OXFORD LASERS
INDUSTRIAL DIVISION

# *"Laser Microdrilling in Industrial Applications"*

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OXFORD LASERS INDUSTRIAL DIVISION

# Outline

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

# MicroDrilling Industrial Applications

## Industry Sectors

-Semiconductor

-Automotive

-Aerospace

-Electro-optics

-Photonics

-Medical

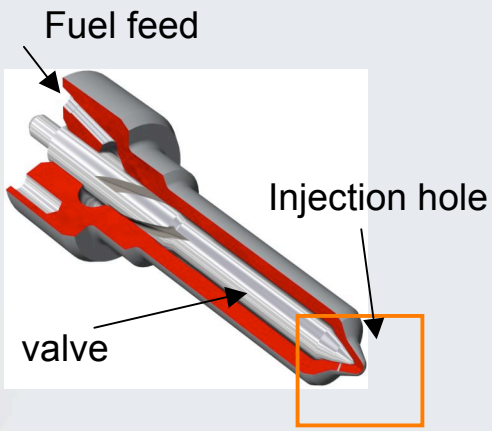
-Food

## Manufacturing Applications

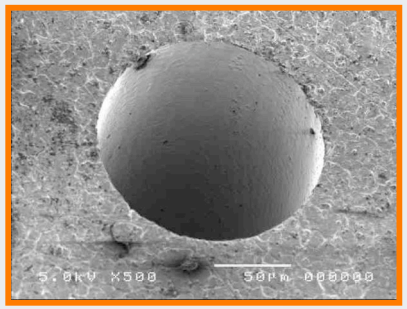
- Inkjet Printer Nozzles
- Via Circuit Electrical Interconnects
- Optical Switch Fab
- Test Probe Cards
- Gas Flow – Chemical Sensors
- Leak Detection
- Biomedical Sensors
- Fuel Injection Nozzles
- Aerosol Atomisers
- Engine Silencing
- Food Packaging
- Particulate Filters
- Solar Cell Technology
-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

# Example Applications

## Fuel-injection nozzle drilling



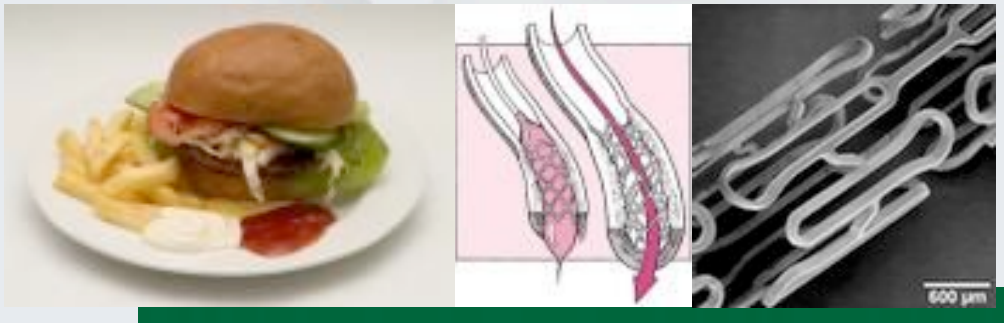

150µm Ø, 511nm,
1mm thick steel



## PCB via drilling

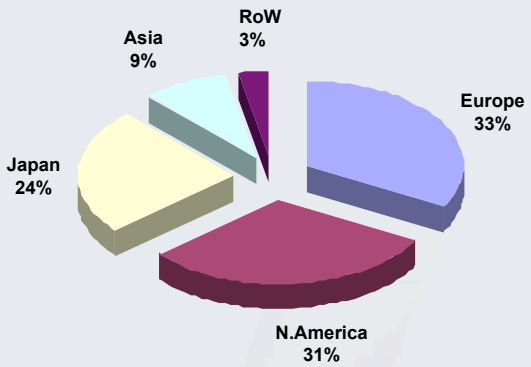
## Inkjet printer manufacturing

## Cardiac stent manufacturing

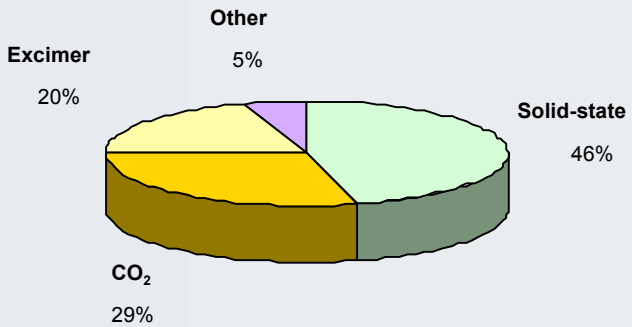


# Industrial Lasers Market (2004)

## Worldwide Laser System Installations

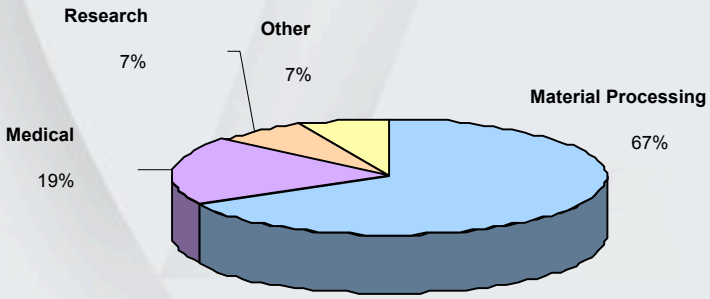



## Industrial Laser Sales (2003)

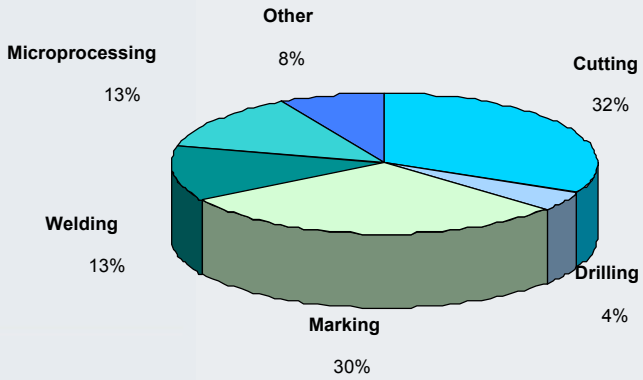



## Industrial Laser Applications

***Market Segmentation (2003)***




## Laser-Material Processing

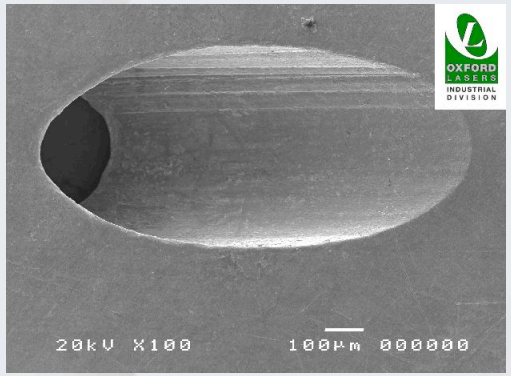



Global Laser Material Processing Market: ~$1.3 bn (2004)
Annual Market Growth: 10% (10 yr average)
Projected Worldwide Laser Market (2008) : ~$3 bn

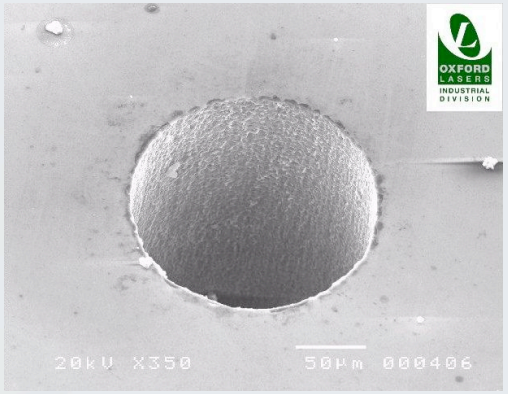
Source: Laser Focus World,
BCC Inc. Market Analysis,
Industrial Laser Solutions

# Which Industrial Materials to Drill?

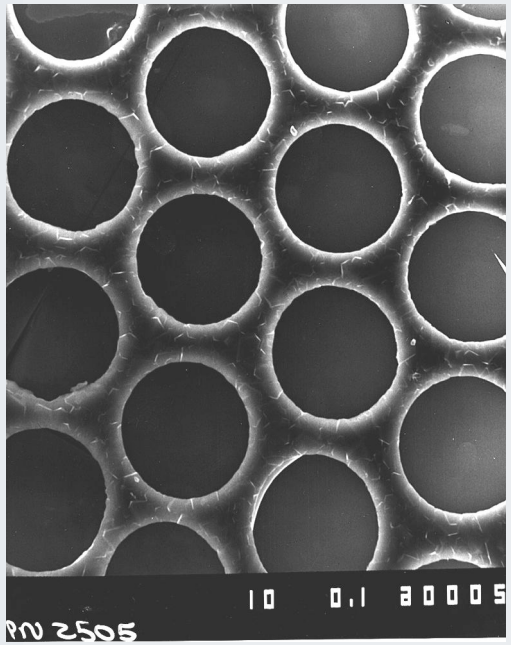
## Metals



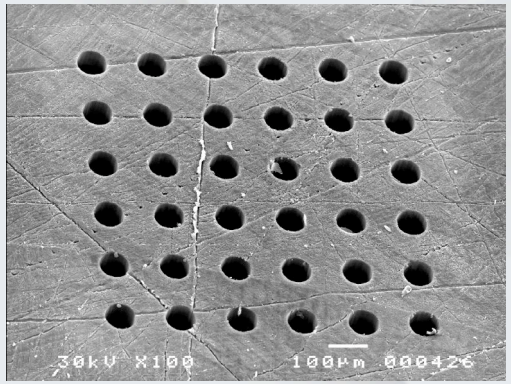

## Silicon



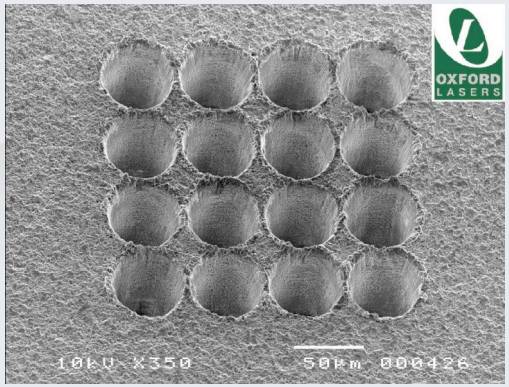

## CVD Diamond



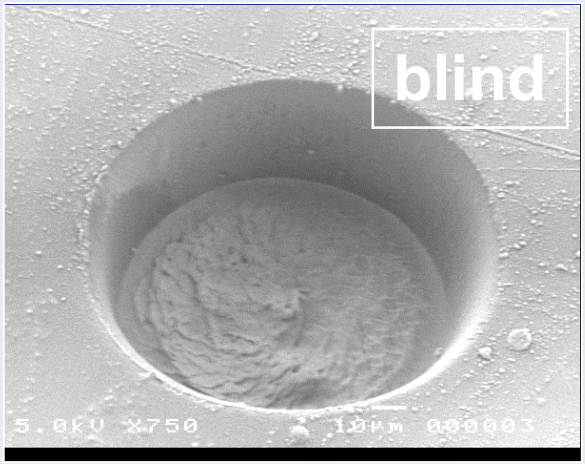
## Plastics

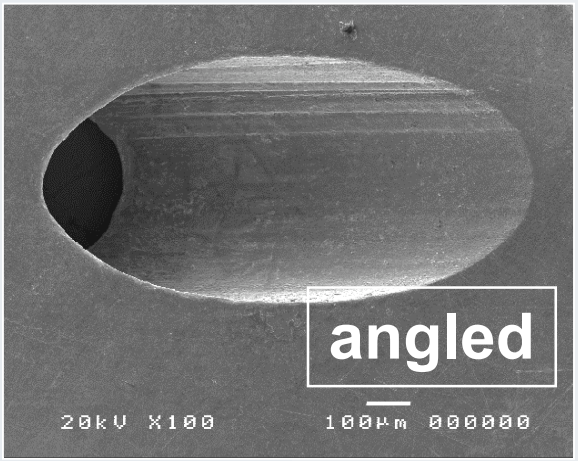


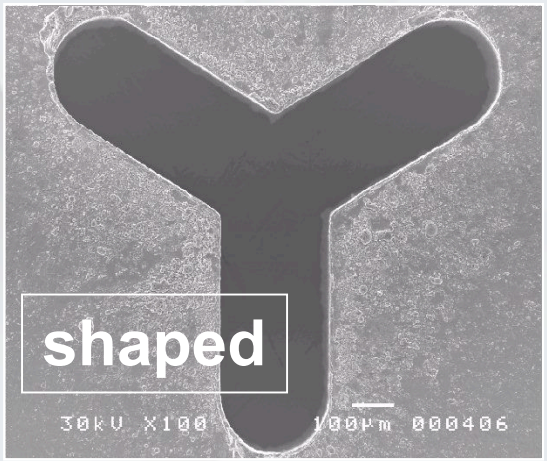

## Ceramics

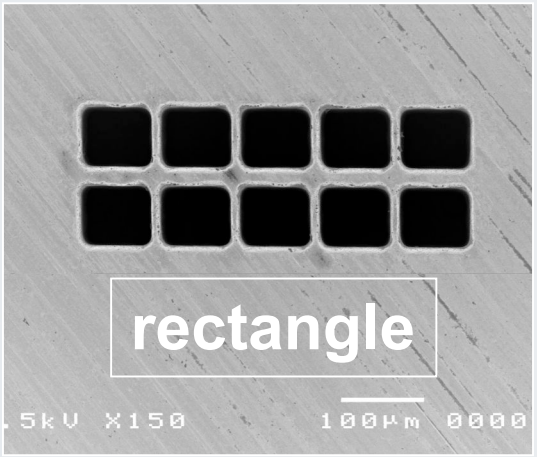


# Examples of Laser Drilled Shapes



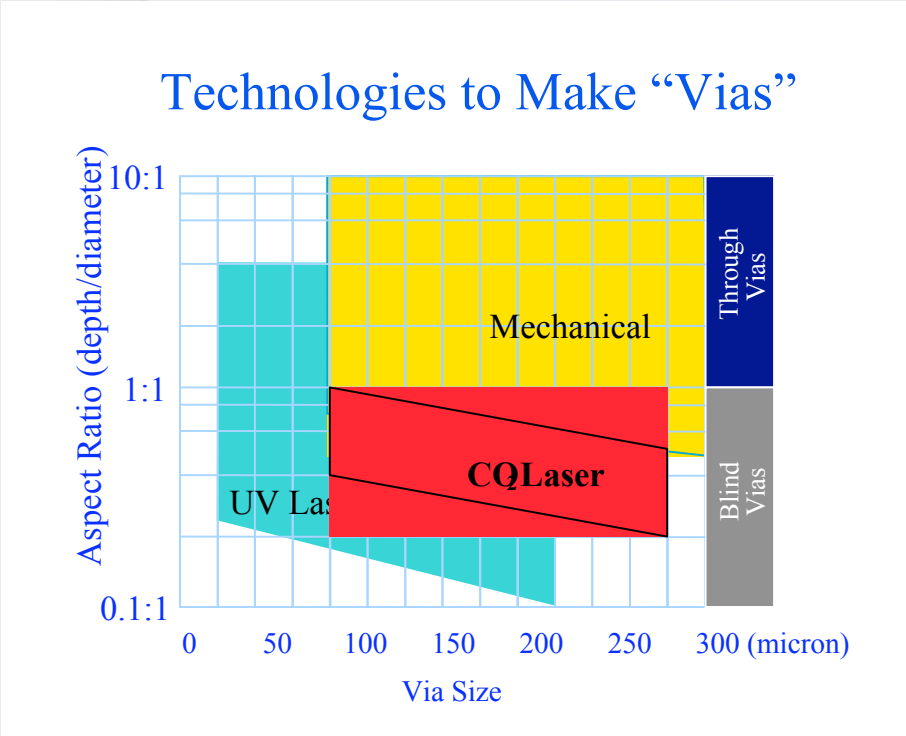
# Why Use Lasers to Drill Holes?

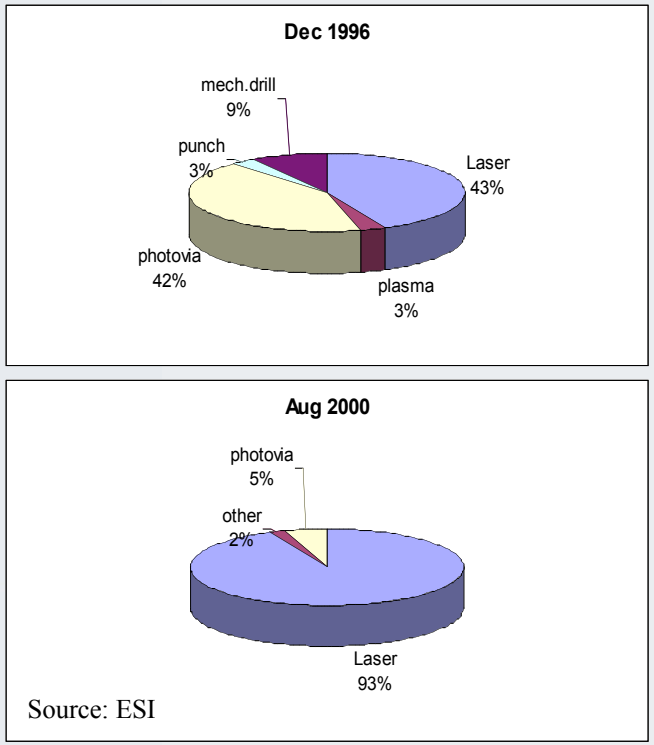
- Non-contact enabling technique
- High Processing Speed
- High Resolution
- Flexibility (hole size, shape)
- Compactness (small machine footprint)
- Cost effectiveness

# Important Laser-Drilling Markets

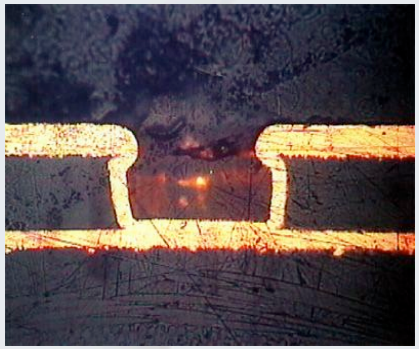
**Main Drivers:** Semiconductor (micro via-holes, ink-jet printing)
Aerospace (turbine cooling)

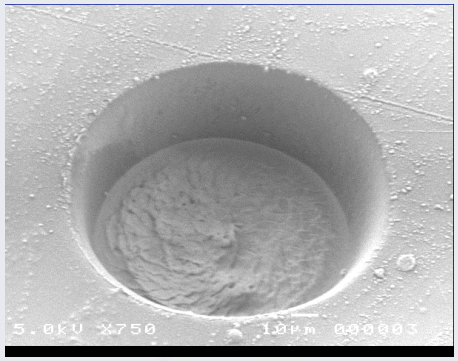
**Emerging Markets:** Automotive, Pharmaceutical, Biomedical

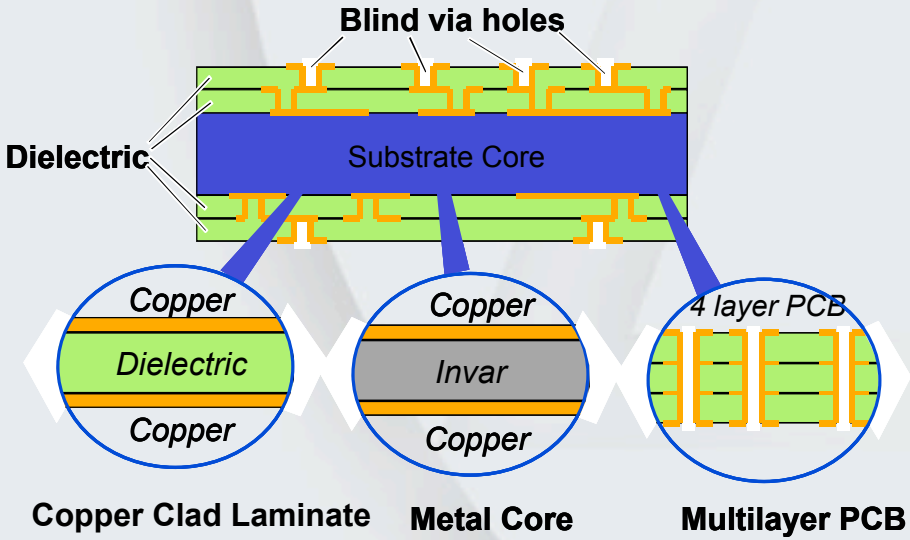


# Micro-Via Drilling








## 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

**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?

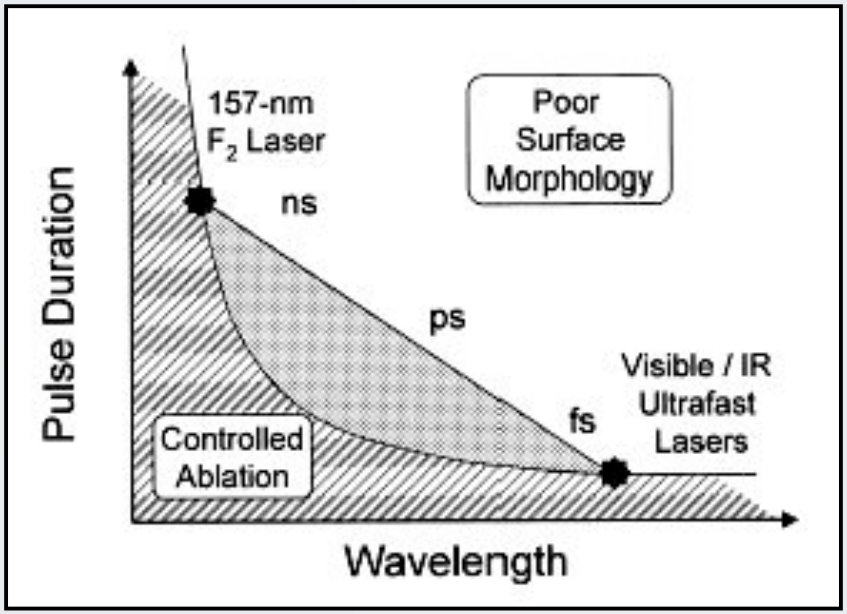
It is always a case of balancing


by adjusting laser parameters

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

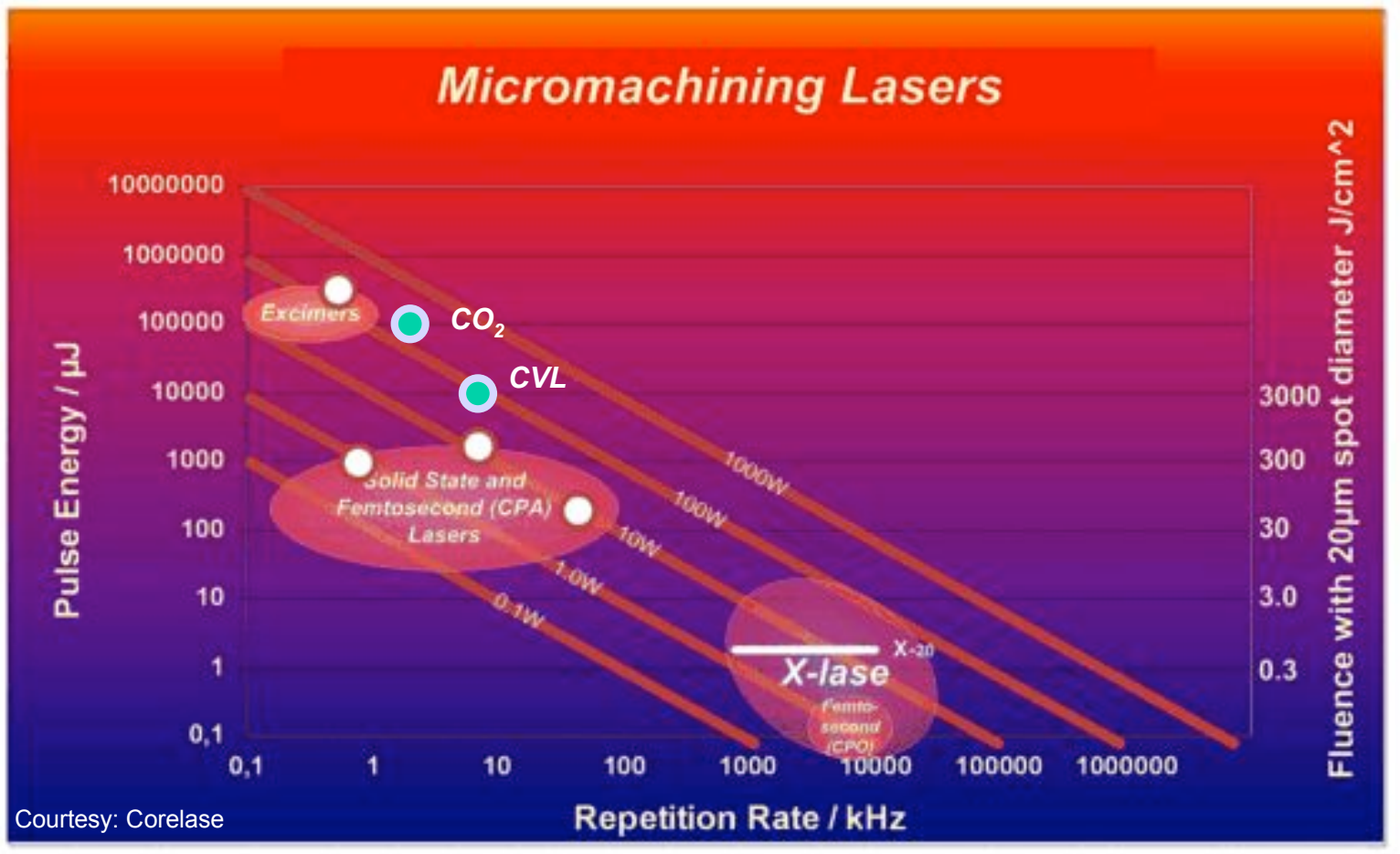
Industrial Laser Choice

- $CO_2$
- Excimer
- Copper
- DPSS
- Ultrafast (ps, fs)
- Fiber/Disc




From *P.R. Herman et al.rApplied Surface Science 154–155 (2000) 577–586*

# 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

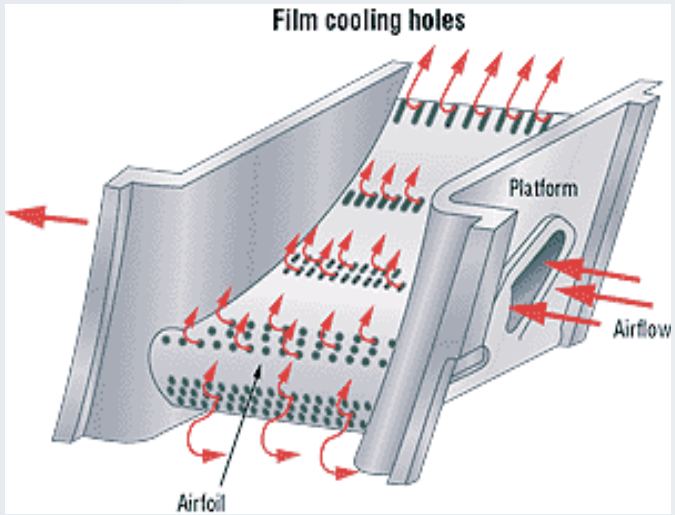
Rep.Rate: 1 Hz – MHz

Focussability: $M^2$ ~ 1 - 40

Price: from $20k +

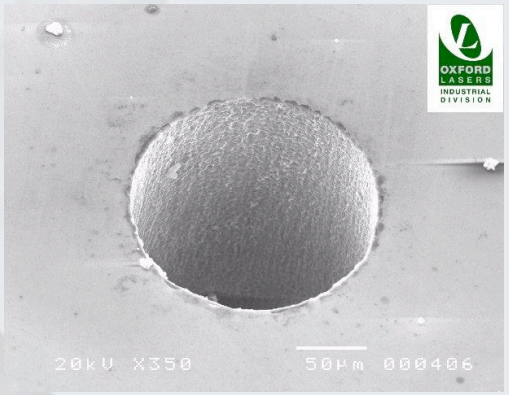
Aerospace

Turbine blade cooling

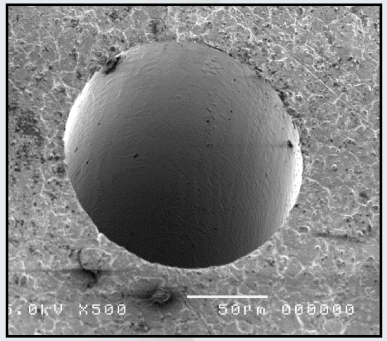



Semiconductor

Silicon wafer drilling

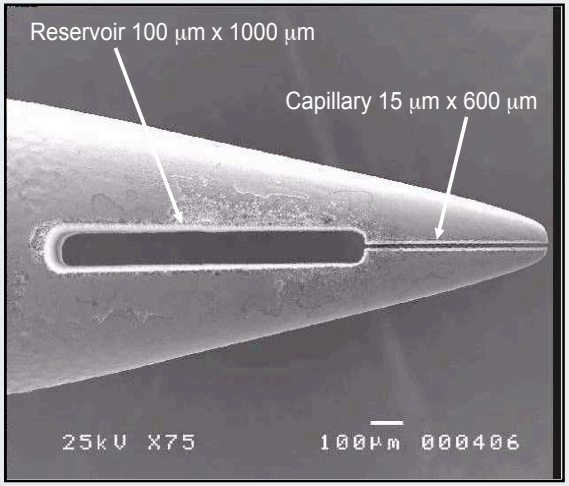


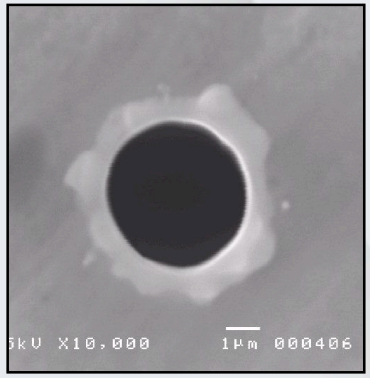
# Copper-Vapour Laser Drilling



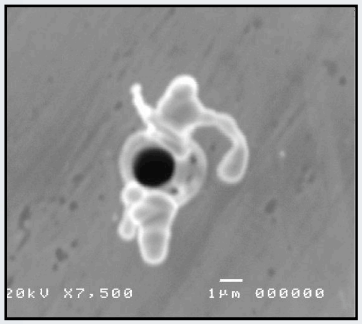

1 mm steel

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



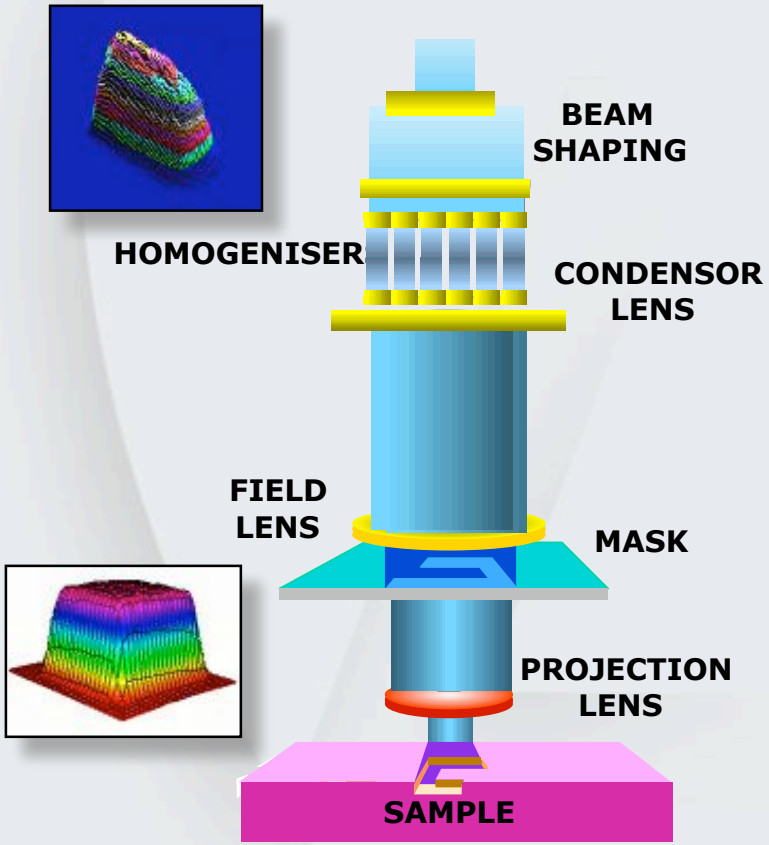




50 µm s. steel




1 µm gold

# Excimer Laser Drilling





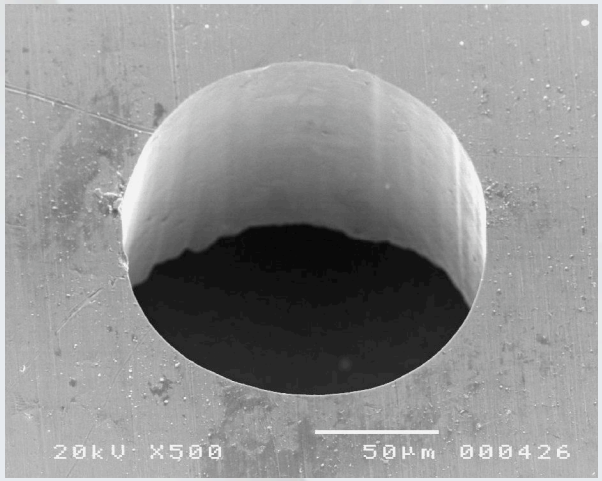

## Typical Manuf. Applications

- Inkjet printer nozzles
- Biomedical sensors
- Environmental sensors
- Telecom
- Display

# Ultrashort-Pulsed Laser Drilling

## Picosecond or Femtosecond Lasers

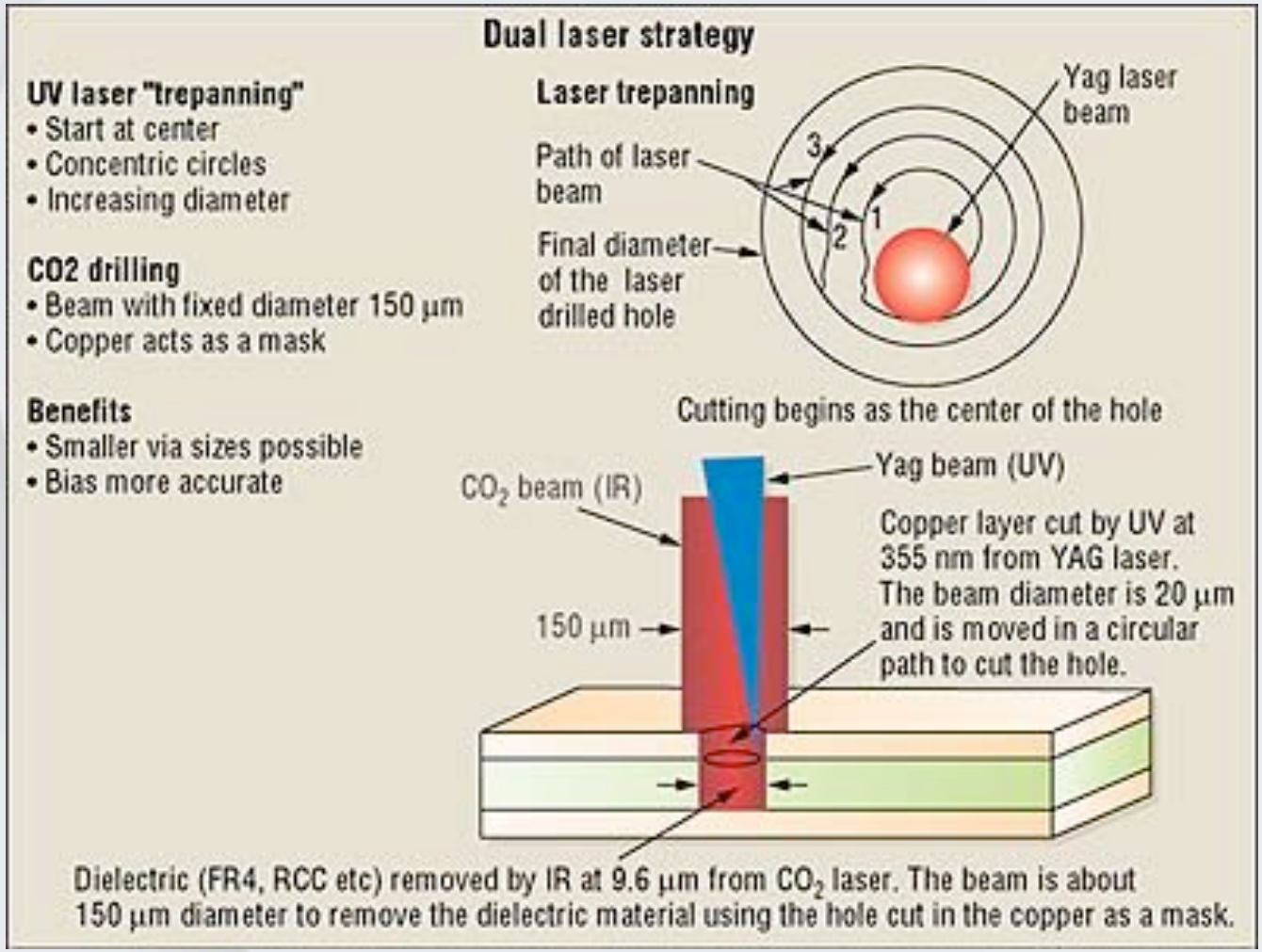
Ti:Sapphire, mode locked Vanadate
Wavelength: 780 or 1064 nm and harmonics
Power range: up to10W, up to 500kHz
Pulse Length: 10ps – 30fs




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

**Disadvantages**
- High Cost *($150k+)*
- Complex
- Frequent Maintenance
- Not mature yet

# Dual-Laser Beam Drilling



# Q: “Which laser to use?”

*Answer:*

*Every application is different and should be judged on its merits*

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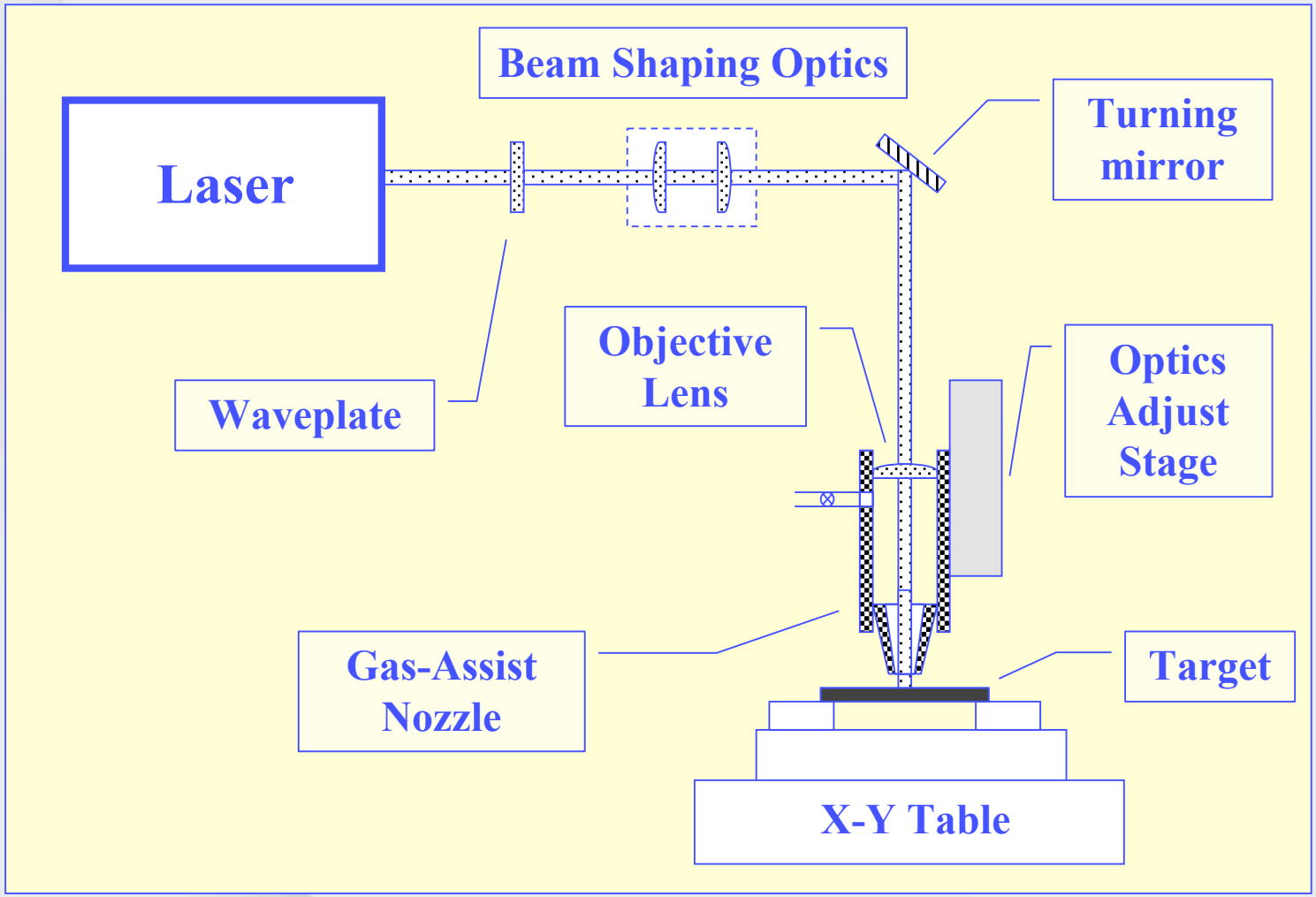
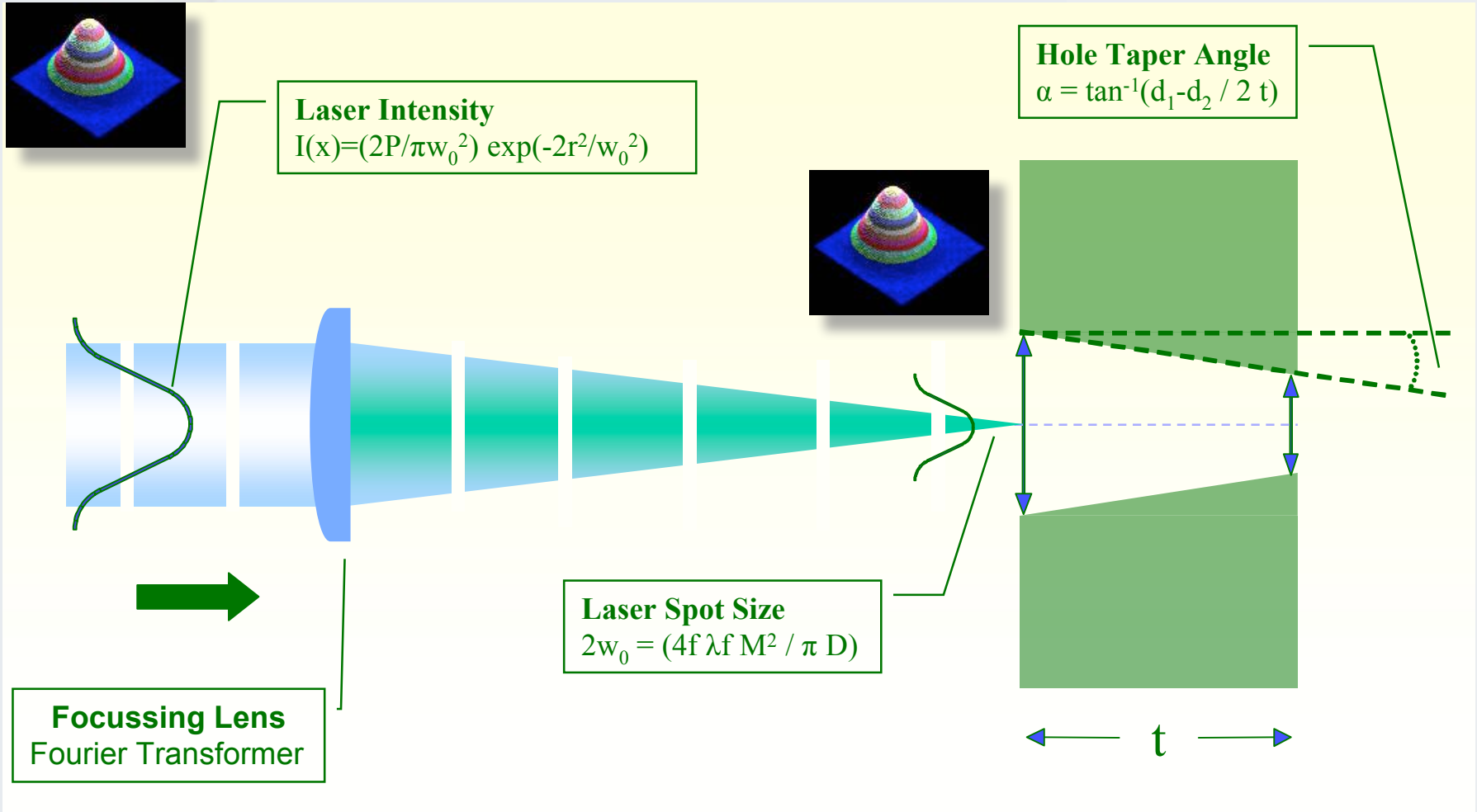
# Basic Laser-Hole Drilling Setup



# Laser-Hole Drilling: Basic Definitions



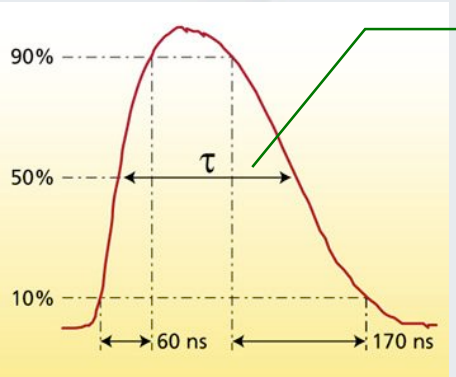
# Laser-Drilling: Important Parameters

- **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

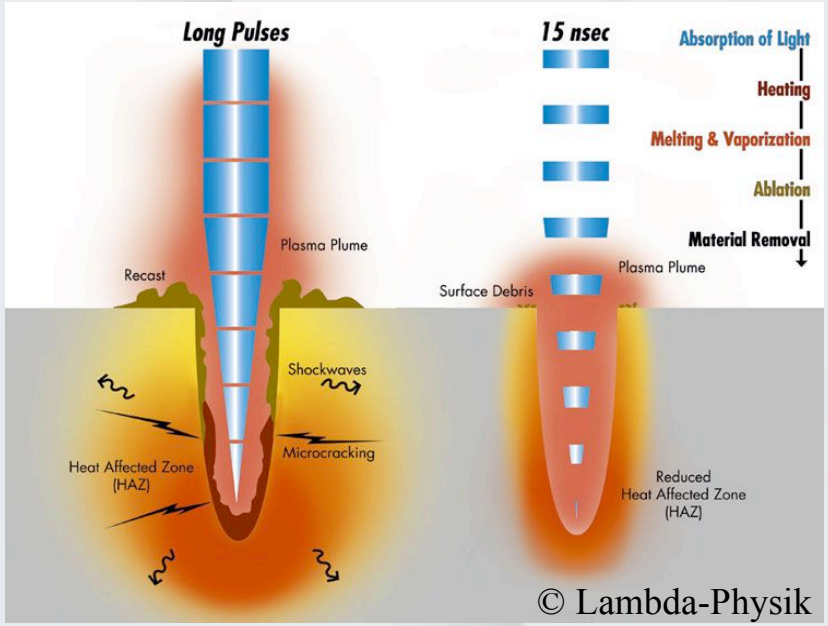
**! IMPORTANT NOTE:**

Most parameters are interrelated and vary with temperature, pressure, time,etc.

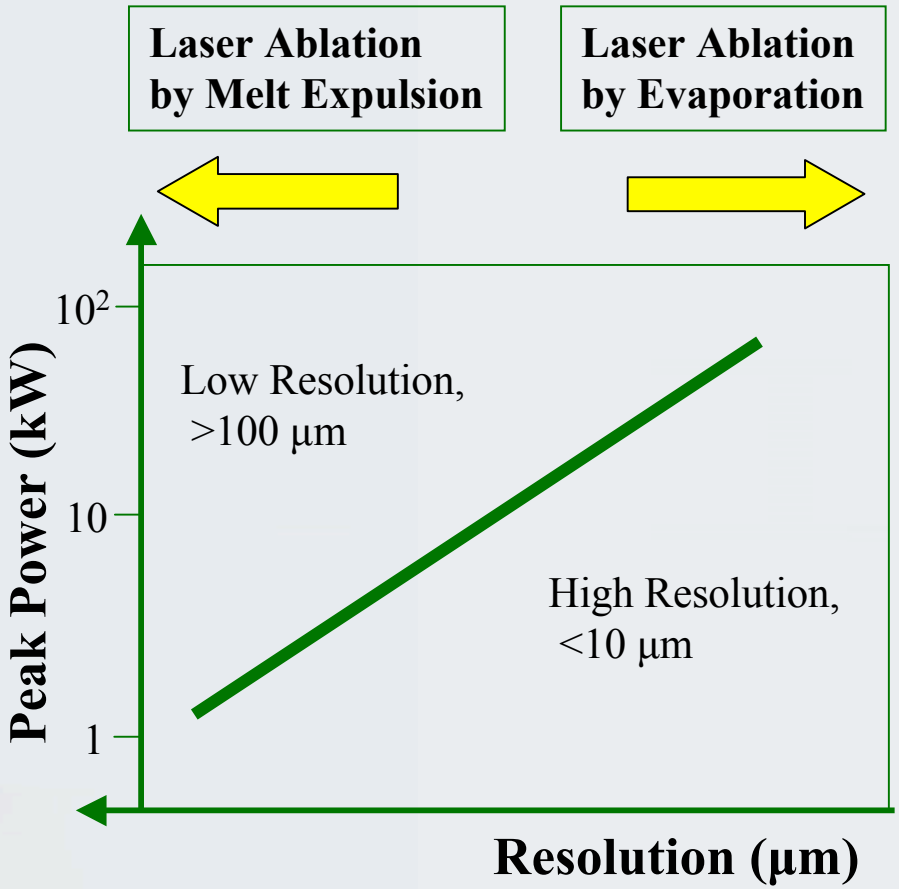
# Example: Importance of Pulse Length




**Pulse Length (FWHM)**




© Lambda-Physik



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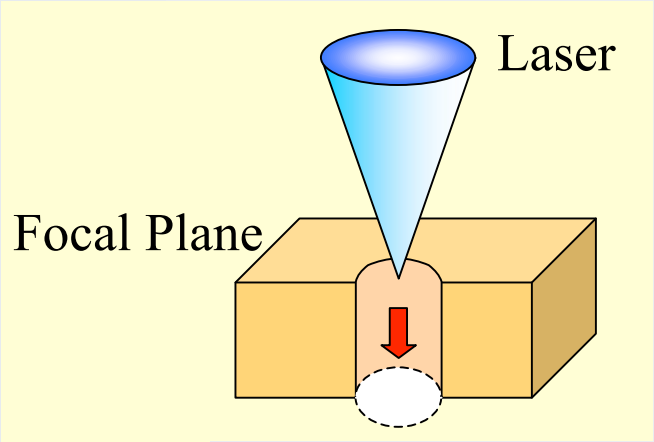
# Laser Drilling Techniques

**Percussion Drilling = Static Drilling**

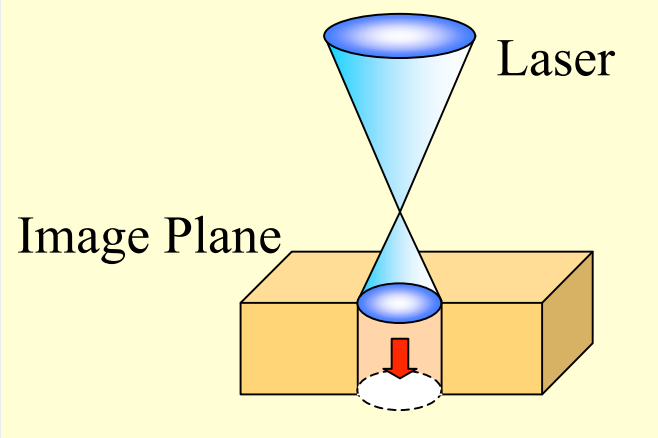
## Direct Focussing

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

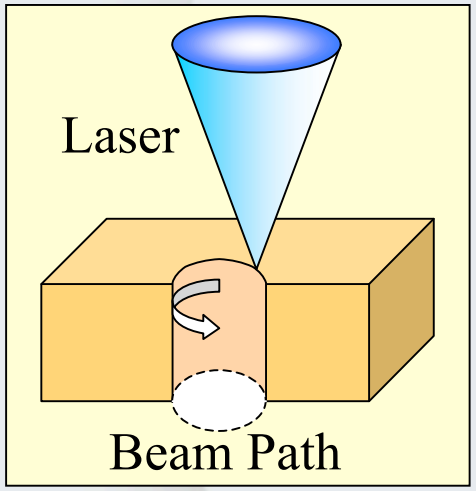


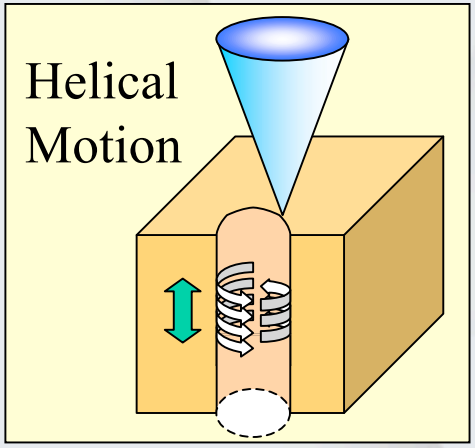

## Projection Imaging

-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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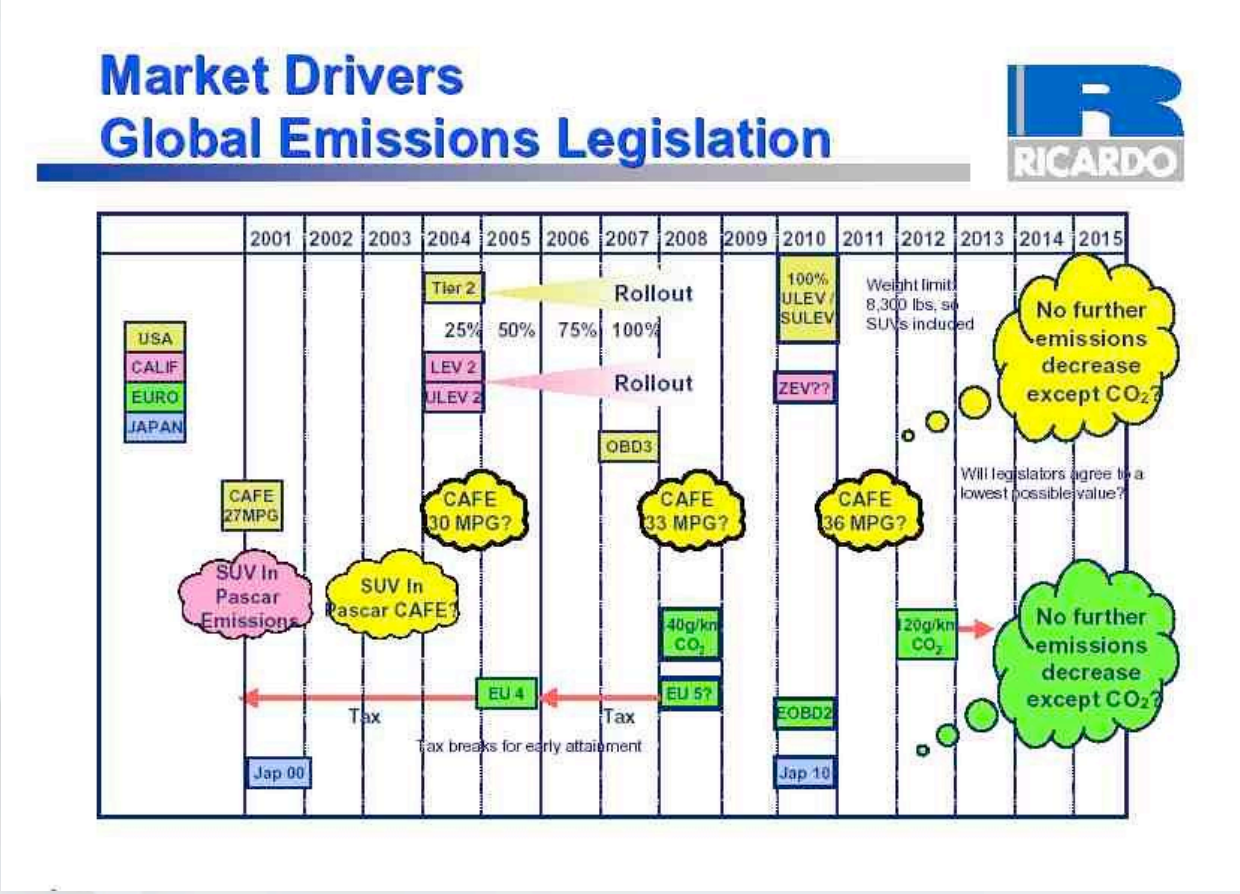
# Fuel-Injection Nozzle Drilling

## Main Technology Drivers

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

| | |
|---|---|
| **Current Manuf.Technology:** | -wire EDM (*min hole Ø: 130µm*)<br>-punching<br>-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

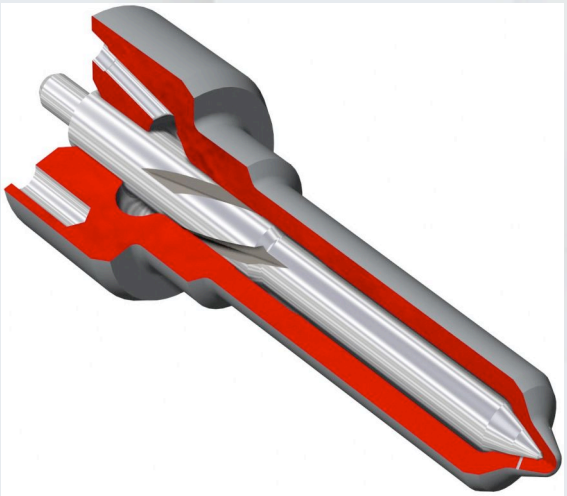
⇒ decreased hydrocarbon & particle emission

**Automotive Industry needs:**

⇒ small spray droplets in piston chamber

⇒ smaller diameter fuel-injector holes needed

⇒ new drilling technology required

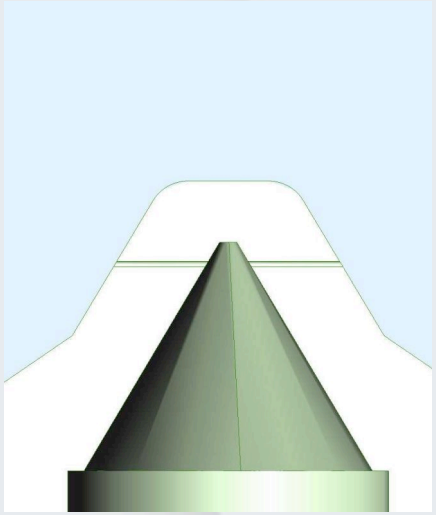


Micro hole Laser drilling

## Injector Hole Specification

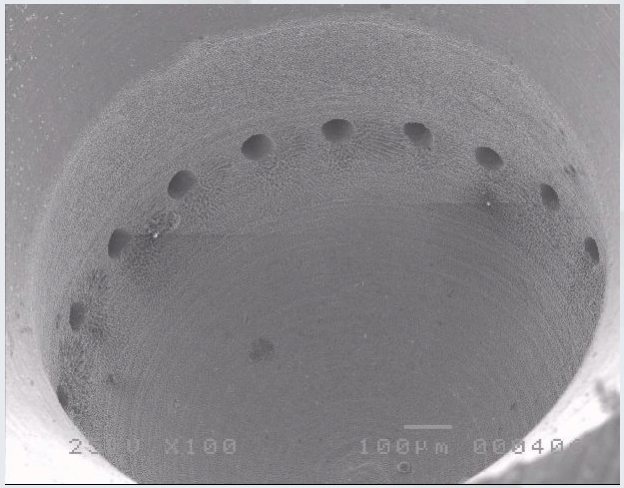
- High Resolution
- High Aspect Ratio
- Best Accuracy
- Best Quality
- Backwall Protection
- Design Flexibility
- Production Cost
- Reliability
- Repeatability
- New Materials to drill

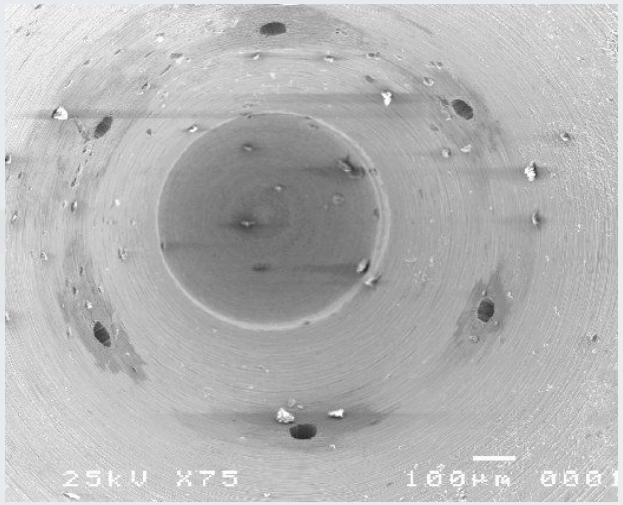
# Diesel-Injection Nozzle Drilling



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*

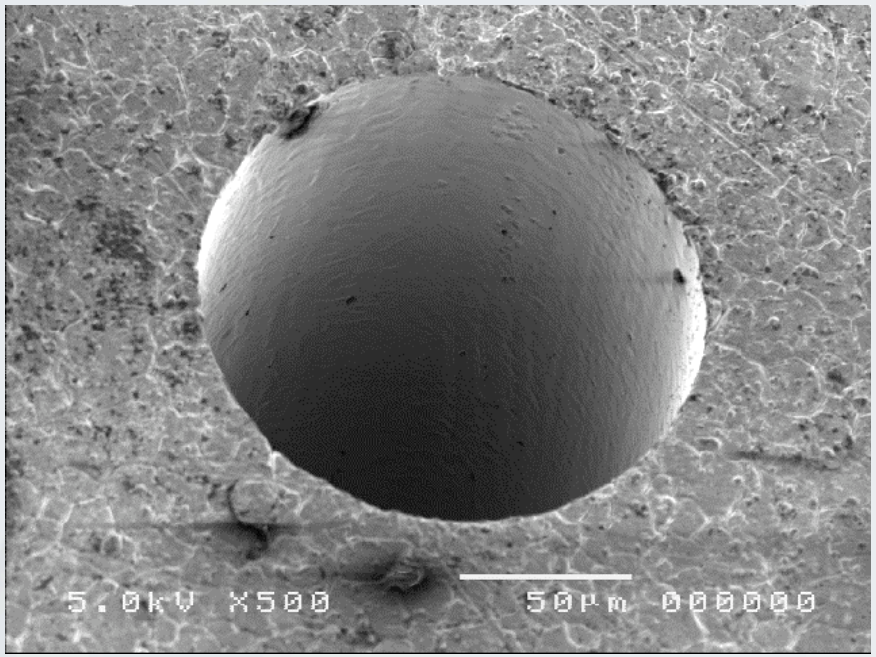
*Material Thickness: <1mm*

Laser-drilled section

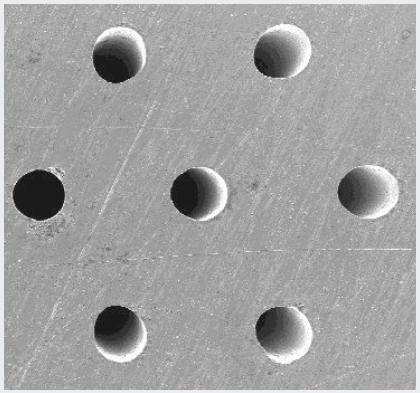
Courtesy: Lasag Industrial Lasers

# Diesel-Injectors: Trepanning Drilling

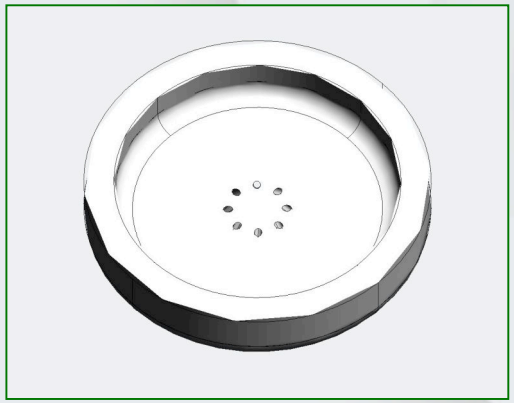
Steel
1mm thick

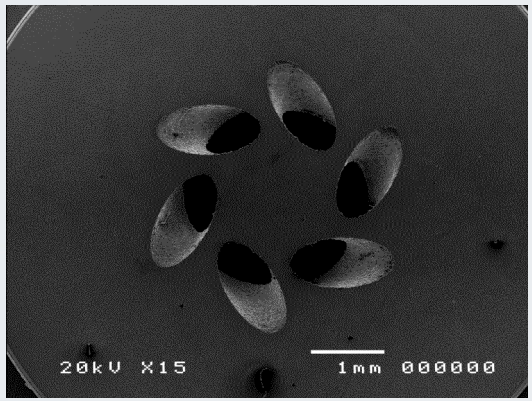


# Gasoline-Injection Nozzle Drilling

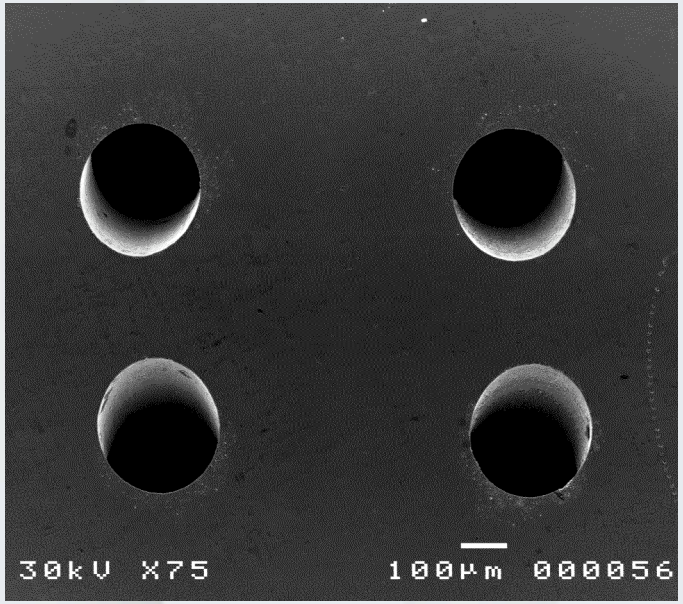


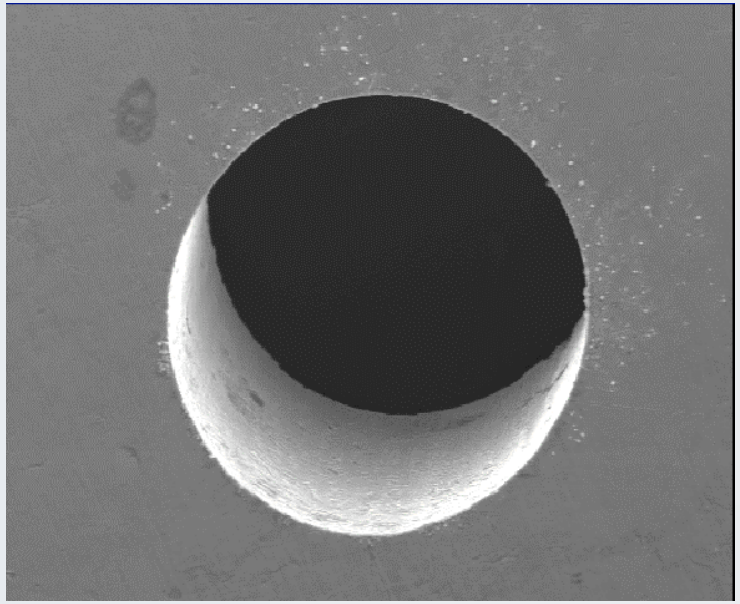
Different
Gasoline Injector
Configurations





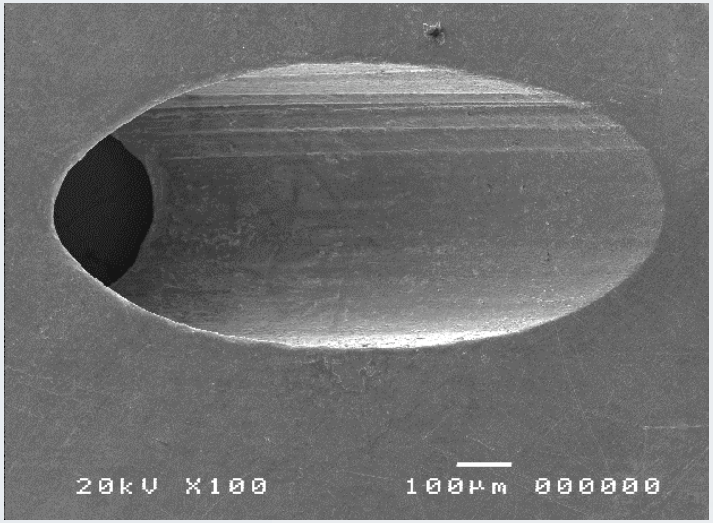
# Gasoline-Injection Nozzle Drilling



- 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)*