Laser Micromachining of Bulk Substrates and Thin Films

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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

<u>We offer:</u>

- Turn-key Laser Micromaching Systems
- Sub-contract Laser Micromachining
- Proof-of-Concept Trials, Contract R and D

Importance of laser wavelength

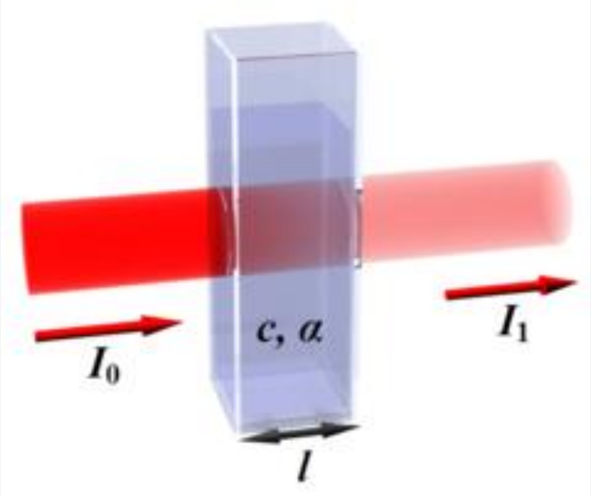
The laser wavelength and material optical properties determine **light absorption** (i.e. the extent to which the material takes up the deposited energy)

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)

$$I_1 = I_0 \exp[-\alpha L]$$

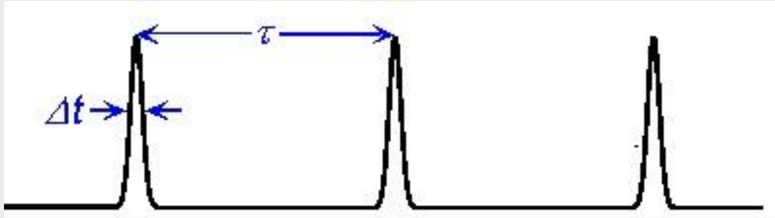


I_0 (W/cm^2) ; incident intensity after reflection
I_1 (W/cm^2) ; transmitted intensity
α (cm^{-1}) ; material absorption coefficient
L (cm) ; material thickness

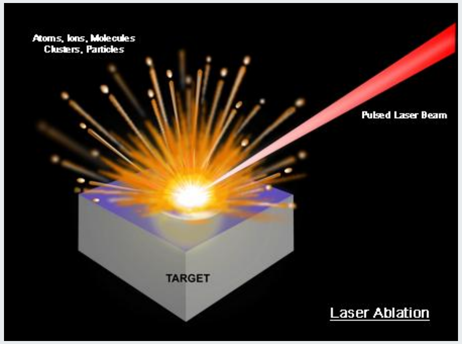
1/ α : optical penetration depth (typically in μm)

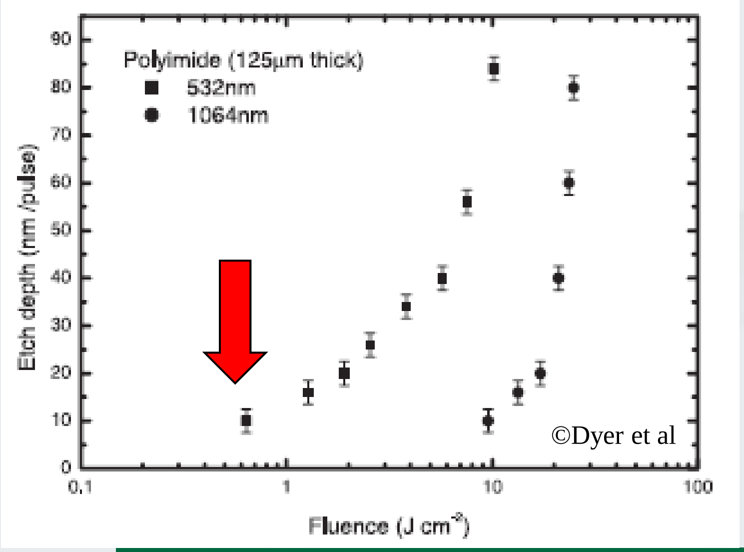
Importance of laser output and pulse frequency

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.



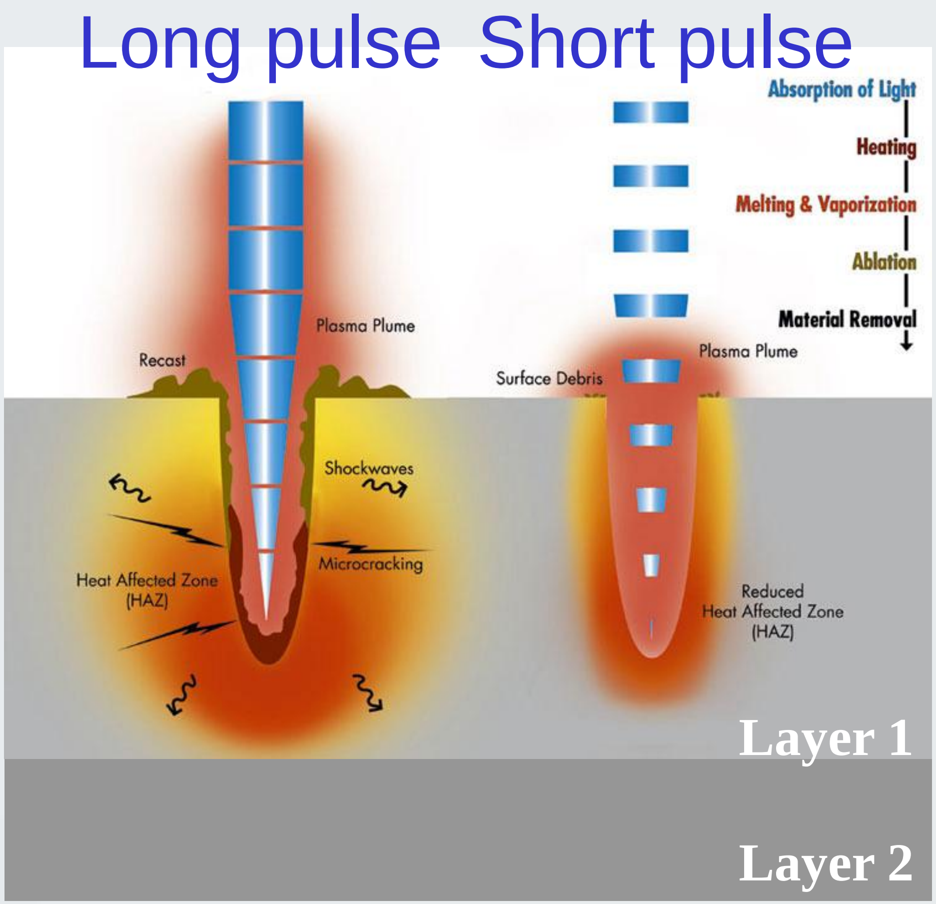


If enough energy is delivered on the surface to exceed the **ablation threshold**, material removal begins called ***laser ablation*** and soon a crater is formed

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

Laser

- Type
- Wavelength
- Output Power
- Pulse Energy
- Rep.Rate
- Pulse Length
- Beam Diameter
- Beam Polarisation
- Beam Divergence
- Beam Intensity Profile
  - Spatial
  - Temporal

Material

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

Processing

- Lens NA
- Spot Size
- Shot Overlap
- Gas Assist
- Focal Plane
- Processing Speed
- Drilling Technique

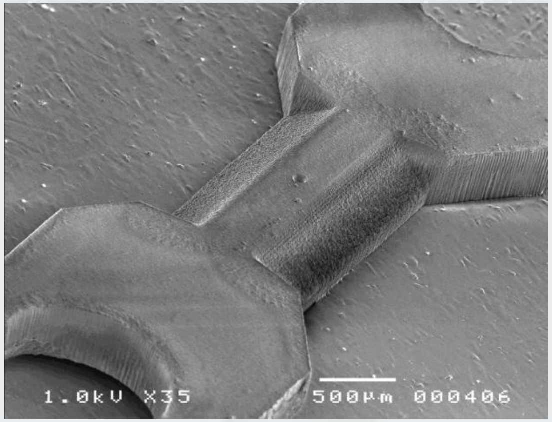
! IMPORTANT NOTE:

Process is key !!!

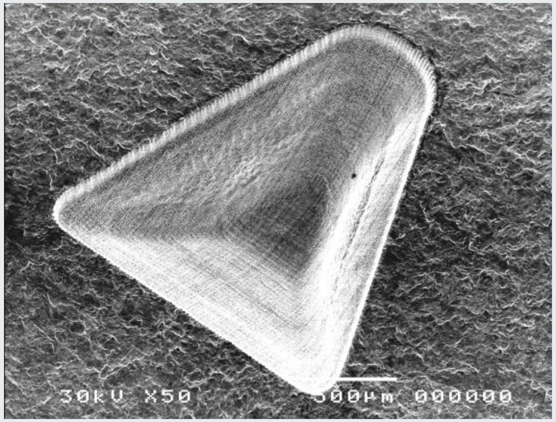
Nanosecond Pulse Ablation : Micro-Milling

Examples of optimised processes with nanosecond laser sources

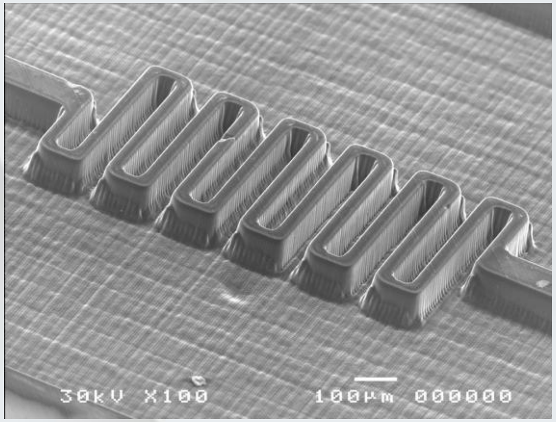
Alumina



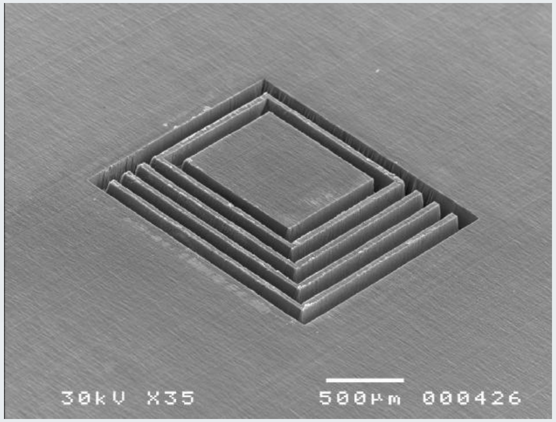
Tungsten



Diamond

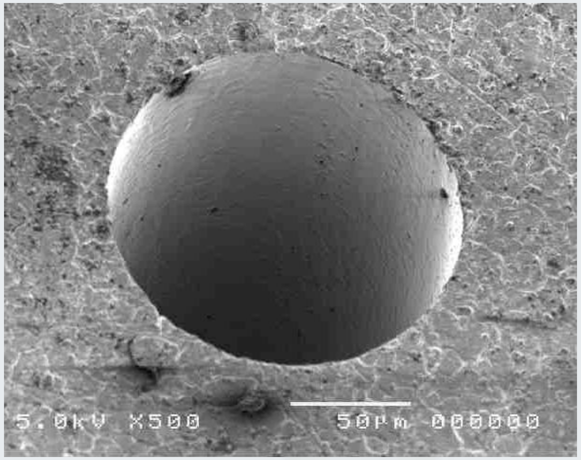


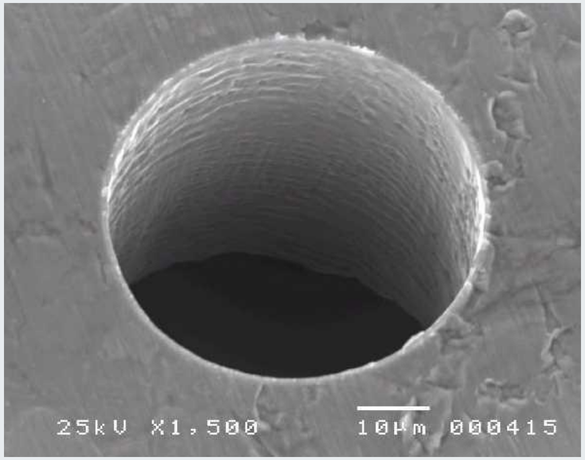
Polyimide



Micro-Drilling

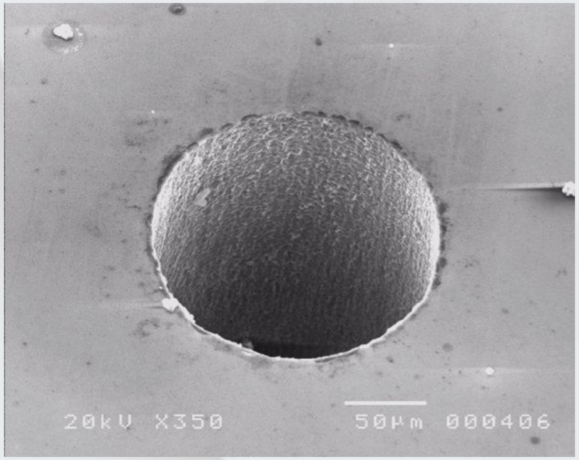
150 μm dia thro' 1mm steel

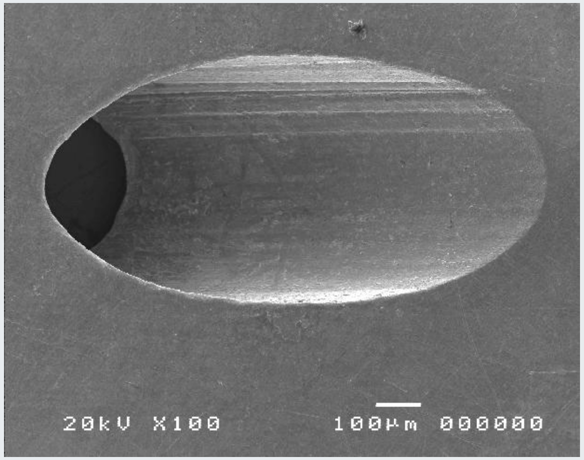




50 μm dia thro' 0.1mm steel

150 μm dia thro' 0.5mm silicon

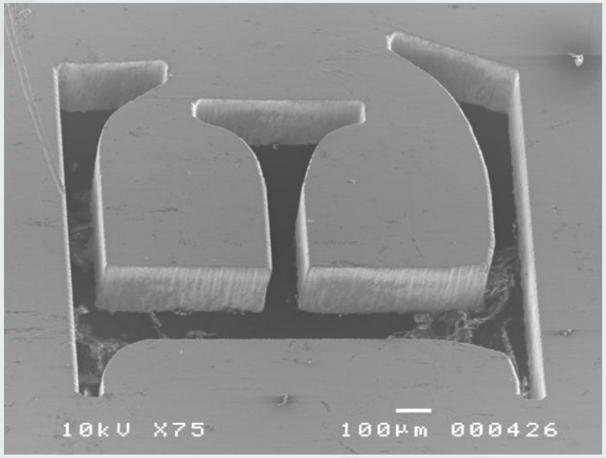


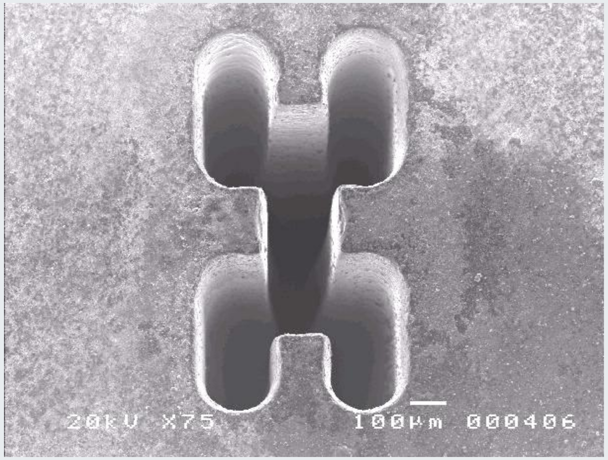


30 degree hole in steel

Micro-Cutting

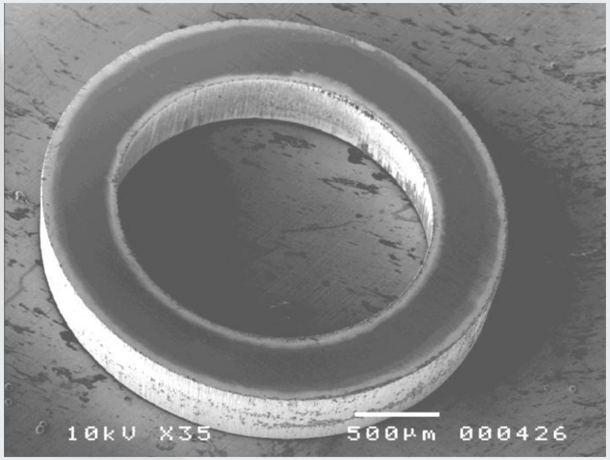
Steel

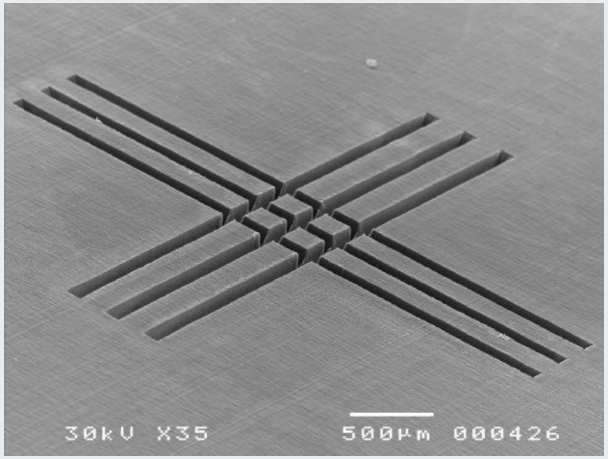




Diamond

Silicon



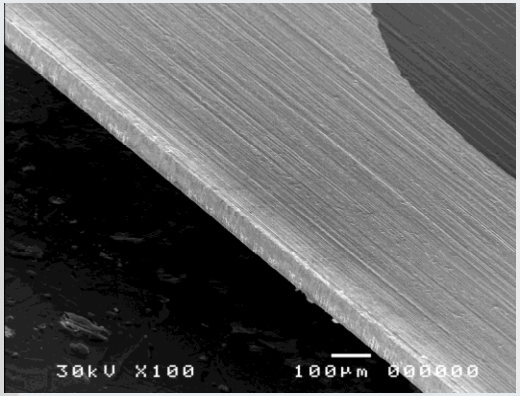


Polyimide

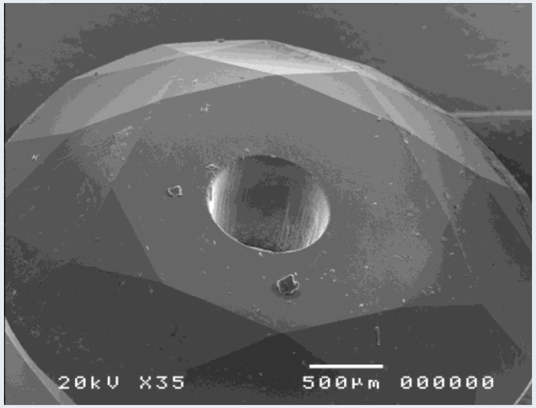
Expert Process Technology

… 20 years experience in laser micromachining

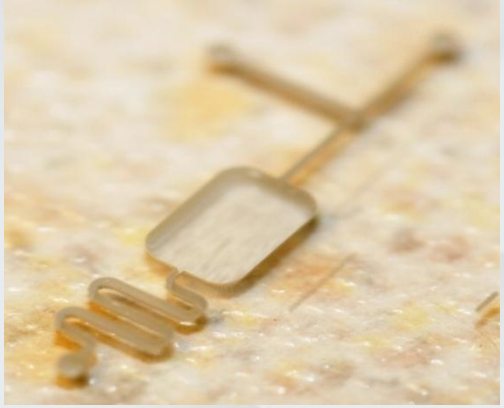
Examples of ps laser machined features



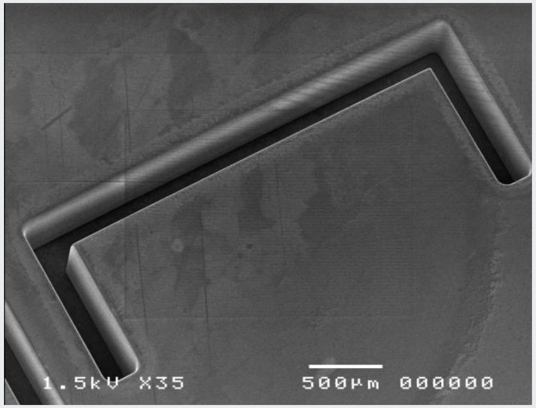
Nickel



Diamond

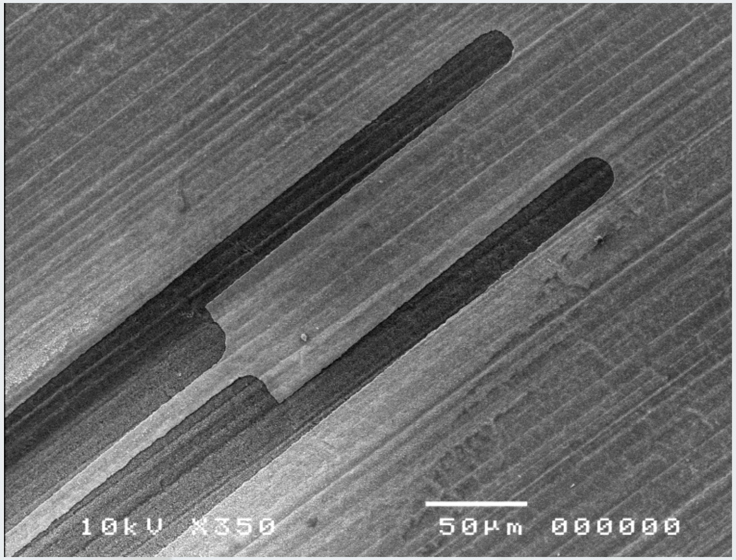


Borosilicate

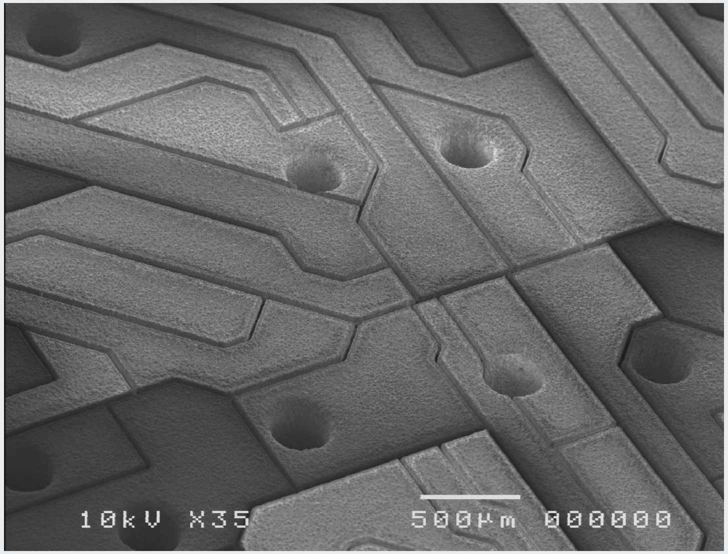


Sapphire

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

Transparent Materials

Organic LED Production

(thin film removal)

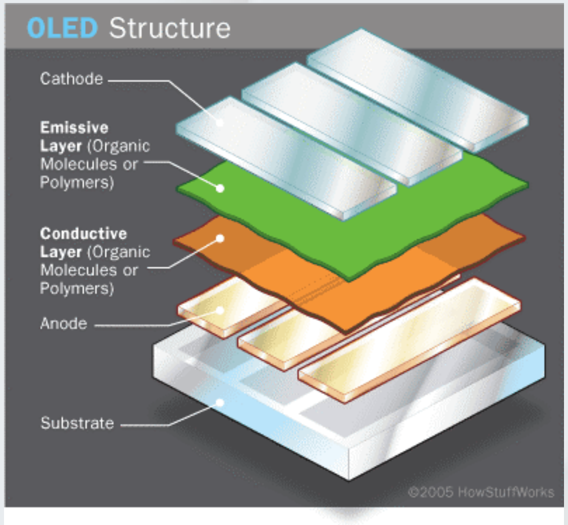
OLEDs advantages over LCDs -

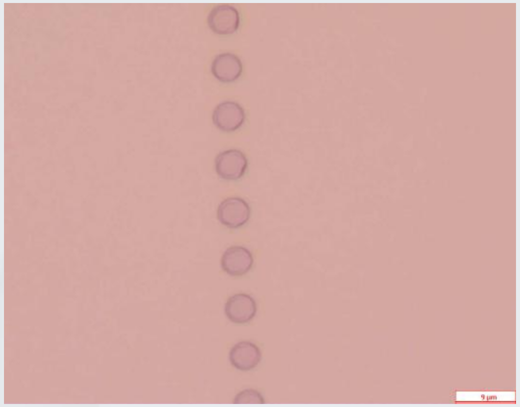
- No backlight - so more efficient and thinner displays
- High contrast ratios, deeper blacks etc
- Richer deeper colours (direct colour production)
- OLED screens are emissive - so no viewing angle problems
- Flexible Screens (newspapers)

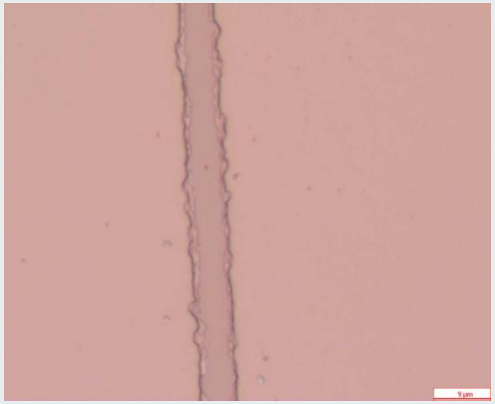
The Sony 11-inch OLED TV

Courtesy of Holst

Patterning Thin Films on Flexible Substrates







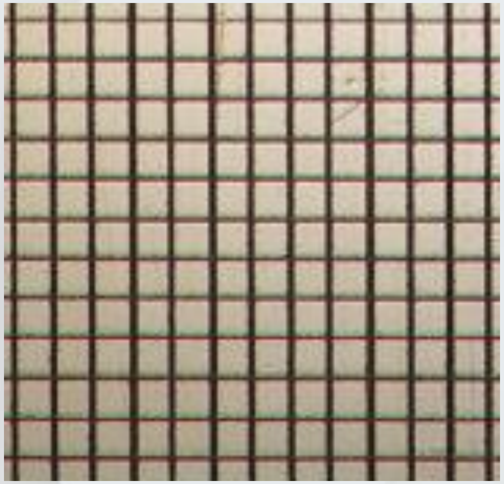
Laser scribed ITO on Flexible Substrate using 532nm (a) 4 micron spots with depth of 100nm and (b) scanning five times slower. Bar denotes 9 microns

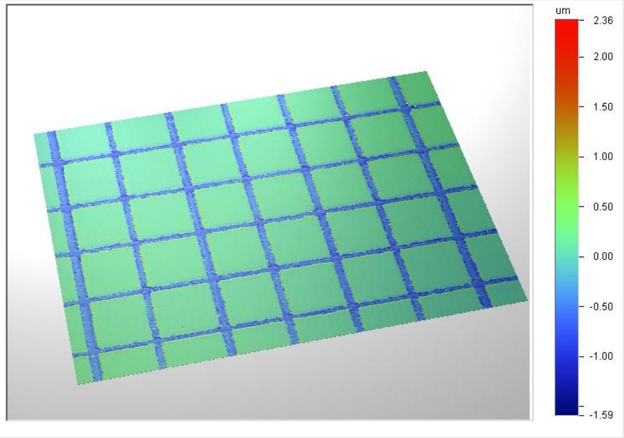
Demonstration of thin film removal

Expert Process Technology

…20 years experience in laser micromachining

Parallel processing with ps laser system





<u>OLED Cathode Scribing</u>

532nm, 30mm/s,

Effective speed of 450mm/s !

15 diffracted spots

Line pitch approx. 85microns

Scribed depth d=300nm

European projects

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)

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)

OXFORD LASERS
INDUSTRIAL DIVISION

OXFORD LASERS
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Advanced Laser Micro-machining Solutions

Range of Standard System Platforms

Laser Micromachining Subcontract Services

Laser Micro-machining Expertise