"Laser Microdrilling in Industrial Applications"

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1. Market Overview
2. Which Lasers to use?
3. Physical Mechanisms
4. Laser Drilling Techniques
5. Case Study: Fuel-Injectors
6. Future Trends
## Industry Sectors

- Semiconductor
- Automotive
- Aerospace
- Electro-optics
- Photonics
- Medical
- Food

## Manufacturing Applications

- Inkjet Printer Nozzles
- Via Circuit Electrical Interconnects
- Optical Switch Fab
- Test Probe Cards
- Gas Flow – Chemical Sensors
- Leak Detection
- Biomedical Sensors
- Fuel Injection Nozzles
- Aerosol Atomisers
- Engine Silencing
- Food Packaging
- Particulate Filters
- Solar Cell Technology
- Turbine Blade Cooling
Example Applications

**Fuel-injection nozzle drilling**

- 150µm Ø, 511nm, 1mm thick steel
- Injection hole
- Valve
- Fuel feed

**PCB via drilling**

**Cardiac stent manufacturing**

**Inkjet printer manufacturing**
Annual Market Growth: 10% (10 yr average)

Source: Laser Focus World, BCC Inc. Market Analysis, Industrial Laser Solutions
Which Industrial Materials to Drill?

Metals

Silicon

CVD Diamond

Plastics

Ceramics
Examples of Laser Drilled Shapes

- Blind
- Angled
- Shaped
- Rectangle
Why Use Lasers to Drill Holes?

• Non-contact enabling technique
• High Processing Speed
• High Resolution
• Flexibility (hole size, shape)
• Compactness (small machine footprint)
• Cost effectiveness
Important Laser-Drilling Markets

**Main Drivers:**
Semiconductor (micro via-holes, ink-jet printing)
Aerospace (turbine cooling)

**Emerging Markets:**
Automotive, Pharmaceutical, Biomedical

![Graph showing via sizes and aspect ratios](image)

Source: ESI
**Micro-Via Drilling**

**Consumer Electronics**
Example: Hand-held devices (Mobile phones, video & digital cameras)

Real-Estate Requirement:
High Packing Density of PCB Boards
⇒ Multi-layered PCBs needed
⇒ Via interconnects holes needed

**Technology Comparison**

**Mechanical Drilling** (hole Ø > 0.1mm)
- Drill speed: ~ 500 holes /min
- Cost: ~$2400 / \(10^5\) holes

**Laser Drilling** (hole Ø < 0.025 mm)
- Drill speed: ~ 34000 holes /min
- Cost: <$1 / \(10^5\) holes
### Indicative Cost of Laser Processing

#### Capital Cost
- Laser/Optics
- Motion (CNC, galvo, etc)
- Cleanroom/ Environment
- Machine Vision
- Software
- Sample Handling
- Metrology Equipment
- Safety Equipment
- Downtime

#### Running Cost
- Optics
- Laser consumables
  - diode arrays
  - flashlamps
  - assist gases
- Water, Power
- Sample postprocessing
- Other consumables

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**Main Q: Which laser to use?**
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Why Use **Pulsed** Lasers to Drill Holes?

**Pulsed Lasers:**

- **Provide Overall Excellent Feature Quality**
  Short interaction time with material
  Small heat affected zone (HAZ)

- **Fine Resolution**
  Controlled material removal

- **Enable Machining of Transparent Materials**
  High laser intensity enables micromachining of any material
Which Laser to Use?

It is always a case of balancing

by adjusting laser parameters

wavelength, pulse width, power, rep.rate, etc

Industrial Laser Choice

• CO₂
• Excimer
• Copper
• DPSS
• Ultrafast (ps, fs)
• Fiber/Disc

Feature Quality  Proc.Speed

Available Industrial Lasers

Courtesy: Corelase
Nd:YAG Laser Drilling

**Typical Laser Specs:**
- **Wavelength:** 1064, 532, 355, 266, 213 nm
- **Power:** $1 - 10^3$ W
- **Pulse Length:** $10^{-12} - 10^{-3}$ s
- **Rep. Rate:** 1 Hz – MHz
- **Focussability:** $M^2 \sim 1 - 40$
- **Price:** from $20k +$

**Aerospace**
Turbine blade cooling

**Semiconductor**
Silicon wafer drilling
Copper-Vapour Laser Drilling

Wavelength: 511 & 578 nm
Power: up to 75 W
Rep. Rate: 5-30 kHz
Pulse Length: 25 ns
Focusability: $M^2 = 1.5$
Price: from $60k+
Excimer Laser Drilling

Typical Manuf. Applications
- Inkjet printer nozzles
- Biomedical sensors
- Environmental sensors
- Telecom
- Display
Ultrashort-Pulsed Laser Drilling

Picosecond or Femtosecond Lasers

Ti:Sapphire, mode locked Vanadate
Wavelength: 780 or 1064 nm and harmonics
Power range: up to 10W, up to 500kHz
Pulse Length: 10ps – 30fs

Advantages
• Material independent
• Min HAZ
• No post-processing necessary

Disadvantages
• High Cost ($150k+)
• Complex
• Frequent Maintenance
• Not mature yet
Dual-Laser Beam Drilling

- **UV laser "trepnanning"**
  - Start at center
  - Concentric circles
  - Increasing diameter

- **CO2 drilling**
  - Beam with fixed diameter 150 µm
  - Copper acts as a mask

**Benefits**
- Smaller via sizes possible
- Bias more accurate

**Laser trepanning**
- Path of laser beam
- Final diameter of the laser drilled hole

**CO2 beam (IR)**
- Copper layer cut by UV at 355 nm from YAG laser.
  - The beam diameter is 20 µm and is moved in a circular path to cut the hole.

**Dielectric (FR4, RCC etc)** removed by IR at 9.6 µm from CO2 laser.
- The beam is about 150 µm diameter to remove the dielectric material using the hole cut in the copper as a mask.

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Q: “Which laser to use?”

Answer:

Every application is different and should be judged on its merits.
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Basic Laser-Hole Drilling Setup

- Laser
- Waveplate
- Beam Shaping Optics
- Turning mirror
- Objective Lens
- Optics Adjust Stage
- Gas-Assist Nozzle
- Target
- X-Y Table
Laser-Hole Drilling: Basic Definitions

Laser Intensity
\[ I(x) = \frac{2P}{\pi w_0^2} \exp(-2r^2/w_0^2) \]

Laser Spot Size
\[ 2w_0 = \frac{4f \lambda f M^2}{\pi D} \]

Hole Taper Angle
\[ \alpha = \tan^{-1}\left(\frac{d_1-d_2}{2t}\right) \]
Laser-Drilling: Important Parameters

! IMPORTANT NOTE:
Most parameters are interrelated and vary with temperature, pressure, time, etc.
Example: Importance of Pulse Length

- **Pulse Length (FWHM)**

- **Laser Ablation by Melt Expulsion**
- **Laser Ablation by Evaporation**

### Resolution (µm)
- **Low Resolution, >100 µm**
- **High Resolution, <10 µm**

- **Peak Power (kW)**

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Laser Drilling Techniques

Percussion Drilling = Static Drilling

Direct Focussing
- Coherent Sources ⇒ tight focussing
- Focussed Spot Size ⇒ hole size
- High Fluence ⇒ high drilling speed
- Low Pulse-to-Pulse Stability

Projection Imaging
- Incoherent Sources
- Mask Projection ⇒ shape flexibility
- Low Fluence ⇒ slow drilling
Laser Drilling Techniques

Trepanning Drilling

For Fast Drilling
⇒ Sample or Beam Motion Necessary
⇒ Need High Fluence = Small Spot Size
⇒ Crater < Hole Dimensions
⇒ Helical motion for High Aspect Ratio Features

(Technique offers Good Repeatability, Versatility)
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Main Technology Drivers

- Emissions Legislation
- Lower manufacturing cost
- Consumer demand for higher performance

Current Manuf. Technology:
- wire EDM \((\text{min hole } \varnothing: 130\mu m)\)
- punching
- mechanical drilling

Future Technology:
Laser Drilling
Global Emissions Legislation

“…vehicle emissions are set to reduce in all regions but with different criteria…”

Courtesy: Ricardo Automotive consultancy
Diesel-Injection Nozzle Drilling

EU & US Emissions Standards Regulations (2007) increasingly require:
⇒ improved fuel combustion
⇒ decreased hydrocarbon & particle emission

Automotive Industry needs:
⇒ small spray droplets in piston chamber
⇒ smaller diameter fuel-injector holes needed
⇒ new drilling technology required

Micro hole Laser drilling

Injector Hole Specification

• High Resolution
• High Aspect Ratio
• Best Accuracy
• Best Quality
• Backwall Protection
• Design Flexibility
• Production Cost
• Reliability
• Repeatability
• New Materials to drill
Diesel-Injection Nozzle Drilling

Different Nozzles Geometries

High Speed Imaging

Nozzle Internal View

No back wall Damage from Laser
Diesel Fuel Filter Drilling

- Fuel filters are used to block fuel impurities before they reach the injectors

Laser Drilling Speed: 100-500 holes / sec
Hole Diameters: 0.05 – 0.3 mm
Material Thickness: <1mm

Courtesy: Lasag Industrial Lasers
Diesel-Injectors: Trepanning Drilling

Steel
1mm thick
Gasoline-Injection Nozzle Drilling

Different Gasoline Injector Configurations
Gasoline-Injection Nozzle Drilling

- Four-hole nozzle
- 250 µm diameter holes
- 250 µm thick steel
- 70 Degree angle
- 5 seconds per hole
Gasoline-Injection Nozzle Drilling

- Eighteen-hole nozzle
- 500 µm diameter holes
- 500 µm thick steel
- 60 degree angle
- 45 seconds per hole
Laser Hole Drilling: Future Trends

- **Better Resolution**
  
  *shorter wavelength, 4th, 5th harm DPSS*

- **Higher Processing Speed**
  
  *higher rep.rate, higher average power*

- **Better Quality**
  
  *shorter pulsewidth, higher motion control speed*

- **New Complex Materials**
  
  *alloys, composites, multi-wavelength systems*

- **Industrial Robustness**
  
  *compact, fully diode-pumped laser systems*