Introduction to Picosecond Laser Tutorial

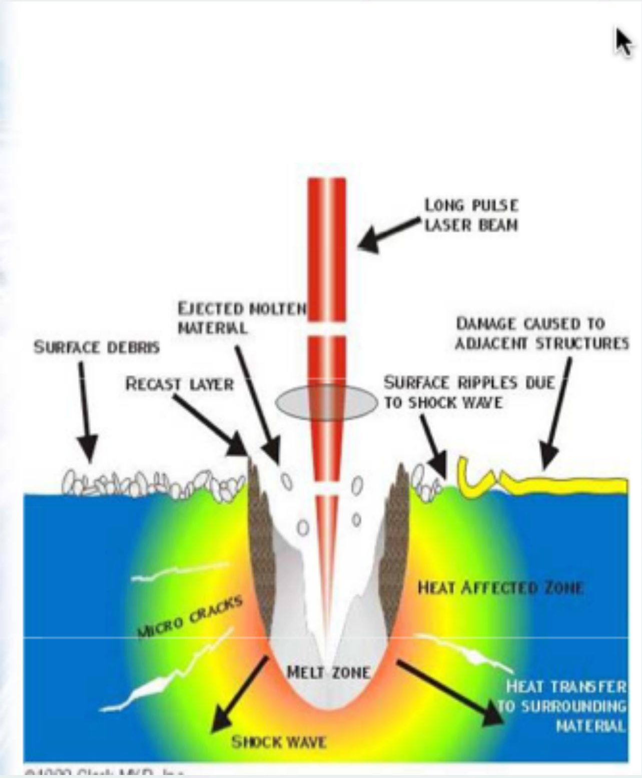
CMC Laboratories, Inc.

Pico-second

- Ultra-short light pulses
- 1 picosecond is 10^{-12} seconds
- Light travels 300,000,000 meters per second, in 3 picoseconds it travels 1 mm

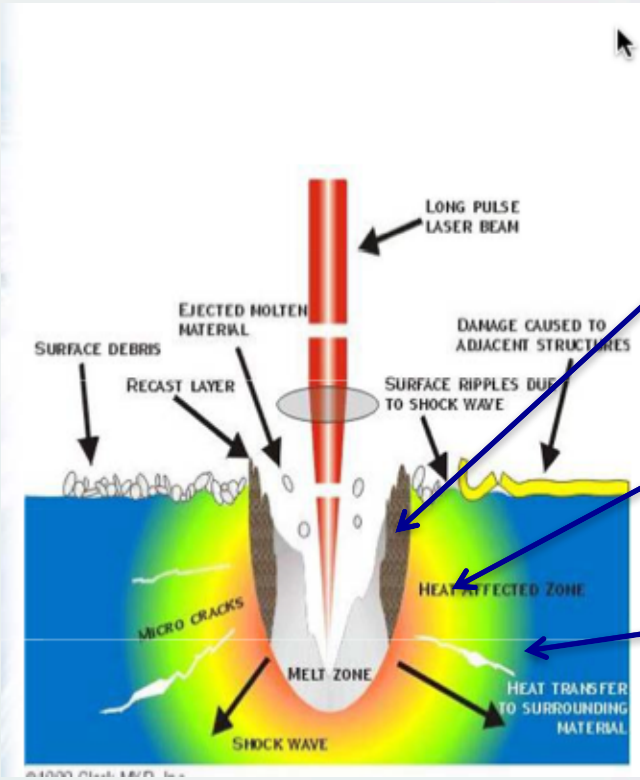
Why Process with Ultra-Short Pulses?

- Long laser pulse processing (typically 10 nanoseconds or longer)
  - High average power, low peak power
  - Thermal drilling (drill by injecting heat into the substrate at the drill site)
  - Injected heat melts and vaporizes the substrate material



Schematic- Thermal Drilling Process

Issues with thermal drilling

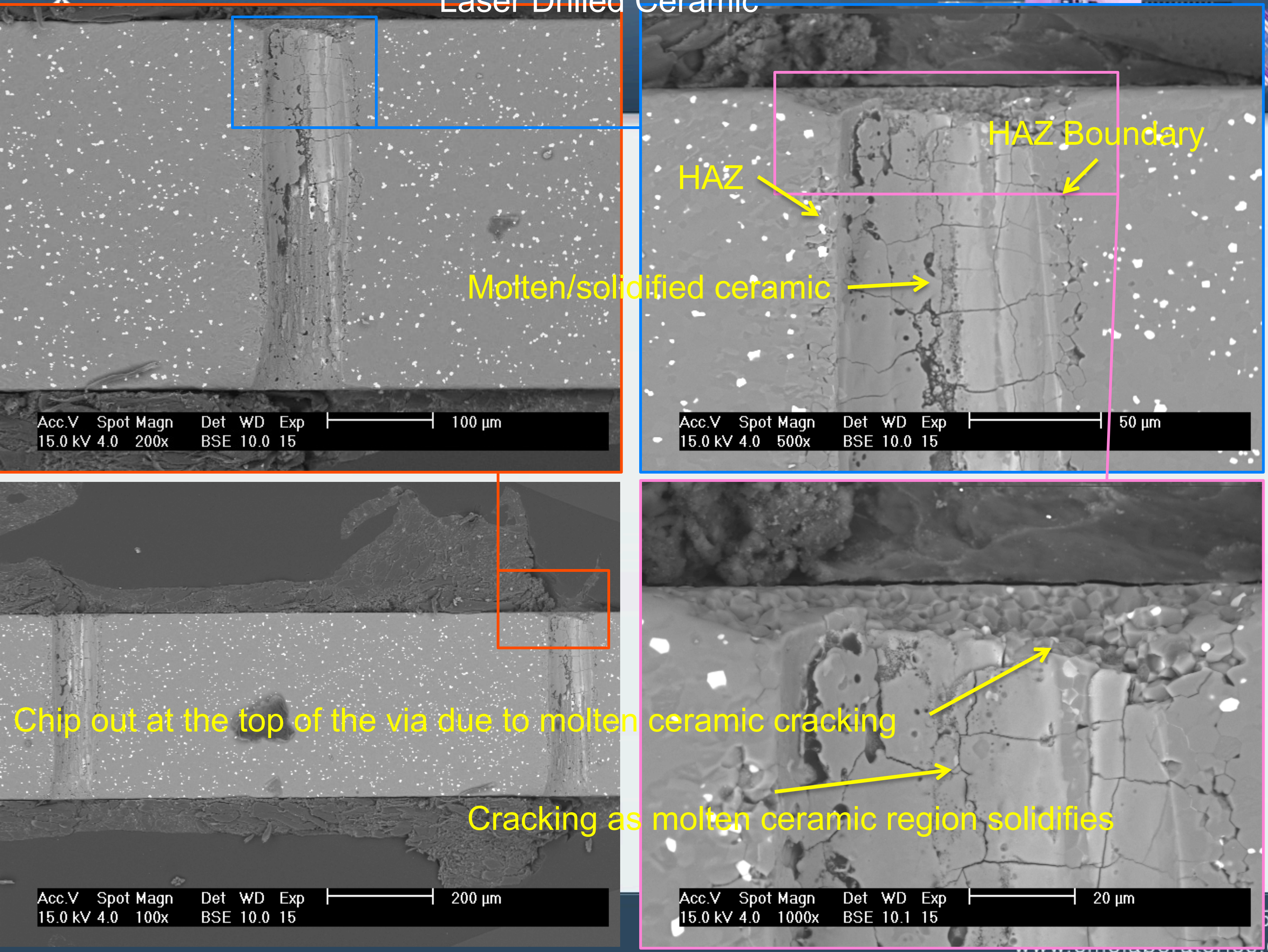


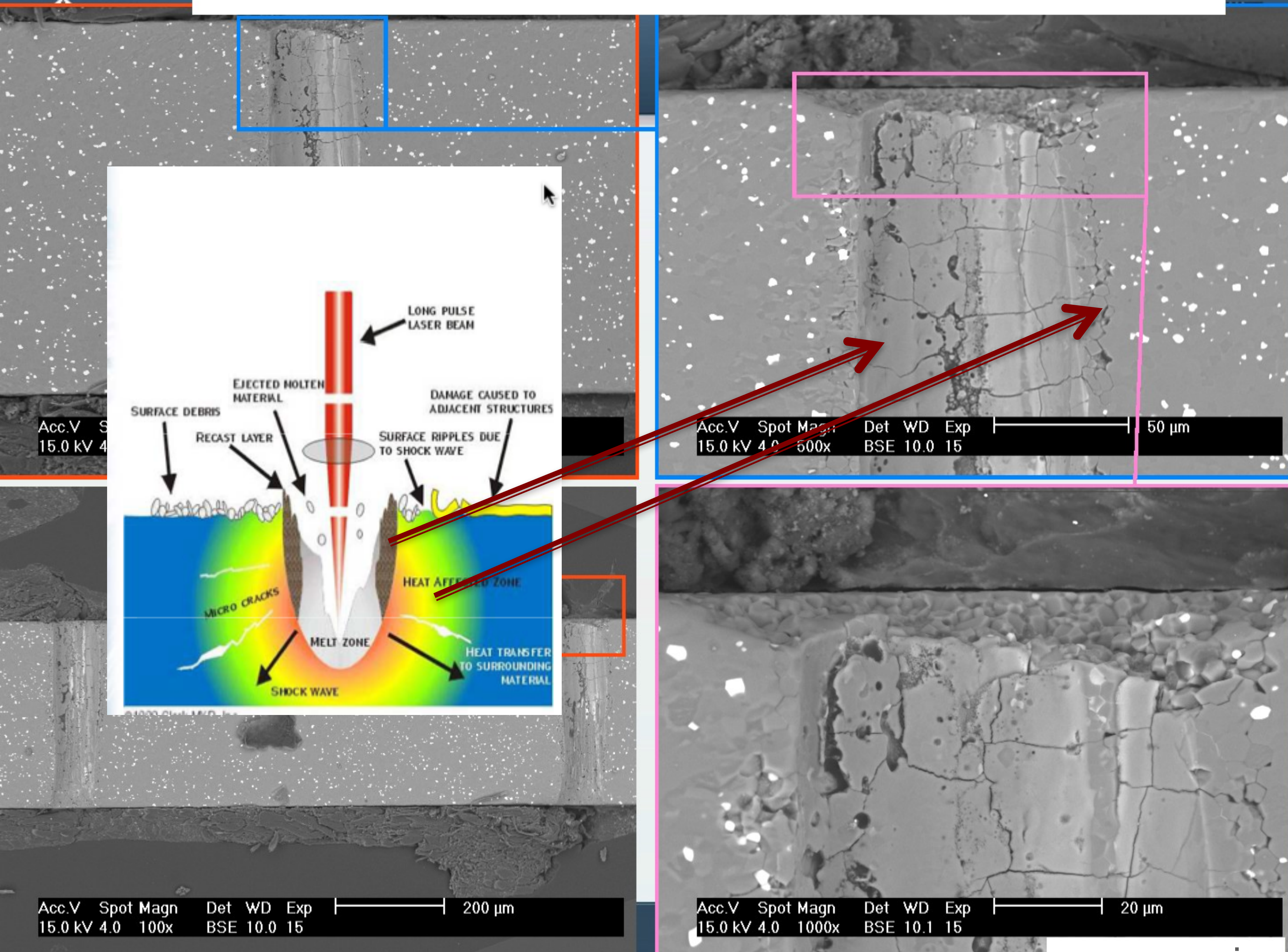
Build up of solidified and vapor deposited material inside the drill site and around the edges: LASER SLAG→ Metallization failures as slag breaks off

Areas around the drill site heat up enough to change microstructure- HEAT EFFECTED ZONE (HAZ) → Metal failures and pores which can cause blistering

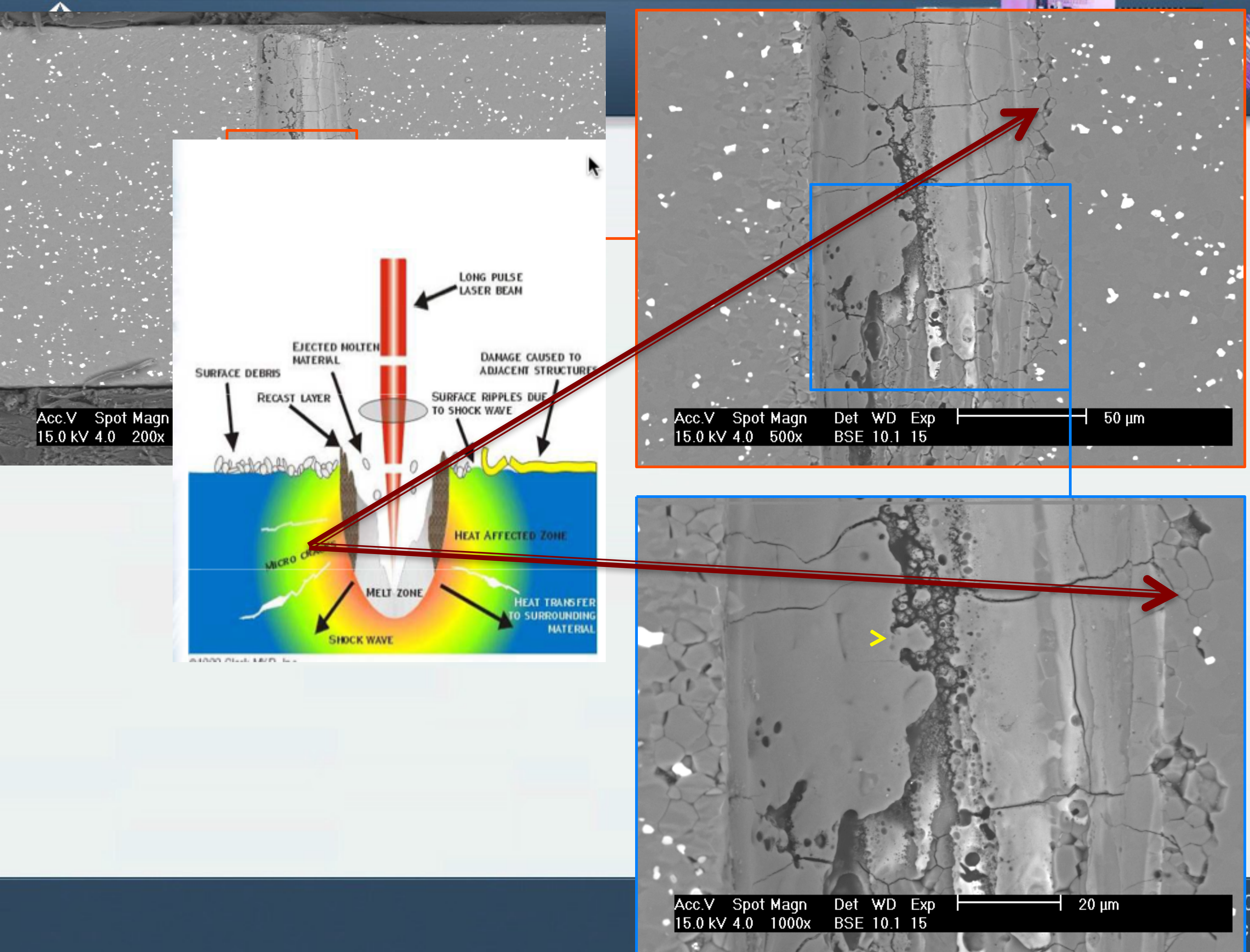
At the interface between the HAZ and non-heated areas there is a large CTE stress from expansion of HAZ which can result in cracks → Surface blisters or cracks that propagate

Laser Drilled Ceramic





Long pulse laser beam
Ejected molten material
Surface debris
Recast layer
Damage caused to adjacent structures
Surface ripples due to shock wave
Heat affected zone
Micro cracks
Melt zone
Heat transfer to surrounding material
Shock wave
Acc.V Spot Magn Det WD Exp 50 µm
15.0 kV 4.0 500x BSE 10.0 15
Acc.V Spot Magn Det WD Exp 200 µm
15.0 kV 4.0 100x BSE 10.0 15
Acc.V Spot Magn Det WD Exp 20 µm
15.0 kV 4.0 1000x BSE 10.1 15



Acc.V Spot Magn
15.0 kV 4.0 200x
Long pulse laser beam
Ejected molten material
Surface debris
Recast layer
Damage caused to adjacent structures
Surface ripples due to shock wave
Micro cr...
Heat affected zone
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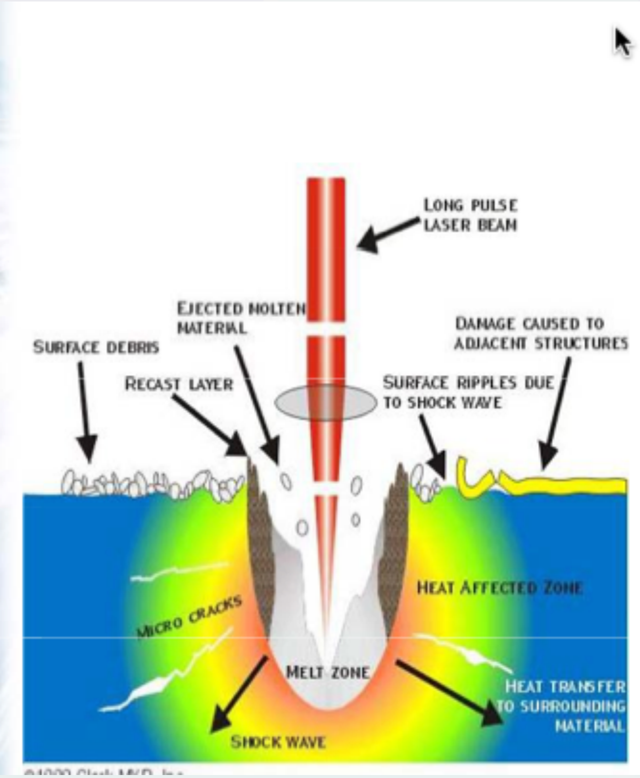
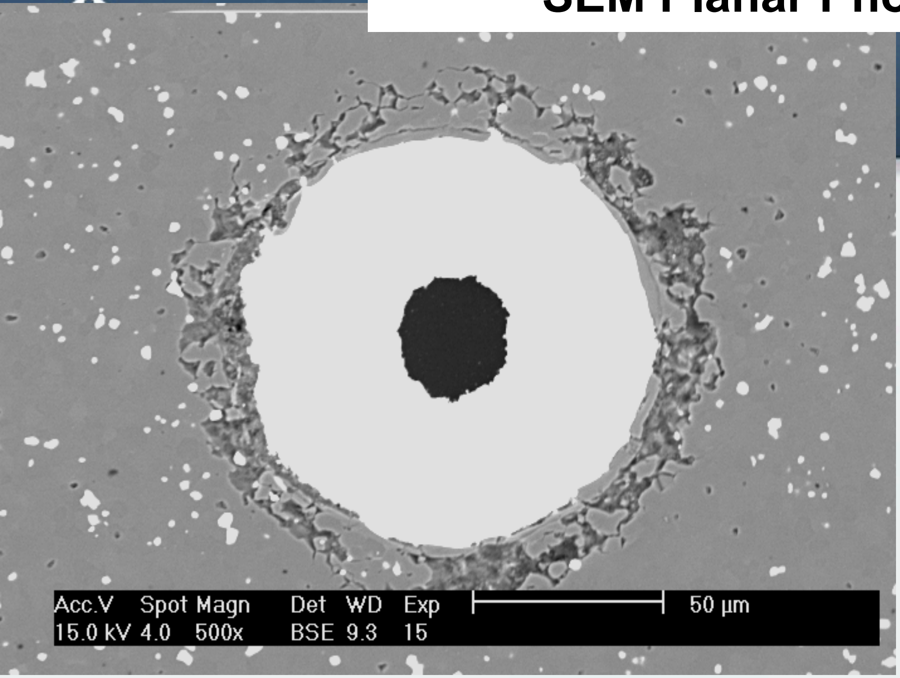
Shock wave
Acc.V Spot Magn Det WD Exp 50 µm
15.0 kV 4.0 500x BSE 10.1 15
Acc.V Spot Magn Det WD Exp 20 µm
15.0 kV 4.0 1000x BSE 10.1 15

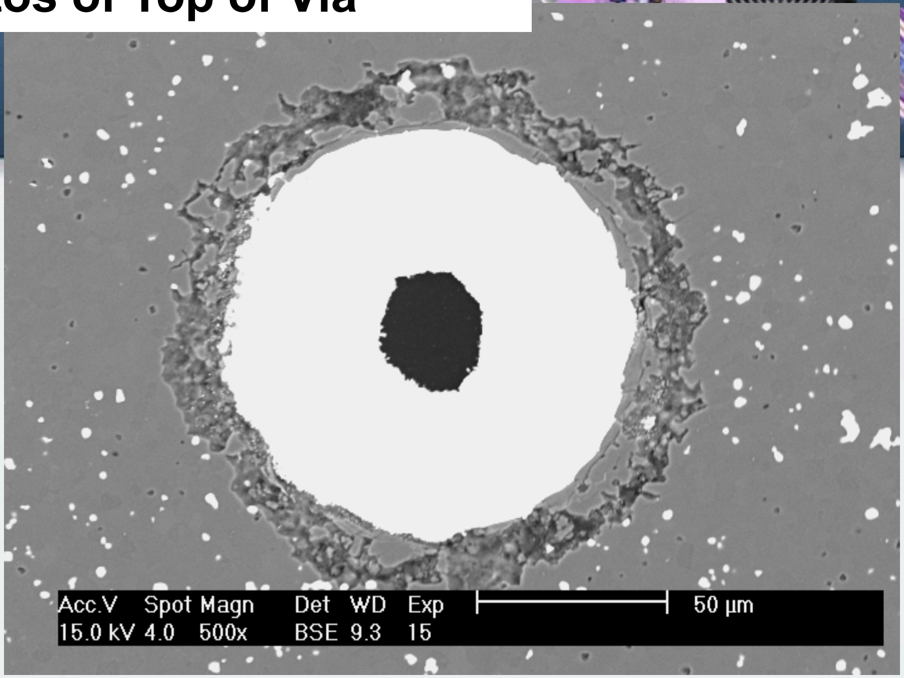
Observations from Cross Sections

- Re-caste zone where molten ceramic re-solidifies and cracks
- HAZ formation
- Cracking at HAZ/non HAZ interface

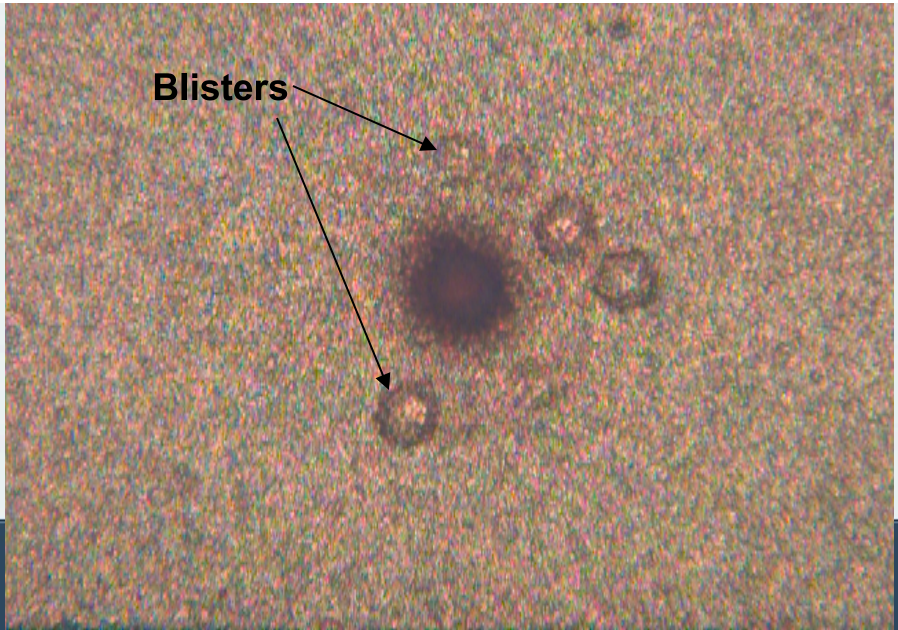


SEM Planar Photos of Top of Via

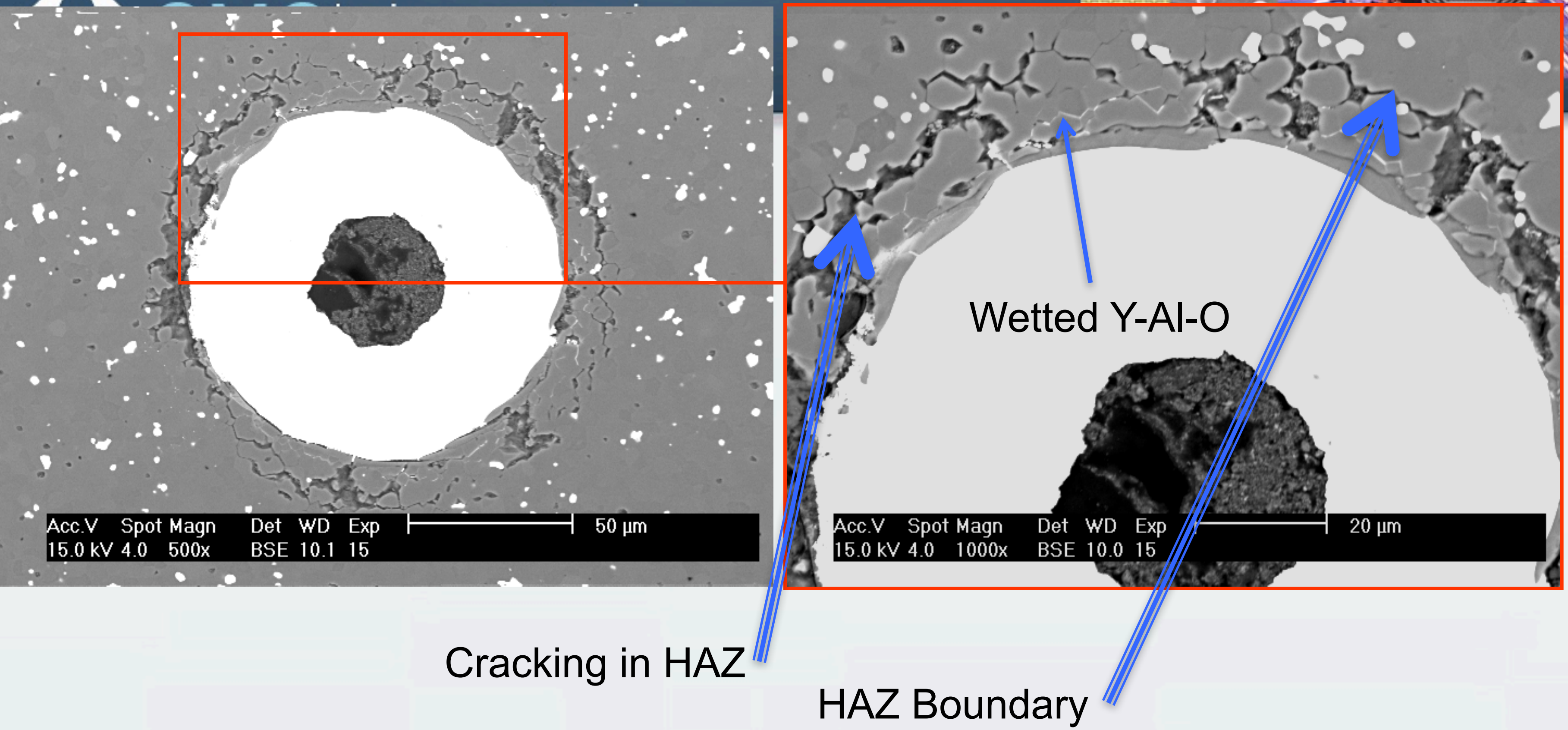




Optical Photos of Top Surface for AlN Part



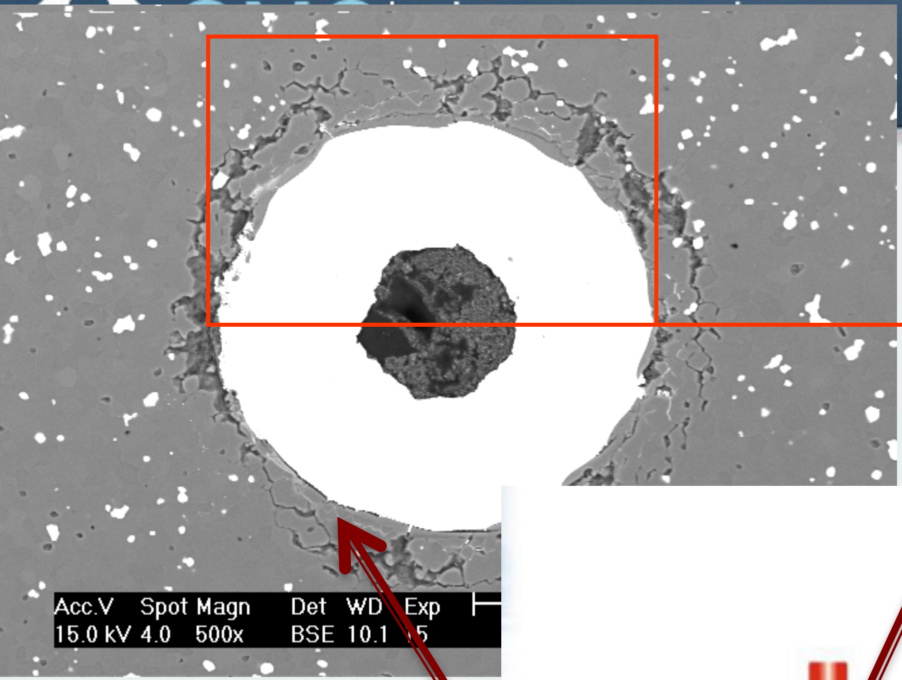
SEM Planar Photos of Top of Via after Vacuum Impregnation with Epoxy and Re-Polishing

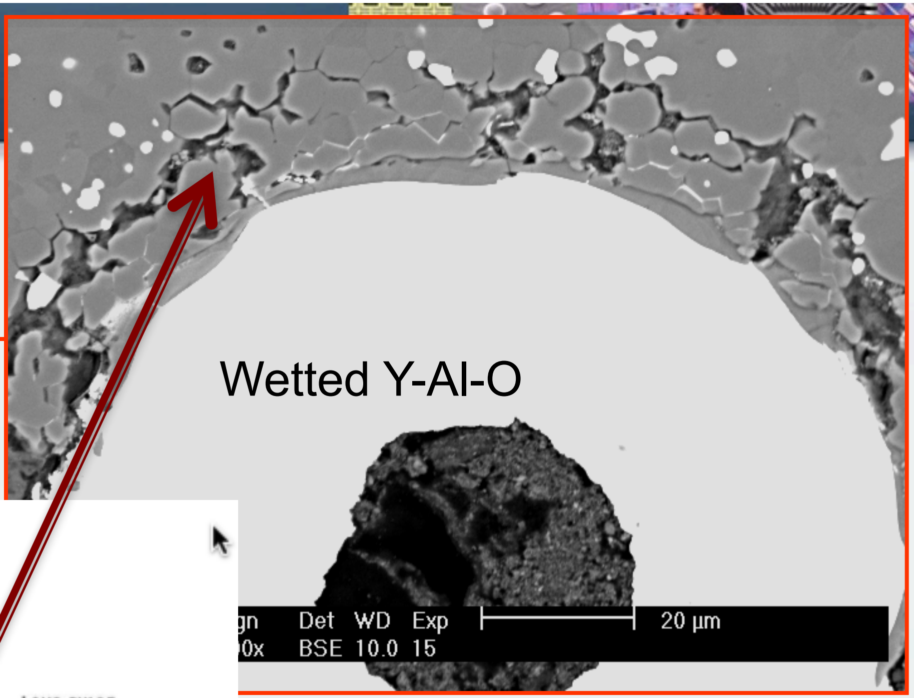


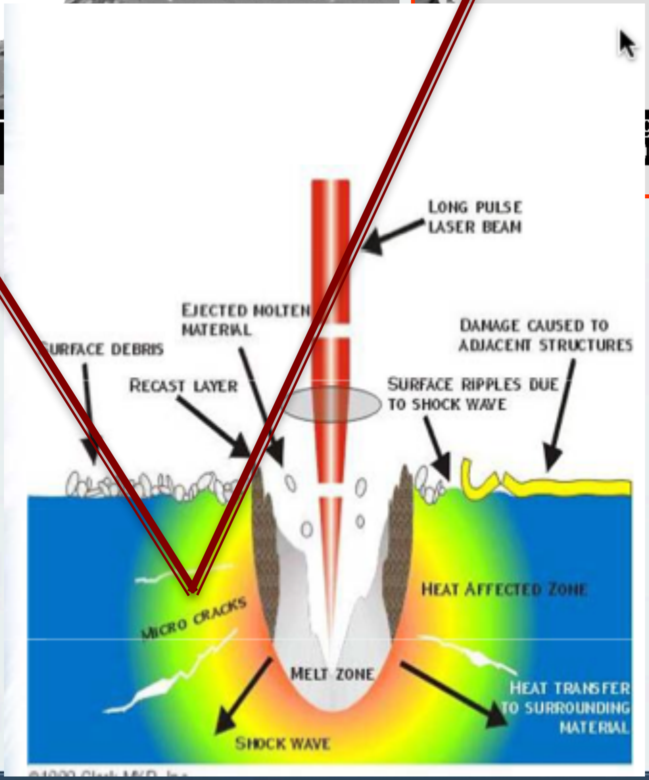
Drilling is thermal (melt/vaporize) vs. direct vaporization

- Average power is too high
- Peak power may be too low
- Use shorter laser pulses if possible to increase peak power and decrease average power

SEM Planar Photos of Top of Via after Vacuum Impregnation with Epoxy and Re-Polishing



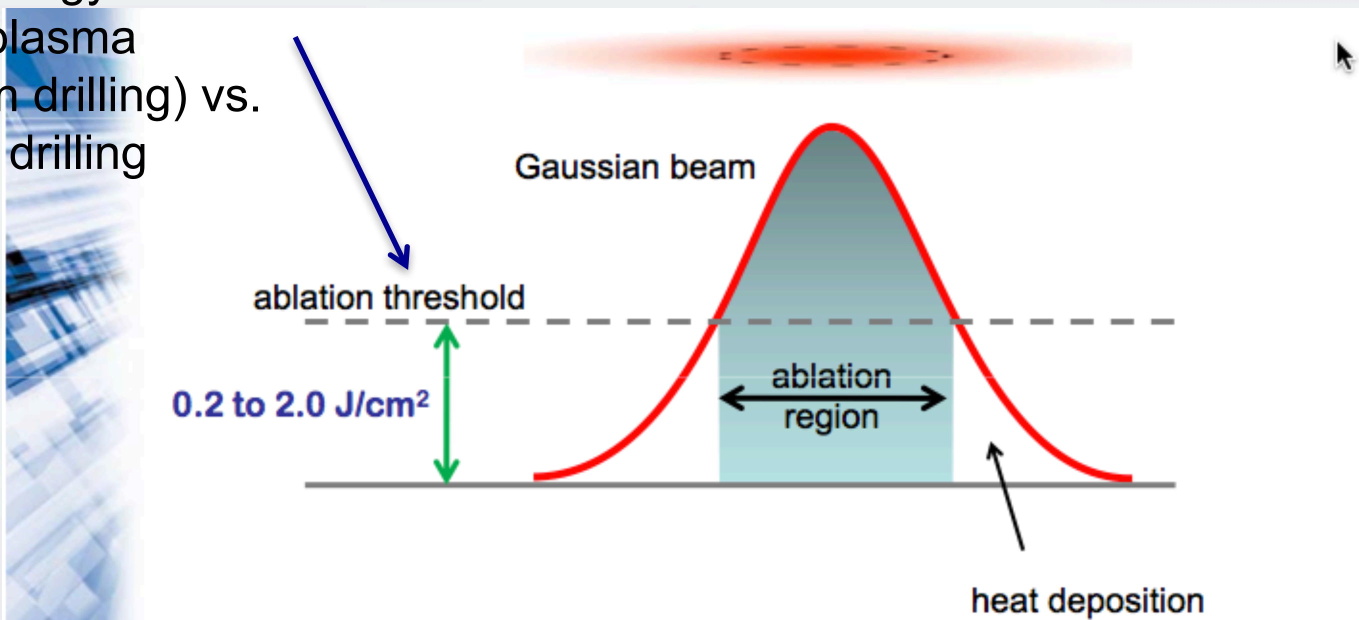




Why Process with Ultra-Short Pulses

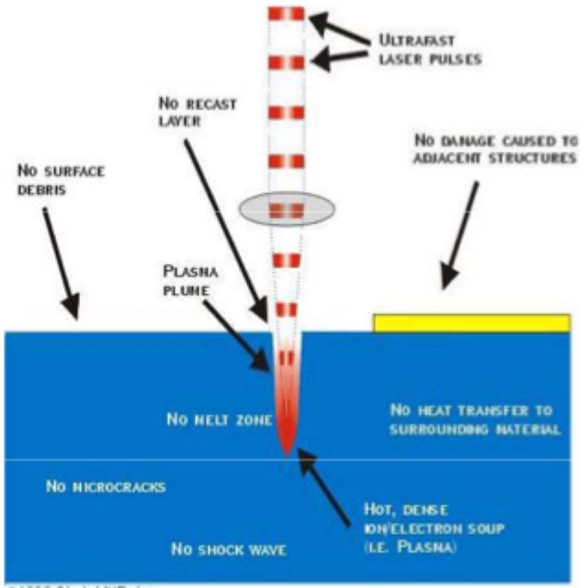
- 10 femtosecond (10^{-14} seconds) to 10 nanoseconds (10^{-8} seconds) which includes the picosecond regime
- Very high peak power, very low average power
- Drill without heat and without melting the substrate using “cold ablation”
- Substrate material is directly converted into a plasma

Threshold of laser pulse energy to create plasma (ablation drilling) vs. thermal drilling



Intensity > ablation threshold leads to ionization and Coulomb repulsion

Intensity < ablation threshold contributes to heating



No heat transfer to surrounding material→ NO HAZ FORMATION AND NO CRACKING AT HAZ/ NON HAZ INTERFACE

No melting or vaporizing of substrate → NO SLAG ON SURFACE OR WITHIN THE VIA

Key sacrifice for improved quality → LOWER DRILLING SPEED

Laser Drill with NO HEAT

match

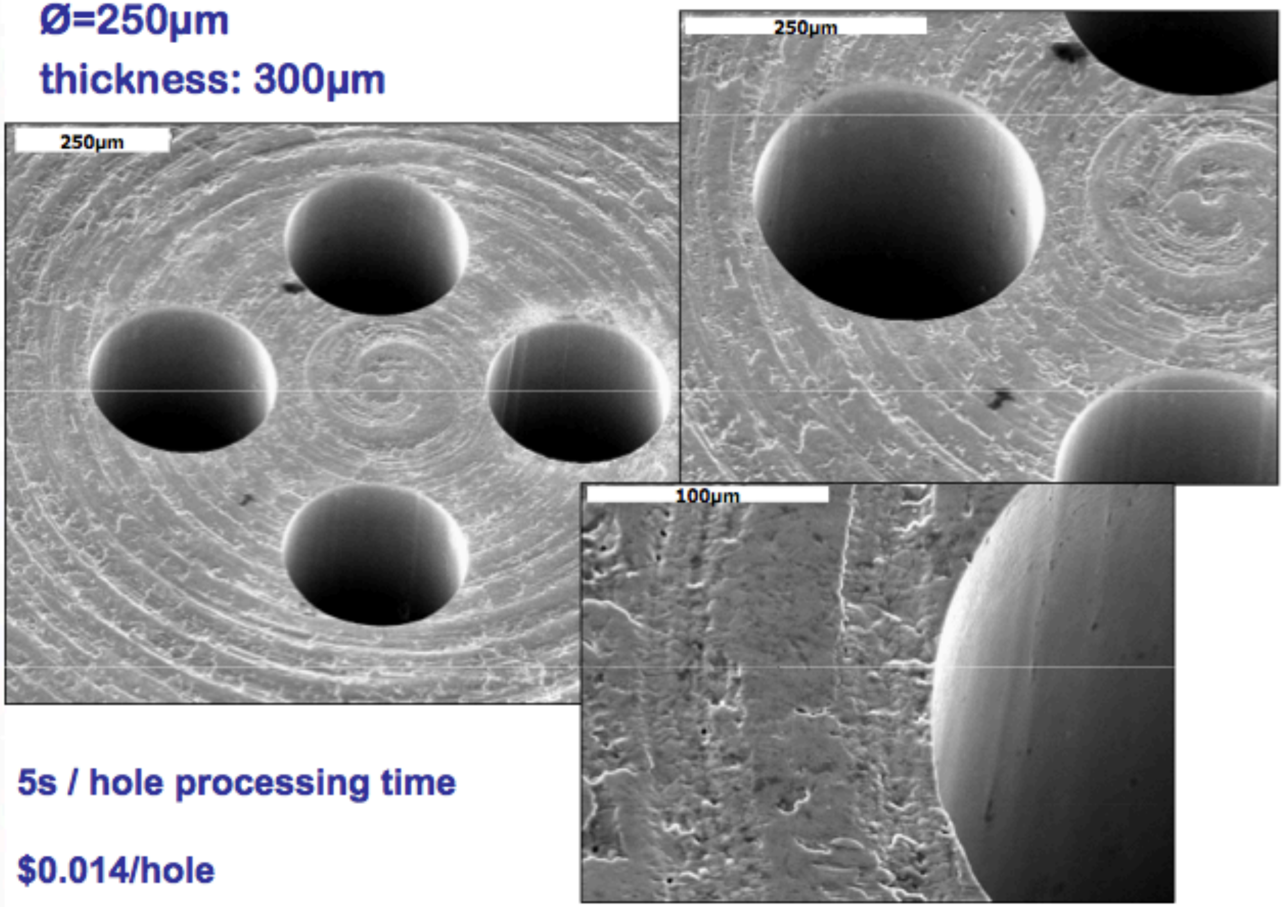
dry ice

Examples of Materials Drilled with Picosecond Pulses

Drilling Stainless Steel

Ø=250µm

thickness: 300µm

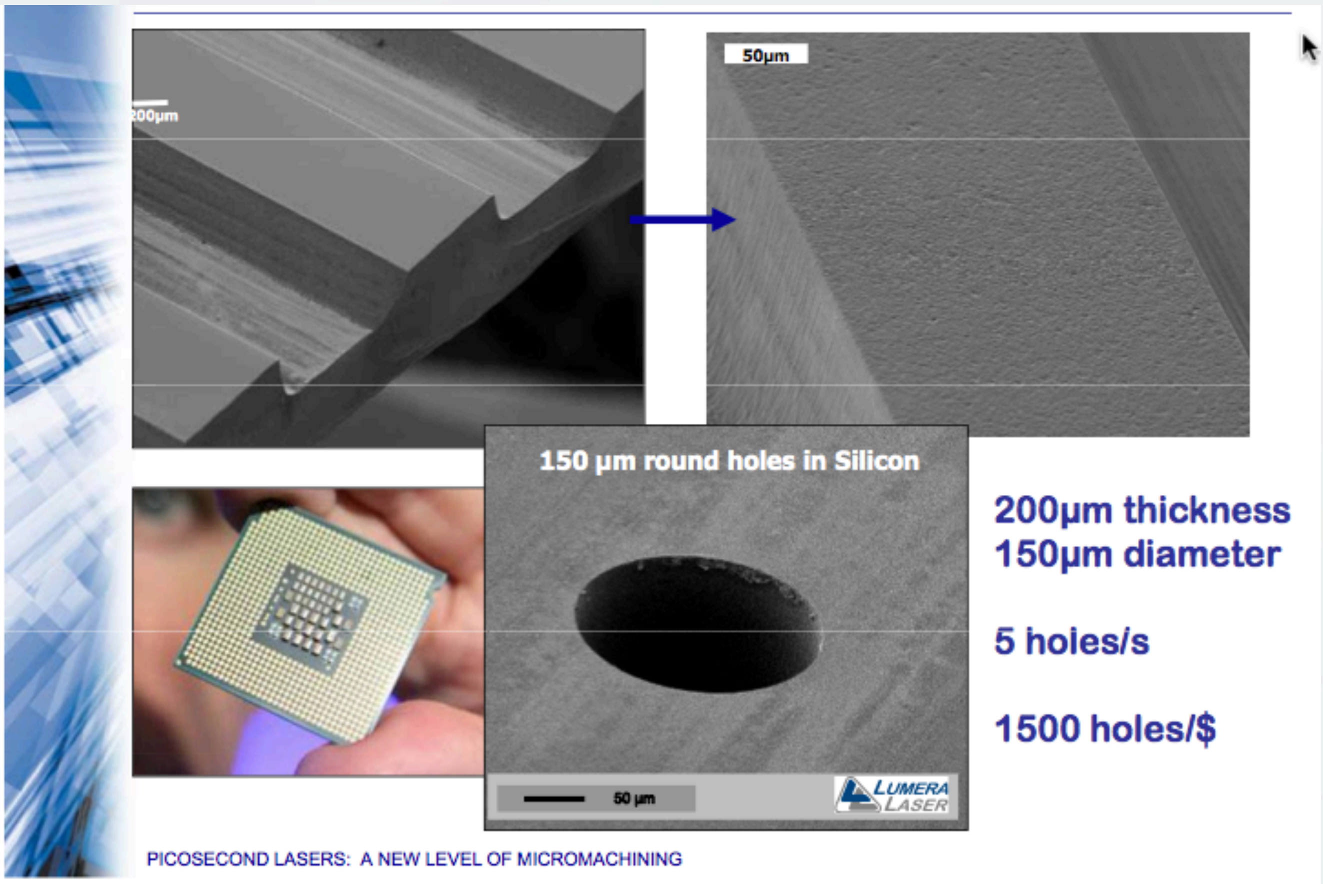


5s / hole processing time

$0.014/hole

PICOSECOND LASERS: A NEW LEVEL OF MICROMACHINING

Silicon


200µm
50µm
150 µm round holes in Silicon
50 µm
LUMERA LASER
200µm thickness
150µm diameter
5 holes/s
1500 holes/$
PICOSECOND LASERS: A NEW LEVEL OF MICROMACHINING

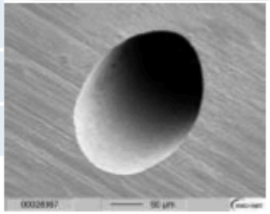
Picosecond Laser Systems

Picosecond Laser Characteristics

TRUMPF

TruMicro Series 5000

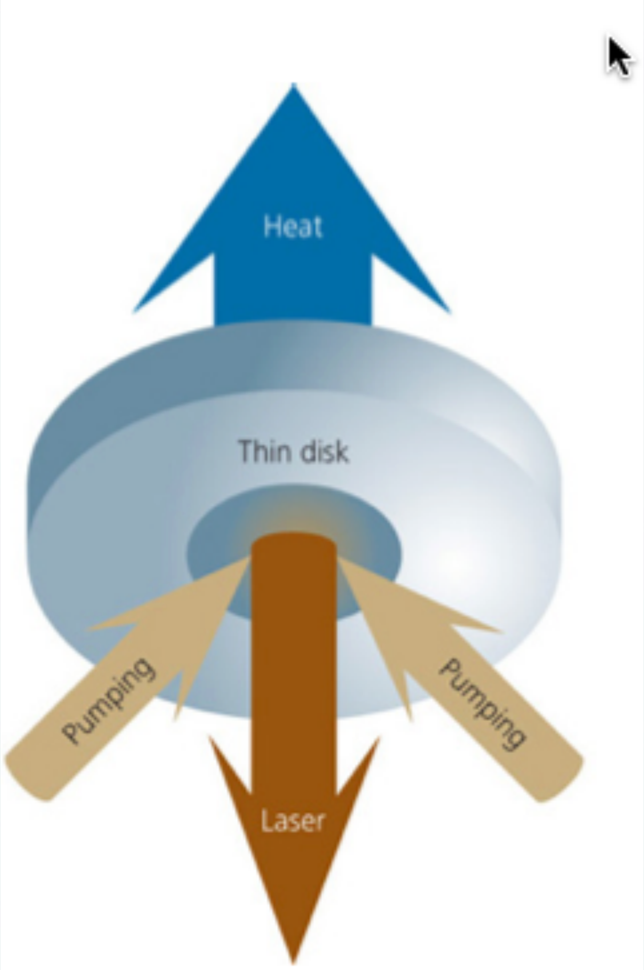
	TruMicro 5050	TruMicro 5250	TruMicro 5350
Average Power	50 W	25 W	> 15 W
Wavelength	1030 nm	515 nm	343 nm
Pulse Duration	< 10 ps	< 10 ps	< 10 ps
Max. Pulse Energy	250 µJ	125 µJ	> 75 µJ
Repetition Rate*	200/400 kHz	200/400 kHz	200/400 kHz
Beam Quality	$M^2 < 1.3$	$M^2 < 1.3$	$M^2 < 1.3$



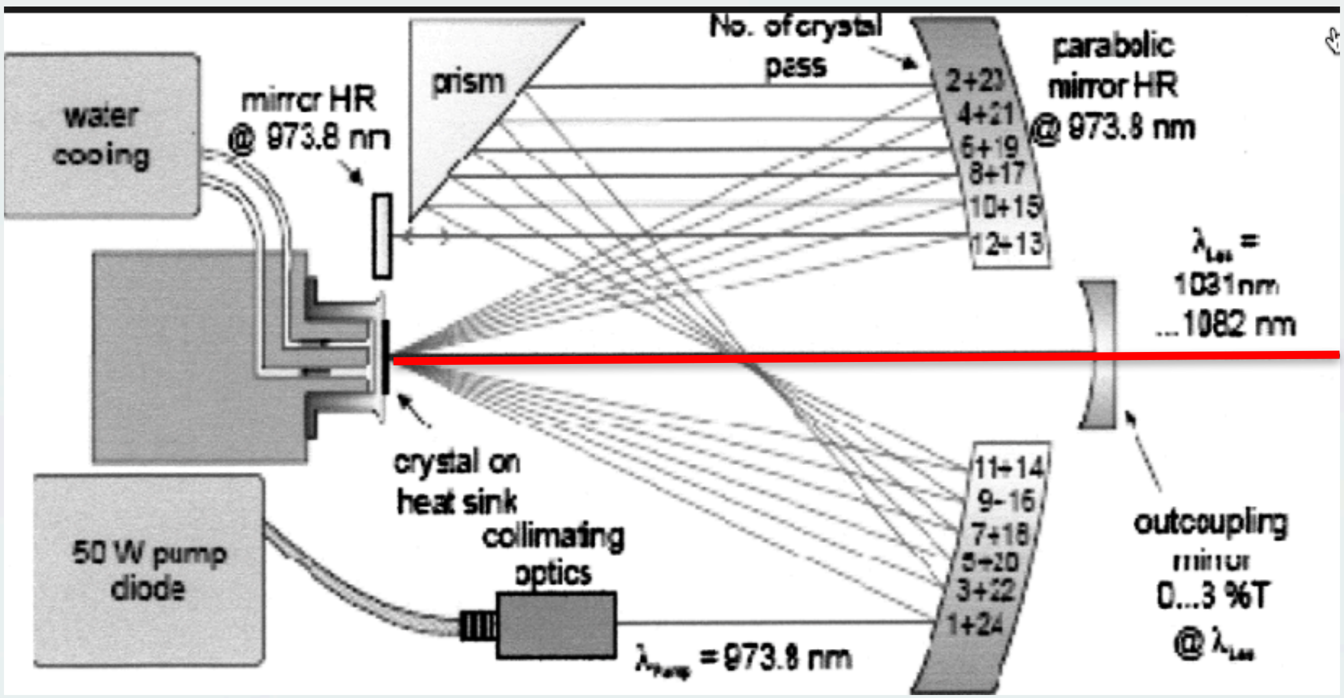
* Higher Repetition Rates upon request

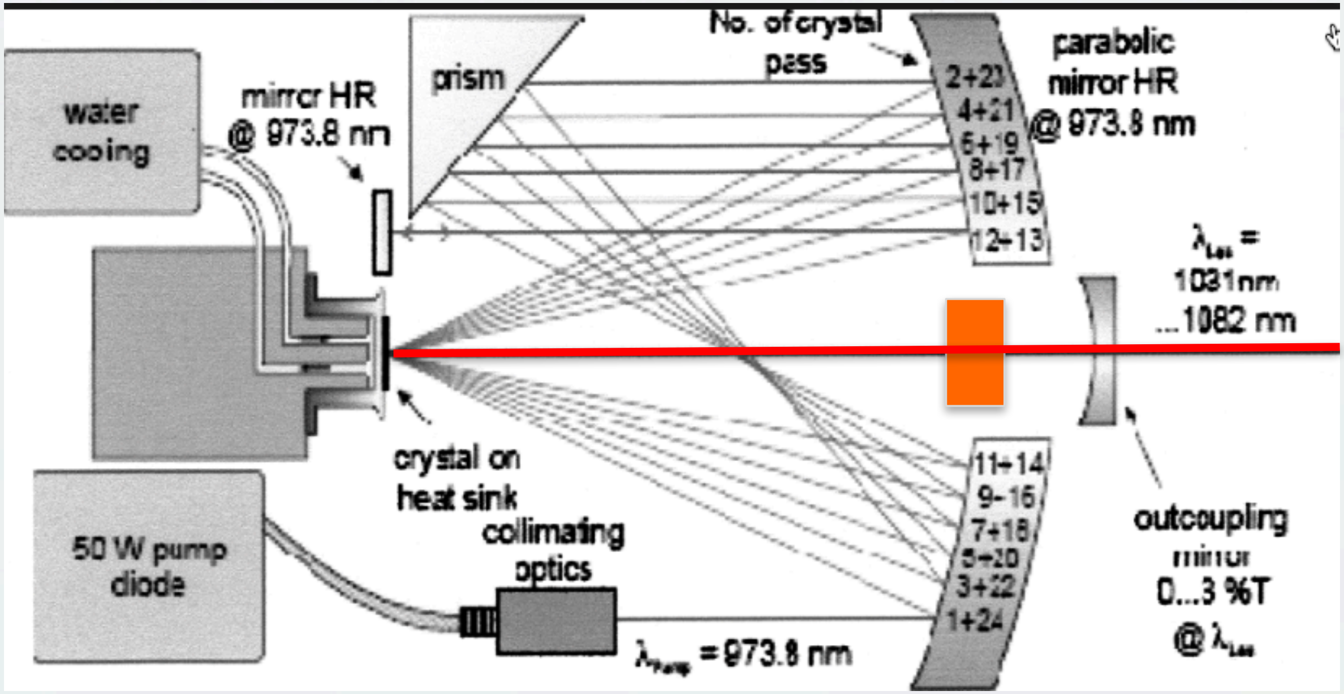
Thin Disc Lasers

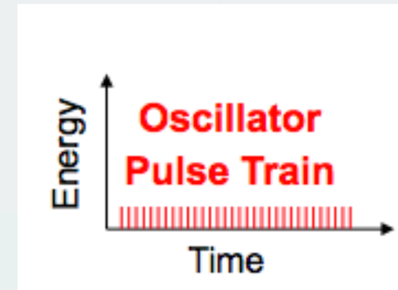
- Gain medium is a thin disc (typically Yb doped YAG Crystal)
- Attached to a heat sink for very efficient heat removal
- Pumped with a diode laser



Pump Laser incident on Yb:YAG disc to provide energy







Crystal Oscillator driven by RF signal inserted in laser cavity. Only certain laser mode are now supported by the cavity, a condition called “mode locked”. This results in a laser output of a stream of short pulses.

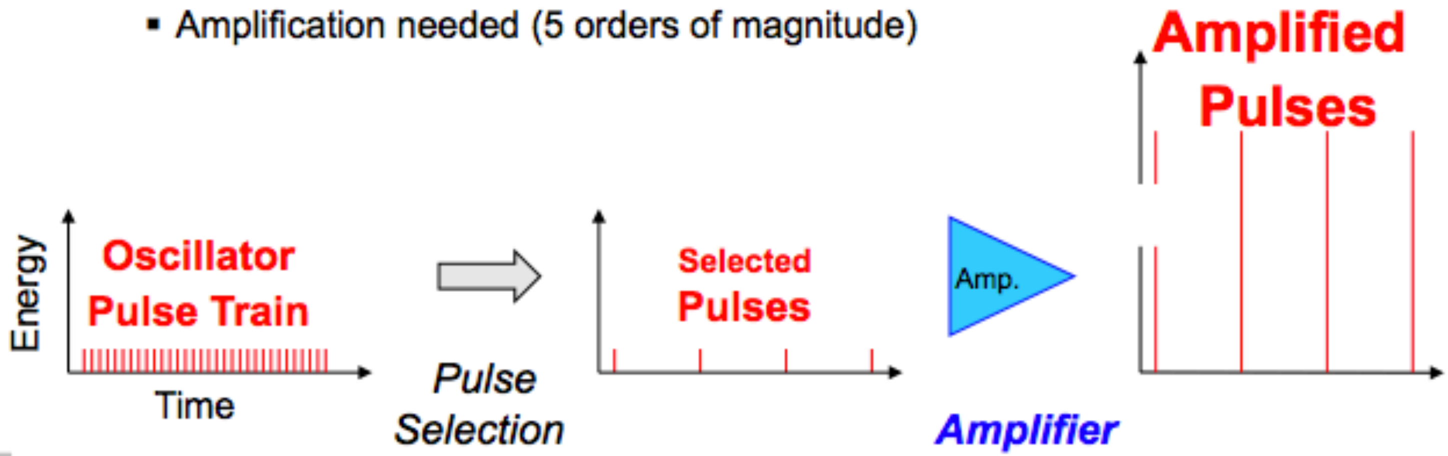
Pulsed laser output is followed by Pulse Selection and Amplifier(s)

Obtaining ps-Pulses

ps (and fs) Oscillators:

- Tens of MHz Repetition Rate (given by resonator length)
- Pulse selection to lower Repetition Rate

- Pulse Energies in nJ scale
- Amplification needed (5 orders of magnitude)



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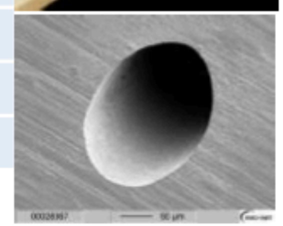

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Comparison with Longer Pulse Drilling

Optimum Range: 10-100 ps

Thermal Drilling Effects

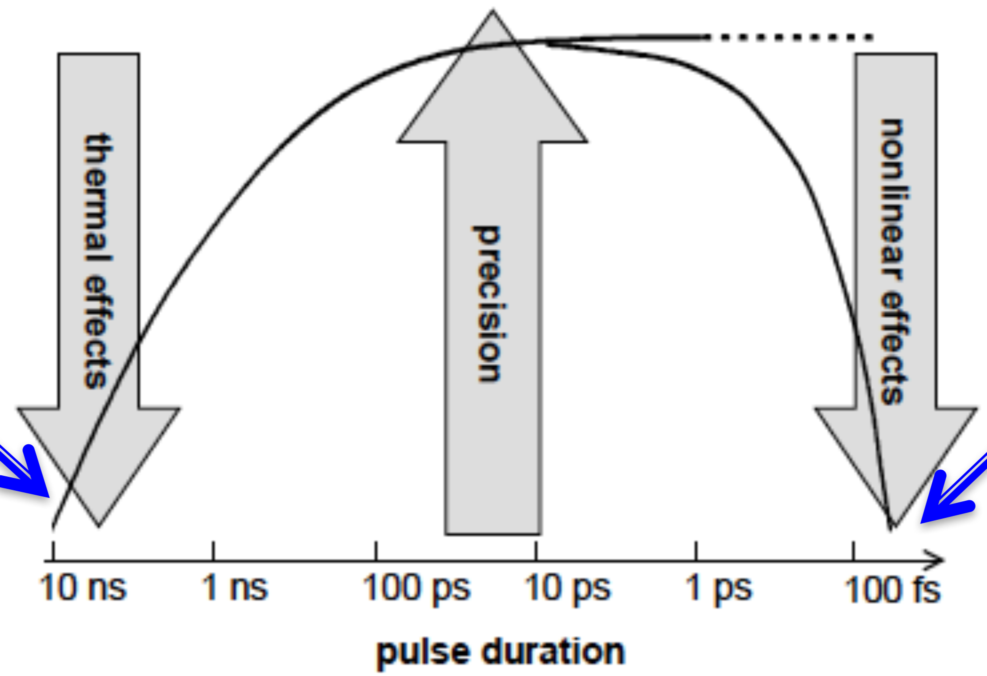

Figure 17 Precision depending on pulse duration in drilling of metals

Peak powers so high that non-linear optical effects start to occur

Shorter Pulses- Longer Drill Times (for Fixed Frequency and Pulse Energy)

In this example:
20 ns is 1 μm/pulse
100 ns is 7 μm/pulse

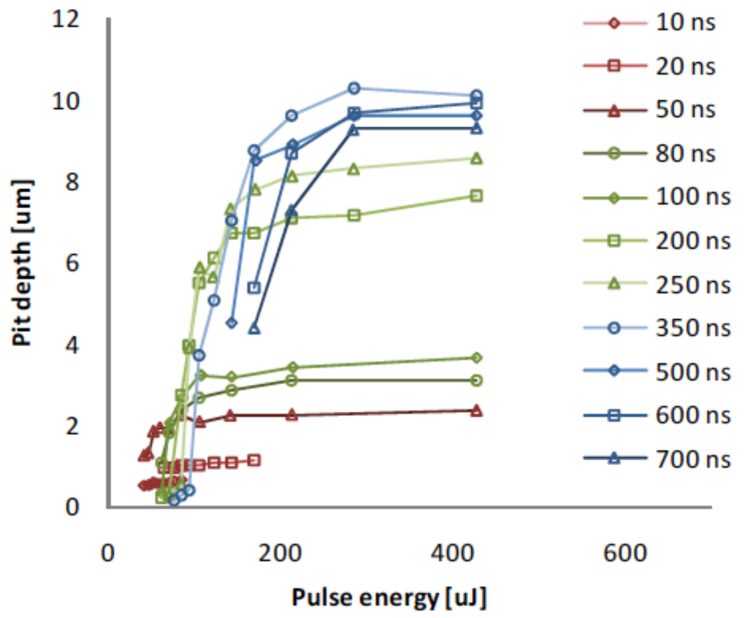

Figure 5. Pit depth as a function of the pulse energy for different pulse durations

Summary

- Picosecond pulse width => optimum for hole quality
  - Cold ablation with minimal thermal effects
  - Minimize: slag, HAZ formation, cracking at HAZ interface
- Trade off with slower drilling speed
  - Material removal per pulse scale with pulse energy
  - Shorter pulse, higher peak energy, lower pulse energy
  - 50W ps laser could be 10x slower than CO_2 laser at same frequency