High power applications of the Laser MicroJet

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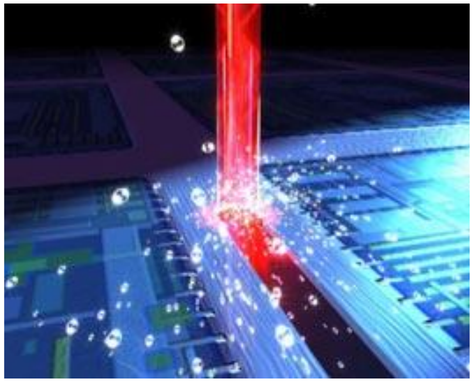
CTO
Synova SA



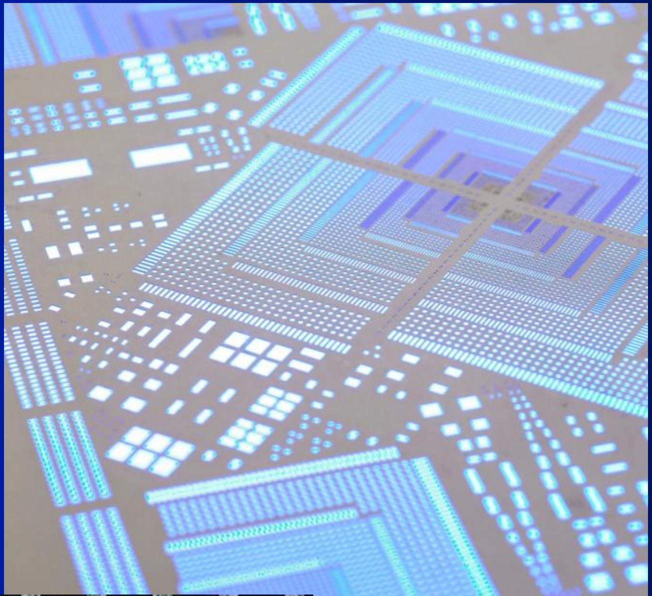
Outline

- Company & products
- Laser MicroJet principle
- Example of high-power applications:
  - increase speed: cutting of solar cells
  - cut hard materials: CVD diamond, PCD/WC, CBN/WC, WC
- Cutting with high-power green and IR disc lasers
- Laser Chemical Processing
- Conclusion

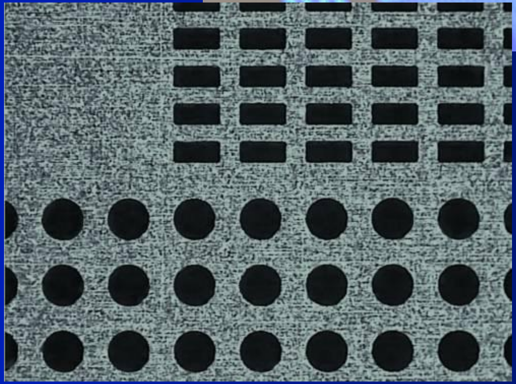
Company

Founded: 1997
Headcount: 70 employees

Laser Stencil System (LSS)



Applications:	stencils and OLED masks
Working area:	630 mm x 850 mm
Accuracy:	+/- 5 µm
Repeatability:	+/- 2 µm
Speed:	1000 mm / s
Acceleration:	1 G



Cutting of stencils

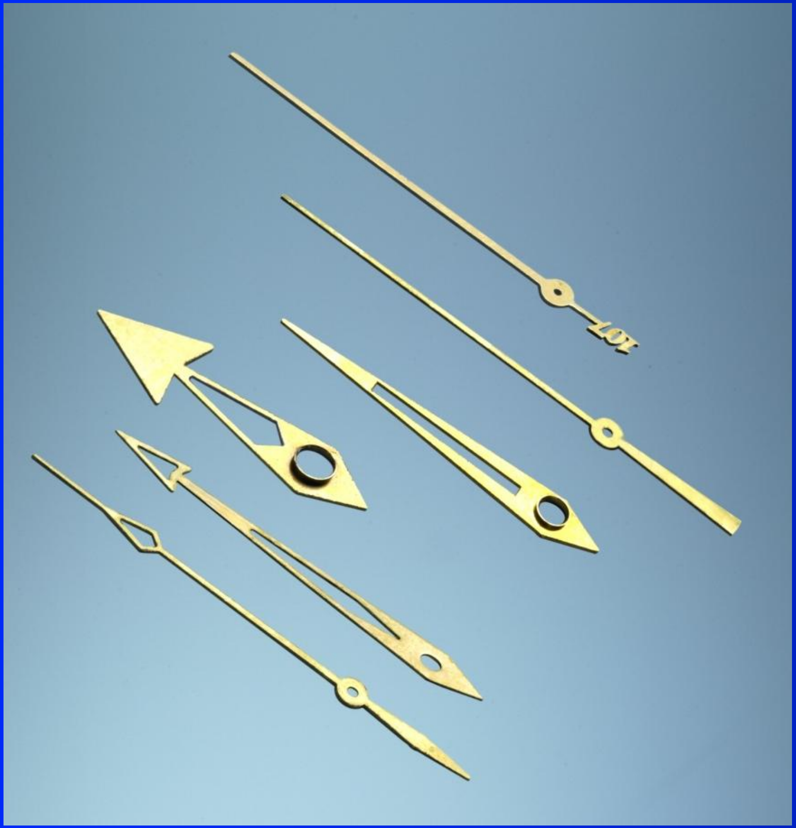
Laser Cutting System (LCS)

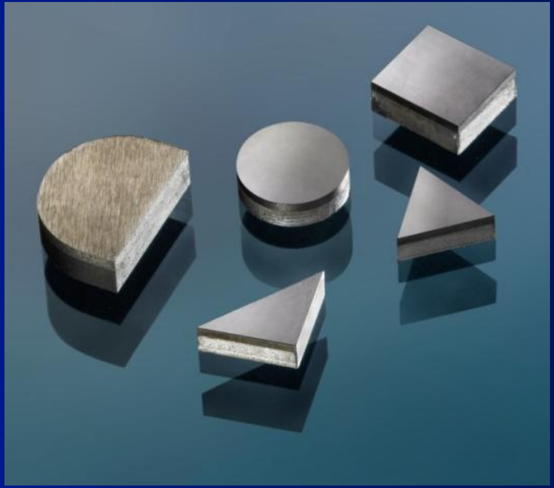
Working area:	150 mm x 150 mm
Accuracy:	+/- 5 µm
Repeatability:	+/- 2 µm
Speed:	300 mm / s
Acceleration:	0.5 G

Working area:	300 mm x 300 mm
Accuracy:	+/- 3 µm
Repeatability:	+/- 1 µm
Speed:	1000 mm / s
Acceleration:	2 G

Laser Cutting System (LCS)

Industries: watch, automotive, medical, tooling, …



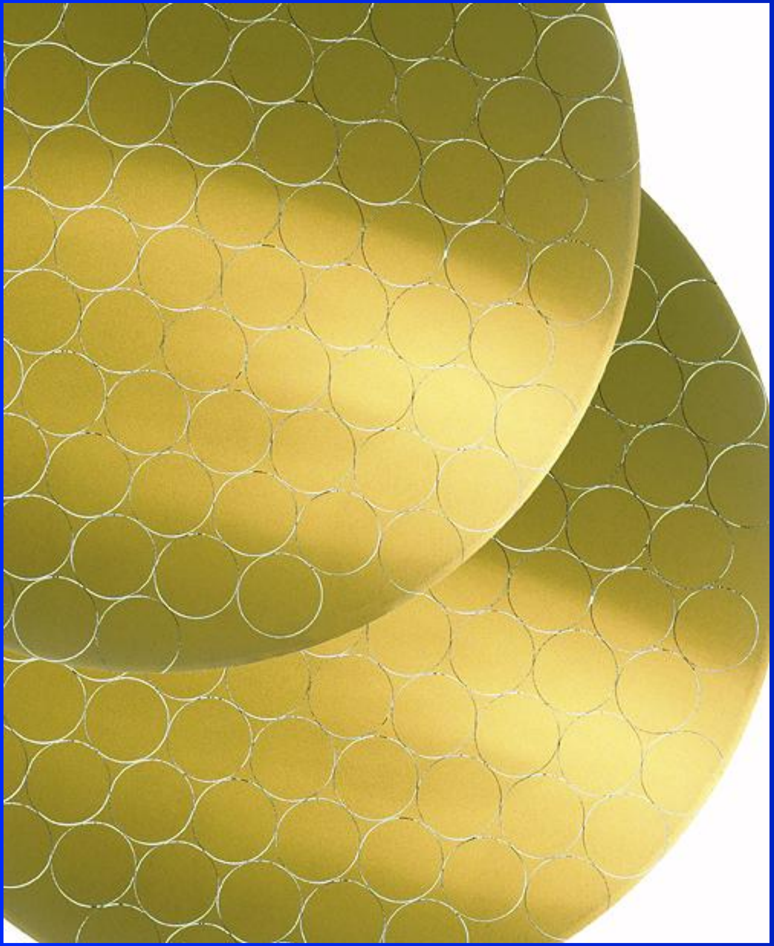


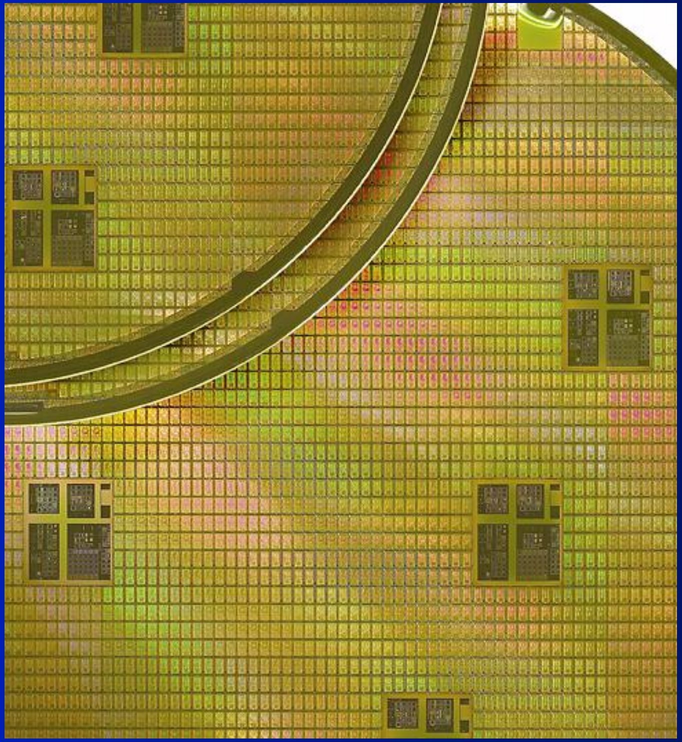
Laser Dicing System (LDS)

Applications: wafer dicing and grooving, edge isolation of solar cells, …

Working area:	240 mm x 240 mm
Accuracy:	+/- 3 µm
Repeatability:	+/- 1 µm
Speed:	1000 mm / s
Acceleration:	2 G

Laser Dicing System (LDS)

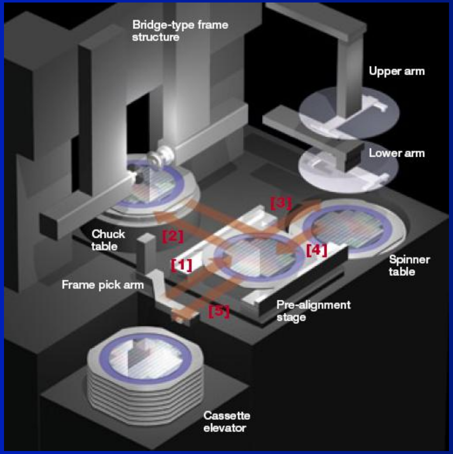




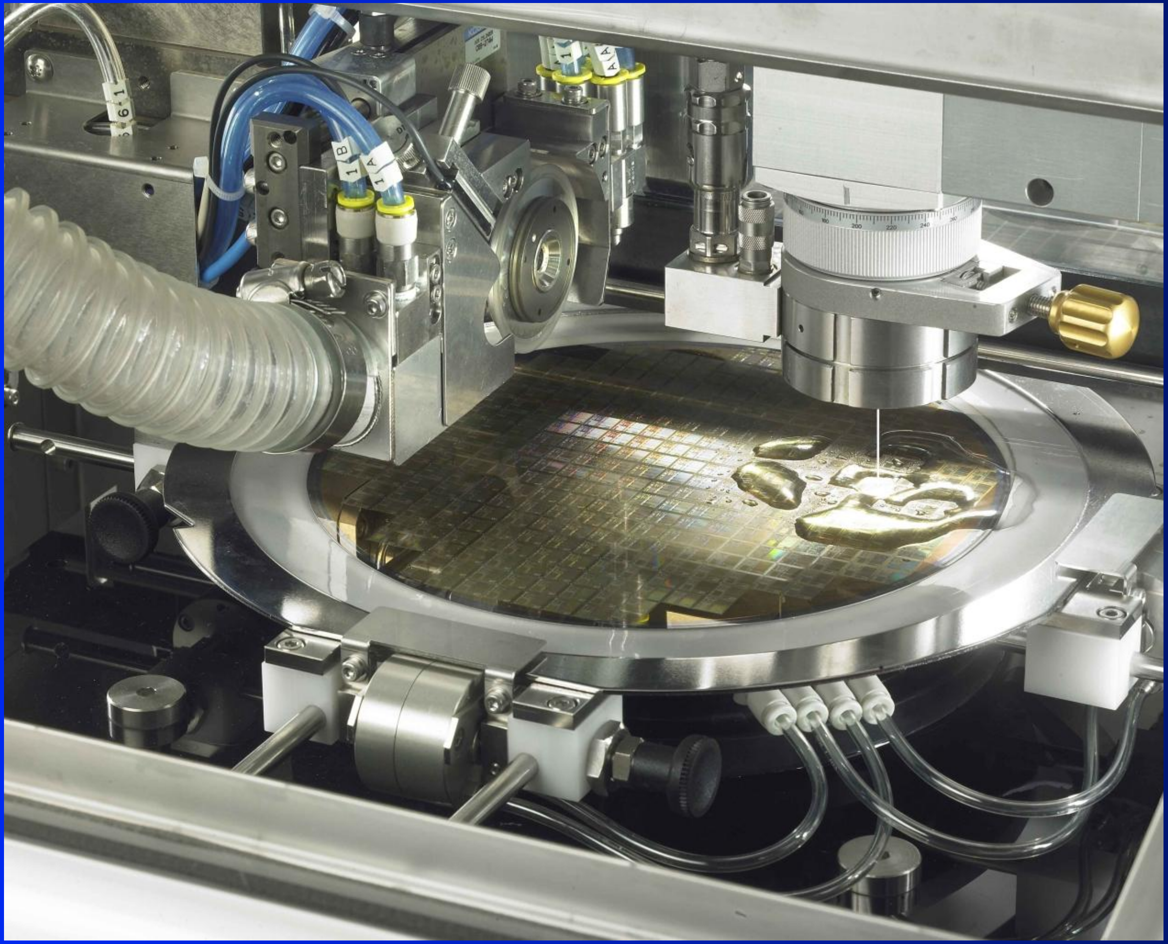
Industries: solar, semiconductors, HBLEDs, …

Hybrid Laser Saw (HLS)

- **Based on Disco dual parallel spindle DFD6361 Fully Automatic Dicing Saw**
- **Performs loading, alignment, cutting, cleaning, drying and unloading fully automatically**
- **Wafer diameter up to Ø300 mm**
- **Cutting speed 0.1 - 600 mm/s**

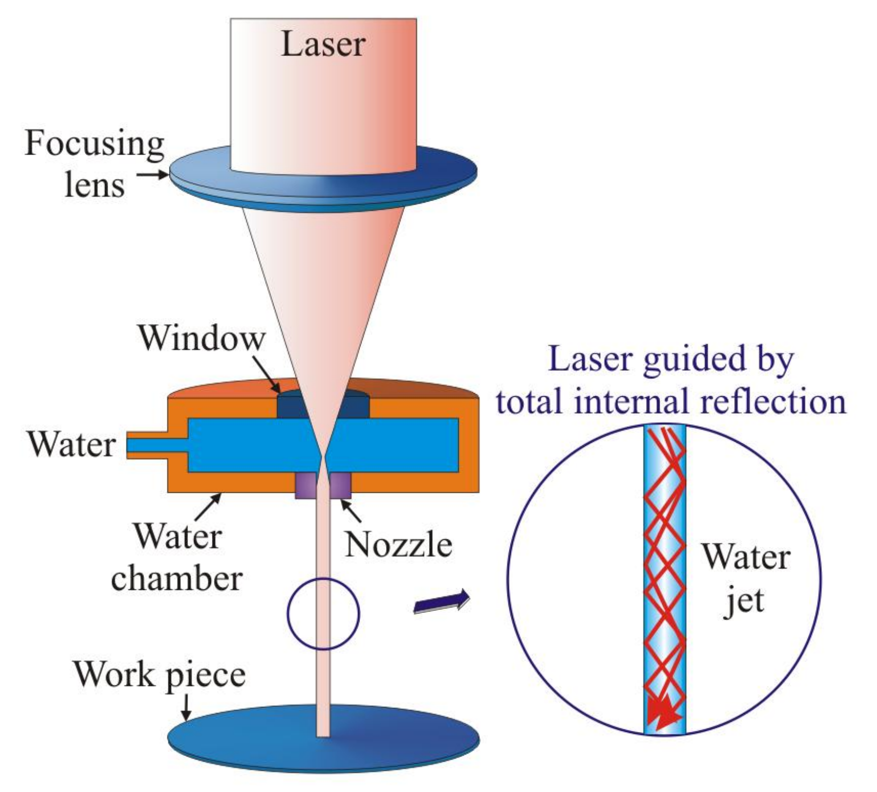


Hybrid Laser Saw (HLS)



Laser MicroJet Principle

- Water jet generated using small nozzles (20 – 160μm) and low water pressure (500 – 50bar)
- High-power pulsed laser beam focused into nozzle in water chamber
- Laser beam guided by total internal reflection to work piece
- Long working distance (>100 mm)

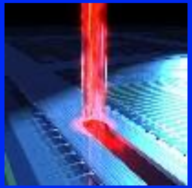


Laser MicroJet advantages

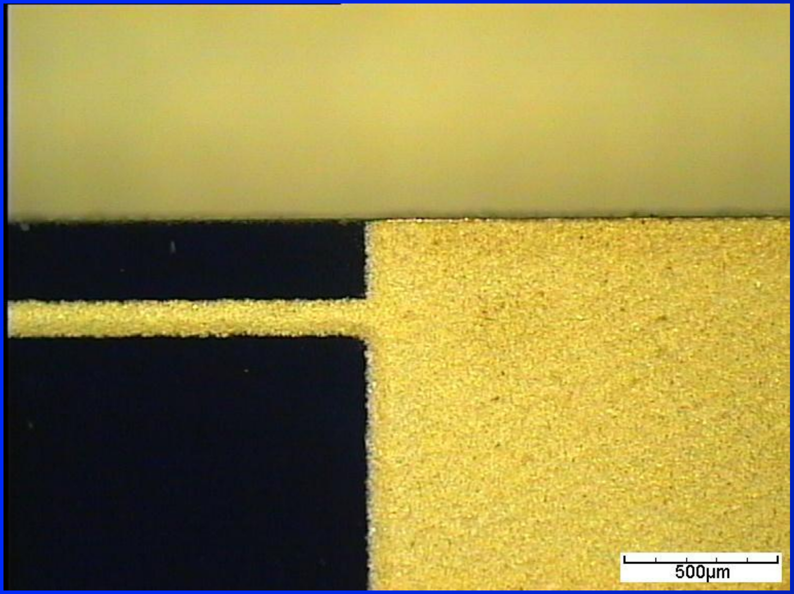
- Produces perfectly parallel kerf walls without focusing optics
- Achieves high aspect ratios
- Reduced HAZ as water cools cut edges between laser pulses
- Ablated material flushed clear of kerf
- No surface contamination or deposition due to presence of water film

Cutting of monocrystalline cells

Material: SiNx / Si
Dimension: 156 x 156 mm^2
Thickness: 180 - 230µm

	**SYSTEM**	Machine type	LDS 300	
	**MICROJET® PARAMETER**	Nozzle diameter	50	*µm*
		MicroJet® diameter	45	*µm*
		Water pressure	250	*bar*
	**LASER PARAMETER**	Laser type	Q-switched YAG	
		Wavelength	532	*nm*
		Pulse frequency	50	*kHz*
		Average power	150	*W*
	**CUTTING PARAMETER**	Cutting speed	250	*mm/s*
		Number of passes	2	
		Overall speed	**125**	***mm/s***

Cutting of monocrystalline cells

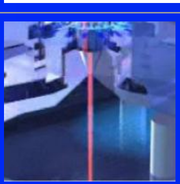
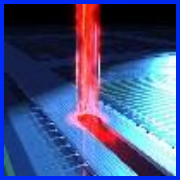


Dark field, top view

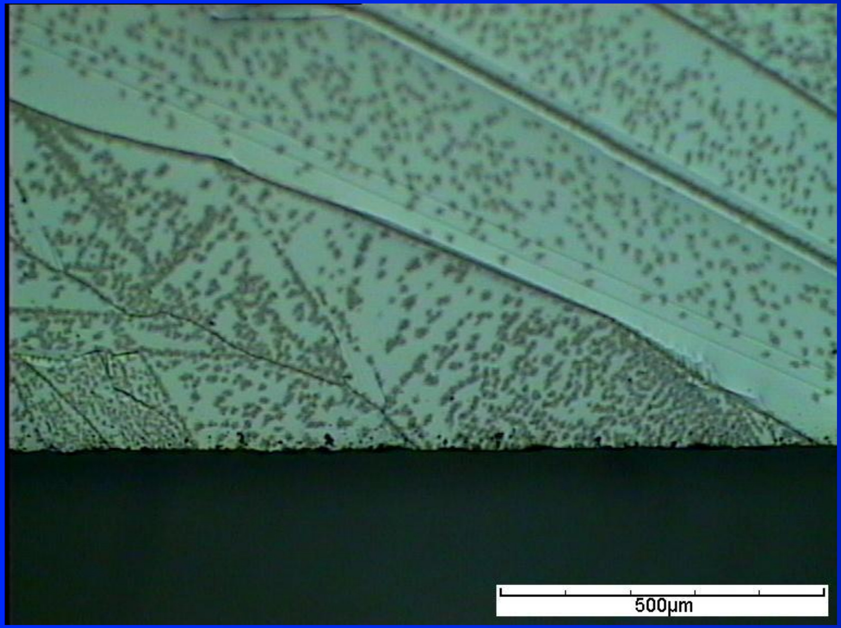
Dark field, cross-section

Cutting of polycrystalline cells

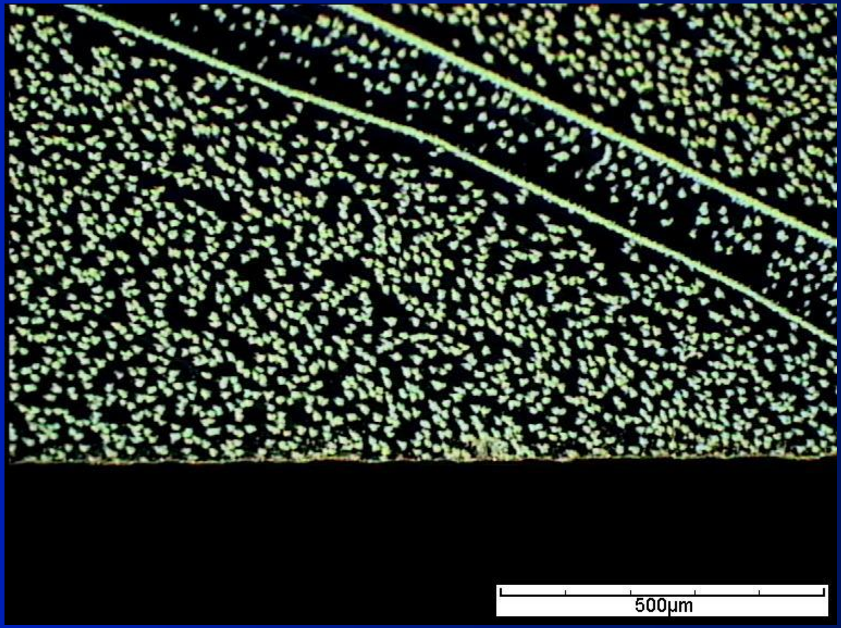
Thickness: 180 - 300μm

	**SYSTEM**	Machine type	LCS 300	
	**MICROJET® PARAMETER**	Nozzle diameter	80	*µm*
		MicroJet® diameter	72	*µm*
		Water pressure	125	*bar*
	**LASER PARAMETER**	Laser type	Q-switched YAG	
		Wavelength	532	*nm*
		Pulse frequency	50	*kHz*
		Average power	150	*W*
	**CUTTING PARAMETER**	Cutting speed	300	*mm/s*
		Number of passes	3	
		Overall speed	**100**	***mm/s***

Cutting of polycrystalline cells



Bright field, top view



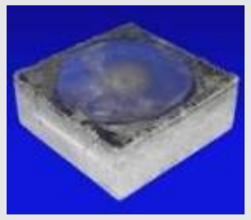
Dark field, top view

Cutting of crystallized thin tubes

Jena

Conventional Wafer Technology

① Ingot-Crystallisation



→

② Blocking

→

③ Wafering

Alzenau

EFG-Technologie
(**E**dge Defined **F**ilm Fed **G**rowth)

① Pulling

→

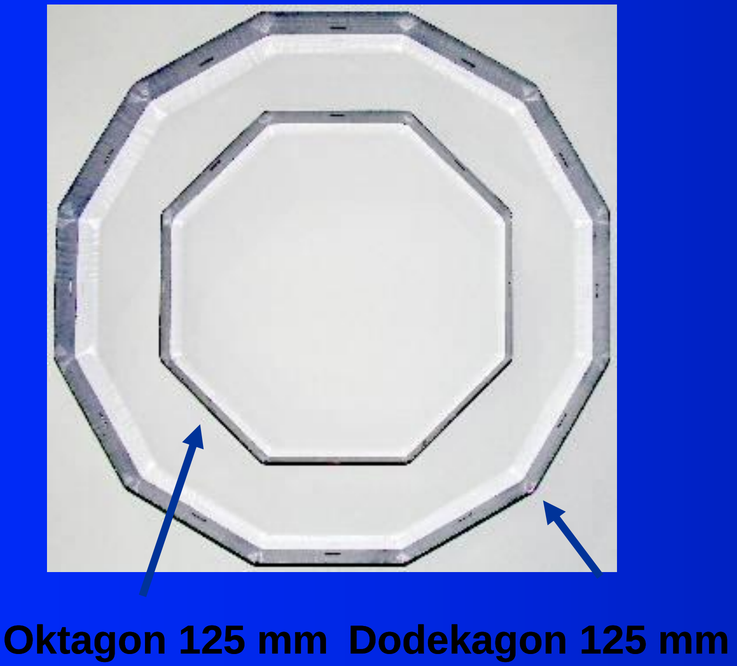
② Wafering by Laser

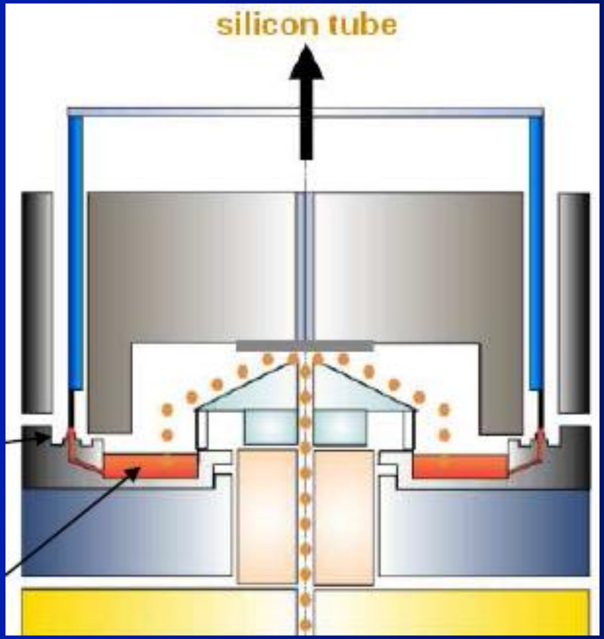
Courtesy of Wacker Schott Solar

Crystallisation of thin tubes

- EFG: „**E**dge-defined **F**ilm-fed **G**rowth“
- Feedstock: Granular silicon
- Drawing of thin tubes directly out of Si melt
- Tube length ca. 6,5 m, thickness 270 µm
- Tube geometries:

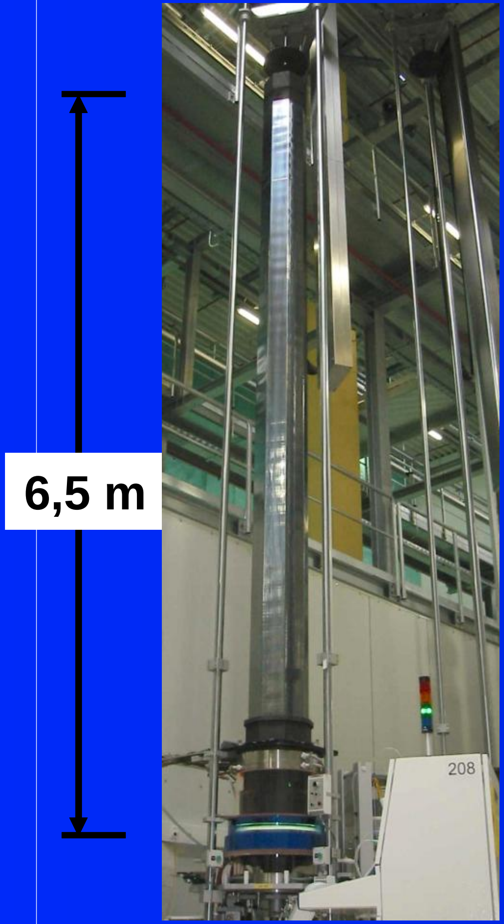
  8-corners and 12-corners (125 mm)

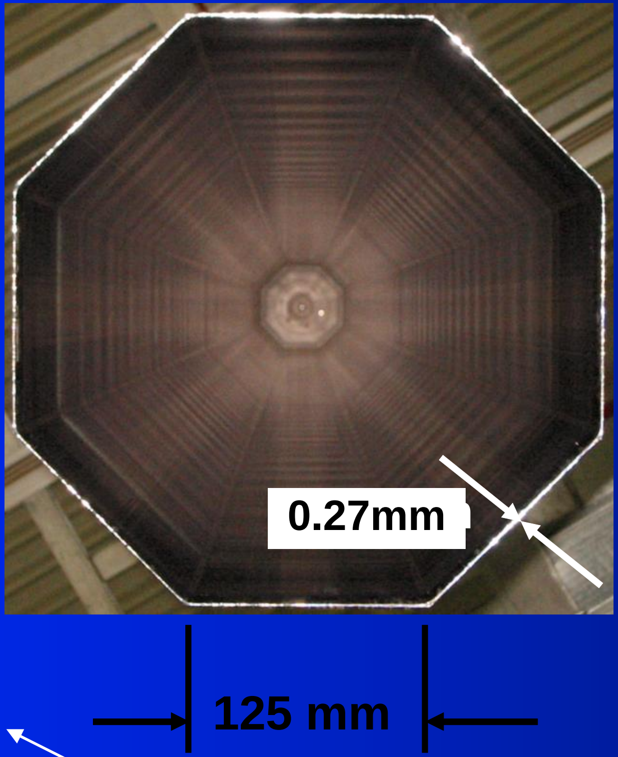




Courtesy of Wacker Schott Solar

Crystallisation of thin tubes





Crystal Growing

Laser Cutting

Courtesy of Wacker Schott Solar

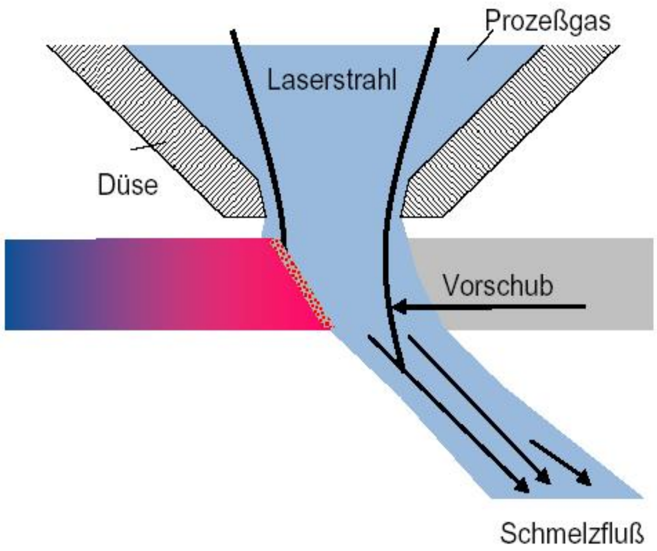
Production of thin tubes

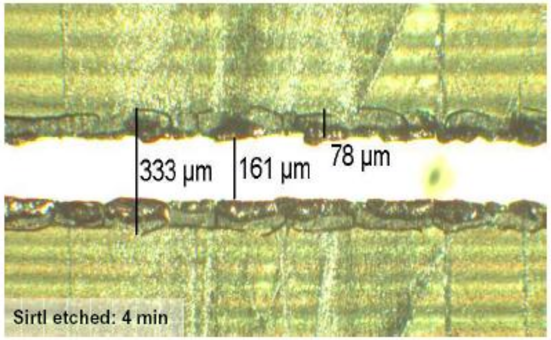
Courtesy of Wacker Schott Solar

Dry laser cutting

- Successive laser cutting of wafers out of each face of the tube
- Wafer dimensions: 125x125 mm^2 (5“)
  156x156 mm^2 (6“) under development
- Pulsed solid state laser (Nd:YAG)
- Nozzle distance control required, process gas blows melt out of kerf
- Significant edge damage due to laser process and cutting speed
- Edge damage limits wafer strength; as-cut wafer strength ~ 40 MPa
  → Removal of damage by separate etching necessary

Fusion cutting process





Courtesy of Wacker Schott Solar

Cutting results

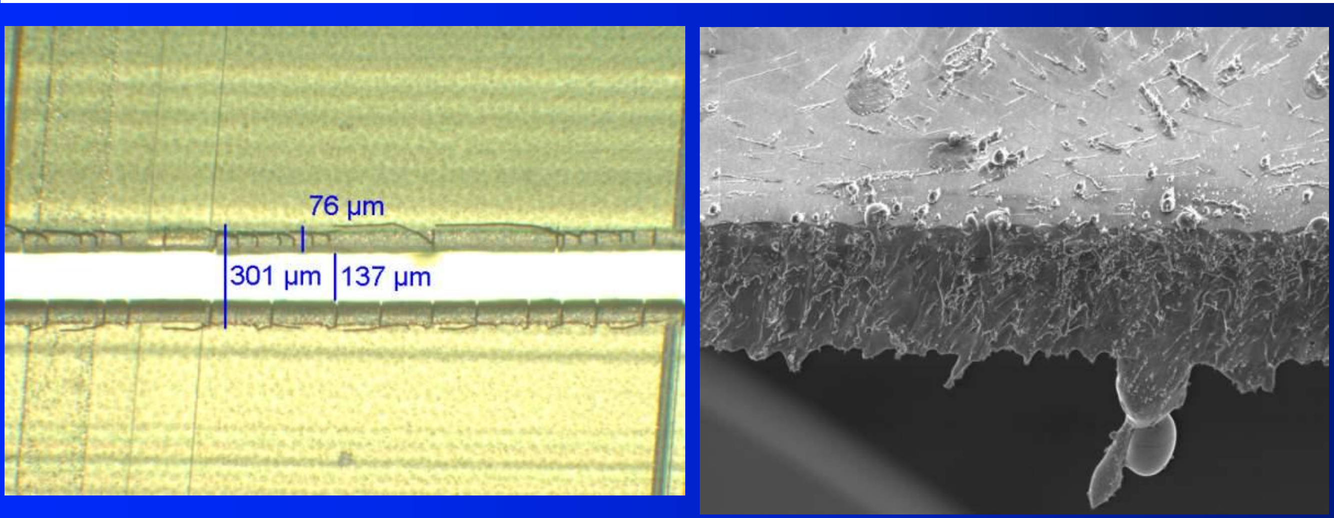
Laser MicroJet® Technology

→ No micro cracks along the whole wafer edges on both front and backsides

→ No droplets

→ No burr formation

→ High fracture strength



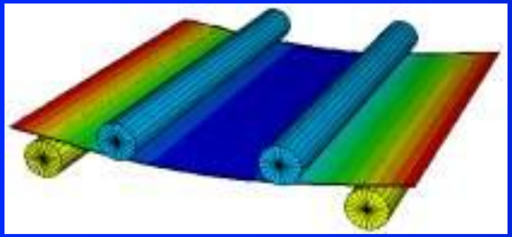
Conventional Technology

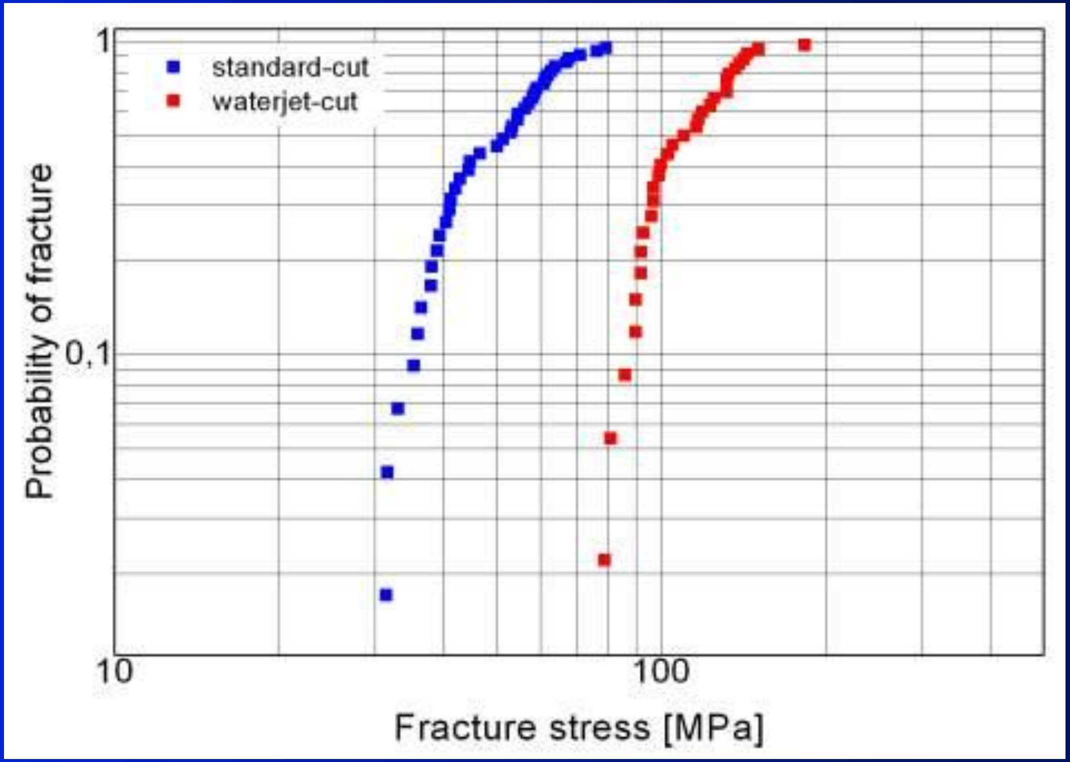
(dry laser)

Courtesy of Wacker Schott Solar

Wafer fracture strength

Wafer strength (4 point bending test): 120 - 150 MPa



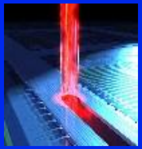


- ⇨ Nearly damage-free edges, no edge etching necessary
- ⇨ 2.5 higher fracture strength compared to dry laser

Courtesy of Wacker Schott Solar

CVD diamond tipped insert cutting

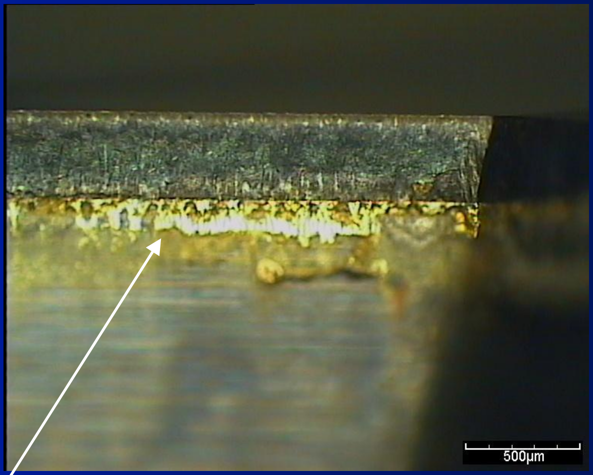
Material:	CVD diamond
Thickness:	400μm
Application:	conventional milling inserts, 20° relief angle

	**SYSTEM**	Machine type	LCS300
	**MICROJET® PARAMETER**	Nozzle diameter	75 *µm*
		MicroJet® diameter	68 *µm*
		Water pressure	250 *bar*
	**LASER PARAMETER**	Laser type	2x Nd:YAG
		Wavelength	532 *nm*
		Pulse frequency	15 *kHz*
		Average power	120 *W*
	**CUTTING PARAMETER**	Scanning speed	60 *mm/s*
		Number of scans	70
		Cutting speed	35 *mm/min*

CVD diamond tipped insert cutting

Final insert

Bright field, front side

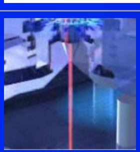
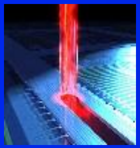


Dark field, cross section

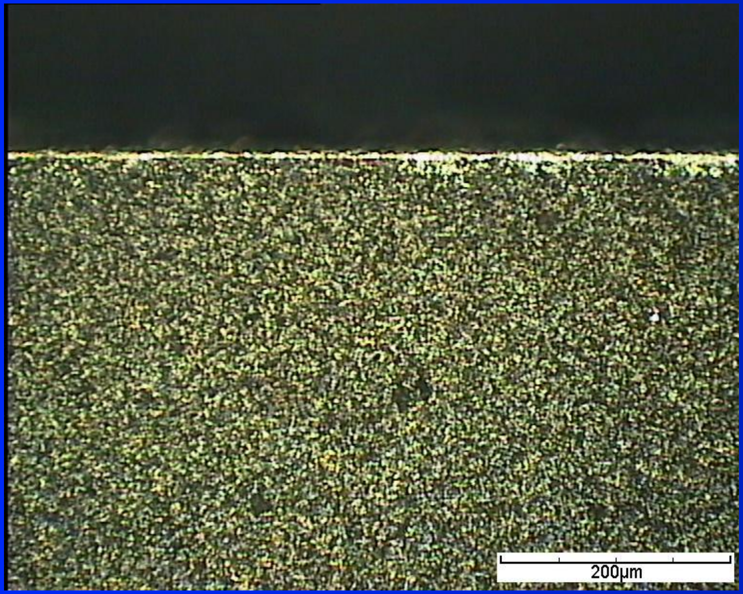
Solder

PCD / WC insert cutting

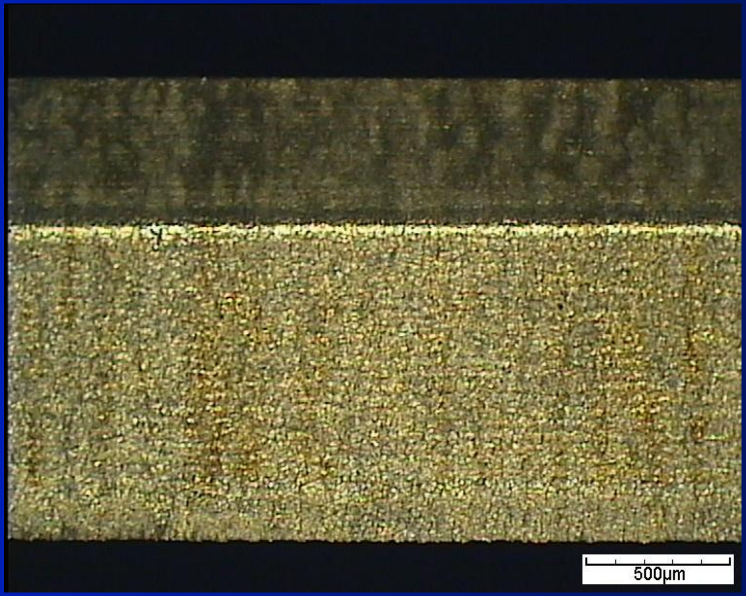
Material:	PCD/WC inserts
Thickness:	1.6 mm

	**SYSTEM**	Machine type	LCS300	
	**MICROJET® PARAMETER**	Nozzle diameter	80	*µm*
		MicroJet® diameter	64	*µm*
		Water pressure	250	*bar*
	**LASER PARAMETER**	Laser type	Double Nd:YAG	
		Wavelength	532	*nm*
		Pulse frequency	14	*kHz*
		Average power/laser	70	*W*
		Total power	140	*W*
	**CUTTING PARAMETER**	Linear acceleration	3000	mm/s^2
		Scanning speed	25	*mm/s*
		Number of passes	46	
		Cutting speed	**28**	***mm/min***

PCD / WC insert cutting



Dark field, insert edge



Dark field, cross section

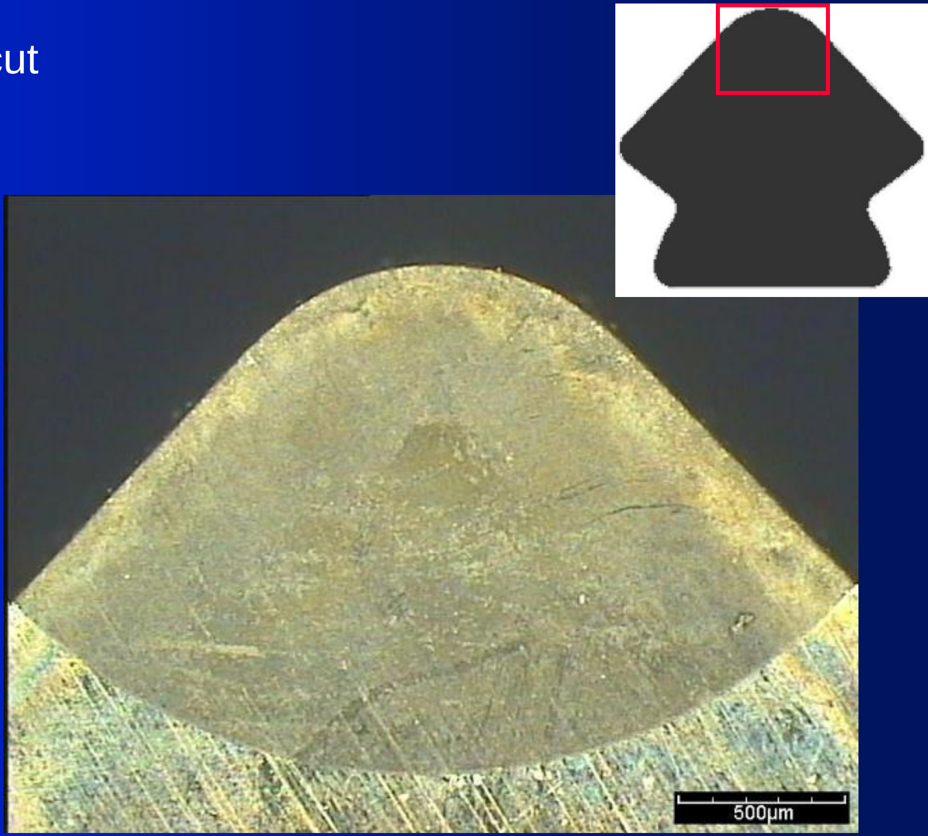
Edges are sharp and perfectly clean. No recast nor thermal effect.

CBN / WC disc cutting

5 mm thick CBN insert in WC disc through cut

λ: 532nm (dual cavity laser)
Jet diameter: 66 µm
Cutting speed: 2.7 mm/min (220 passes)

Pulse Freq.	8	kHz
P average	140	W
Water Pres.	400	bar

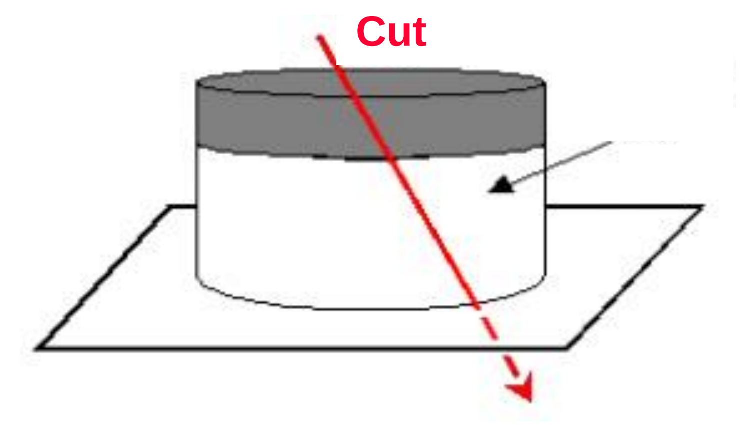


Microscopic top view of front side of insert tip

Fast process, high aspect ratio, no burrs or particle contamination

CBN / WC disc cutting

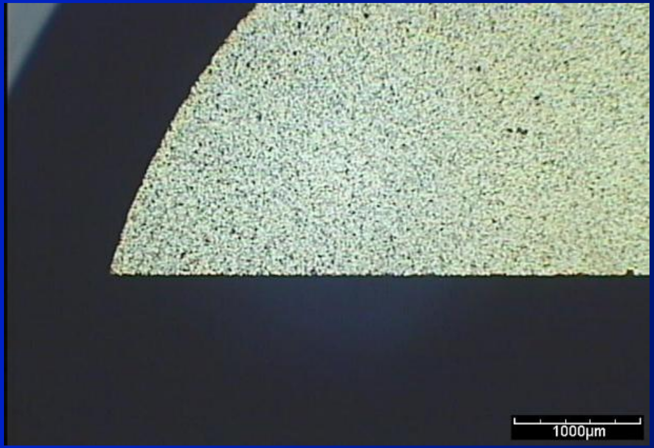
1.5 mm thick CBN on 7 mm WC backing chamfered cut through



Sketch of cutting requirements

λ: 532nm (dual cavity laser)
Jet diam: 66 µm
Cutting speed: 1.7 mm/min

Pulse Freq.	8	kHz
P average	140	W
Water Pres.	400	bar

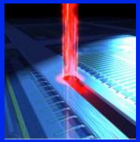


Microscopic view of topside of CBN tip

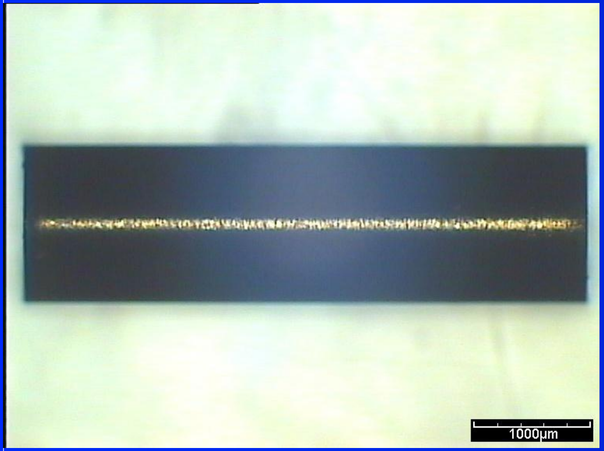
Flexibility, high quality clean edges, no HAZ

WC rod cutting

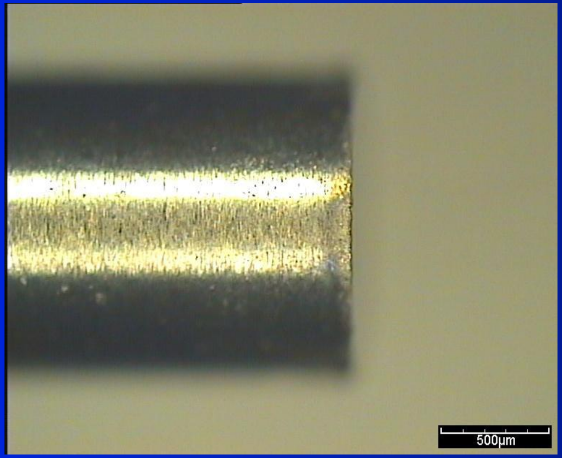
Material:	pure WC rods
Thickness:	1.42 mm
Length:	5 mm

	**SYSTEM**	Machine type	LCS300
	**MICROJET® PARAMETER**	Nozzle diameter	80 *µm*
		MicroJet® diameter	72 *µm*
		Water pressure	350 *bars*
	**LASER PARAMETER**	Laser type	Q-switched YAG
		Wavelength	532 *nm*
		Pulse frequency	18 *kHz*
		Pulse sync delay	250 *ns*
		Average power	140 *W*
	**CUTTING PARAMETER**	Cutting speed	60 *mm/s*
		Number of passes	60
		Overall speed	50 *mm/min*

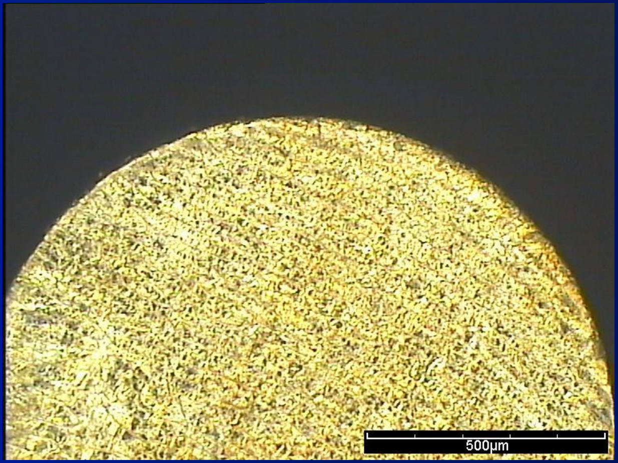
WC rod cutting



Bright field, side view



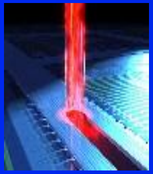
Dark field, side view



Bright field, top view

Thick WC cutting

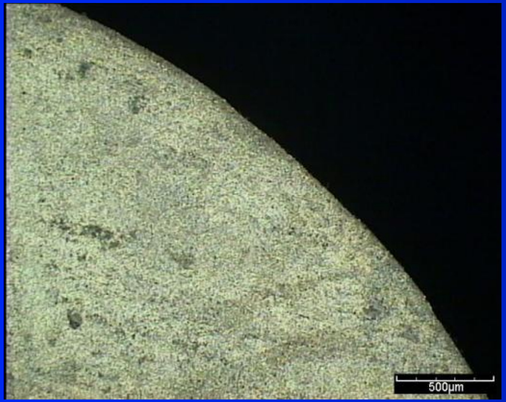
Material: WC
Thickness: 5 mm

	**SYSTEM**	Machine type	LCS300
	**MICROJET® PARAMETER**	Nozzle diameter	80 *µm*
		MicroJet® diameter	~72 *µm*
		Water pressure	300 *bar*
	**LASER PARAMETER**	Laser type	Dual Nd:YAG
		Wavelength	532 *nm*
		Pulse frequency	12 *kHz*
		Average power	125 *W*
	**CUTTING PARAMETER INNER CIRCLE**	Scanning speed	20 *mm/s*
		Number of scans	200
		Cutting speed	**5.5 *mm/min***

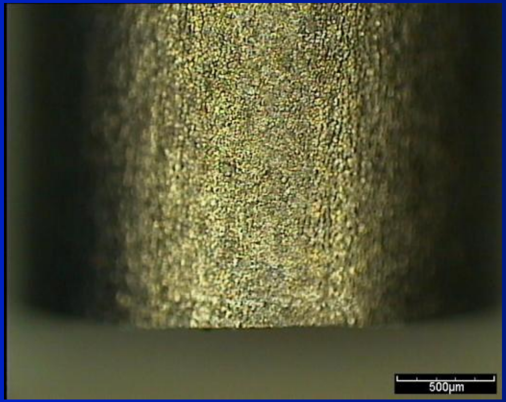
Thick WC cutting

Dark field, front side

Dark field, back side



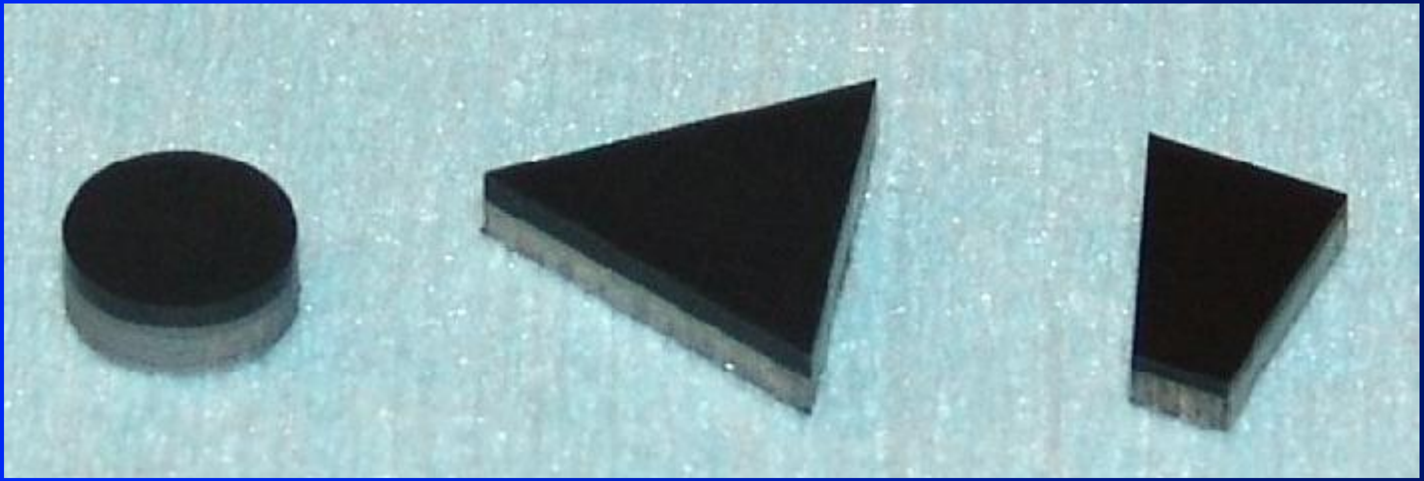
Dark field, back side



Dark field, cut side

High-power green disc laser

High-power green disc laser

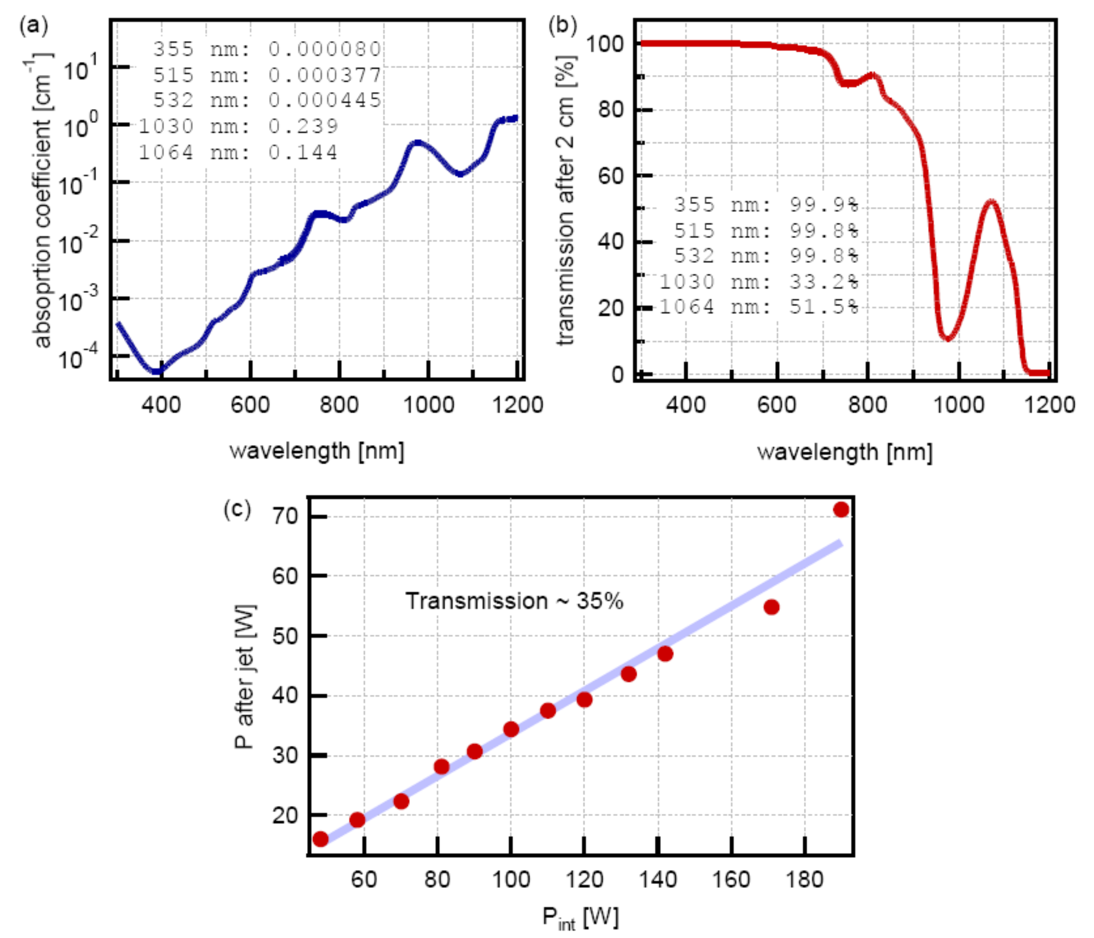


Cutting of tool inserts (1.6mm)
PCD (polycrystalline diamond, 0.2mm) and WC (tungsten carbide, 1.4mm).

Effective cutting speed = 30 mm/min (scanning speed = 60 mm/s)
Laser rep rate = 14 kHz
Average power = 132 W (100% diode current)
80 µm nozzle (70 µm jet diameter = kerf width)

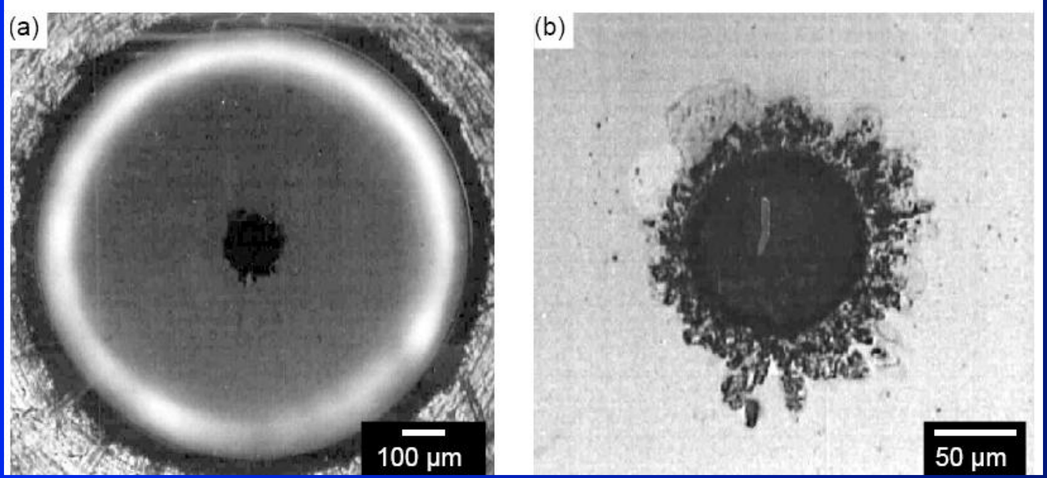
High-power IR disc laser

High-power IR disc laser



(a) Absorption coefficient of water at different wavelengths. (b) Calculated transmission after 2 cm travel in water jet at different wavelengths. (c) Experimental data confirming the low transmission for 1030 nm laser.

High-power IR disc laser



Optical microscopy images of a damaged nozzle at different magnifications

Issues at high power levels when using IR lasers:

1. Only a small fraction (30%) of the power is delivered to the work piece (expected)
2. Nozzle damage due to cavitation effects above 350W (100 μm nozzle,10 kHz repetition rate). Laser absorption creates water vapour bubbles, which upon collapsing generate shock waves and high speed jets that damage the nozzle

Laser Chemical Processing

Idea from ISE[*], based on Synova IP:

Start from water jet-guided laser technology; replace water by chemical jet

⇨ Laser Chemical Processing (LCP)

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[*] *Willeke, G.P. and D. Kray, A new route towards 50 µm thin crystalline silicon wafer solar cells*
Proceedings of the 17th European Photovoltaic Solar Energy Conference, 2001, Munich, Germany

Laser Chemical Processing

Applications :

- doping for selective emitter formation
- doping for LFC contact formation
- wafering

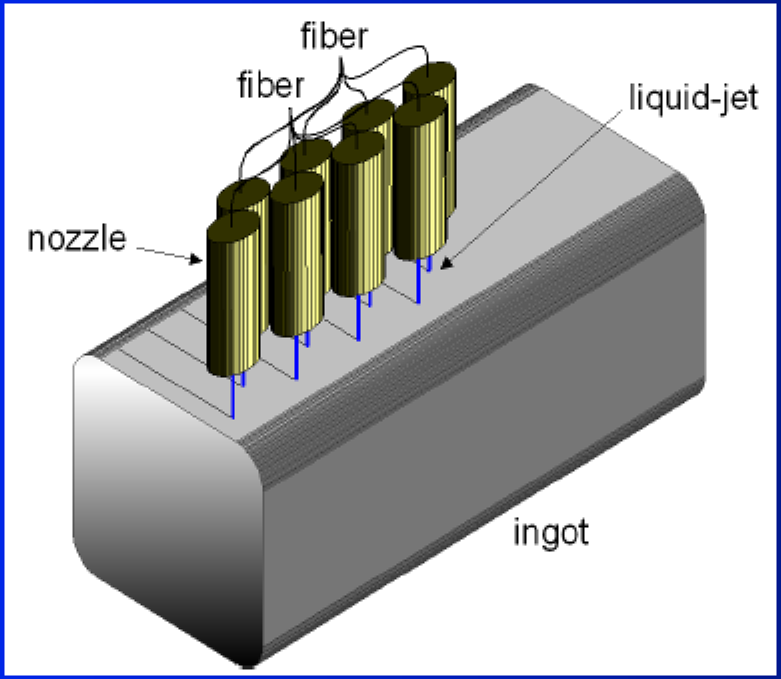
Wafering

Goal: slice mono and polycristalline ingots into wafers

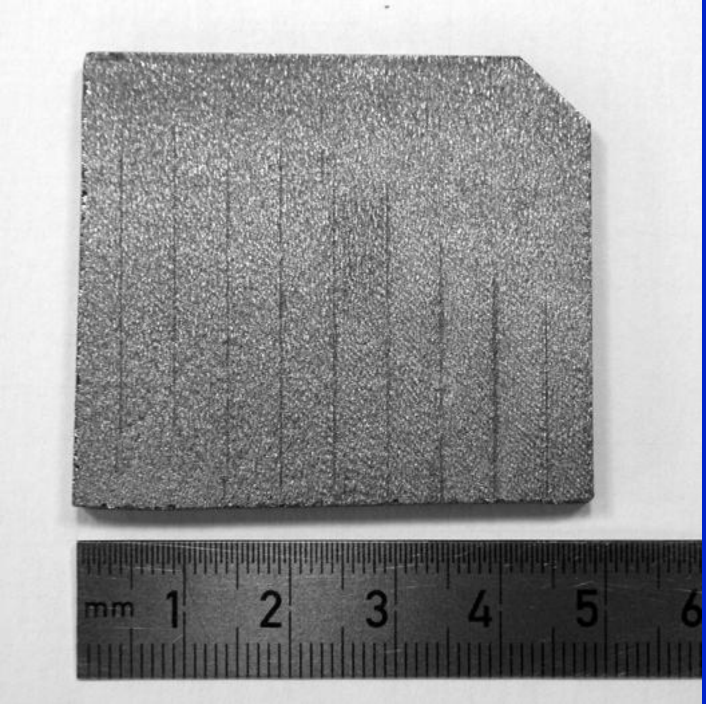
Current technology: multi-wire slurry saw (300 wafers / hr)

Problem: 160µm wire ⇨ 200µm kerf ⇨ about 50% material loss

Wafering



Wafering



70 mm deep laser cut with a long pulse IR laser (Tumpf): $P=260$ W, $\nu=85$ Hz, $\tau=0{,}5$ ms, $w=1$ mm/s and a 100 µm nozzle

42x45 mm^2 wafer cut with same laser

Comparison of Laser Chemical Processing and Laser MicroJet for structuring and cutting silicon substrates, Applied Physics A, H. Hopman et al, 01/2009

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Wafering

	Average cutting speed $S_{n\ exp}$ **[μm/s]**	**Experimental cutting time for** 100x10 mm^2 T_{exp} **[min]**	**Material removal rate (for single laser groove)** M **[mm^3/s]**	**Cutting speed of first laser groove** $S_{1\ exp}$ **[μm/s]**	**Theoretical cutting time for 100x10 mm^2** T_{tc} **[min]**
MWSS typical	**~7,5**				~22,2
1064 nm Spectron (3,5 mJ, 670 ns, 45 W)	**17,8**	**9**	**0,42**	**61**	**3,2**
532 nm Lee (12 mJ, 360 ns, 120 W)	**42**	**4**	**0,7**	**68,6**	**2,4**

- laser-based wafering provides faster speed and improved surface quality
- Technique still requires massive parallelization to be competitive

Comparison of Laser Chemical Processing and Laser MicroJet for structuring and cutting silicon substrates, Applied Physics A, H. Hopman et al, 01/2009

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Summary

Laser Microjet gives also excellent results at high power levels

Typical applications at high power: cutting of solar cells or hard materials

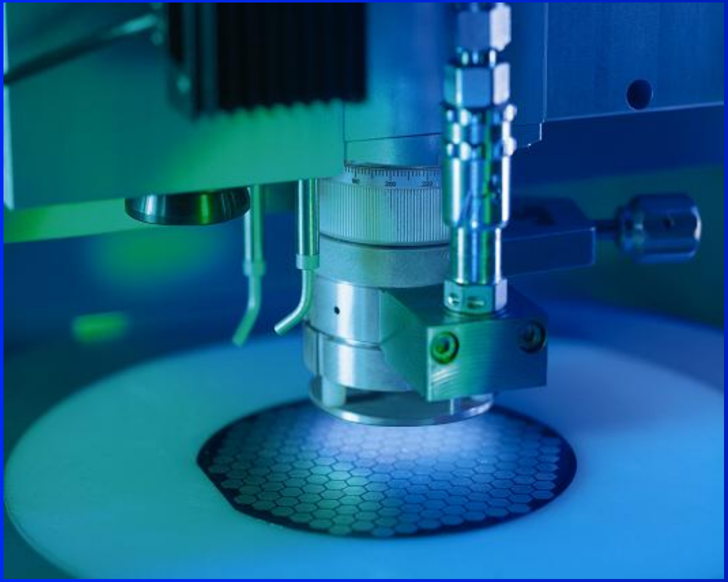
Advantages of using LMJ technology for hard material cutting:

- Higher throughput than standard diamond blades or electro erosion
- Superior quality to standard lasers; no burring, eliminating need for post processing
- Greater tool flexibility, able to cut all patterns
- Low operating costs, as there are no blades or cooling liquid
- Faster prototyping

Limitations at highest power levels are

1) Cavitation effects at 1030nm – 1064nm
2) Thermal effects at 510 – 532nm

Contact



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Where others see impossibilities, we see solutions