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Industrial Applications of a fiber-based, high average power picosecond laser

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COHERENT. Engelberg Lectures 2009 Talisker

Introduction

- Why use picosecond pulses?
- Laser specifications and design features
- Example applications
- Conclusions

Talisker

Why use picosecond pulses?

- Many industries are being driven by lighter, smaller products with greater functionality. -> Requirement for smaller feature sizes, so higher quality and precision are required from a laser.

- Also, materials are becoming thinner and so are also more thermally sensitive to laser irradiation.

- Typically, for most current laser processes require chemical post-cleaning. For many applications, it is highly desirable to eliminate these post-cleaning steps.

- Hence, shorter pulse durations are of increasing interest in order to improve micromachining quality, especially for sensitive materials.

Advantages of picosecond pulses

- Picosecond pulses improve machining quality in 3 ways:

- 1 The shorter pulse duration limits the amount of heat diffusion into the material.
- 2. A larger proportion of the laser ablated material is removed in its vaporized state, permitting so-called “cold ablation.”
- 3. The laser ablation threshold is lower, meaning lower fluences can be used, resulting in less thermal damage.

- It is possible to achieve high quality features in many materials with ps pulses without the need for the complications of femtosecond lasers.

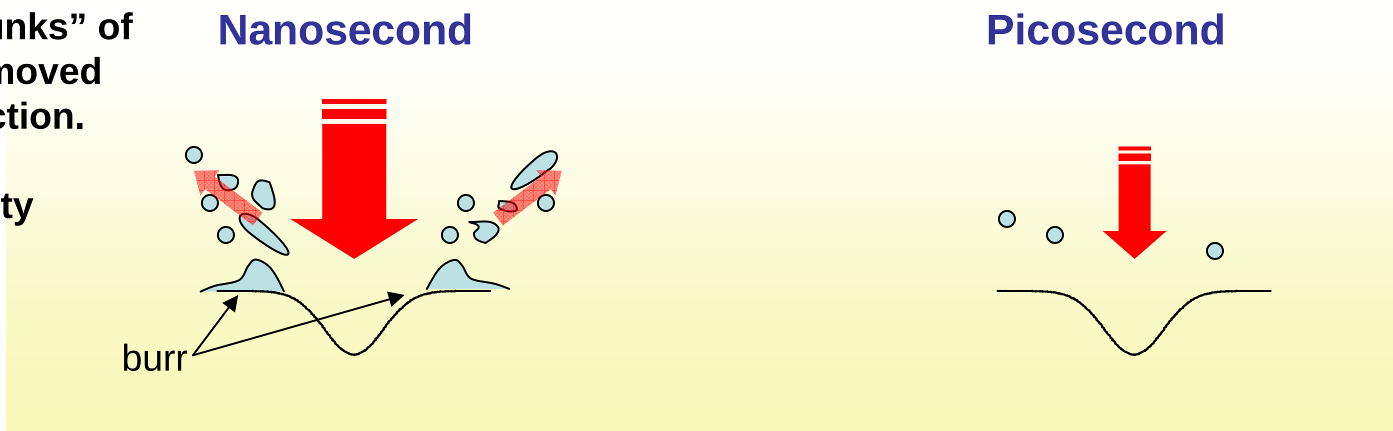
Advantages of picosecond pulses

- Material removal rates are typically a little slower than nanosecond, since more of the material is removed in its vaporized state, which is a less efficient process than melt ejection.

- A high repetition rate is essential to maximize throughput. 200kHz of the Talisker meets this need.

Larger “chunks” of material removed by melt ejection.

Lower quality features

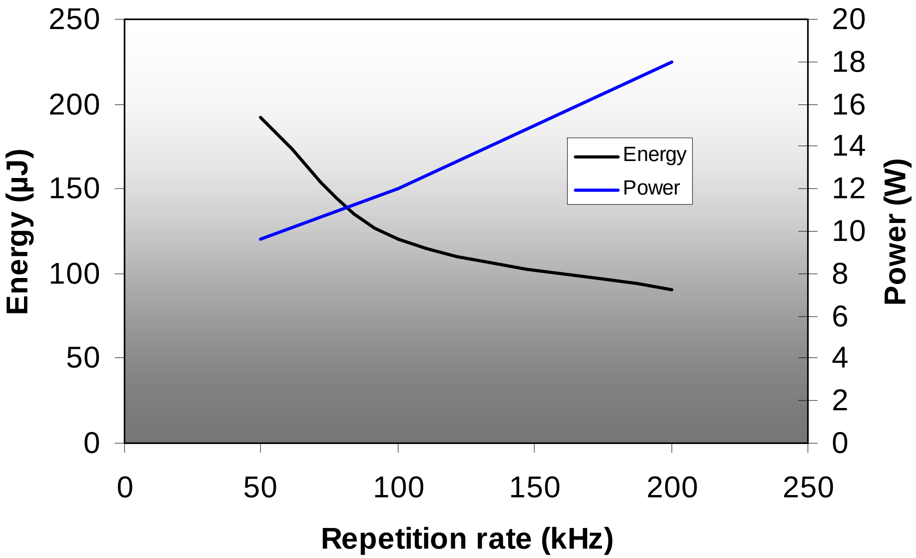


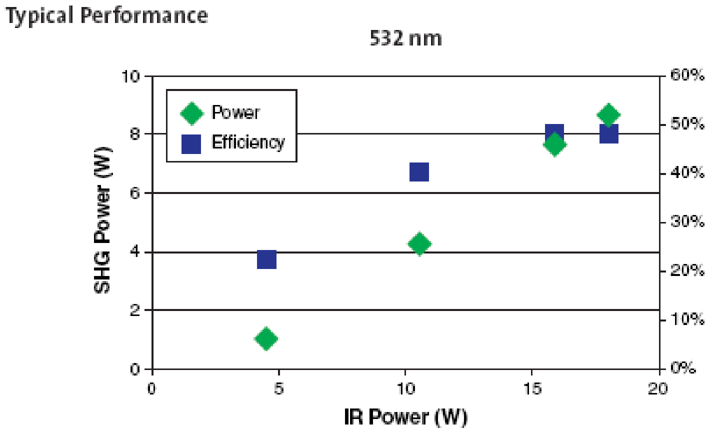
Quality versus speed trade-off!

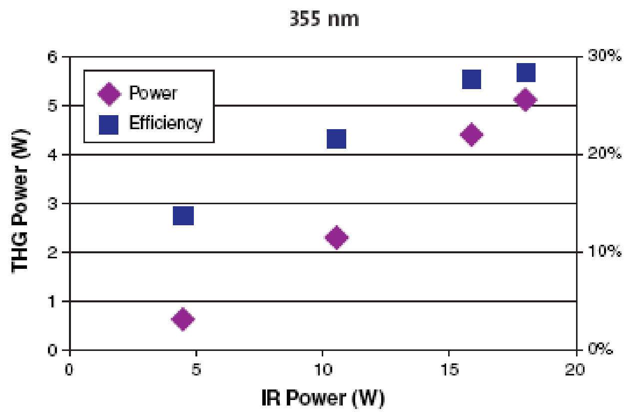
Laser Specifications and Features

Talisker Laser Design Features

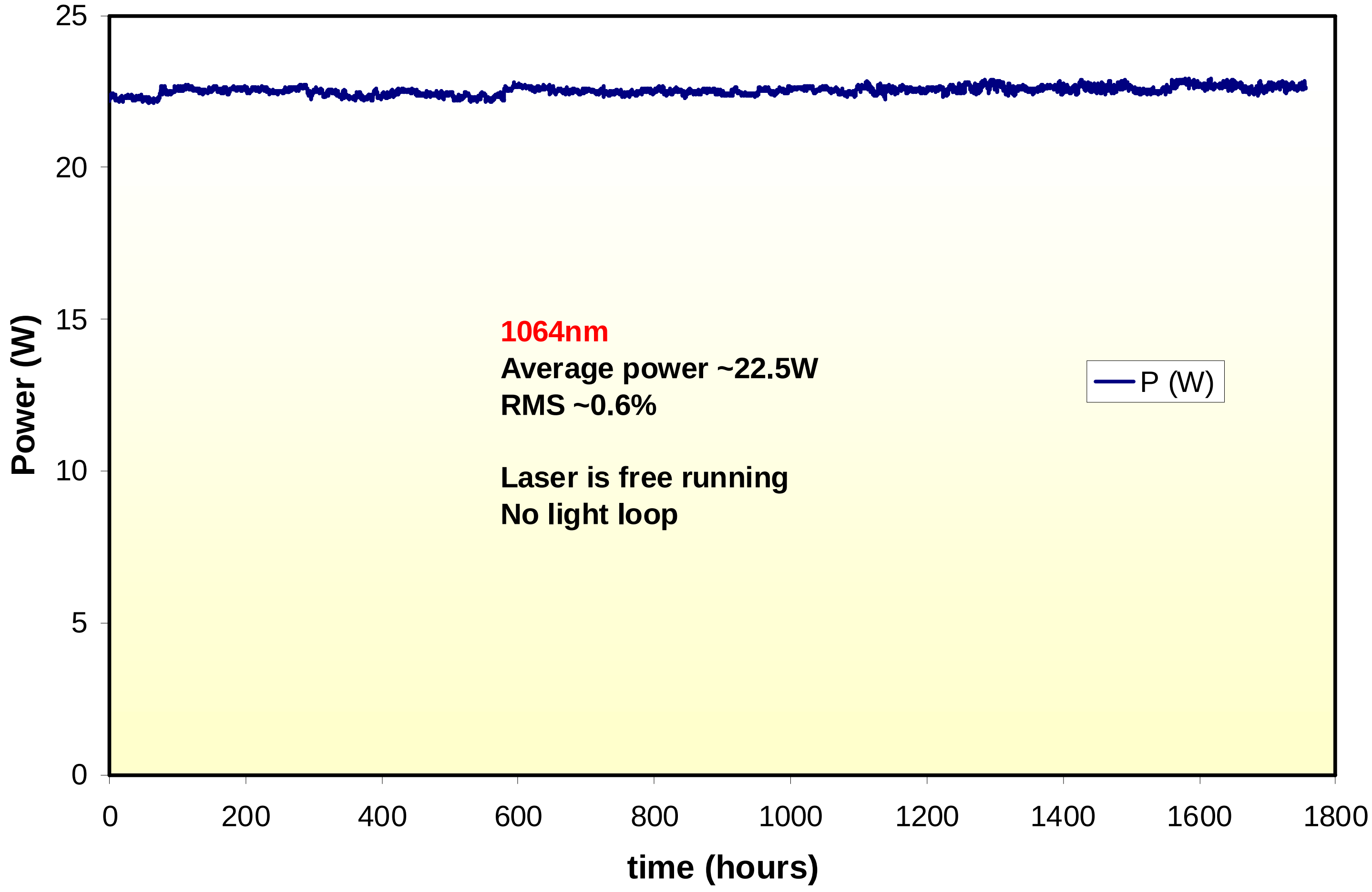
- For 200kHz operation maximum pulse energy in the IR is ~90µJ.







Talisker Power stability

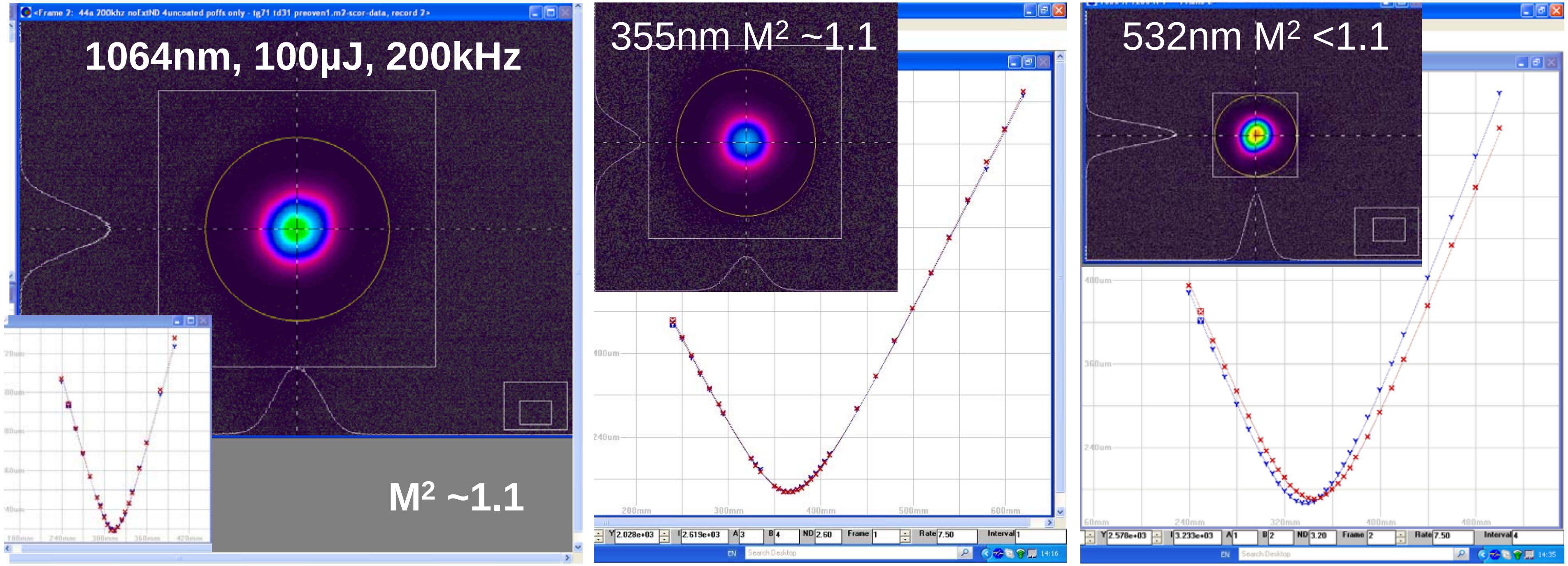


Talisker Laser Design Features

- The Talisker laser uses a combination of a fibre seed oscillator to produce picosecond pulses and a free-space amplifier to give the high average power output.
- A high voltage switch (Pockel's cell) controls the trapping and amplification of the picosecond pulses. This also sets the output repetition rate of the laser.
- The laser output is controlled using an Acoustic Optic Modulator (after the amplifier), which acts as a pulse picker.

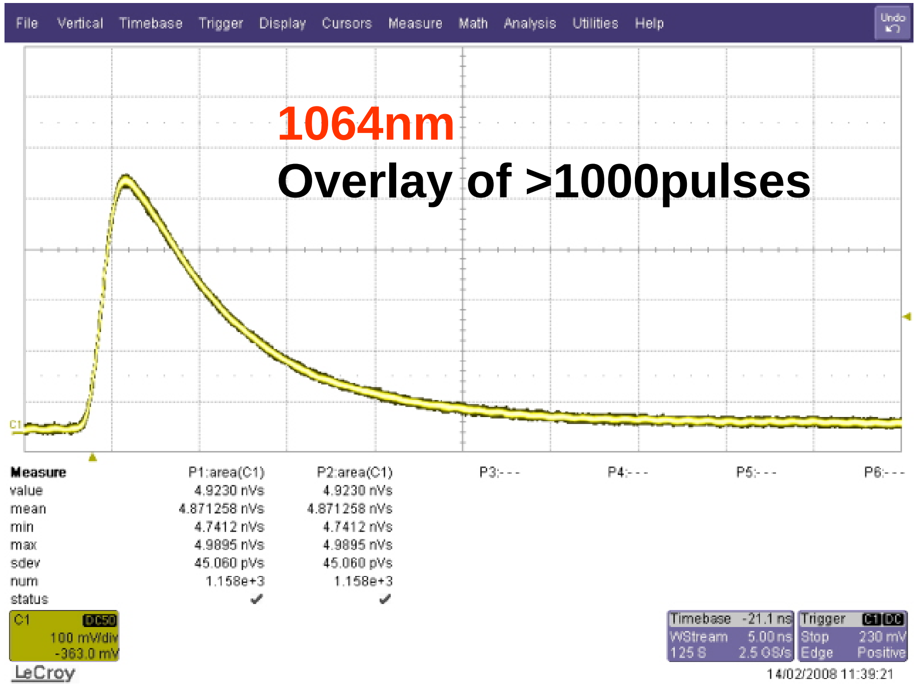
Talisker Beam Quality

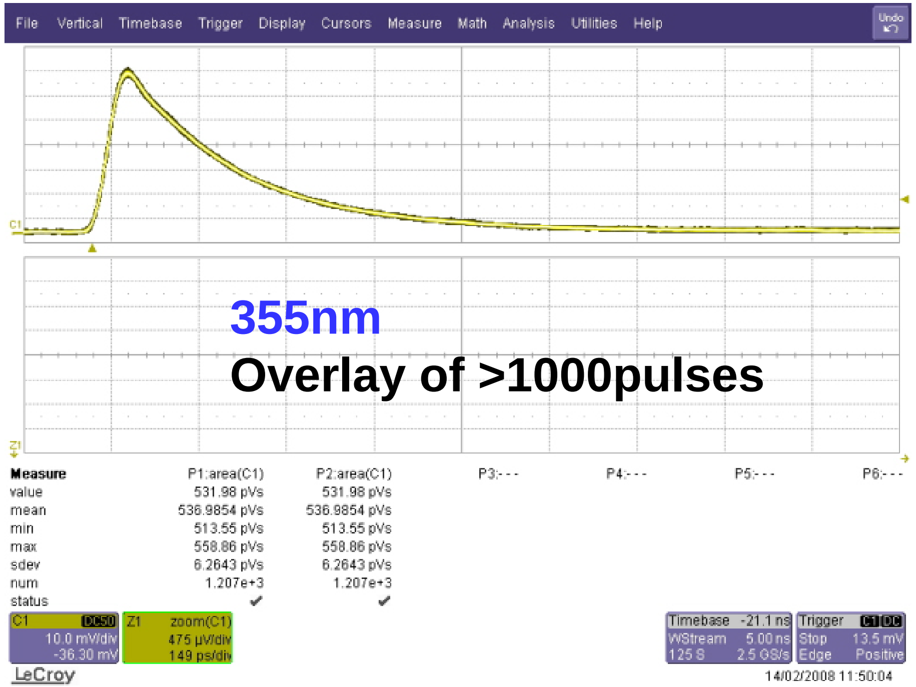
- M^2 ~1.1 is obtained for all 3 wavelengths (1064, 532 & 355nm) at 200kHz.



- High beam roundness and zero astigmatism has been demonstrated for all three wavelengths.

Talisker pulse-to-pulse stability



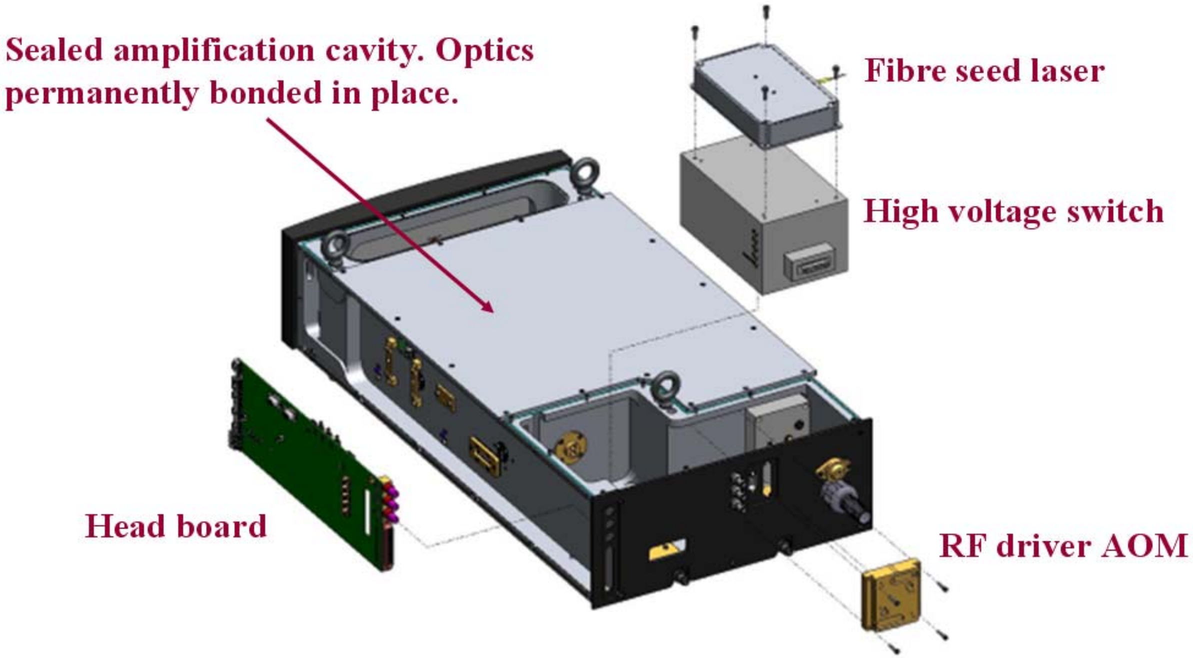


- LeCroy WaveSurfer 44Xs oscilloscope (which can record a maximum of 2.5GSa/s) used to record the pulse stability of ~1000pulses.
- Pulse to pulse stability ~0.9% for 1064nm and 1.1% for 355nm (standard deviation).

Talisker Laser Design features

- Laser has separate “service” compartment, where field replaceable components are placed.
- 3 wavelength version has the option to switch between 1064, 532 & 355nm.

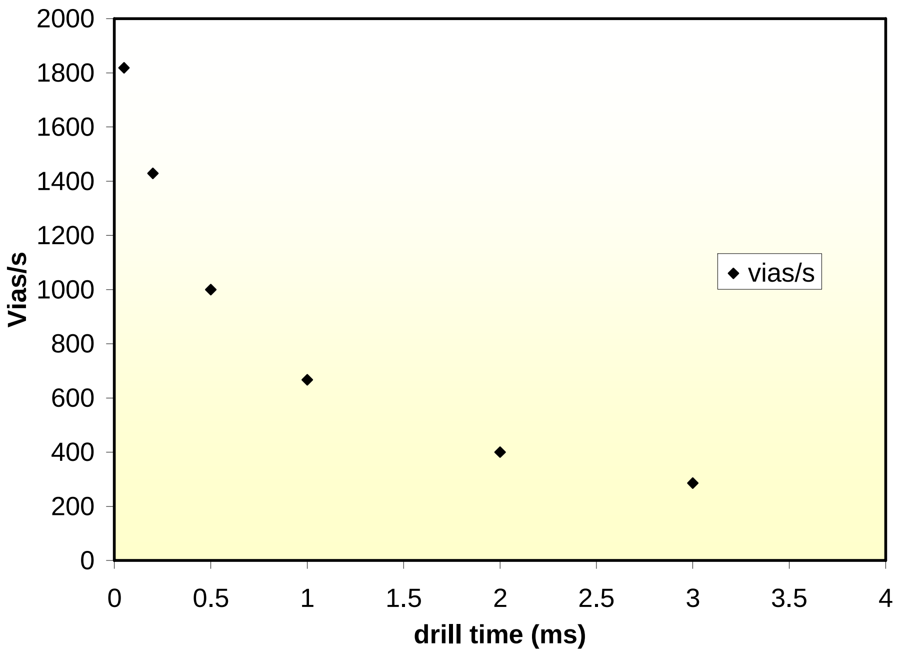
3 output ports for selection of 1064, 532 or 355nm output

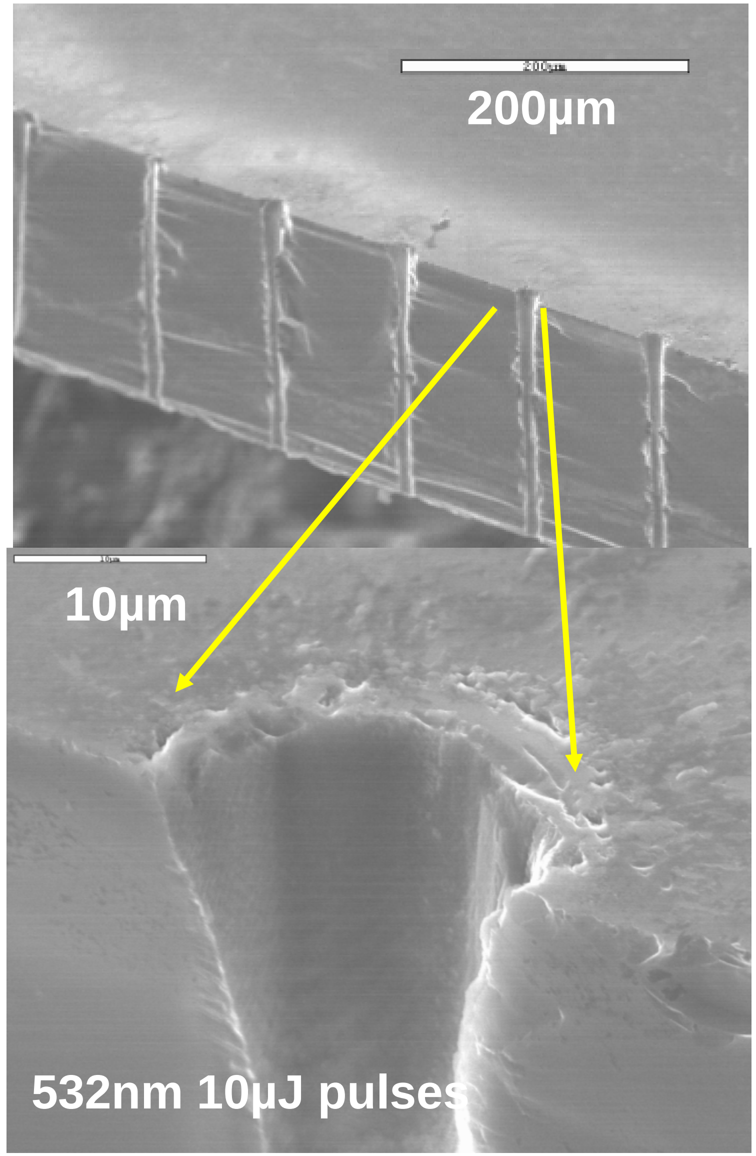


Example applications

Silicon through Via (STV) drilling

- 532nm or 355nm pulses
- 5 pulses can drill through 200µm of silicon.
- Key is to use a small focused spotsize ~10µm.





SEM images courtesy of University of the West of Scotland

Thin film removal – solar cells

- Backside contact holes contact holes in thin films of SiO_2.
- Essential to limit damage to underlying Si to give high solar cell efficiency.
- Holes can be opened with a single pulse and lower damage to the silicon with ps pulses.

Laser drilled back contact holes

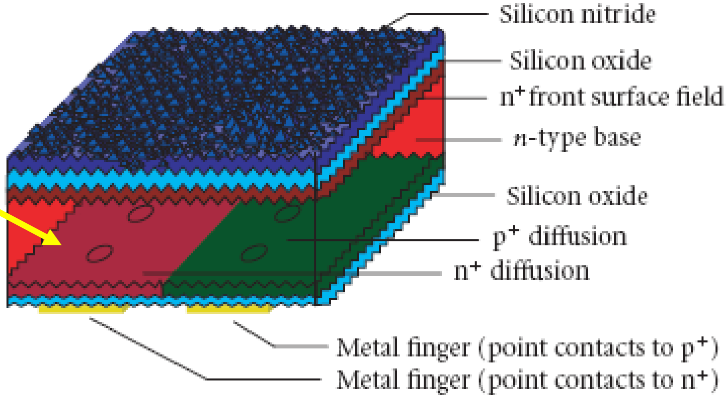
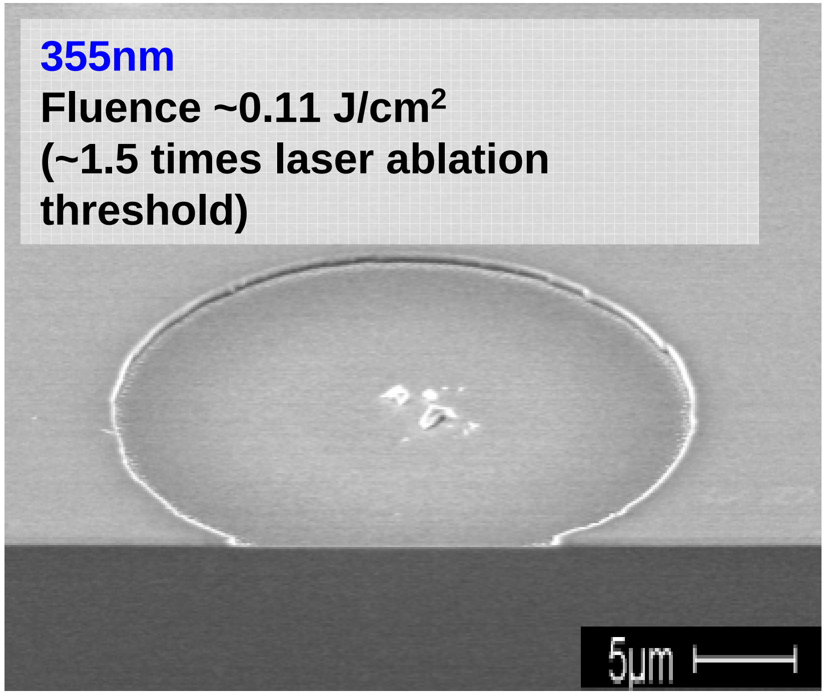
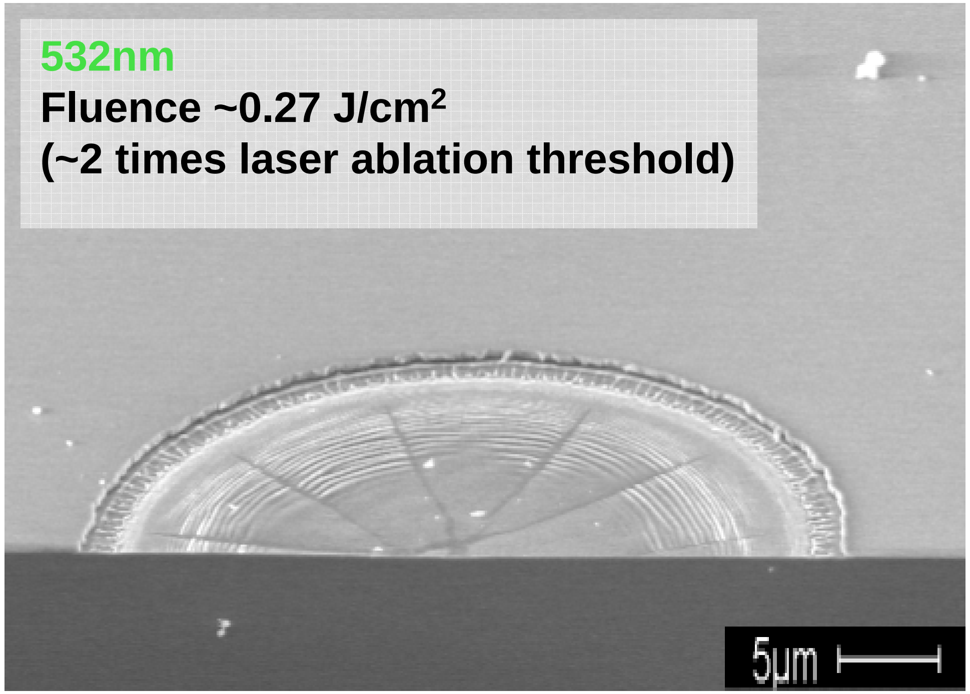


Figure 8: Schematic drawing of an IBC solar cell of SunPower.

Image courtesy of “Industrial Silicon Wafer Solar Cells,” Advances in OptoElectronics, Vol. 2007, Article ID 24521, 2007

Thin film removal – solar cells





- No melt visible when using 355nm close to the laser ablation threshold.
- More melt is visible on the silicon when using 532nm.

Silicon carbide drilling

- Silicon carbide has a wide bandgap and typically only absorbs in the UV.

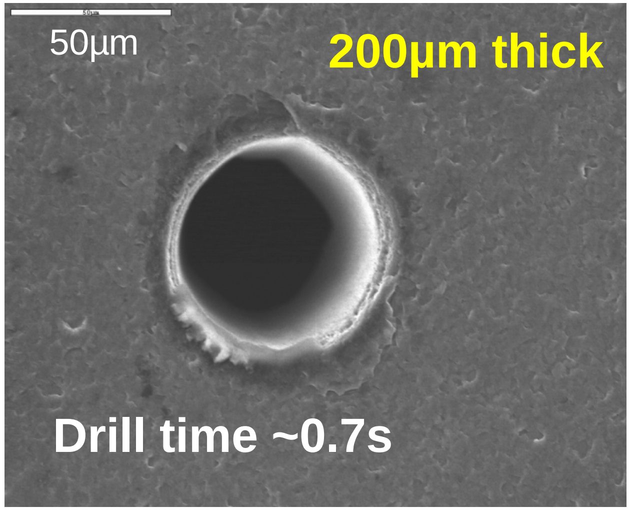
λ (nm)	α (cm^{-1})	Reflectivity
1064	0	19.5%
532	0	20.8%
355	39000	22.8%
266	95000	26.4%

Data courtesy of Purdue University, http://www.ecn.purdue.edu/WBG/Introduction/Index.html

- With picosecond pulses, SiC can be machined with any wavelength. However, the highest material removal rate is obtained with 355nm.

- Image right shows trepanned hole in SiC trepanned using 532nm pulses.

- Only cleaning used is an ultrasonic bath to remove ejected particulate.



SEM images courtesy of University of the West of Scotland

Micromachining glass

- Glass is transparent and so has poor absorption as shown below:

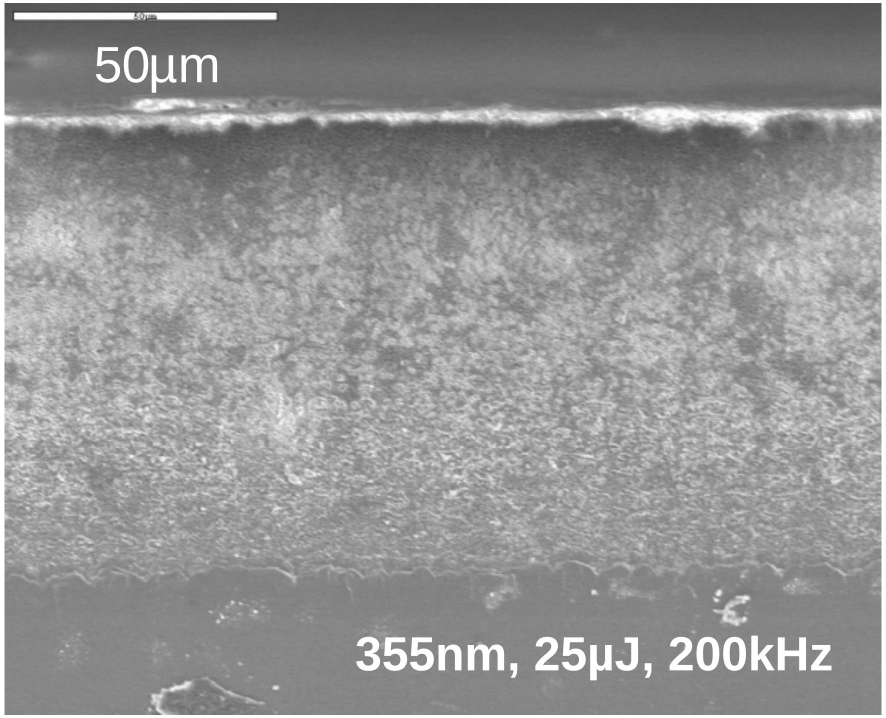
λ (nm)	α (cm^{-1})	Transmission
1064	0.7	86%
532	0.3	92%
355	0.8	85%
266	1300	0%

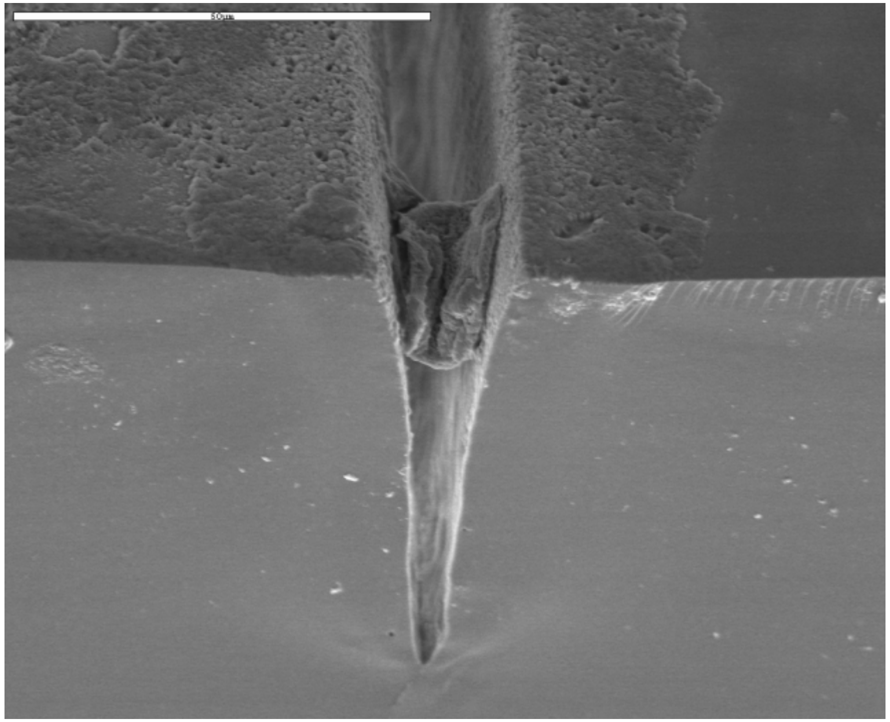
Data courtesy of:
Raciukaitis, G., "Patterning of ITO layer on glass with high repetition rate picosecond lasers," Journal of Micro/Nanoengineering, Vol. 2, No. 1, p. 1-7, 2007

- With longer pulsewidth lasers, it is difficult to machine glass without cracking.
- Using 355nm, picosecond pulses it is possible to drill high quality features in glass with no microcracking.
- Application areas include solar, flat panel displays, microfluidics and medical devices

Glass scribes

- 355nm pulses can produce high quality scribes in glass with no micro-cracking.

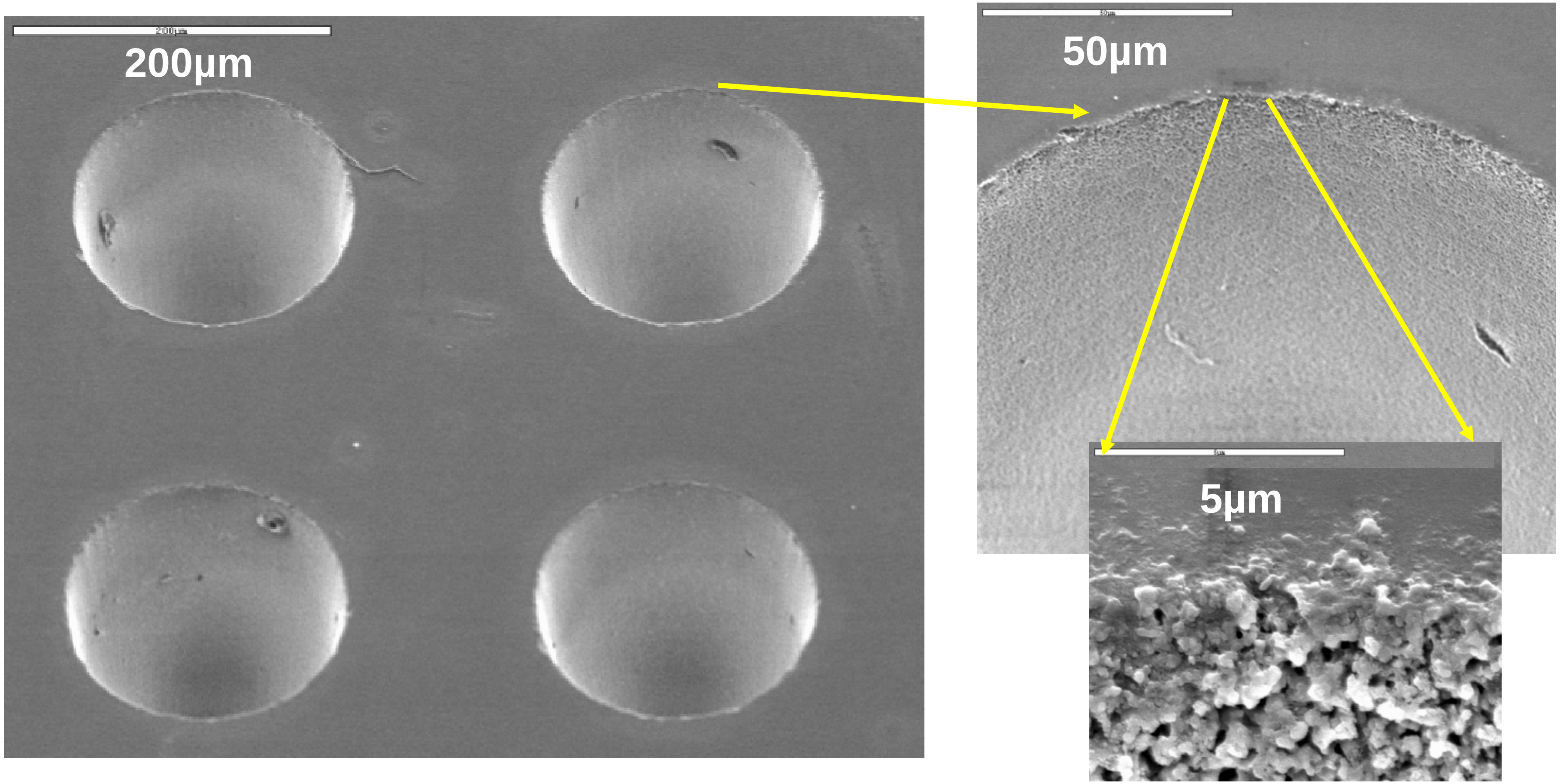




SEM images courtesy of University of the West of Scotland

Glass scribes

- 355nm pulses can also produce high quality holes in glass as shown below. Still some micro-chipping.



SEM images courtesy of University of the West of Scotland

Conclusions

- The advantages of picosecond pulses have been outlined and applications in a wide variety of materials have been demonstrated.
- The design advantages of a high average power, picosecond laser for industrial use have been outlined.
- Picosecond pulses can be used to selectively remove thin films with minimal damage to the underlying layers. This is particularly advantageous for solar cell applications.
- The capability to use shorter wavelengths is particularly advantageous to produce high quality features in glass, SiC and silicon amongst others.