold (GW cm$^{-2}$)</td>
<td>8–10</td>
<td>5–6</td>
<td>5–6</td>
<td>3–4</td>
<td>2–3</td>
</tr>
<tr>
<td>Breakdown threshold (J/cm$^{-2}$)</td>
<td>56–70</td>
<td>50–60</td>
<td>50–60</td>
<td>60–80</td>
<td>80–120</td>
</tr>
<tr>
<td>Ablation pressure at the threshold (GPa)</td>
<td>7.2–8.2</td>
<td>4.7–5.2</td>
<td>4.7–5.2</td>
<td>3.6–4.2</td>
<td>2.9–3.6</td>
</tr>
<tr>
<td>Range of simulated intensities (GW cm$^{-2}$)</td>
<td>2.5–6.0</td>
<td>//</td>
<td>1.3–5.0</td>
<td>1.5–2.3</td>
<td>0.8–2.0</td>
</tr>
<tr>
<td>Plasma temperature range (eV)</td>
<td>10–14</td>
<td>//</td>
<td>8–12</td>
<td>10–12</td>
<td>8–13</td>
</tr>
<tr>
<td>Range of plasma thickness ($\mu$m)</td>
<td>8–12</td>
<td>//</td>
<td>9–13</td>
<td>17–20</td>
<td>20–30</td>
</tr>
<tr>
<td>Range of ablated aluminum thickness ($\mu$m)</td>
<td>1.7–3.0</td>
<td>//</td>
<td>2.2–2.3</td>
<td>3.5–3.9</td>
<td>3.2–5.5</td>
</tr>
</tbody>
</table>
Laser Plasma breakdown at the surface of water
Laser Plasma breakdown at the surface of water

Figure IV-4: Observation de l'interaction confinée par eau avec la caméra rapide: $I_{\text{inc}} = 28$ GW/cm$^2$, (a) $t=-10$ ns, (b) $t=0$ ns.
\[
\frac{dn_e}{dt} = \text{MultiPHotonionisation} + \text{AvalancheElectronique} + \ldots \text{Pertes}
\]

\[
\text{MPH} : A + h\nu^- \rightarrow A^+ + e^-
\]

\[
\text{AV} : A + e^- h\nu^- \rightarrow A^+ + 2e^-
\]

Transmission=0 at \( n_c \)
Tank configuration

(a) Laser pulse

DOE

Water Tank

20 cm water

Window

- Pyroelectric detector
- Photodiode

(b) Laser pulse

DOE

Water Tank

10 cm

Plasma

10 cm

Al Foil

20 cm water

Window

VISAR Interferometer
Laser interaction in a water tank configuration: Higher confinement breakdown threshold and greater generated pressures for laser shock peening

- Hephaistos facility
- 532nm, 10 ns

Transmission
Hephaistos facility
- 532nm, 10 ns

Transmission
- Pressure up to 12 GPA
- Patented configuration

Pressure Profile
A long time ago...

Wright Flyer 1903
all with natural material/bonding
Weak bond detection for Carbone Fibers Reinforce Polymer assemblying

Issues?

- How to ensure properties during manufacturing and use?
- How to quantify the state of composite structure?
- NDT can not discriminate weak bond because two parts are in contact
US C-scan of weakbond
LASAT > selective sollicitation

Simple impact  Double Impact  Symmetrical Impact - Patented

- Shock
- Release

Time  Interface  free surface  Space

Tensile

adhesion test
- Well-controlled Mechanical Sollicitation
- Local - Proof test - no contact
- Target recovering and diagnostic
LASAT > selective solicitation

Simple impact

Double Impact

Symetrical Impact - Patented

adhesion test

▶ Well-controlled Mechanical Sollicitation
▶ Local - Proof test - no contact
▶ Target recovering and diagnostic
LASAT > selective sollicitation

adhesion test

- Well-controlled Mechanical Sollicitation
- Local - Proof test - no contact
- Target recovering and diagnostic
How does it work?

- **Calibrate**: Reference threshold evaluation
- **Sollicitate**: Interface test with laser shock
- **Reveal**: Damage reveal weak or kissing Bonds
- **Detect**: Damage detection by NDT technique

![Bar chart showing Loading of LASAT and Adhesion Level]

- ▶ **Damage weak Bond**
- ▶ **No Damage for correct Bond**

80% of correct bond adhesion
Sollicitate, Reveal, Detect: Shock laser + US C-scan - PhD R. Ecault

Without shock sollicitation > no weak bond detection > LASAT reveal weak bond

but... 3 mm is limit detection
Sollicitate, Reveal, Detect : Shock laser + US C-scan - PhD R. Ecault

- Without shock solicitation > no weak bond detection > LASAT reveal weak bond
- but... 3 mm is limit detection
EUs Projects to NDT assessments

- Controled contamination of assembling

- Monopulse - "Very weak" Production scenarios

- 2 symetrical pulses - Weak and Extented to Repair scenarios
EUs Projects to NDT assessments

- Controled contamination of assembling
- Monopulse - "Very weak" Production scenarios
- 2 symmetrical pulses - Weak and Extented to Repair scenarios

Two Symmetrical pulses

Adhesion Level

Correct Bond

Weak Bonds

95%

80%

20%

6%

Monopulse

Controled contamination of assembling

- Monopulse - "Very weak" Production scenarios
- 2 symmetrical pulses - Weak and Extented to Repair scenarios
Release agent detection sensitivity - Laser Shock

- No damage inside base material
- Threshold damage decreases with release agent level contamination
- But...adhesion at 20% of correct bond.
- No threshold for correct bond

Release agent detection sensitivity - Laser Shock

- No damage inside base material
- Threshold damage decreases with release agent level contamination
- But...adhesion at 20% of correct bond.
- No threshold for Correct Bond
All contaminations - PhD Maxime Sagnard

PRODUCTION

- Reference symmetrical bond threshold

REPAIR

- Single shot
- Symmetrical dt=0

- No damage inside base material
- Impossible Test with monopulse
- Detection of all levels of contamination
Design by Simulations - monopulse configuration

- Simulation using Abaqus
- Sollicitation tracking to design

Space time diagram - full scale

80% of the maximum stresses

Same sollicitation in depth - selection by bond weakness
Design by Simulations - Symetrical configuration

- Simulation using Abaqus
- Solicitation tracking to design

Space time diagram - full scale

80% of the maximum stresses

Sollicitation at the interface
Representative Panels

Production Panel

Fig. 10. Production panel: (a) front view with laser shot position and (b) side view with specified thicknesses.

Repair Panel

Fig. 11. (a) figure of the shot pattern realised on the repair panel and (b) cross-section of the repair patch geometry.
<table>
<thead>
<tr>
<th>Panel</th>
<th>Area</th>
<th>SYMMETRICAL SHOT SETUP</th>
<th>SINGLE SHOT SETUP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>S-LASAT threshold $I_t$ (intensity per beam)</td>
<td>Total number of shots at 80% of $I_t$</td>
</tr>
<tr>
<td>Production</td>
<td>Healthy</td>
<td>0.85 GW/cm²</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Contaminated</td>
<td></td>
<td>21</td>
</tr>
<tr>
<td>Repair</td>
<td>Healthy</td>
<td>0.72 GW/cm²</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Contaminated</td>
<td></td>
<td>8</td>
</tr>
</tbody>
</table>

Success rate: 100%  
Success rate: 20%
Conclusion

- New progress on processes related to laser control and Hydrodynamic simulations
- Laser shock peening: repetition rate, small spot, fiber

Perspectives

- New lab and academic facility
- Multiscale simulations for design ....
Laser shock projects

- CNRS/CNRC Satact
- ANR Syprodyn
- ANR Arcole
- ANR Glass
- ANR Forge : LSP
- Vanesses
- CleanSky/Vulcan
- Monarque
- Compochoc
- ENCOMB
- Sesame IDF Hephaitos
- LASAT
- Cronos
- GDR Chocolas

Projects: LASAT, ANR Syprodyn, ANR Arcole, ANR Glass, ANR Forge : LSP, Vanesses, CleanSky/Vulcan, Monarque, Compochoc, ENCOMB, Sesame IDF Hephaitos, CNRS/CNRC Satact, GDR Chocolas, Cronos
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Laurent Berthe

@ : laurent.berthe@ensam.eu
M: +33 6 87 29 45 88