Emerging Applications Enabled by High Power Nanosecond Pulse Diode Pumped Solid State Lasers (1403)

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Introduction

- Latest Generation DPSSL
- Plasma Phenomena at High Intensity
- Empirical Study of Two Key Emerging Applications
  - Laser Milling of Nickel Alloys
  - Fine Hole Drilling of Steels
- Conclusions

Developments in DPSSL Technology

DPSSL Development

Diode Lifetime >5000hrs

High Average Power > 400W

Robust Cavity Design

Electrical-Optical Efficiency >12%

Industrial Uptake

Low Maintenance

High Productivity

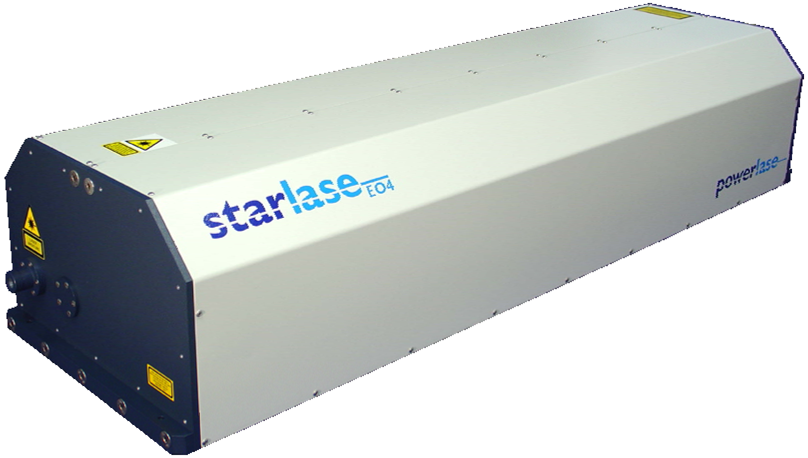
High Uptime (MTBF)

Reduced CoO

Customer Requirements

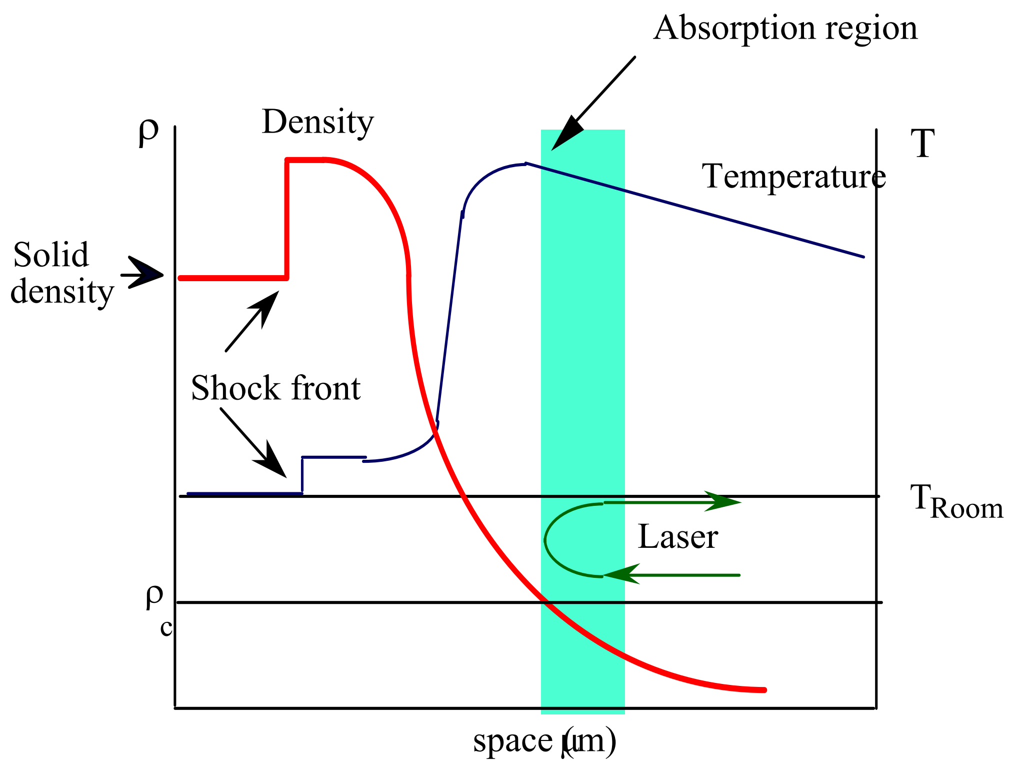
Next Generation DPSSL

- Starlase AO Series
  - Acousto-optical switching
  - Average power 80 - 400W+
  - Pulse Duration 20-200ns
  - Rep. Rate 3-50kHz
  - Tailored M2



- Starlase EO Series
  - Electro-optic switching
  - Average power 25 - 160W
  - Pulse Duration <10ns
  - Rep. Rate 3-10kHz
  - Tailored M2

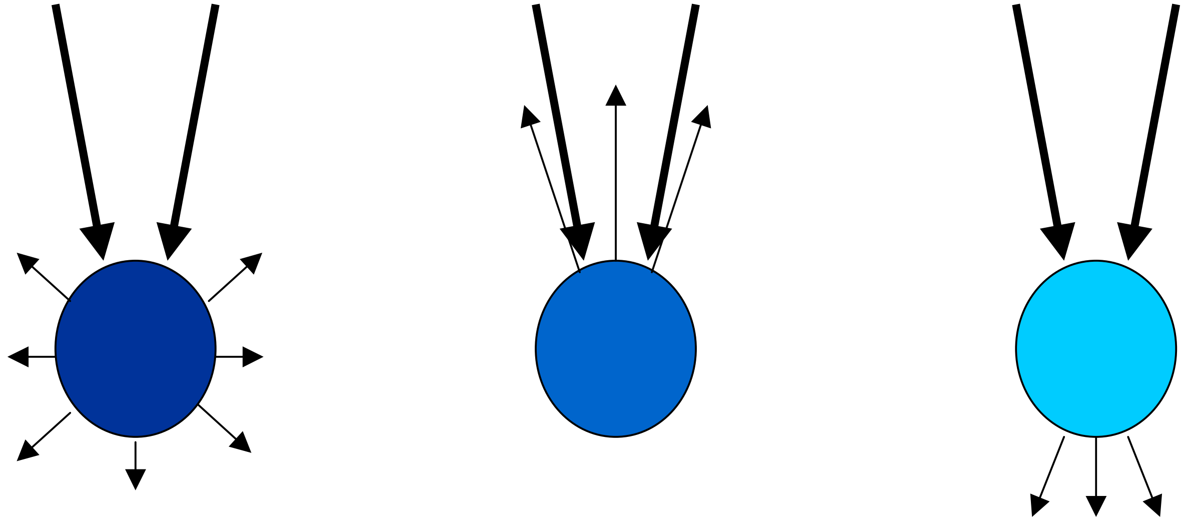
Plasma Effects 1



- Energy intensity 10^7-10^{10} W/cm^2
- Plasma onset for metals 10^6 W/cm^2

Plasma Effects 2

- Mechanisms on Incident Beam



Absorption and Re-irradiation (Inverse Bremsstrahlung)

'Plasma Mirror'

'Plasma Lensing'

Plasma Effects 3

Plasma Density (PD)

$$PD \propto I = E/(A^*\tau)$$

Where I=Intensity (W/cm^2), E=Pulse Energy (J),

A=Area of focussed spot (cm^2) and τ = Pulse duration (s)

Critical Density (ρ_c)

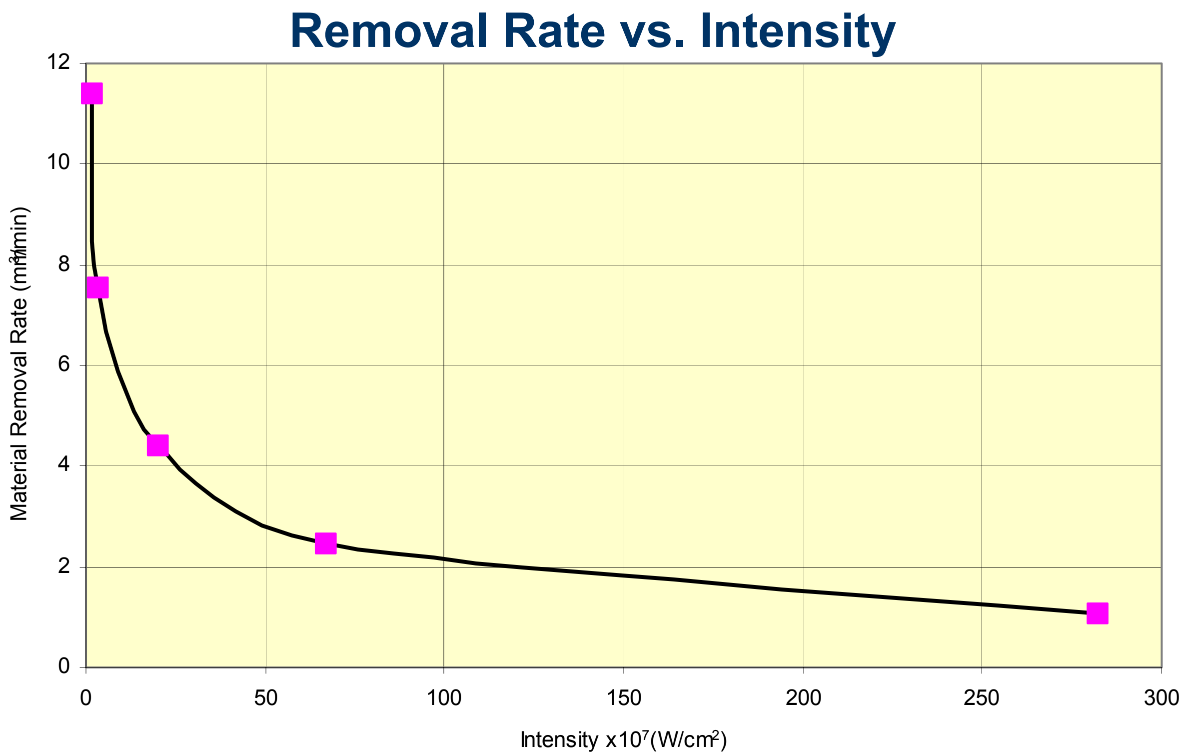
$$\rho_c \propto 1/\lambda^2$$

Where λ = Laser Wavelength

Laser Milling: Application

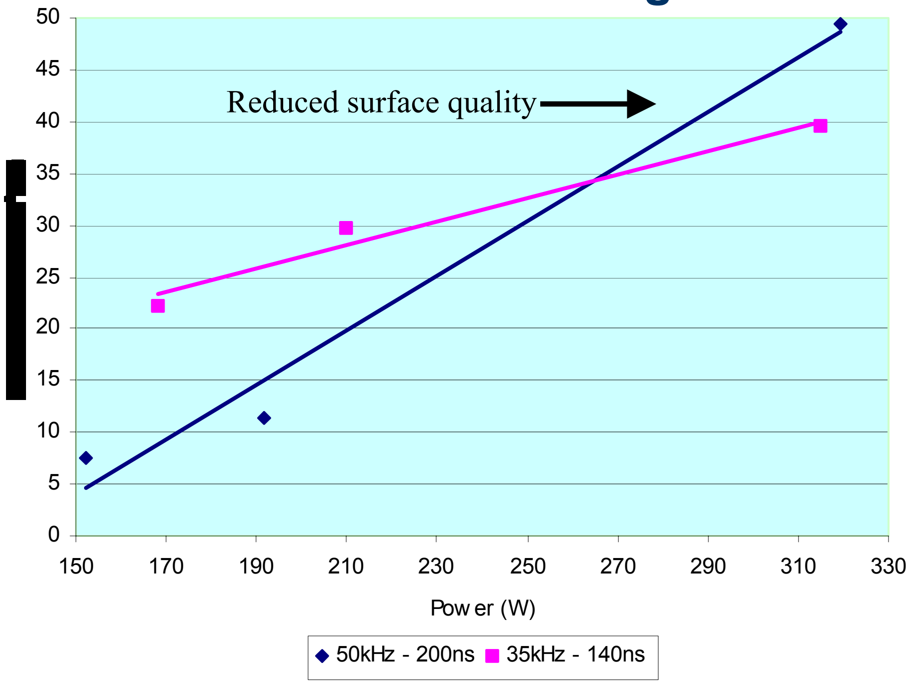
- **Application**
  - Machining 3D flow structures in superalloys
  - Aerospace and IGT sectors
  - Combined TBC removal (>30mm^3/min)
- **Target**
  - Commercially attractive material removal rates
  - Geometric accuracy
  - Low recast/HAZ
  - Potential for combined processing; multi-element milling and drilling

Laser Milling: Intensity Effects

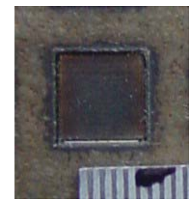


Laser Milling: ‘Plasma Braking’

Removal Rate vs. Average Power



1. High Intensity - $6.7x10^8 W/cm^2$



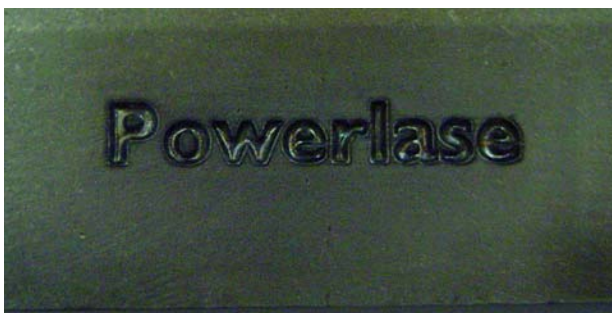
- High Quality
- Low Material Removal Rate - $2.5mm^3/min$
- Excess plasma shielding

2. Low Intensity - $1.2x10^7 W/cm^2$

- Low Quality
- High Material Removal Rate - $49.4mm^3/min$
- Insufficient plasma shielding

3. Optimal Intensity - $4.6x10^7 W/cm^2$
   - Acceptable quality
   - Commercial removal rate - $23mm^3/min$
   - ‘Plasma braking’

Laser Milling: Optimum Parameters

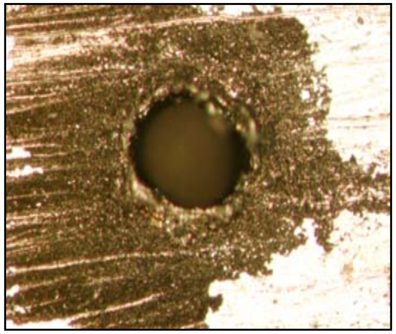


- **High Frequency 30-40kHz**
- **Power >200W**
- **Intensity 4-5x10^{7}W/cm^{2}**
- **Material Removal Rate >20mm^{3}/min**
- **Recast <40µm**
- **No Cracking**
- **3D Shapes Possible**
- **TBC Milling In Same Pass >30mm^{3}/min**

!Plasma control is key!

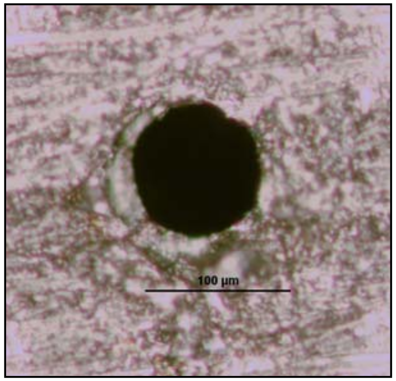
Fine Hole Drilling - Application

- Fuel injector drilling
  - <100µm diameter holes in 1mm thick stainless/tool steel (>10:1 aspect ratio)
  - Minimal taper (preferably reverse)
  - High degree of circularity (<3% variation)
  - Repeatability
  - Negligible dross at entrance and exit
  - Commercially competitive process time >1hole/30s
  - Replacement for EDM limited to 120µm+ holes
- Starlase EO12
  - <10ns pulse, 3.5kHz, 30W, low M2
  - Intensities of $10^9 W/cm^2$ - $10^{10} W/cm^2$



Percussion drilled

vs.



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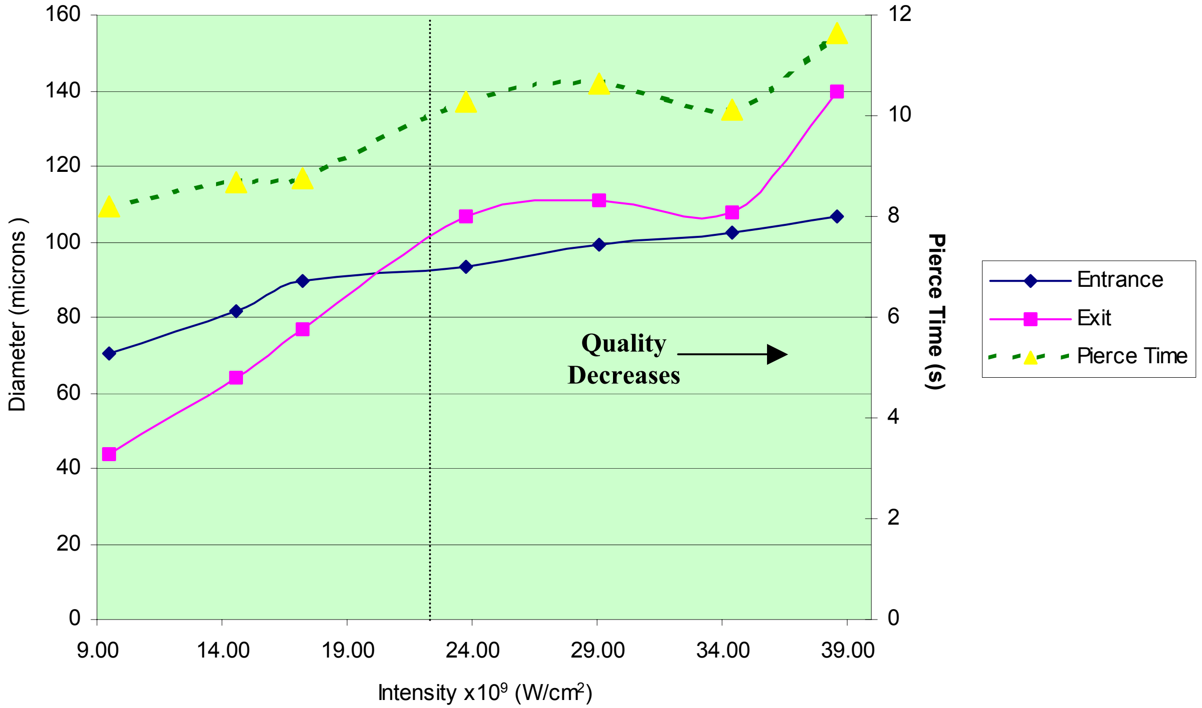
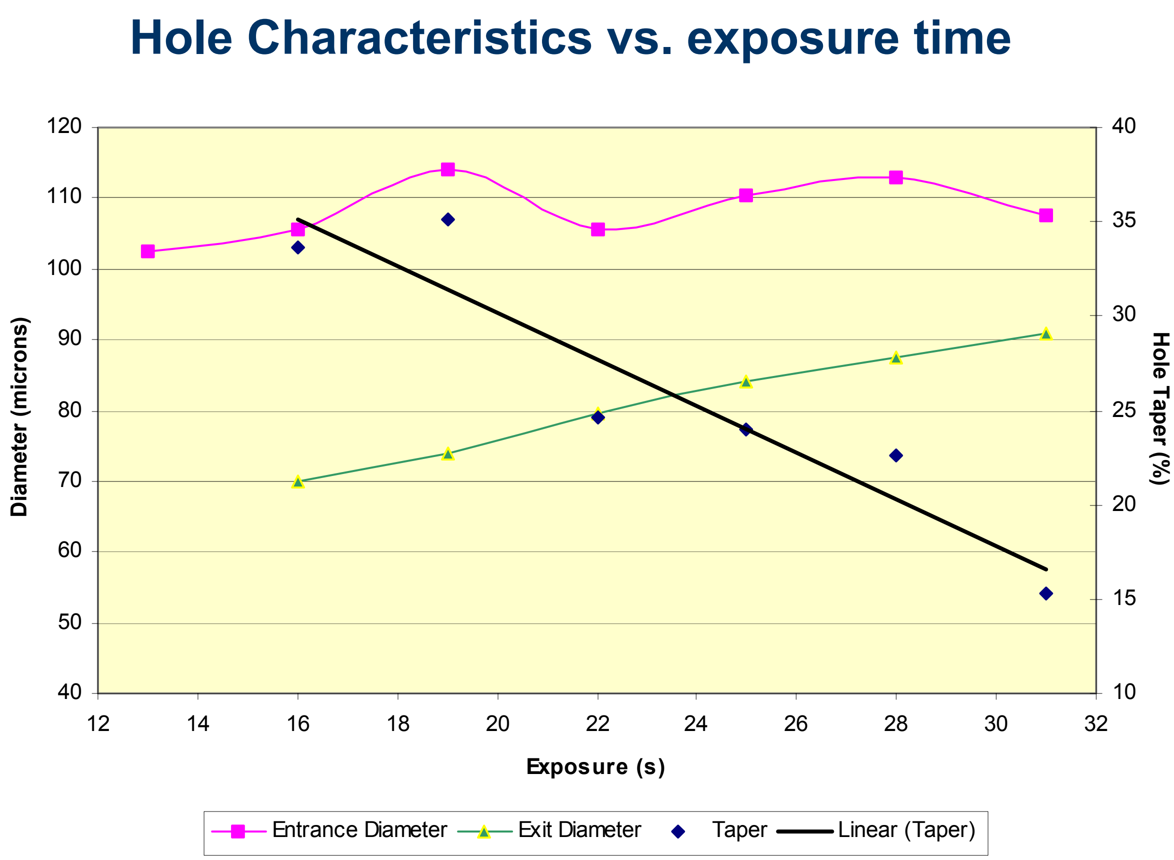
Fine Hole Drilling – Plasma Effects

Entrance, Exit Diameter and Pierce Time vs. Intensity

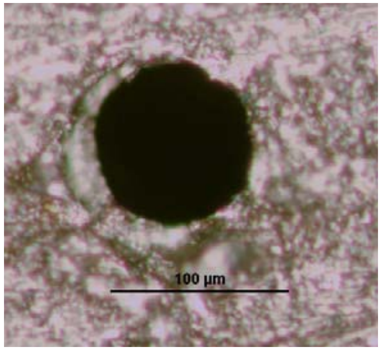


Fine Hole Drilling – Exposure

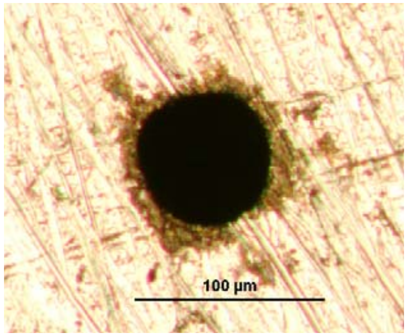


Fine Hole Drilling – Production

- **Achievements**
  - Holes <100μm diameter
  - Taper <10%
  - Circularity >5%
  - Variation <6%
  - Recast <20μm
  - Low dross entrance
  - Zero dross exit
  - 1 Hole in 20s Using 20% Power
  - Beamsplitting 12-15 holes/min!
- **Targets**
  - Eliminate/reverse taper
  - Eliminate entrance dross
  - Reduce recast
  - Improve repeatability



Entrance



Exit

Conclusions

1. Modern Q-switched DPSSL – mature industrial solutions
2. Plasma formation is inevitable for metal processing in ns regime
3. Understanding plasma effects – key for successful applications
4. Laser Milling of superalloys – commercially viable process
5. Laser Milling enabled by ‘plasma braking’
6. Fine Hole Drilling (fuel injectors) – close to commercial readiness
7. Plasma affects hole size, taper, circularity and quality

Questions?

www.powerlase.com