Outline:

1. LASER TECHNOLOGY: FUNDAMENTALS FOR PEDESTRIANS.

2. LASER-MATERIAL INTERACTION.

3. EXAMPLES IN MATERIALS SCIENCE & TECHNOLOGY.
   
   3.1. SURFACE HEATING
   
   3.2. MELTING AND DIRECTIONAL SOLIDIFICATION
   
   3.3. ABLATION
1. LASER TECHNOLOGY: FUNDAMENTALS FOR PEDESTRIANS

¿What is a LASER?
“Light Amplification by the Stimulated Emission of Radiation”

Elements within a Laser Cavity:
1. Active Medium
2. Excitation mechanism
3. Optical resonator
# LASER SYSTEMS FOR INDUSTRIAL APPLICATIONS

<table>
<thead>
<tr>
<th>LASER TYPE</th>
<th>SPECTRAL RANGE</th>
<th>ACTIVE MEDIUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXCIMER</td>
<td>157-390 nm</td>
<td>UV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Excimer gas mixture (XeCl, …)</td>
</tr>
<tr>
<td>DIODE</td>
<td>800-940 nm</td>
<td>n-IR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P-N junction (semiconductor)</td>
</tr>
<tr>
<td>Nd:YAG</td>
<td>1064 nm</td>
<td>n-IR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>YAG single crystal doped with Nd$^{3+}$</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>10.6 µm</td>
<td>mid-IR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gas mixture: CO$_2$, N$_2$, He</td>
</tr>
<tr>
<td>Fibre</td>
<td>1070 ±10 nm</td>
<td>n-IR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Doped fibre (Yb$^{3+}$)</td>
</tr>
<tr>
<td>Disc</td>
<td>1030 nm</td>
<td>n-IR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Single crystal thin disc of Yb:YAG, …</td>
</tr>
</tbody>
</table>
LASER SYSTEMS FOR INDUSTRIAL APPLICATIONS

Laser diode system

APLICACIONES:
- **mW**: fibre optics communications, medicine, noncontact measurements (metrology), ...
- **kW**: materials processing, ...

Power range:
- 0-2 W (low)
- 0-6 kW (high)
LASER SYSTEMS FOR INDUSTRIAL APPLICATIONS

Nd:YAG Laser system

APPLICATIONS:
- Materials processing (cutting, welding, marking, ...)
- Scientific & Measurements (nuclear fusion, environment, ...)
- Applications in medicine

Power range:
- 5 W-5 kW
LASER SYSTEMS FOR INDUSTRIAL APPLICATIONS

CO₂ Laser

1. Laser beam
2. Beam modifying unit
3. Exit mirror
4. Cooling water
5. RF excitation
6. Cooling water
7. Back reflecting mirror
8. RF excitation discharge
9. Electrodes

De-excitation from higher energy levels:
- Fast transition (002)
- Fast transition (001)
- Fast transition (020)
- Fast transition (010)
- Fast transition (000) Fundamental state

APPLICATIONS:
- Materials Processing (cutting, welding, thermal treatment, ...)
- Others

Power range:
- 0.1-5 kW SLAB
- 20 W-20 kW Others
2.- Laser-Material Interaction

LÁSER PARAMETERS

\[
\begin{align*}
\text{Wavelength} & \quad \text{IRRADIANCE} \\
\end{align*}
\]

\text{Physico-Chemical mechanisms}

\[
\begin{align*}
\text{Heating} & \quad \text{Melting} & \quad \text{Evaporation} & \quad \text{Plasma formation}
\end{align*}
\]
LASER ← LIGHT → LAMP

8 W, 20 Hz, 5 ns, $\lambda = 1064$ nm, 80 MW pulses,
focus 300 $\mu$m$^2$

$\approx 2.6 \times 10^{13}$ W/cm$^2$

QTH lamp, 1 kW, cw, $\lambda$ range <400 to >2500 nm, focus 3 cm$^2 \approx 330$ W/cm$^2$

Collimated beam

Noncollimated
Characteristic Emission of different light sources

- 266 nm
- 355 nm
- 532 nm
- 810 nm
- 1064 nm

UV  QTH  IR

266 nm  532 nm  1064 nm
2. LASER-MATER INTERACTION

WHAT WE CAN SEE
2. - LASER-MATER INTERACTION
2. LASER-MATER INTERACTION

WHAT WE CAN SEE
HUMAN SUBJECTS AFTER A PROLONGED IR EXPOSURE
HUMAN SUBJECTS AFTER A PROLONGED UV EXPOSURE
2. - LASER-MATER INTERACTION

Irradiance

- P(W)
- E/pulse(J)

Continuous Regime
Pulsed Regime

- Heating
- Melting
- Ablation

Pulse Width
- milliseconds ($10^{-3}$ s)
- femtoseconds ($10^{-15}$ s)
Laser Irradiation

- **Surface Heating**
  - Local high temperatures
  - Solid State Diffusion or High thermal gradient

- **Continuous Mode**
  - Melting + Rapid / Controlled Solidification

- **Pulsed Mode**
  - Ablation
    - Sublimation
    - Transitory melting + evaporation
    - Shockwaves - particle/grain ejection
¿IS THERE ATOMIC DIFFUSION?
CERAMIC MACHINING IN PLASTIC REGIME

SiN Ring - no microcracks observed

Diode Laser
1.2 kW, λ=940 nm
1.5 x 5 mm beam
≥ 1000 °C
LASER CLADDING

Material is supplied simultaneously to laser irradiation
Stainless Steel cutting
Melting + GAS pressure

High Speed Laser Cutting
(Finnpower)

WE THINK LASER
Diode Laser Emission at 808 nm

Cylindrical lens

Focal: 5 cm line

Travelling Stage
Diode Laser source (cw mode)

Laser incidence (Line)

Sintered products

Reactants
Laser Zone Melting of Al$_2$O$_3$-ZrO$_2$ Eutectics

$V=72$ mm/h, Al support $^{2}R = 0.9 \times 10^{-17}$ m$^3$/s

- LASER INDUCED TEXTURE

Focused Laser line

Molten Zone

Bi-2212

support

$v \approx 30-50$ mm/h (tipical $l_c \approx 60$ A)

Approx. size 100 x 10 x 1 mm$^3$


- LASER ZONE MELTING (IN-PLANE)
*Metallic support reduces thermal gradients on the sample
Externally heated support vs. $I_c$ (Critical Current in A)

<table>
<thead>
<tr>
<th>$T$ (°C)</th>
<th>$I_c$ (A)</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>25°C</td>
<td>9.6</td>
<td>cracks</td>
</tr>
<tr>
<td>145°C</td>
<td>13.2</td>
<td>cracks</td>
</tr>
<tr>
<td>150°C</td>
<td>14.0</td>
<td>cracks</td>
</tr>
<tr>
<td>330°C</td>
<td>16.0</td>
<td>no cracks</td>
</tr>
<tr>
<td>430°C</td>
<td>27.5</td>
<td>no cracks</td>
</tr>
</tbody>
</table>

$\text{(CO}_2\text{)} = 10.6 \, \mu\text{m}; \, v=36 \, \text{mm/h}$

Cutting blown glass with a CO$_2$ Laser

ADVANTAGE OF LOCALIZED THERMAL STRESS
THERMAL STRESS/SHOCK
LASER FURNACE

Optical beam steering

Rofin-Sinar SLAB CO₂ LASER 350 W

Roller system for Sample displacement

Molten Zone Up to 200mm wide

Sample speed: 1-10 m/h

Processed Samples

CONTINUOUS LASER FURNACE: THE CONCEPT
SURFACE AT EXTREME TEMPERATURE
SUBSTRATE AT MUCH LOWER TEMPERATURE
I. de Francisco, V. Lennikov, L. A. Angurel, L. C. Estepa, R. Lahoz, G. F. de la Fuente
ICMA (Materials Science Institute of Aragón) CSIC-University of Zaragoza, Zaragoza.
F. Rey-García, C. Bao
UA Óptica & Micro-Óptica GRIN, University of Santiago de Compostela.
Novelty: Laser processed glass/TORRECID
SURFACE ABLATION STRUCTURING AND IN-SITU PIGMENT DEVELOPMENT
THE LASER FURNACE

• LONG PULSE & CW MODE LASERS + HEAT (Laser Furnace)...MAY ALLOW TO...

• SURPASS THE INTRINSIC PROCESSING LIMITS OF KNOWN MATERIALS:
  – GLASS > 1500 °C
  – CERAMICS > 2950 °C

• DEVELOP NOVEL INDUSTRIAL MATERIALS TRANSFORMATION & FABRICATION PROCESSES
ABLATION

"Have no fear I will return."
Laser Ablation Process

Combination of phenomena:
- Melting + Evaporation
- Direct Sublimation
- Shock Waves
- Particle & melt drop ejection

Energy per pulse (J/cm²)

Damage Threshold
Ablation Threshold

Laser pulses
LASER ABLATION

Particles deposited on the Surface
Solidified Layer
Molten Material
Shock Wave Effect
Laser Beam
Damage to adjacent material

Microcracks
10 μm
Molten Zone
Heat Affected Zone
Transfered heat
Shock Wave

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SURFACE ABLATION STRUCTURING COMBINED WITH PVD
SURFACE ABLATION STRUCTURING COMBINED WITH PVD
SURFACE ABLATION STRUCTURING COMBINED WITH PVD
3D image inside a thick glass block
532 nm Laser, ns or ps pulses
Ablation at the focal spot
Laser Surface treatment of a fan blade (Laser Pinning)

Nd:Glass Laser, 100 J pulses at 6 Hz

Effect of a single pulse on Al
STENT FABRICATION

FOCUS ON FINE SOLUTIONS

BAASEL LASERTECH
Mixed Processes

MELTING + EVAPORATION
in cw mode

Ablation in pulsed mode

ALSO

Photochemical or Photothermal Processes
POLYMER BOX MARKING
ON-LINE COMPUTER KEYBOARD MARKING

POLYMER + PHOTOSENSITIVE ADDITIVE
Stainless Steel Perforation
PAINT DESORPTION OVER ALUMINIUM ALLOY
EVEN ON THE RUN…

Laser Railhead Cleaning with Diode-Pumped Solid-State Lasers (LASERTHOR)
SURFACE DESORPTION OF OXIDE LAYER ON STEEL

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A. R. GONZÁLEZ-ELIPE, J. P. ESPINÓS, V. RICO (ICMSE)

THANK YOU!