Laser Micromachining of Bulk Substrates and Thin Films

Celine Bansal

Oxford Lasers Ltd
Moorbrook Park
Didcot, Oxfordshire, OX11 7HP
Tel: +44 (0) 1235 810088
www.oxfordlasers.com
Outline

• Oxford Lasers
• Importance of various parameters
• Examples of Machining bulks substrates with ns, ps, fs lasers
• Examples of Machining thin films
Oxford Lasers Ltd

• Didcot, Oxon (UK), Boston (USA), Paris (France)
• Founded in 1977 (Excimer and Copper Laser Manufacturer)
  Oxford University spinout (inventor gas preionisation technique)
• Two divisions:  (a) Laser micromachining  
  (b) High-speed imaging
• Markets: microelectronics, solar, healthcare, automotive, biomedical, telecoms etc etc

We offer:
• Turn-key Laser Micromaching Systems
• Sub-contract Laser Micromachining
• Proof-of-Concept Trials, Contract R and D
The laser wavelength and material optical properties determine light absorption (i.e. the extent to which the material takes up the deposited energy)

Incident laser light on surface = [reflected] + [absorbed] + [transmitted]

Only [absorbed] light in the material is useful for Laser Micromachining and the optical penetration (absorption) depth defines the process resolution

**Beer-Lambert law**

(assuming linear absorption)

\[ I_1 = I_0 \exp \left[-\alpha L\right] \]

\( I_0 \) (W/cm\(^2\)) ; incident intensity after reflection
\( I_1 \) (W/cm\(^2\)) ; transmitted intensity
\( \alpha \) (cm\(^{-1}\)) ; material absorption coefficient
L (cm) ; material thickness

1/ \( \alpha \) : optical penetration depth (typically in \( \mu \)m)
The laser output and pulse frequency define the maximum pulse energy available in each laser pulse and the maximum rate that energy can be delivered to the sample surface.

*Note:* Too high pulse energy or pulse frequency can result in target cumulative heating and thermal damage - if thermalisation is faster than heat dissipation in the material.

If enough energy is delivered on the surface to exceed the ablation threshold, material removal begins called *laser ablation* and soon a crater is formed.
Importance of laser pulse duration

- Longer pulses (>10ns) associated
  - Thermal ablation processes
  - Prolonged laser+plasma heating
  - Beam attenuation losses
  - Melting and recast debris (evident)
  - Heat affected zone, HAZ (hidden)
  - High removal rates

- Shorter pulses (<0.1ns)
  - “Cold” ablation processes
  - Shorter plasma lifetime
  - Rapid energy deposition (less debris)
  - Deterministic ablation thresholds
  - Restricted HAZ
  - Low removal rate

The laser pulse duration determines the “heat spreading” in the material, crucial here is a lack of heat spreading for thin-film ablation.
Optimisation parameters

<table>
<thead>
<tr>
<th>Laser</th>
<th>Material</th>
<th>Processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Optical</td>
<td>Lens NA</td>
</tr>
<tr>
<td>Wavelength</td>
<td>Absorptivity</td>
<td>Spot Size</td>
</tr>
<tr>
<td>Output Power</td>
<td>Reflectivity</td>
<td>Shot Overlap</td>
</tr>
<tr>
<td>Pulse Energy</td>
<td>Refractive Index</td>
<td>Gas Assist</td>
</tr>
<tr>
<td>Rep.Rate</td>
<td>Surface Roughness</td>
<td>Focal Plane</td>
</tr>
<tr>
<td>Pulse Length</td>
<td></td>
<td>Processing Speed</td>
</tr>
<tr>
<td>Beam Diameter</td>
<td></td>
<td>Drilling Technique</td>
</tr>
<tr>
<td>Beam Polarisation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam Divergence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam Intensity Profile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temporal</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Optical**
  - Absorptivity
  - Reflectivity
  - Refractive Index
  - Surface Roughness

- **Thermophysical**
  - Thermal Conductivity
  - Specific Heat
  - Melting Point
  - Boiling Point
  - Evaporation Enthalpy
  - Surface Tension
  - Vapour Pressure

- **Mechanical**
  - Density
  - Hardness
  - Poisson Ratio
  - Young’s Modulus

! IMPORTANT NOTE: Process is key !!!
Nanosecond Pulse Ablation: Micro-Milling

Examples of optimised processes with nanosecond laser sources

Alumina

Tungsten

Diamond

Polyimide
Micro-Drilling

150 µm dia thro’ 1mm steel

50 µm dia thro’ 0.1mm steel

150 µm dia thro’ 0.5mm silicon

30 degree hole in steel
Expert Process Technology

... 20 years experience in laser micromachining
Examples of ps laser machined features

Nickel

Diamond

Borosilicate

Sapphire
**Thin Films Laser Ablation : Ps/Fs Lasers**

**Patterning** – Gold on Ti on Polymer
20 -45 micron wide tracks

**Patterning** – 17 microns Cu on FR4

**Patterning** – ITO on Glass
10 micron wide tracks on 70 micron pitch
OLEDs advantages over LCDs -

- No backlight - so more efficient and thinner displays
- High contrast ratios, deeper blacks etc
- Richer deeper colours (direct colour production)
- OLED screens are emissive - so no viewing angle problems
- Flexible Screens (newspapers)
Laser scribed ITO on Flexible Substrate using 532nm (a) 4 micron spots with depth of 100nm and (b) scanning five times slower. Bar denotes 9 microns

Demonstration of thin film removal
Parallel processing with ps laser system

**OLED Cathode Scribing**
- 532nm, 30mm/s,
- Effective speed of 450mm/s!
- 15 diffracted spots
- Line pitch approx. 85microns
- Scribed depth d=300nm
1- SMARTONICS

http://www.smartonics.eu/

Targets:

- Development of smart Nanomaterials for Organic Electronics (polymer & small molecule films, plasmonic nanoparticles and super-barriers)

- Development of smart Technologies (r2r printing and Organic Vapour Phase Deposition machines combined with precision sensing & laser tools and processes).

Oxford Lasers’ task:

- Use their ultrafast laser systems to laser pattern those new materials and make 50 μm tracks with a 50 to 100 nm depth. (area of 30 x 30 cm)
European projects: follow on

2- DIGIPRINT

Target:

- Large Area High Resolution Digital Printing for Organic Thin Film Transistor Fabrication

- Both “laser-assisted” inkjet printing (IJ) and “laser-induced forward transfer (LIFT)” of functional materials will be investigated.

Oxford Lasers’ tasks:

- Modify material surfaces with ultrafast lasers to make it hydrophobic (allow to control ink droplet size)
- LIFT (laser printing method) : 4 um droplet size
- High precision laser trimming of transistor (no leakage current, same performance)
3- LASERMICROFAB

http://lasermicrofab.ntua.gr/

Target:

- The development of advanced laser processing technologies (micro nano-patterning, printing, curing) for organic electronics and sensors fabrication.

**Oxford Lasers’ tasks:**

- Selective Laser Micro and Nano-Patterning of thin (500 nm) and of ultrathin (< 50 nm) organic and inorganic layers and multilayer stacks for organic electronics applications.

- LIFT (laser printing method)

- Beam shaping (round or square spot)
Advanced Laser Micro-machining Solutions

Range of Standard System Platforms

Laser Micromachining Subcontract Services

Laser Micro-machining Expertise