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Pulsed Fibre Lasers for Precision Marking, Engraving and Micromachining

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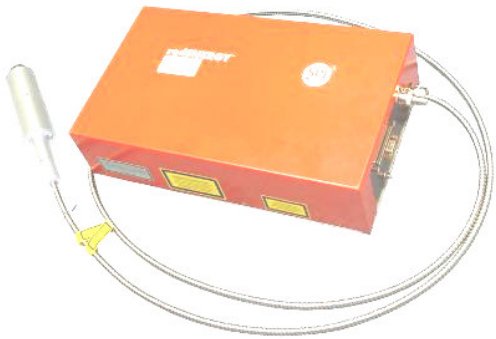
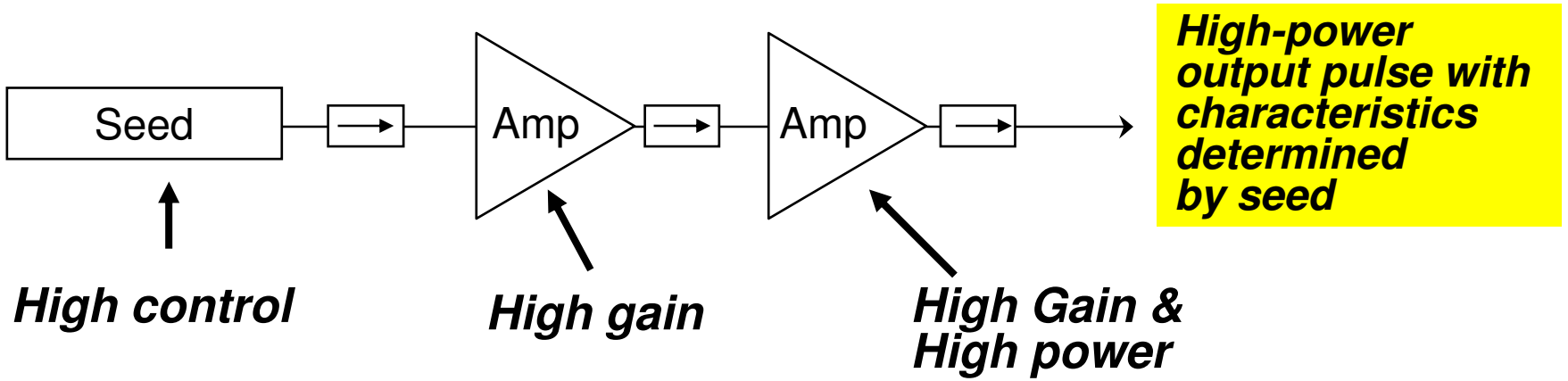
Agenda

- MOPA Architectures for ns Pulsed Fiber Lasers
  - Concepts and Advantages: Why MOPA?
  - Output Pulse Shaping
- High Peak-Power ns Pulsed Lasers
  - Fiber Laser technology & performance
  - Applications Examples
    - Scribing
    - Marking
    - Micromachining
- Summary & Conclusions

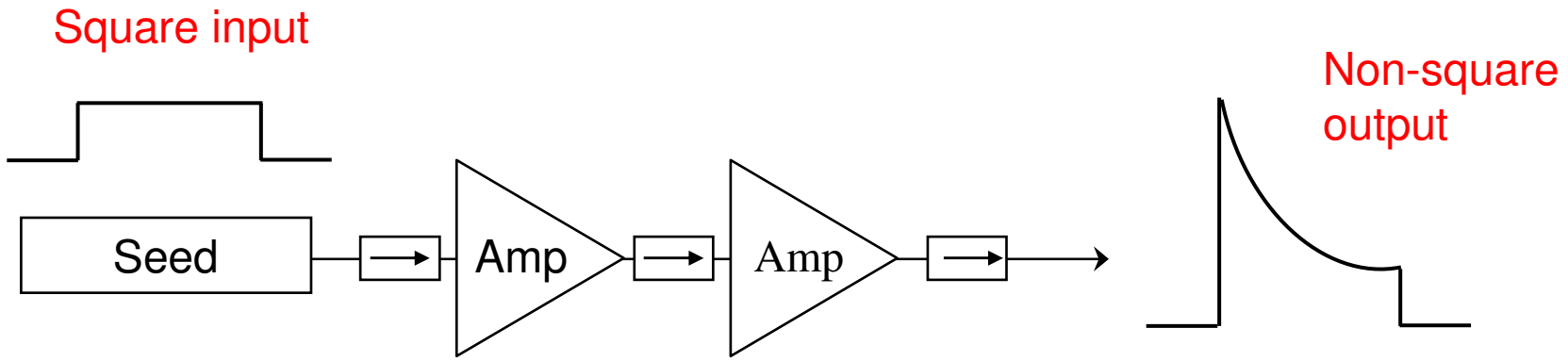


Introduction: Why MOPA Laser Architecture?

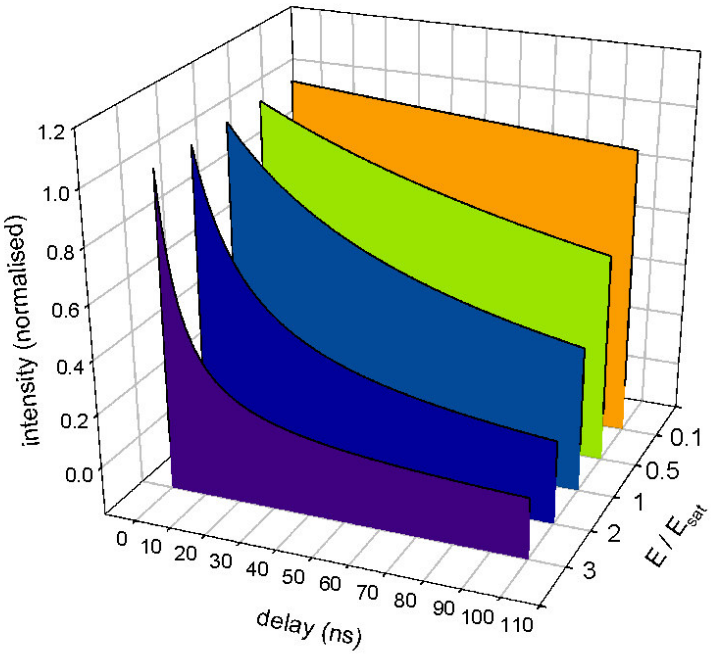


- Precision provided by low-power diode seed
- Fiber amplifiers provide high gain, high power, ready cascadability and dynamic control
- Combined seeded-MOPA allows projection of seed properties to high pulse peak-power levels

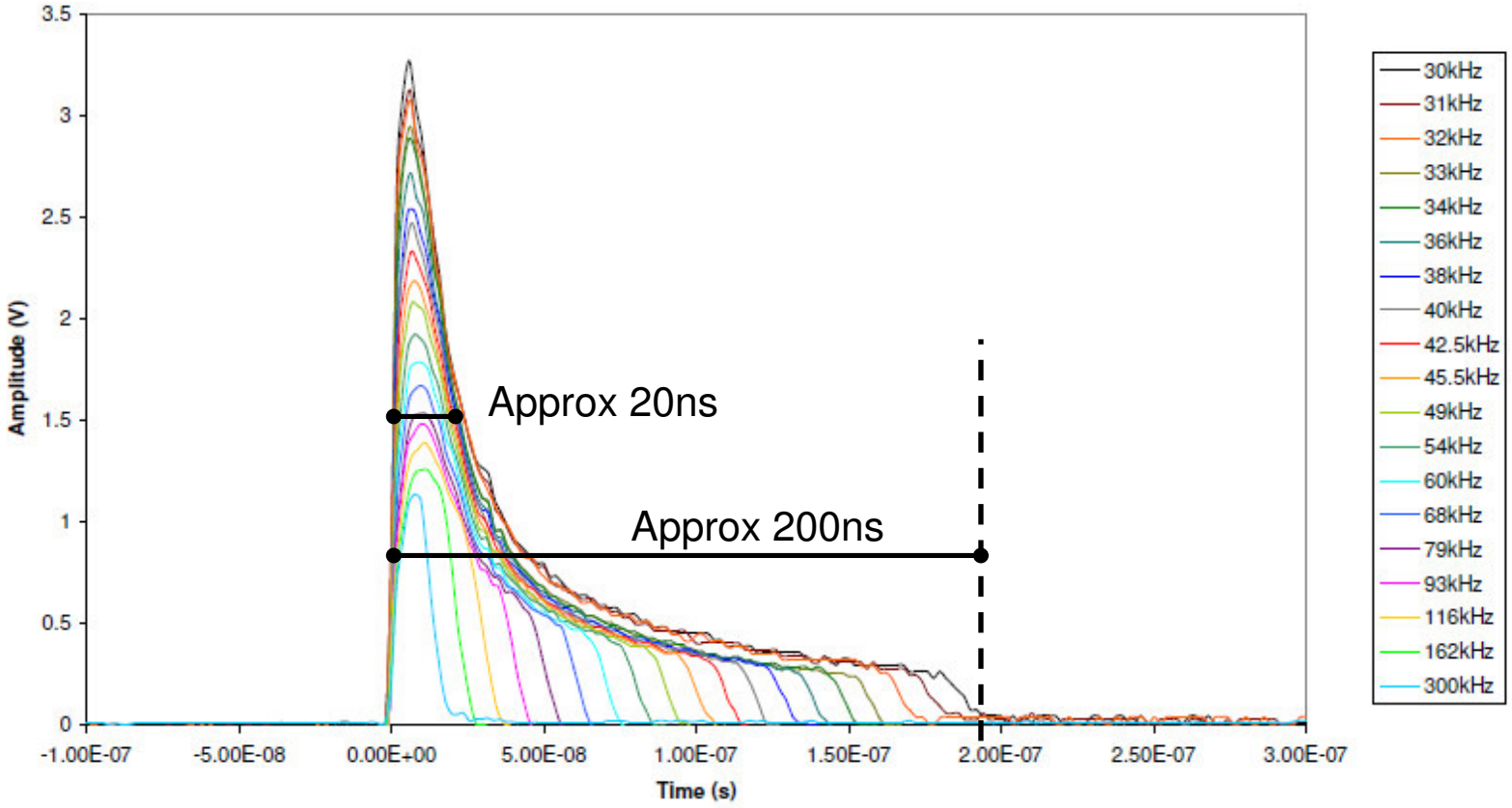
Pulse Shaping due to Amplifier Gain Saturation



- As the pulse output energy approaches the saturation energy the amplifier inversion (gain) varies across the pulse duration, leading to significant pulse distortion.
- This distortion produces pulse shaping with preferential gain at the leading edge, giving higher peak-power
- Pulse duration and gain shaping can be tailored to application needs



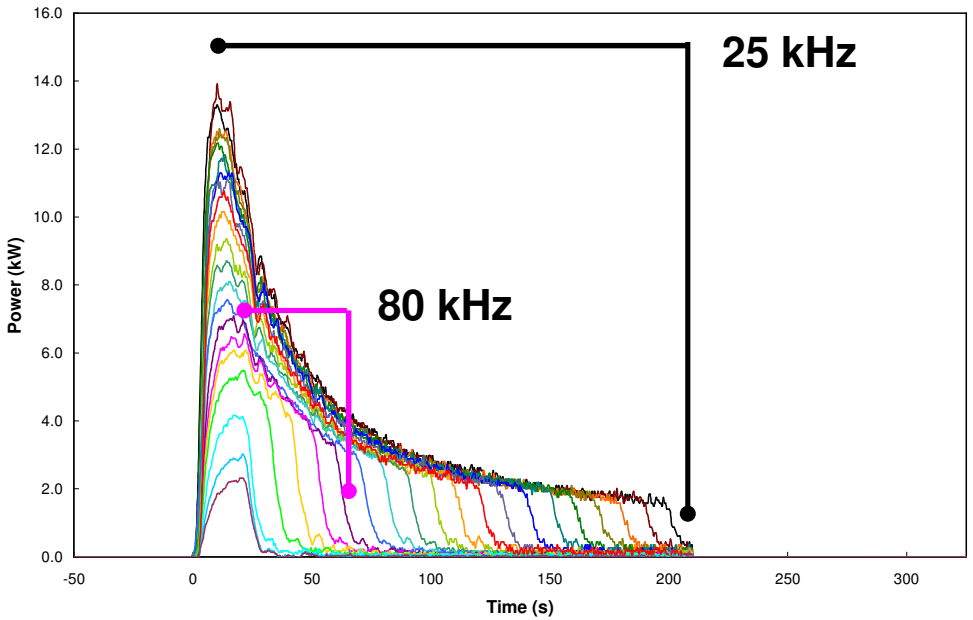
Seeded MOPA: Gain-Shaped Optical Pulses



- Pulse Duration, Repetition Rate and Pulse Peak Power can be independently selected and controlled
- High Peak Powers can be achieved at High PRF by deliberately shortening seed pulse duration

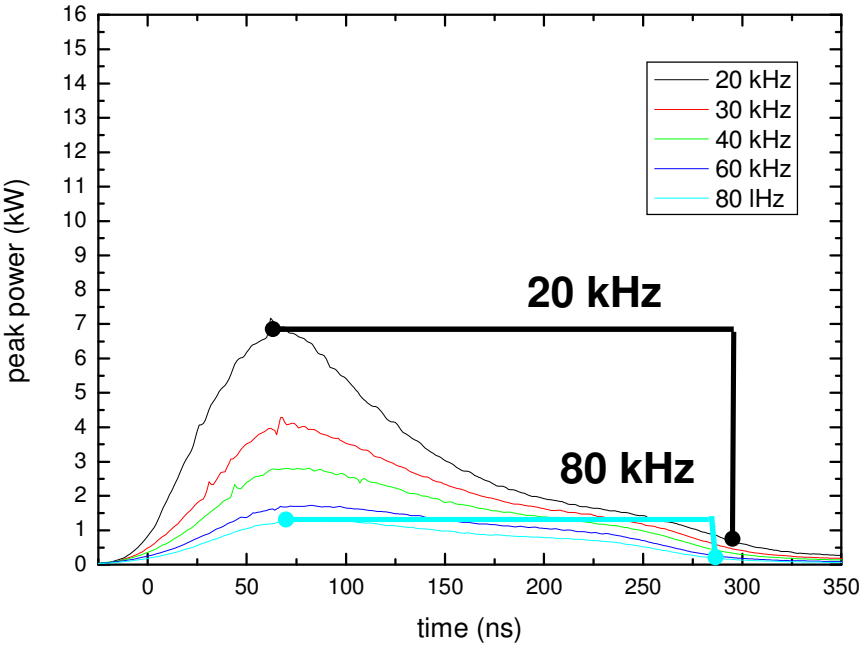
Comparative Performance: Seeded MOPA FL vs Q-Switched FL

20W Seeded MOPA



Reducing pulse duration as PRF is increased holds peak-power high

20W Q-Switched Fiber laser



Peak-power decays significantly as PRF is increased

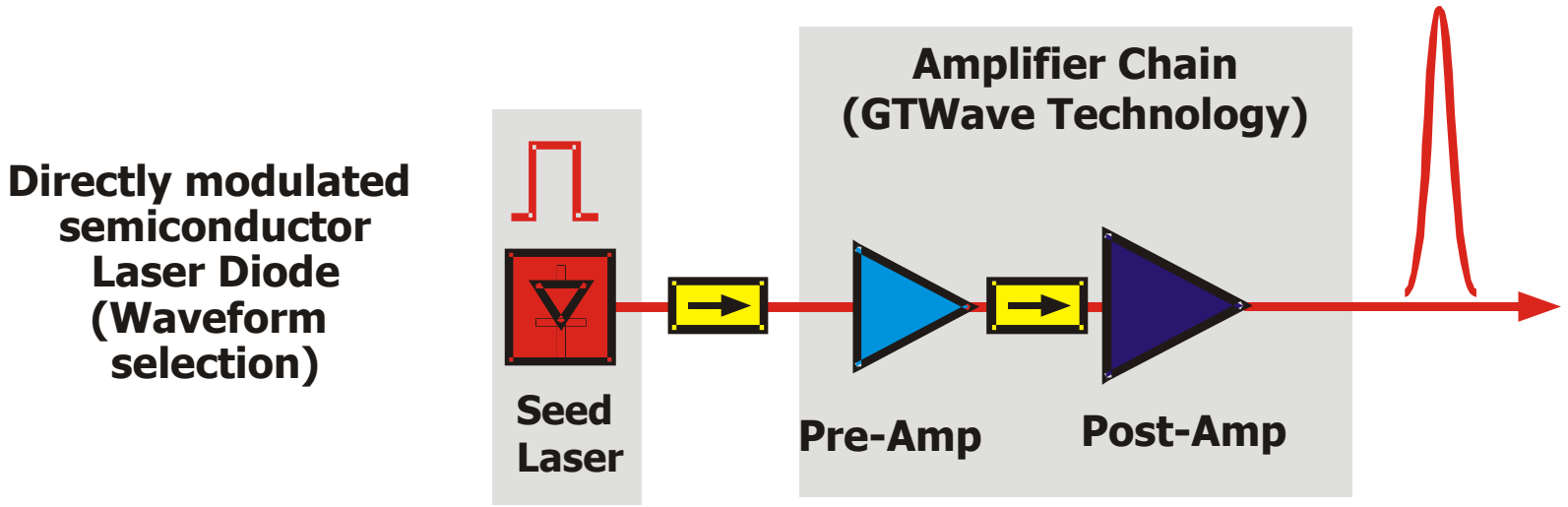
Marking & Micromachining with ns Pulsed Lasers

"....SMART Laser….but how does it benefit my applications?"

Processing Applications

- The majority of materials processing applications are governed by:-
  - **Peak pulse power** - which is typically required to overcome processing thresholds.
  - **Pulse energy** - which governs the amount of thermal energy available to effect any material processing.
  - **Pulse duration** - which impacts the beam material interaction time.
  - **Power Density** – which reflects the intensity of the laser energy on the substrate.
- It is a combination of all four of these parameters that needs to be considered in pulsed laser materials processing applications.

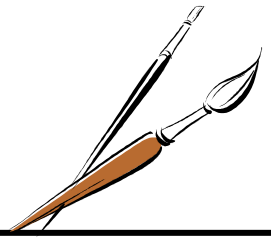
SPI Pulsed MOPA Fiber Laser

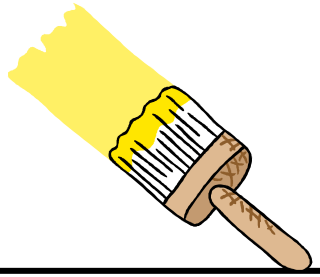


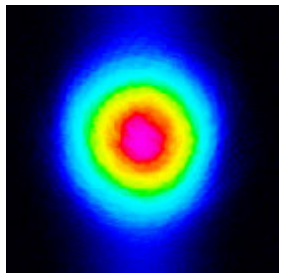
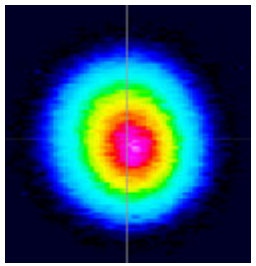
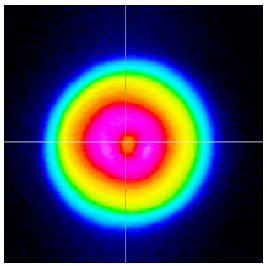
- Preconfigured beam source with Waveform Selection on Demand
  - Waveforms stored within the control FPGA
    - Selectable on demand and “on the fly”
    - RS232 switching or External Hardware (Digital TTL)
  - Average Power, Peak Power, Repetition Rate independently variable
    - Extensive process space from a single source

Tailored Beam Quality & Pulse Energy

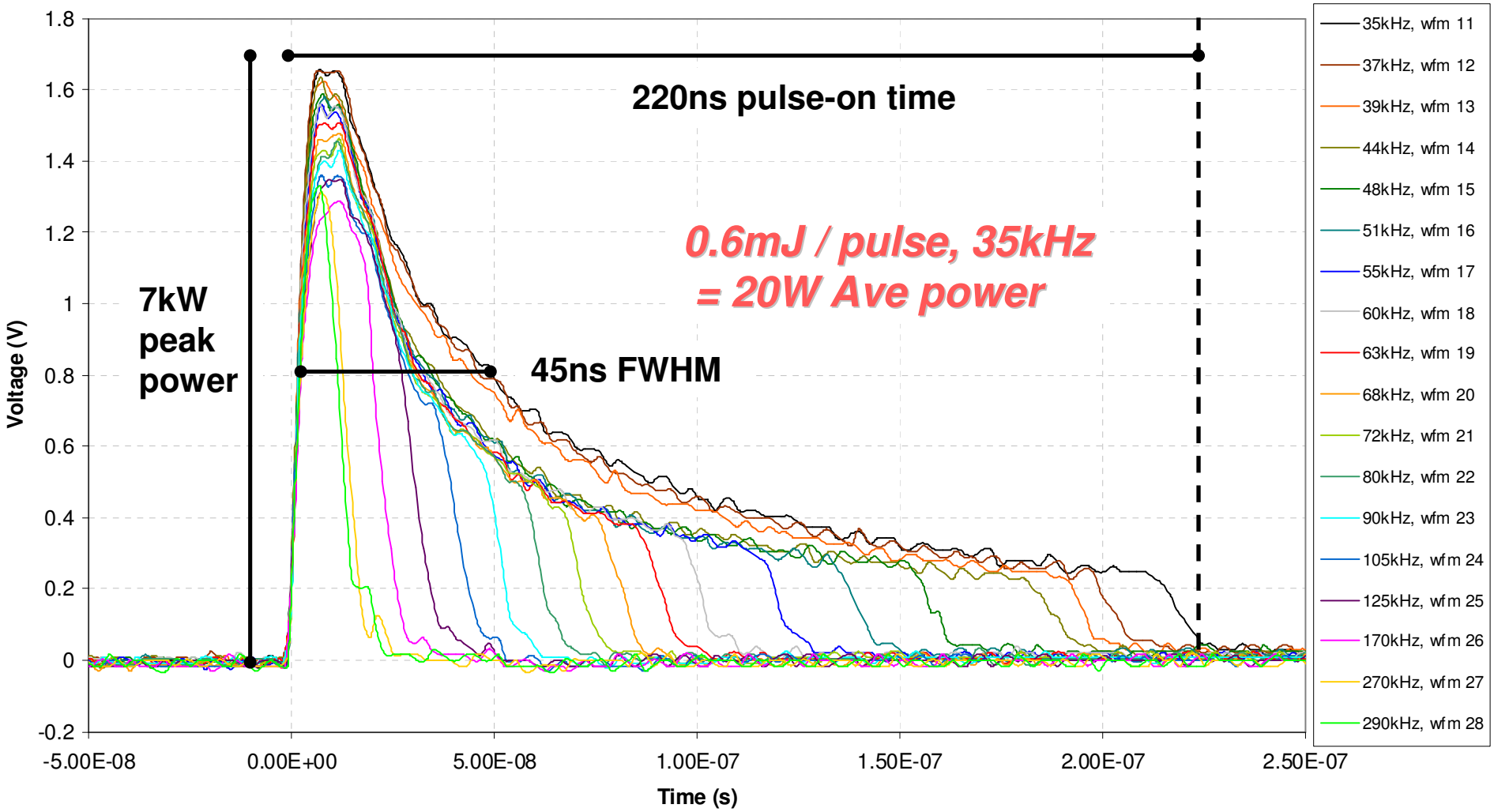
The right tool for every job!





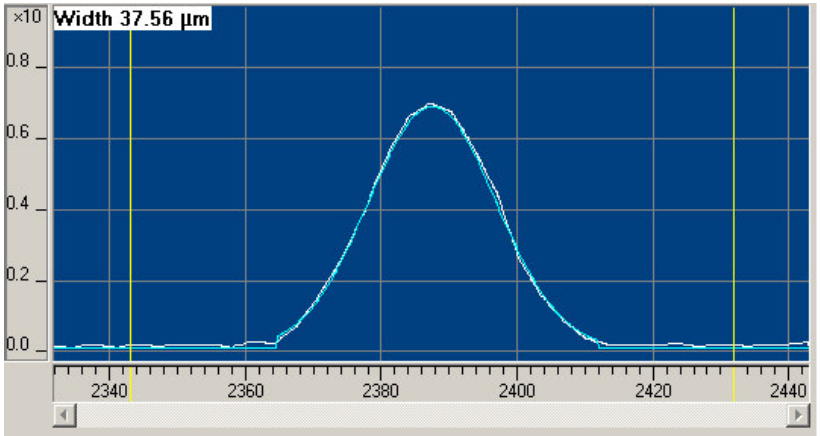
Series	SM	RM/HS	HM
M^2	<1.3 	<2 	~3.2 
Key attribute	**Fine feature <25micron**	**Multi purpose 35-80micron**	**Wider lines >60micron**
Application	**Scribing & fine marking**	**General marking and micro-machining**	**Wide marks deep engrave area/logo**

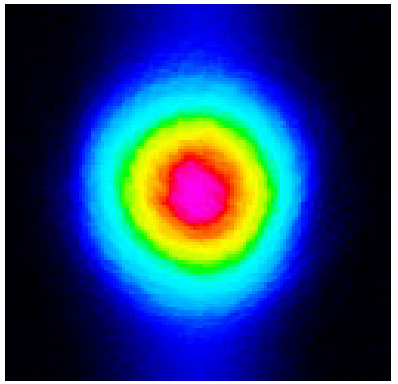
SM Pulse Characteristics @20W Average Power for 18 Preset Pulse Waveforms

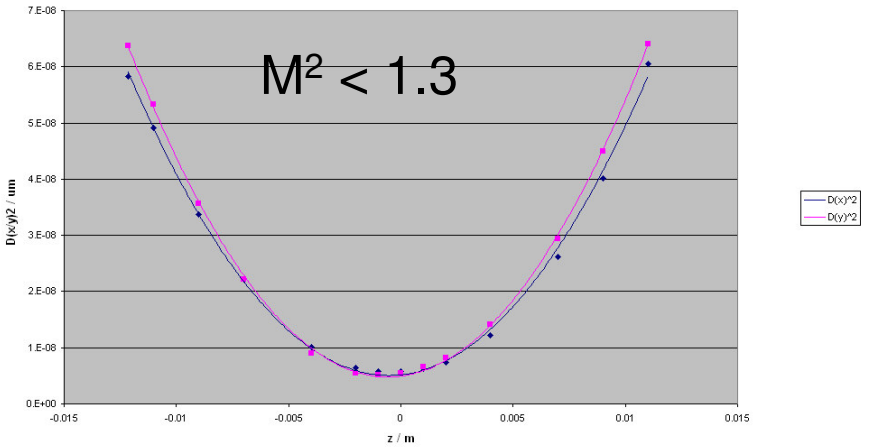


“SM”: Single-Moded Beam Quality

- For Applications requiring higher precision and finer lines – particularly for solar scribing

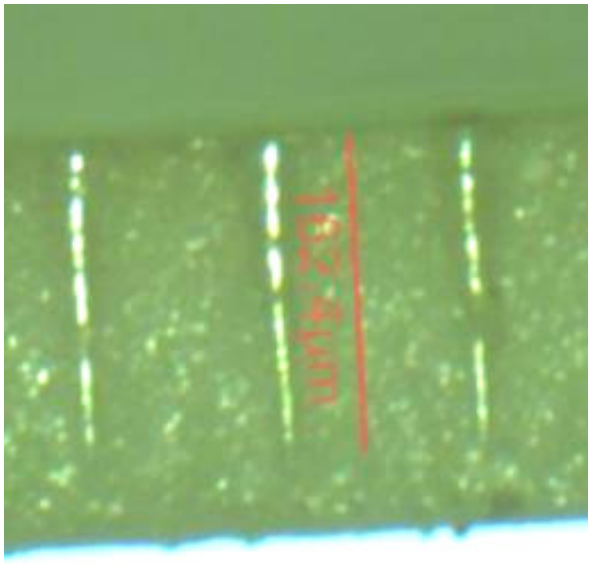






Application Case Studies: SM Laser Ceramic Drilling / Scribing

- SM Laser @ 20W, 0.6mJ/pulse (WF0)

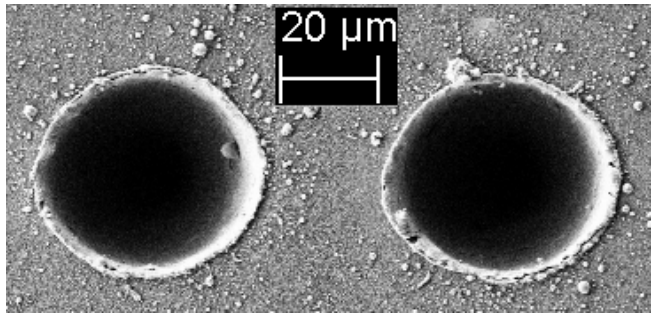


Feature Quality (Hole diameter & Depth)

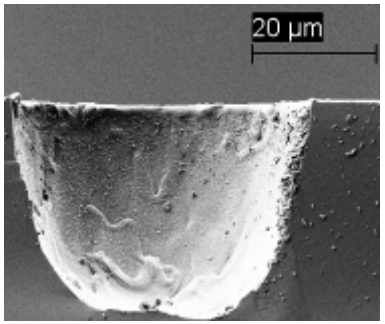
- Hole size 15% smaller than with $M^2 \leq 2$ HS laser
- Hole depth 30% deeper than with HS laser

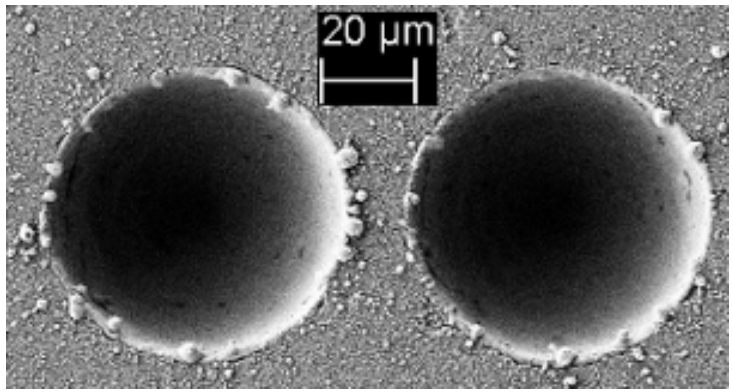
Silicon Drilling with SM Laser

- Blind holes 35kHz WF0, 10 pulses as processed

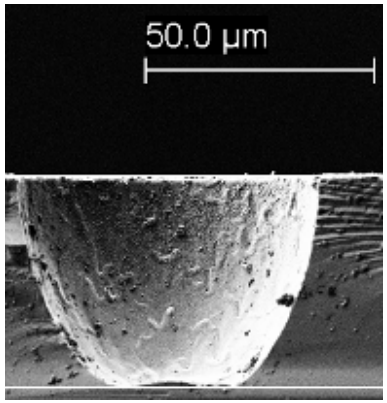


@ 10W
Entry hole
<40µm





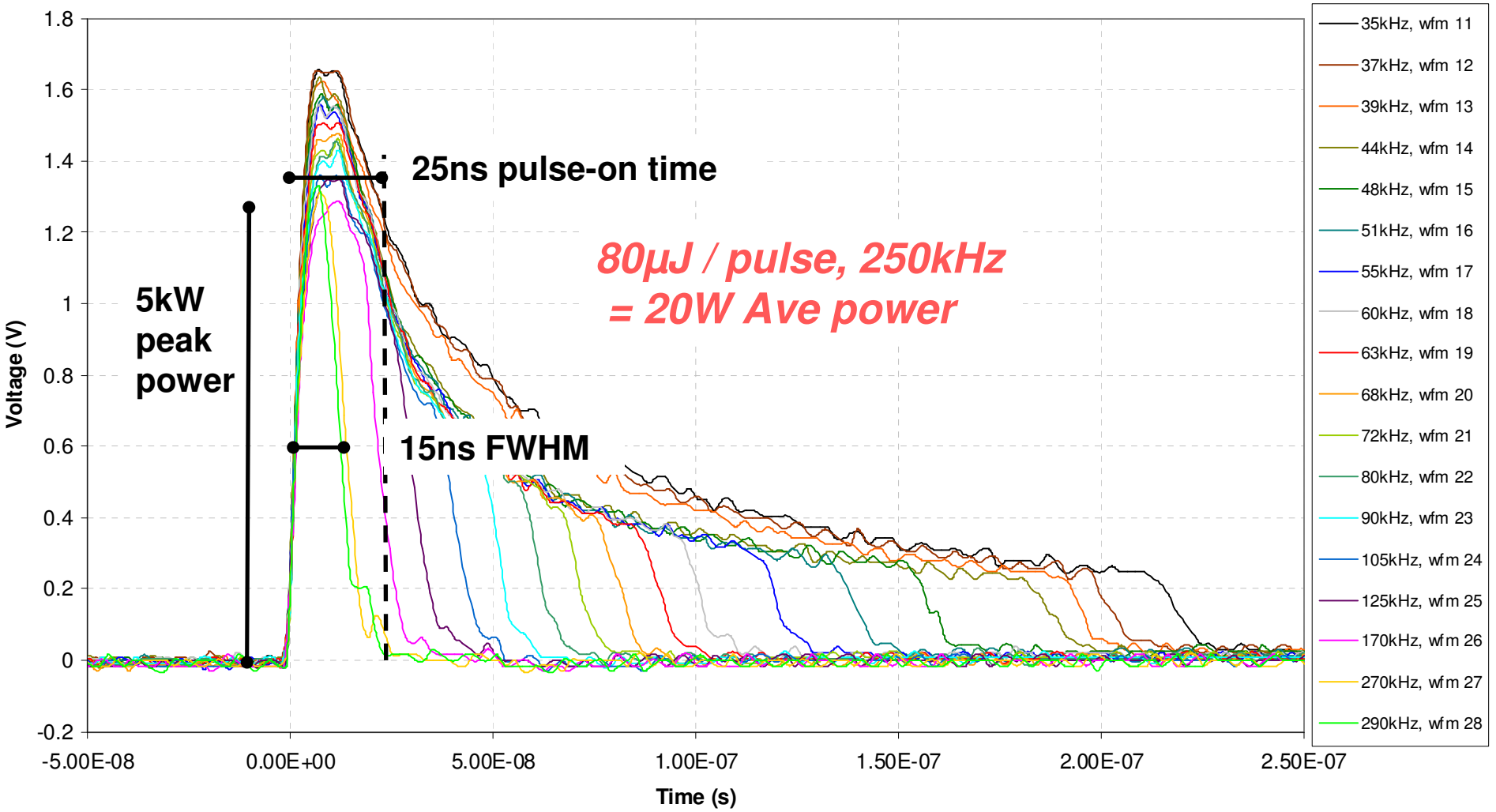
@ 20W
Entry hole
<50µm



SM hole is 30% smaller than with $M^2 \leq 2$ HS Laser

Images courtesy of Cambridge University

SM Pulse Characteristics @ High PRF @20W Average Power

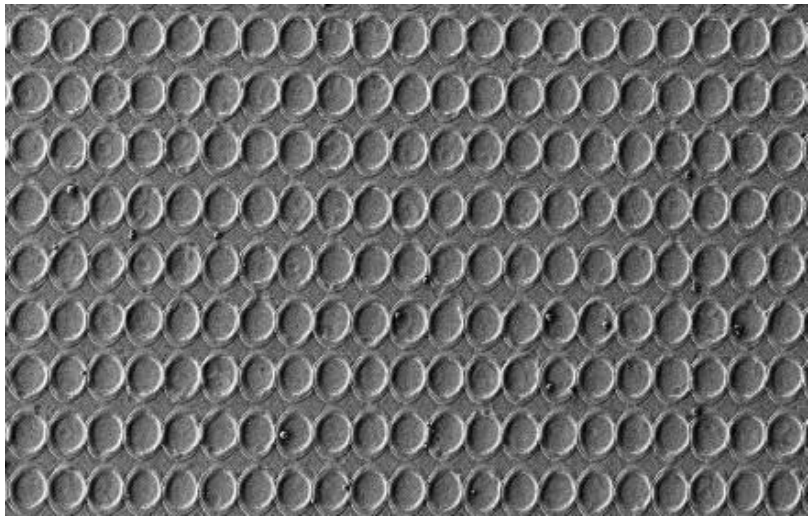


- Each trace is a different wfm at PRF0

Pulse Stability & Repeatability

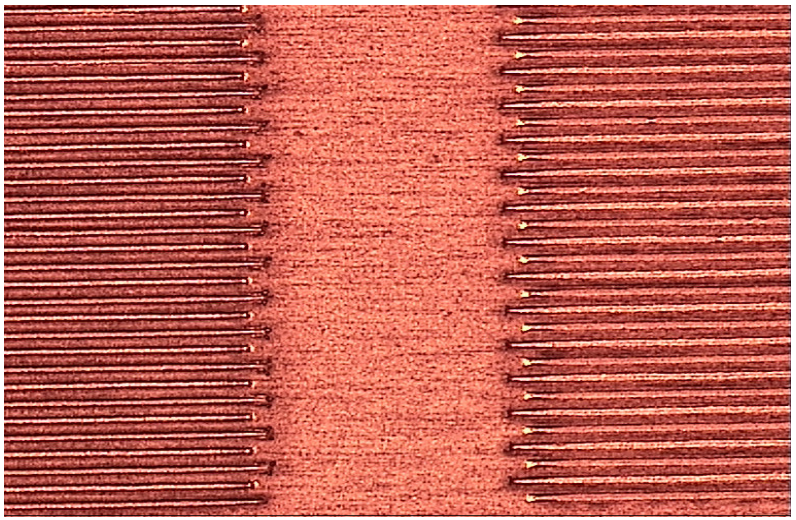
- Example marks on stainless steel
  - Out-standing pulse-to-pulse stability, even at low power

Array of spots with SM Laser
6W Average Power



Mark geometry and uniformity evidence pulse stability

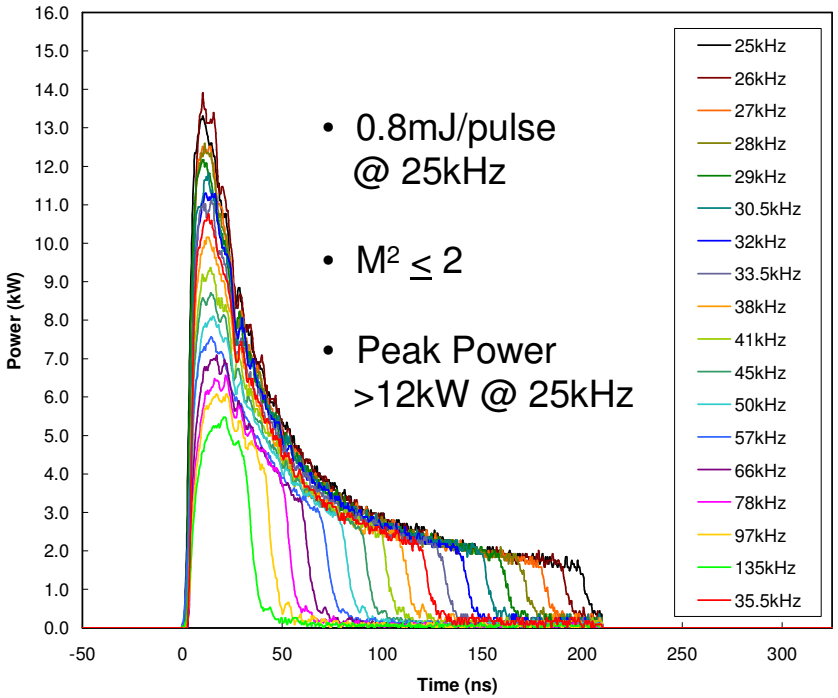
Line scan, 250kHz PRF
50 µm line spacing, 2m/s scan



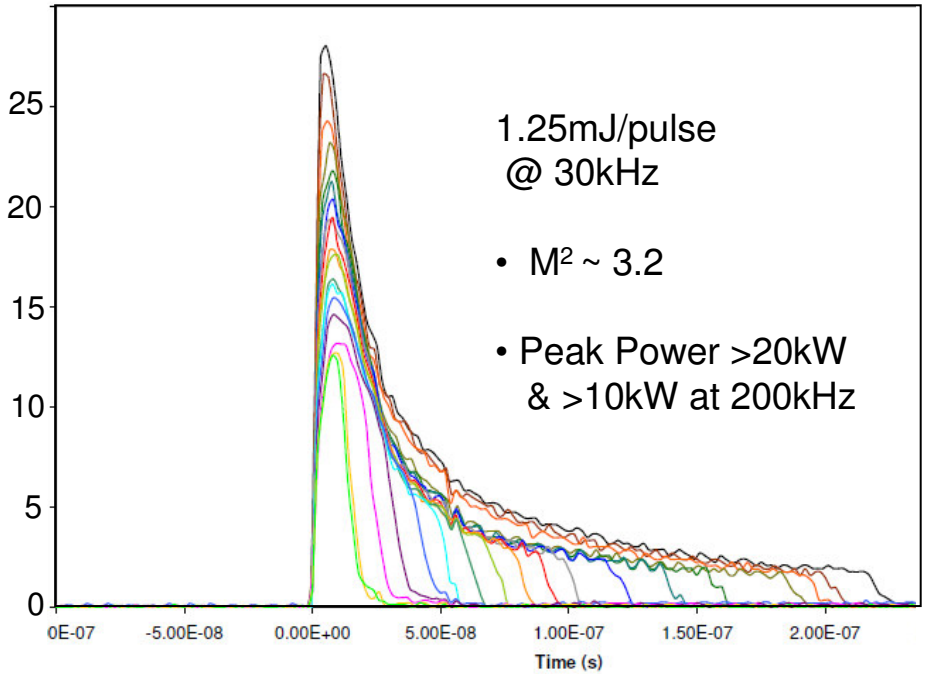
On Off On

20W $M^2 \leq 2$ "HS" & 40W M^2 ~ 3.2 "HM" Pulses

20W "HS"



40W "HM"

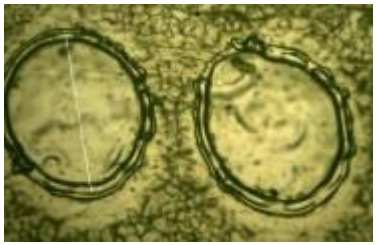


Higher Pulse Energy and Peak Power
from Low-Moded Fibers traded against increased M^2

Standard Dark-Engrave Marking (20W)

- Marking of ferritic stainless steel engineering parts
  - Part numbers
    - ✓ Single pass
    - ✓ Filled fonts
    - ✓ Outline fonts

Spot Overlap: Marking quality up-close
(one of several quality measures)



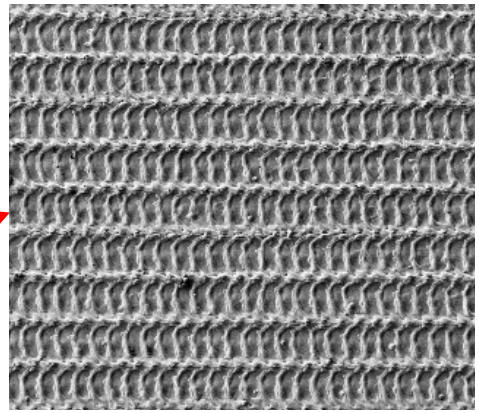
No Spot Overlap
- ***visible mark***
- ***poor resolution***
- ***dotted-line***

<5% Spot Overlap
- ***improved mark***
- ***low resolution***
- ***"scallop" edge***

>60% Spot Overlap
- ***desired mark***
- ***high resolution***
- ***smooth line edge***

Spot overlap is a key visual factor in determining mark quality

- Greater overlap produces a more continuous mark appearance
- >60% overlap desired for many marking applications



Metal Marking
(Black anneal mark on 304 Stainless Steel)

- Criteria:
  - Black anneal mark
    - An anneal mark is created by enhancing the oxide layer thickness. This phenomenon is produced by extremely fine control of time at temperature (must avoid melting).
  - Wide viewing angle without bright reflection
    - Requires formation of "blue" oxide, rather than melted steel

* Image courtesy of Miyachi Unitek

* Image courtesy of LMco

Metal Marking
(Color Marking on Stainless Steel)

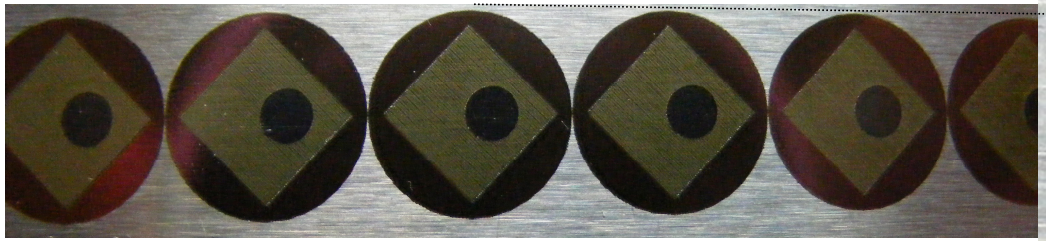
- Niche application but potentially high volume
- High repetition rates gives better contrast colours
- Higher repetition rate allows better control

* Image courtesy of A&P Instruments Co Ltd

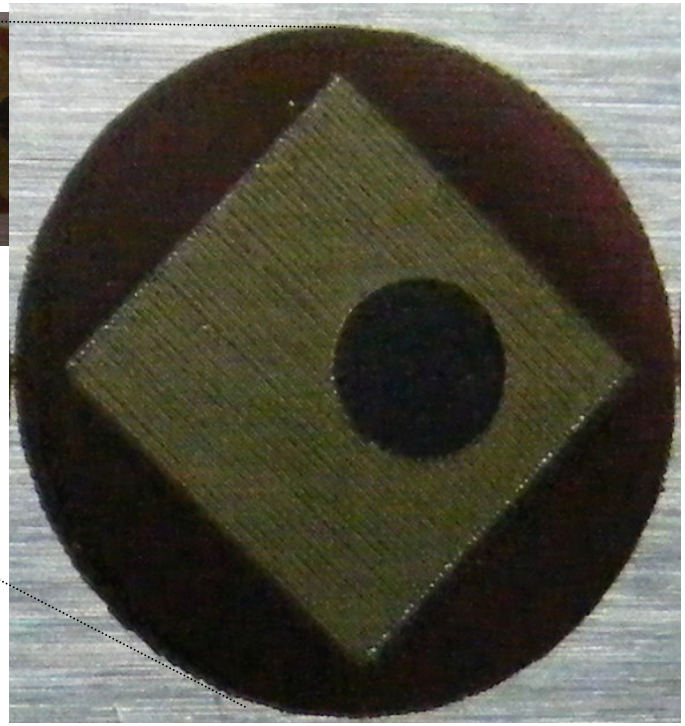
* Image courtesy of Electrox

Example Applications: Decorative marking

- Decorative boarders can be readily produced with high levels of consistency between elements

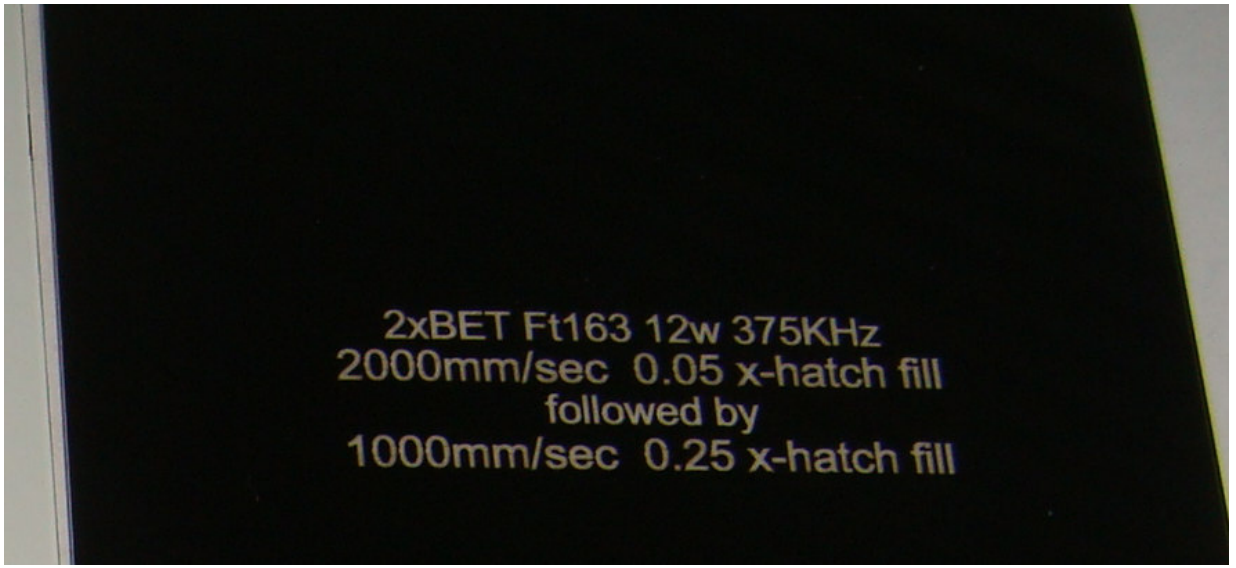


Sample courtesy of Electrox Ltd



- At high magnification the line scan base of the image can be seen.
- Fill patterns and edging to enhance strong colour block definition is employed.

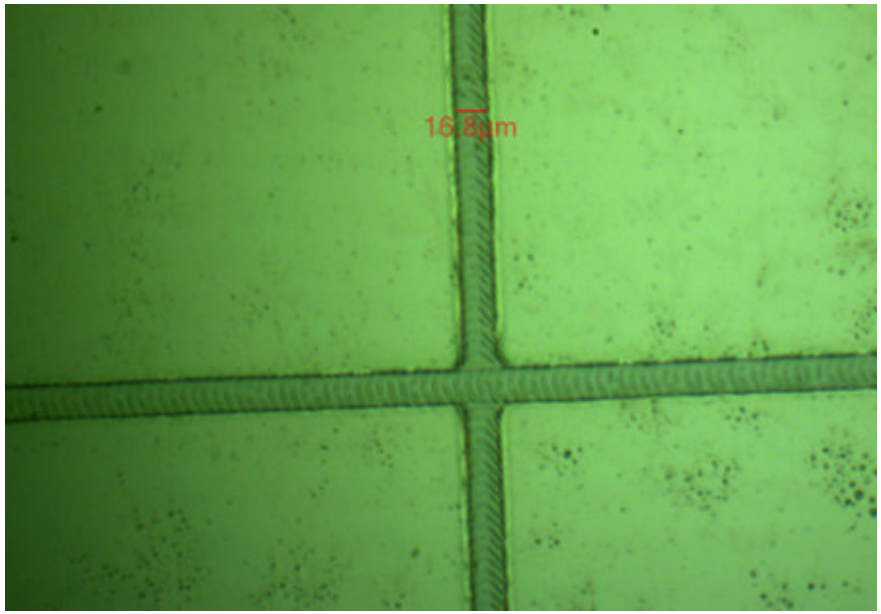
Thin Film Ablation: Ablation on Glass Screen using 375kHz Pulses



Requirement for absolute removal of thin film from coated display glass for subsequent metallisation - High repetition rate, high peak-power, high-speed scan provides reliable cost-effective solution

Thin Film Removal

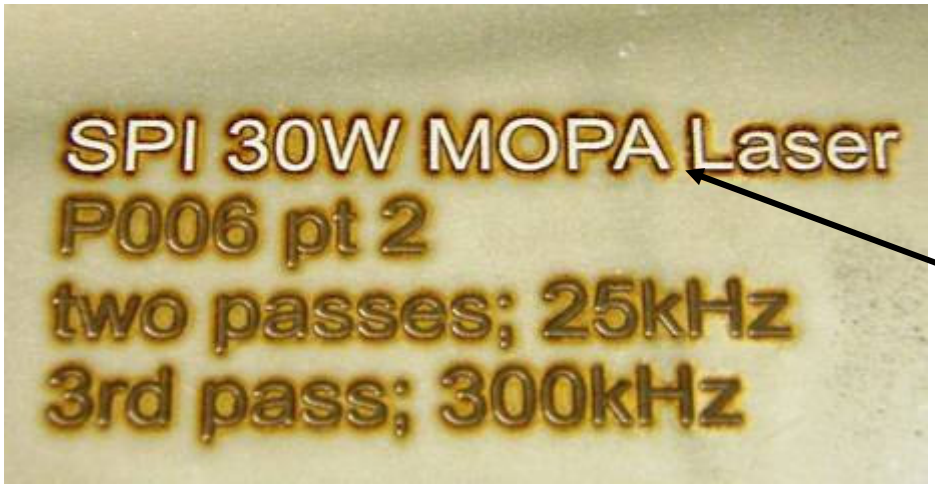
- Application: ITO removal from plastic substrate
  - Fast speed low average power
    - High pulse rate, low pulse energy
      - SM Laser
      - 500kHz PRF
      - 3000mm/s scan
    - Good isolation
    - Excellent depth of field



Metal engraving

- Engraving:
  - slower speeds
  - or higher pulse energies
  - or higher peak powers
- Using short 80-100mm F-theta >8mm beams

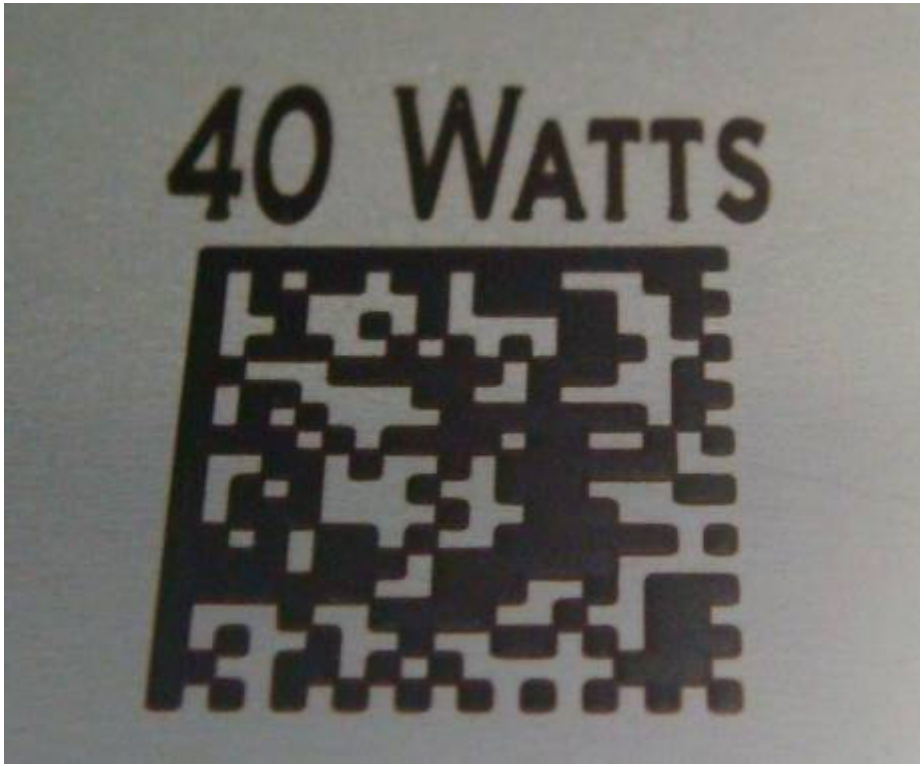
Detailed stamp engraved with 20W HS
Image courtesy of ACSYS GmbH



Multi pass engrave with 30W HM utilising 2 high pulse energy passes and a 3rd smoothing pass at high rep-rate (top line of image only)

Black Anneal Mark

- 40W Higher mode coupled with high rep rate gives exceptional results
- Data matrix 10mm sq
- **WF1 75kHz**
- 35micron fill, 225mm/s
- 2 pass
- Total mark time 17.5sec
- Note edge quality!



Deep Metallic Engraving

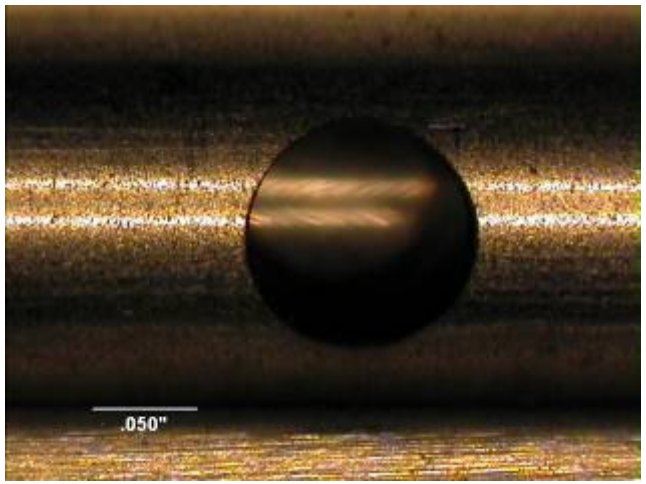
- 40W HM
- Capable of deep marking (350um)
- Small spot size via short focal length lens and high beam expansion
- High Rep Rate "cleaning pass" to improve finish

Cutting with Pulsed Laser

- The high peak power and power density can achieve excellent results in scanner based multi pass fine cutting

Copper

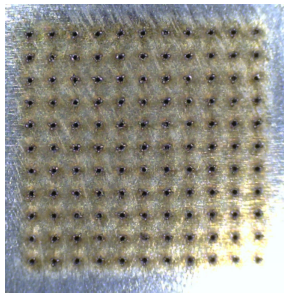
Aluminium



Images courtesy of Miyachi Unitek

Stainless

IN SUMMARY



FLEXIBLE TOOL, DIVERSE APPLICATIONS!
Tailored Pulse characteristics give processing flexibility for multiple application / materials / targeted features

Images and samples courtesy of: Miyachi Unitek, Electrox, LMCo & Orotig