Laser Micromachining: A flexible tool in Vertical Probe Card Manufacturing

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Outline

1. Introduction to Laser Micromachining

2. Laser micro-Drilling capability

3. Laser Drilling for Vertical probe card manufacturing

4. Future Trends
Oxford Lasers

Laser Manufacturer & Laser System Integrator

Founded 1977, spin-off Oxford University
Location: Oxford (UK), Boston (USA)

Main Areas of Activity:
- High-Speed Imaging
- Laser Micromachining

- Turn-key Laser Systems
- Proof-of-Concept Trials
- Contract R&D
- Sub-contract Manufacturing
- Collaborative Projects
- Lasers & Accessories
What is Laser Micromachining?

Laser Ablation - material removal by a combination of evaporation and melt expulsion.

Proportion of evaporation vs melt expulsion depends on laser parameters and material.
Why Use Lasers?

**Conventional**
- Wire Electro-Discharge (EDM)
- Mechanical
- Chemical milling
- Water Jet
- Ion Milling
- Electron Beam
- Punching

**Laser**
- Non-contact technique
- Soft Tooling
- Processing speed
- High Resolution
- Flexibility (hole size, shape)
- Compactness (footprint)
- Cost effectiveness

Low Drilling Speed = High Cost
Benefits of Laser Drilling

1. Lasers can machine all industrial materials (plastics, ceramics, silicon, metals, glasses)

2. Small holes and high packing densities give end user more flexibility in design

3. Lasers can create any toolpath on a workpiece using a CAD/CAM interface (shaped holes possible)

4. Laser drilling systems are safe, easy to operate with minimal training and have minimal downtime

5. Future proof technology

6. Rapid turnaround due to soft tooling
Applications of Laser Micromachining

Diesel-injection nozzle drilling

Pcb via drilling

Cardiac stent manufacturing

Inkjet printer manufacturing

150µm Ø, 511nm, 1mm thick steel
# Industrial Laser Drilling Applications

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<tr>
<th>Semi/Microelectronics</th>
<th>Aerospace/Defence</th>
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<td>Inkjet Printer Nozzle</td>
<td>Turbine component cooling</td>
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<td>Engine Silencing</td>
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<td>Optical Switching</td>
<td>Missile guidance</td>
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<td>Heat management in PCB packaging</td>
<td>Aerofoil laminar flow</td>
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<td><strong>IC Test Vertical Probe Card</strong></td>
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<th>BioMedical MEMS</th>
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<td>Fuel-Injection Nozzle</td>
<td>Catheter Sensors</td>
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<td>Fuel Filter</td>
<td>Aerosol Spray Atomisers</td>
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<td>ABS Car brake sensors</td>
<td>DNA Sampling</td>
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<td>Con-rod lubrication</td>
<td>Vaccine production</td>
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<td>Lab-on-a-Chip</td>
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<td>Cardiac Stent Manufacturing</td>
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<tr>
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<th>Other</th>
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<td>Food Packaging</td>
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<td>Solar Cell Technology</td>
<td>Gem Stone drilling</td>
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<tr>
<td>Fuel Cell</td>
<td>Digital Fingerprinting</td>
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<td>Particulate Filters</td>
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Which Laser to use?

Important Parameters
(hole size)
(hole aspect ratio)
(feature quality)
(processing speed)
(cost per hole)

<table>
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<tr>
<th>LASER</th>
<th>λ (nm)</th>
<th>Pulse width</th>
<th>PRF</th>
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<tr>
<td>DPSS</td>
<td>213-1064</td>
<td>ns-µs</td>
<td>1Hz-200kHz</td>
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<tr>
<td>Copper</td>
<td>255,511</td>
<td>ns</td>
<td>kHz</td>
</tr>
<tr>
<td>Excimer</td>
<td>157-351</td>
<td>ns</td>
<td>1Hz-1kHz</td>
</tr>
<tr>
<td>Ultrafast</td>
<td>390-1048</td>
<td>Fs-ps</td>
<td>1-5kHz</td>
</tr>
</tbody>
</table>

Laser Wavelength
Laser Pulse Width
Laser Beam Profile
Pulse-to-pulse stability

Laser Power
Laser Rep.Rate
Laser Focussability

(Proc.Speed) (Quality)

Important 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:**
Most parameters are interrelated and/or depend on temperature, pressure, etc.
Laser Micro-machining

Importance of correct choice of laser & process
Holes in 1mm thick Steel

Optimum Laser Parameters
Clean hole with no recast
almost no debris

Non-Optimum Laser Parameters
Significant recast, crown and debris
Laser Drilling Techniques

PERCUSSION DRILLING

Direct Writing

[Diagram of laser direct writing]

Laser Trepansing

[Diagram of laser trepanning with beam path]

Helical Trepanning

[Diagram of helical trepanning]

Auto-Trepanning Head

[Trepanning head diagram]

TREPANNING DRILLING

Mask Imaging

[Diagram of laser mask imaging]

1. Start at hole centre
2. Trepan outwards (spiraling, con.circles)

Beam Path

Final Hole Diameter

[Diagram showing beam path and final hole diameter]
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Example of high-speed drilling

Fuel cell mesh

Total: 46,000 holes
Drill speed: up to 250 holes/sec
DPSS ns Laser Ablation of Silicon

Single-shot Laser Ablation
355nm UV DPSS
Max. Pulse Energy: 0.5mJ
Spot size: 9µm
Pulse Duration: 45ns
M² <1.2

• UV ns DPSS lasers can provide high peak power due to diffraction limited small spot sizes on target
• Very high peak power helps drill silicon fast.
• Small holes down to 5µm can be achieved varying peak power with high aspect ratios >100:1
Silicon

UV ns Laser Trepanning Drilling

Example of laser machined channel and hole for micro-fluidic application

Femtosecond laser drilling

125µm Ø, 355nm, c-Si 350 µm thick

- Short (λ) or short (τ) lasers show superb result
- No laser-induced thermal damage
- No Particulate contamination
Special Ceramics

High aspect ratio microholes

Low thermal expansion ceramics

Difficult to process with conventional drilling
Polymers

Laser Optical Trepanning

355nm UV DPSS
High quality, minimal HAZ

Blind-holes
Polymers

Laser Cutting

355nm UV DPSS
High quality, minimal HAZ, sharp features
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Vertical probe heads used for IC electrical testing prior to packaging. They require microholes to guide the contacting wires. Laser drilling of the guide plates allows high packing density with smaller hole sizes and provides flexibility, high processing speed.

**Materials**
- Silicon
- Ceramics
- Plastics

**Hole Geometry**
- Hole size: 40 - 100 µm diameter
- Hole shape: square, circular, elliptical
- Hole Cylindricity: parallel or tapered
- Wafer thickness: 300-700 µm

**Technology challenges**
- Hole position accuracy
- Speed of drilling
- Taper angle control tolerance
- Toolpath flexibility, any hole shape
Ceramic MicroDrilling

500µm thick, 511nm

Si₃N₄

50µm Ø, 60µm pitch

Alumina 650µm thick

50µm square holes
Plastic MicroDrilling

15µm hole, pitch 40µm, 50µm thick

Polyimide 500µm thick

135µm Ø
HOLE POSITION ACCURACY IS PARAMOUNT.

We use:

- High resolution, high position accuracy x-y stages
- Temperature controlled workstation
- Wafer leveling and alignment equipment.

We calibrate all our stages against known National Physical Laboratory standards.
Performance Evaluation Data

Example of 1000 laser drilled holes

**Important!!**
The hole size repeatability depends on:
- Laser pulse-to-pulse stability
- Sample uniformity and surface texture
- Sample levelling

The hole positioning accuracy depends on:
- X-Y table accuracy
- Laser beam pointing

<table>
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<th>X-Y Table Positional Accuracy</th>
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<tr>
<td>X-AXIS</td>
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<tr>
<td>---</td>
</tr>
<tr>
<td>std.dev</td>
</tr>
<tr>
<td>Cp</td>
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<tr>
<td>Cpk</td>
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Hole Size Repeatability

Hole Pitch Accuracy
Wafer levelling and alignment is critical for –µm level position accuracy in laser hole drilling.

• High resolution cameras and on-axis position sensitive detectors are used to align the wafers.

Laser-drilled hole size measurement and inspection can be performed in-situ with user-friendly digital imaging analysis software with custom recipes.
ProbeDrill™

Fully automated turn-key laser drilling system for vertical probe card manufacturing

- Laser
- Proprietary Optical Trepanssion System
- 5-axis part positioning
- Material handling systems (options)
- User-friendly pc interface
Future Trends in Laser Hole Drilling

- **Better Resolution**
  
  *(shorter wavelength, 2\textsuperscript{nd}, 3\textsuperscript{rd}, 4\textsuperscript{th} harm DPSS)*

- **Lower Production Cost**
  
  *(proc. speed, high rep. rate, high power)*

- **Better Quality**
  
  *(shorter pulses, motion control speed)*

- **More Complex Materials**
  
  *(multi-wavelength laser systems)*

- **Industrial Robustness**
  
  *(compact, fully diode-pumped laser systems)*
Summary

- Laser micromachining is a well established industrial processing method
- Lasers can process all commonly used materials in the wafer test arena
- Laser microdrilling is a flexible tooling technique
- Lasers coupled with ultra accurate motion tables offer competitive advantages for vertical probe card manufacturing
- Lasers are an enabling technology – Smaller features in difficult to process materials
Thank You

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