IMI-NFG Glass Processing Course

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Lecture 25: Cutting of Glass

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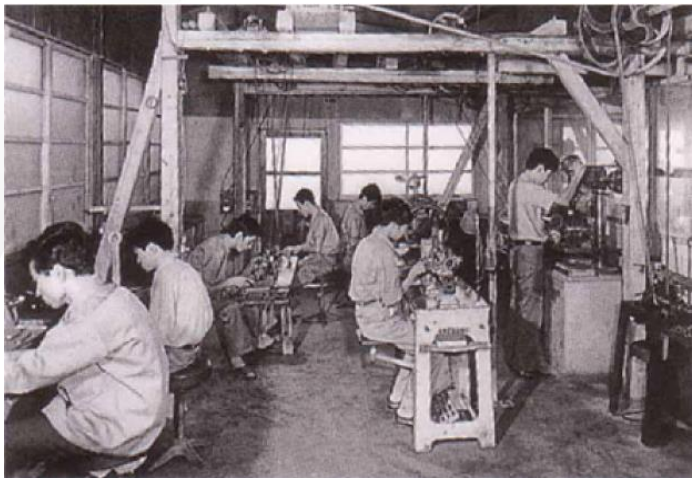
MDI Advanced Processing GmbH

Introduction – Our Mother Company

Mitsuboshi Diamond Industrial Co., Ltd.

- Japanese manufacturer for glass cutting machines and tools mainly for FPD market, established 1935



The company Mitsuboshi Diamond in the 1950's

New factory in Iida / Japan

Introduction – Focus of this Presentation

- This is not a lesson about theory
- This is a introduction into State-of-the-Art cutting methods for glass
- Glass cutting is still dominated by mechanical processing methods; recently laser based processing technologies are entering the market
- Besides the cutting methods mentioned and explained here, there are many other technologies like water jet, diamond dicing, etc.
- The process technology is depending on the specific application, there is neither THE ONE nor THE BEST technology

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1 Cutting of Glass

2 Evaluation of Glass Cut

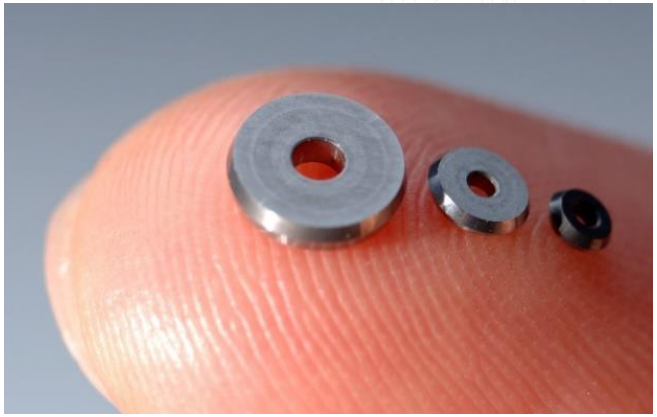
3 Cutting with Wheels

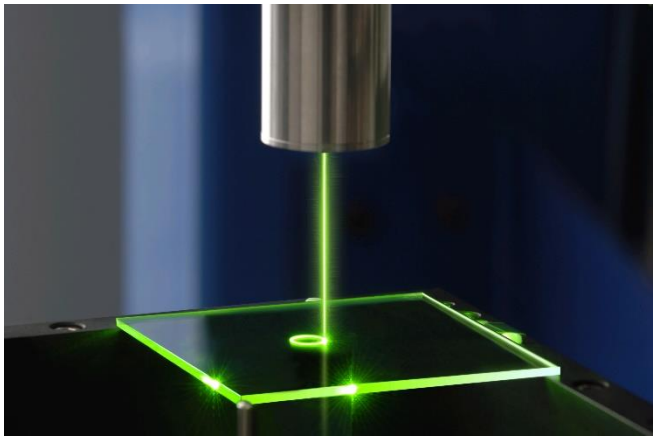
4 Cutting with CO_2 Laser

5 Cutting by Ablation

6 Filament Cutting

7 Conclusion





1 Cutting of Glass – History

In the Middle Ages glass was cut with a heated and sharply pointed rod of iron.

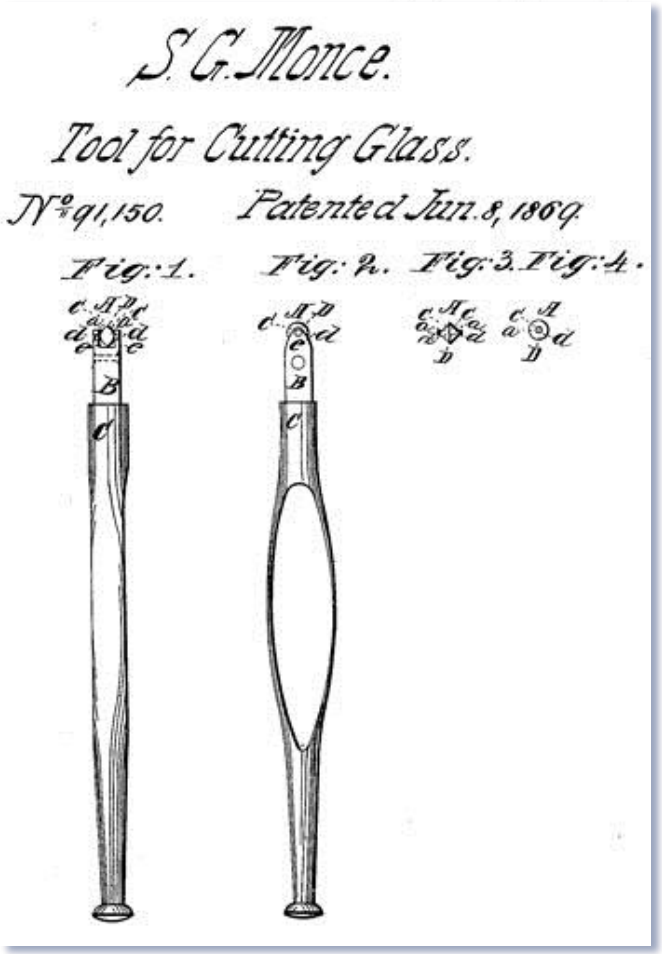
- The red hot point was drawn along the moistened surface of the glass causing it to snap apart.
- Fractures created in this way were not very accurate. Rough pieces had to be chipped or "grozed" down to more exact shapes with a hooked tool called “grozing iron”.

Source: Wikipedia

Grozing Iron

1 Cutting of Glass – History

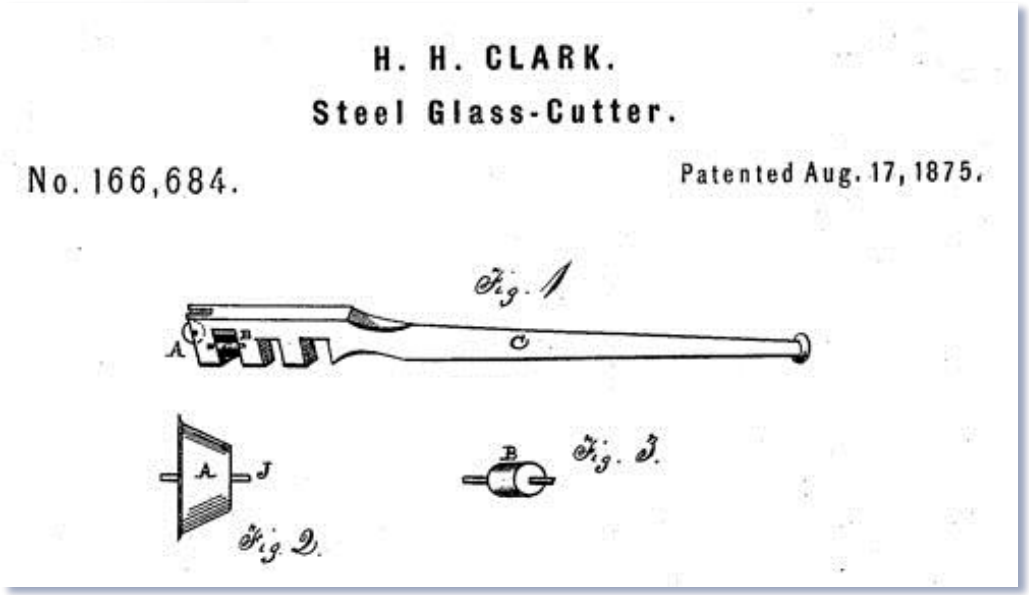
In 1869 the wheel cutter was developed by Samuel Monce of Bristol, Connecticut, which remains the current standard tool for manual glass cutting.


S. G. Monce.

Tool for Cutting Glass.

No. 91,150. Patented Jun. 8, 1869.

Fig. 1. Fig. 2. Fig. 3. Fig. 4.


H. H. CLARK.

Steel Glass-Cutter.

No. 166,684. Patented Aug. 17, 1875.

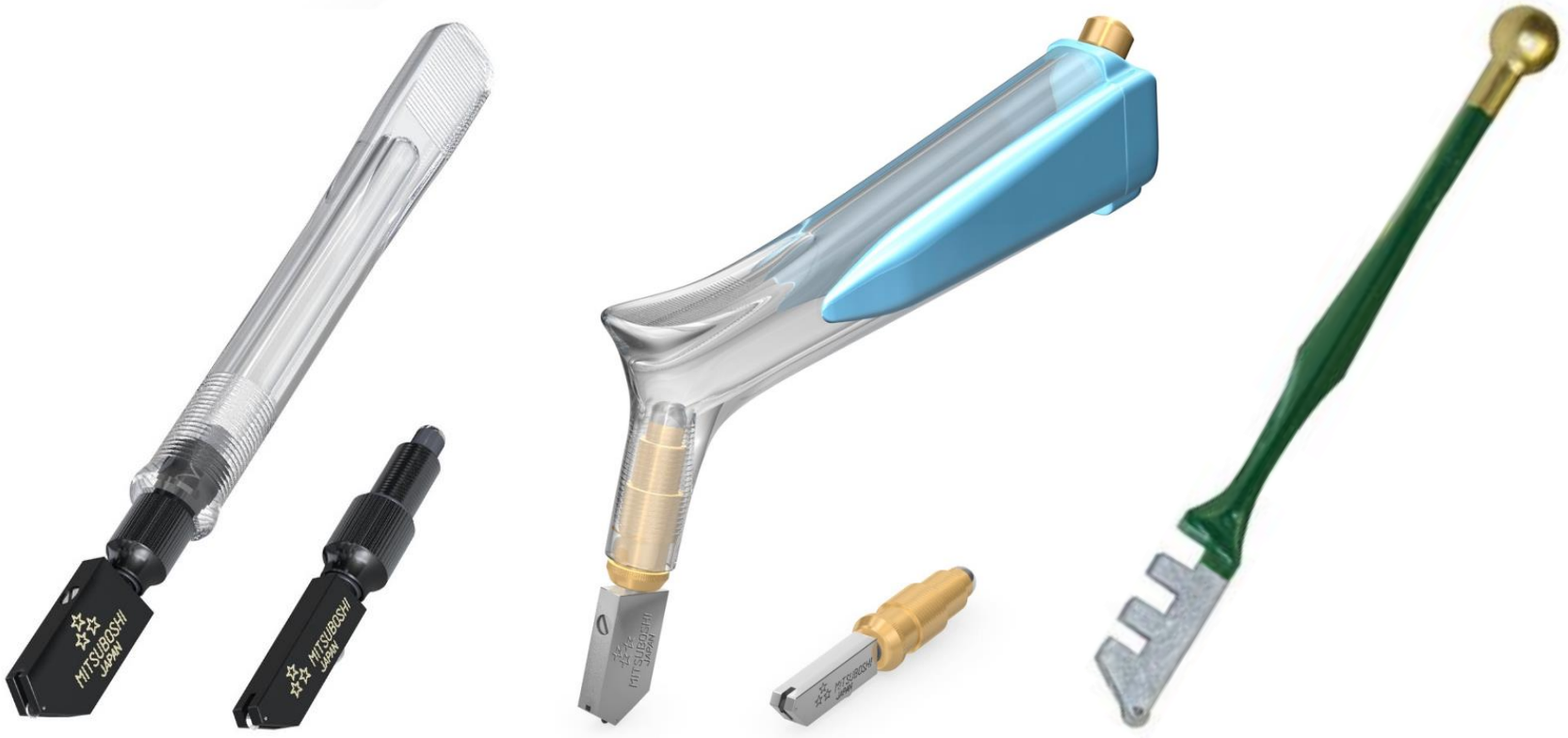
Fig. 1

Fig. 2.

Fig. 3.

1 Cutting of Glass – Tools

- Manual Glass Cutter

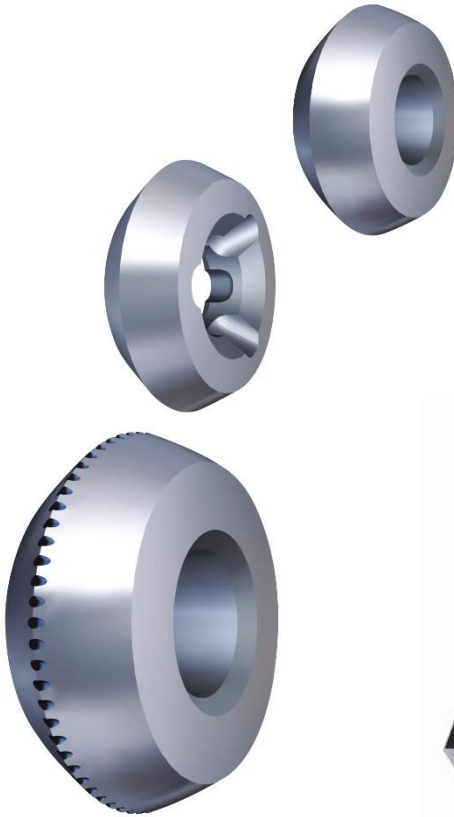


1 Cutting of Glass – Tools

- Normal Cutting Wheels
- Structured Cutting Wheels
- Holders and Axles

Insert

Holder



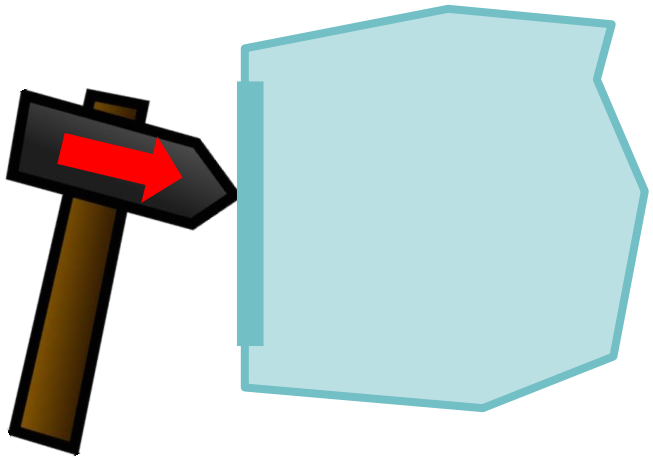
Cutting Wheels

Axle

1 Cutting of Glass

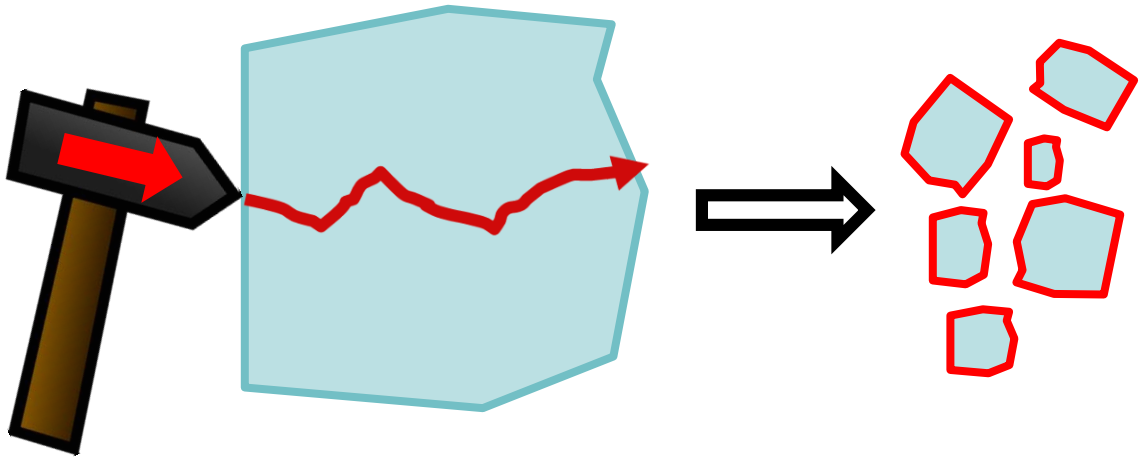
- If you take a piece of glass and try to break it without first scribing it, it will seem quite strong and will resist breaking. It will bend a little, because the force you are applying is evenly applied all over the glass.

- Hitting the glass by mechanical force causes tensions of > 500MPa but it will not break if there are no cracks or damages at the edge.



1 Cutting of Glass

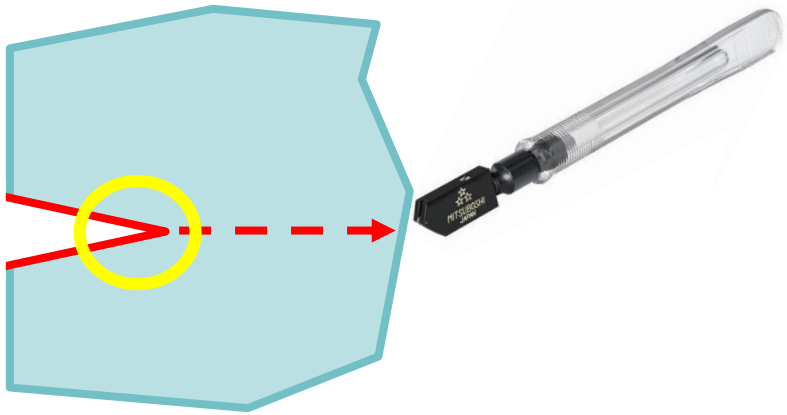
- But, at some point, if you continue to apply force, it will break.
- You will have no control over where it breaks, exactly when it breaks, what the shape of the break will be, or how many pieces it will break into. You will probably cut yourself as well !



1 Cutting of Glass

- However, if you scribe the glass first, it will be weaker than before, because you generate micro cracks and other damages along the scribed line.

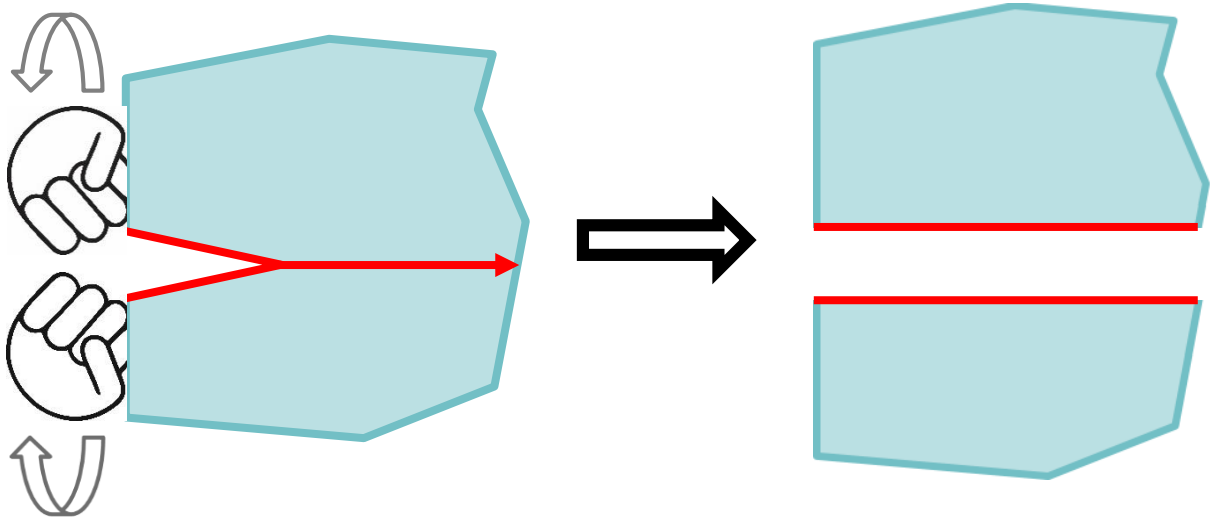
- A scribe line, if left alone long enough, will begin to “repair” itself and close again. In order to avoid the healing, a cutting liquid may be helpful.



1 Cutting of Glass

- The glass is now stressed at that point, and it will take little external pressure to cause it to separate along the scribe line.

- As a result, it will break along the scribe line with considerably less force than it was needed to break an unscored piece of glass e.g. when breaking by hand.



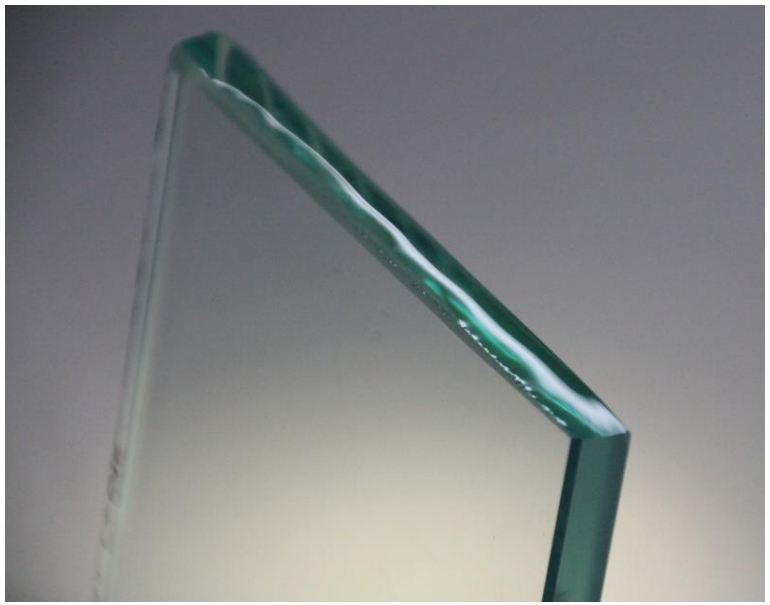
2 Evaluation of Glass Cut

How to evaluate a glass cut ?

Beside investment and running costs there are three important points to consider when evaluating a glass cut:

- **Point 1 – Edge strength:**
  > For most of the final applications a proper edge strength is a must
  > The glass should not break easily

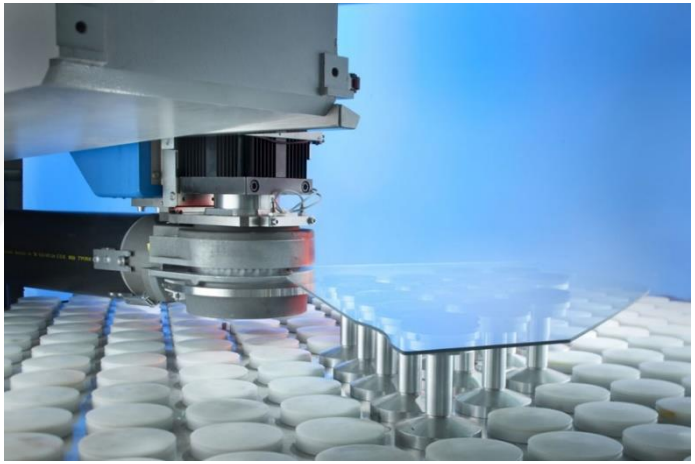
- **Point 2 – Chippings:**
  > Often chipping is not allowed or should be minimized
  > Cleaning is expensive



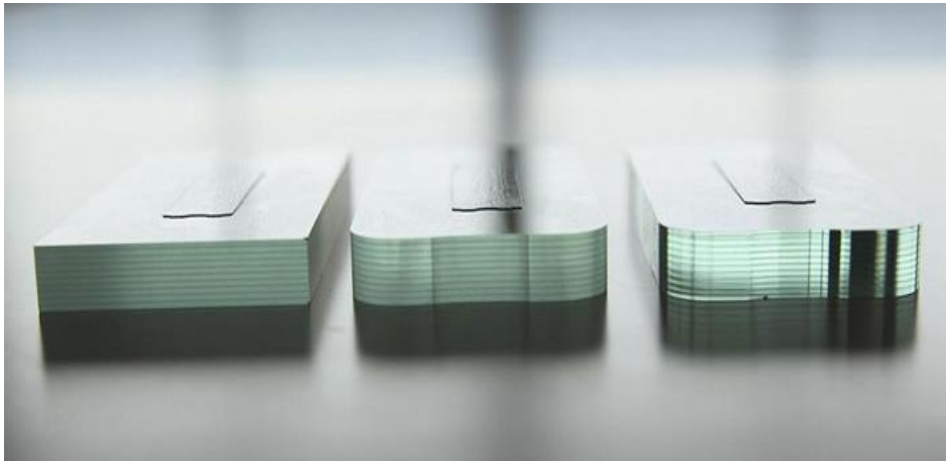
2 Evaluation of Glass Cut

How to evaluate a glass cut ?

- **Point 3 – Post processing:**
  > After cutting the glass following processing methods like grinding or polishing are required
  > Cutting has to be adjusted to the whole process line



Source: Bystronic



Source: Shoda Tech Corp.

2 Evaluation of Glass Cut

Edge strength of glass

Statistical evaluation (> 35 samples at least)

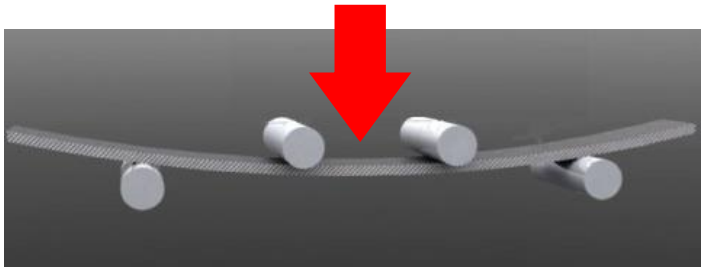
- A sample is stressed until it breaks
- The force / tension needed to break is measured
- Often a Weibull function is used to display

There are several methods in industry to measure the glass strength. Most common tests are:

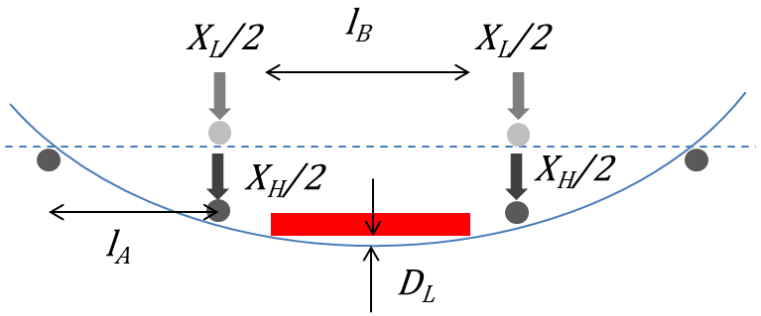
- 4 Point Bending — evaluates the strength of the glass edge
- Ring to Ring — evaluates overall strength of a glass piece
- Ball Drop — evaluates overall strength of a glass piece

2 Evaluation of Glass Cut – Methods

4 Point Bending Test (4PB)



- A Sample is placed on two supporting pins a set distance apart. Two loading pins placed at an equal distance around the center are lowered from above at a constant rate until sample failure.



- **Advantage:**
  constant flexural stress between the two supporting pins

- Calculation of flexural stress:

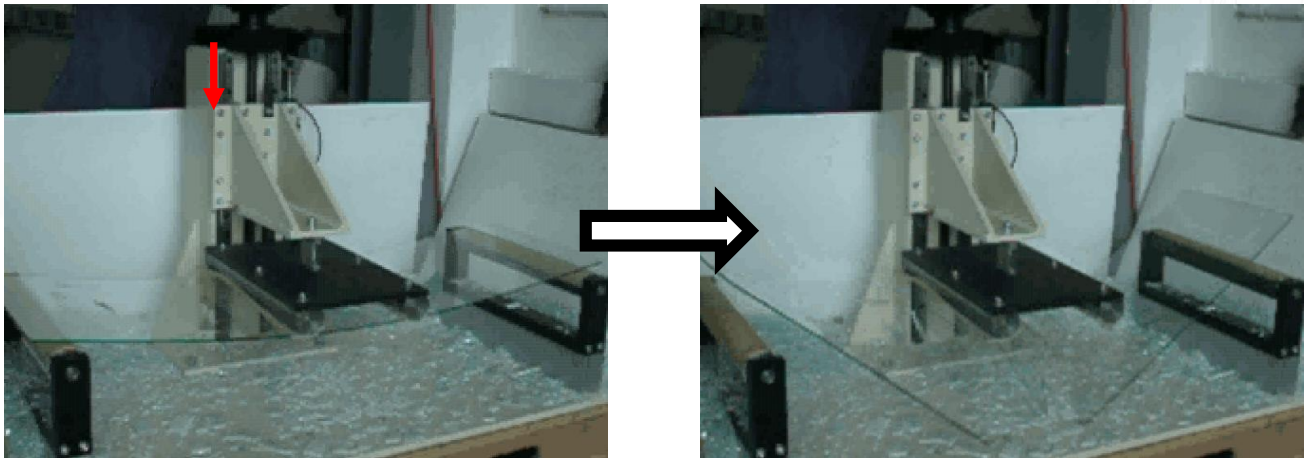
$$E = \frac{3lAlB^2(XH-XL)}{4DLba^3}$$

Source: Wikipedia

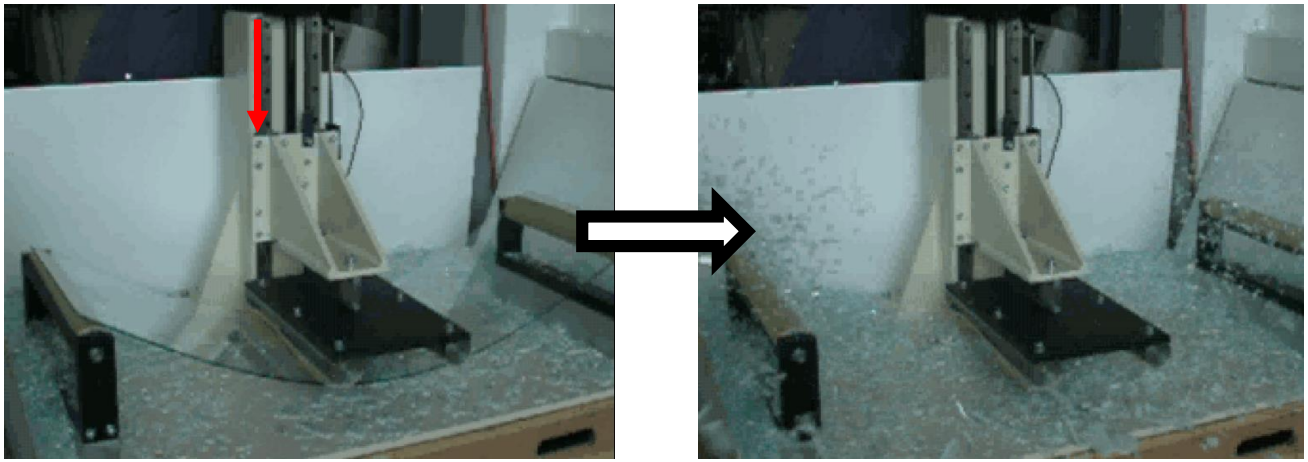
2 Evaluation of Glass Cut – Methods

Comparison 4PB test

- Wheel cut glass



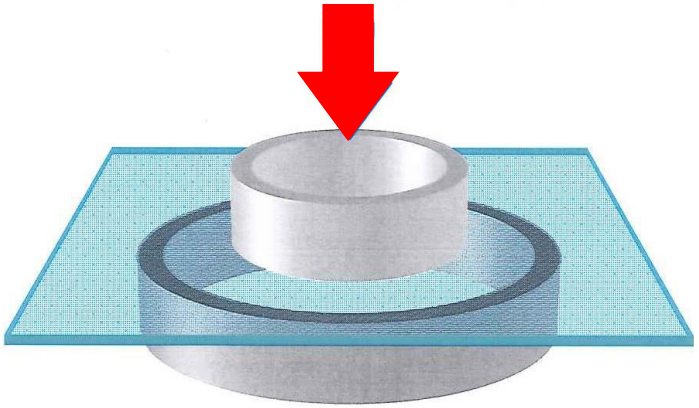
- Laser cut glass



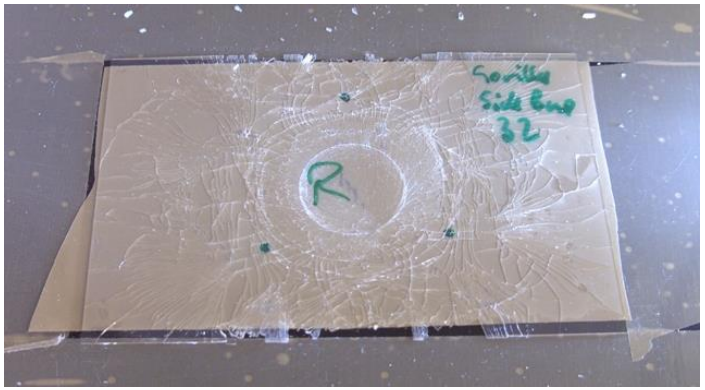
2 Evaluation of Glass Cut – Methods

Ring to Ring Test

- Glass substrate or panel is placed on a ring. A smaller loading ring is placed at an equal distance around the center is lowered from above at a constant rate until sample failure.



- Tests primary surfaces but not edges; highest stress at loading ring



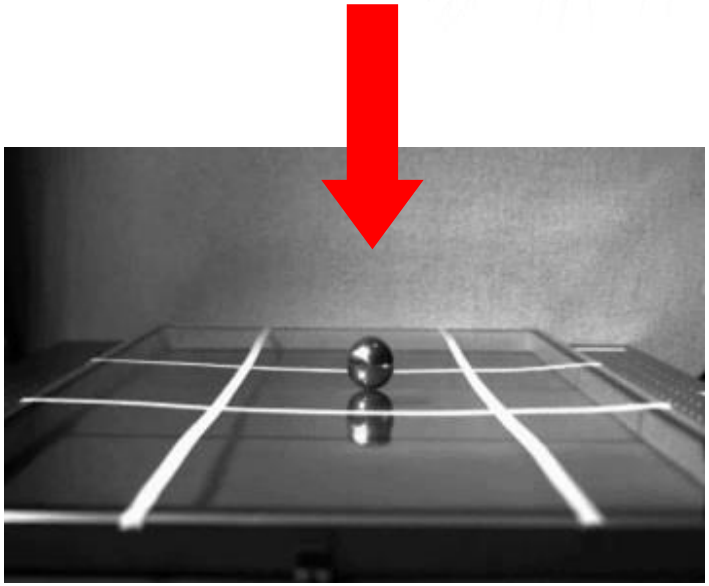
- Continuous stress increase

- **Advantage:**
  simple test setup

2 Evaluation of Glass Cut – Methods

Ball Drop Test

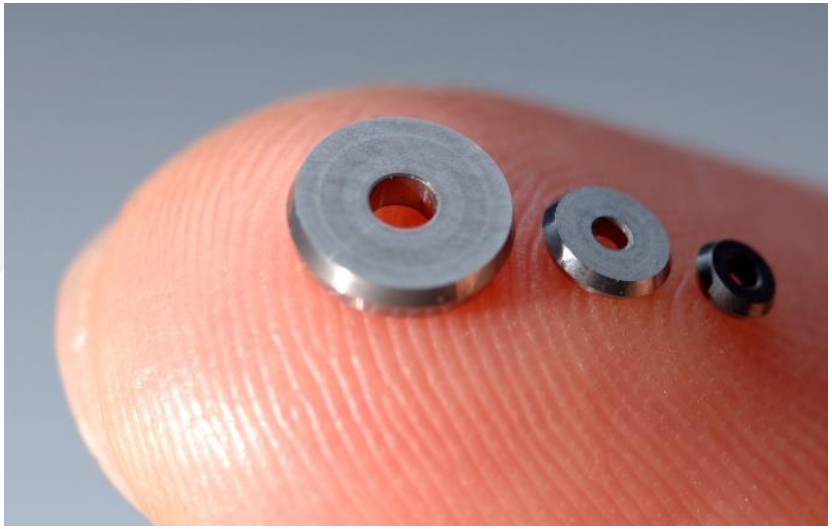
- This method evaluates the height where the glass breaks by dropping a stainless steel ball on the sample.
- Shock by impact



3 Cutting with Wheels – The Process

The Scribing Process

- A cutting wheel, made of tungsten carbide or polycrystalline diamond and with a V-shaped profile, is pressed firmly against the surface of the glass and a line is briskly scribed to form a "score" or "cut".



3 Cutting with Wheels – The Process

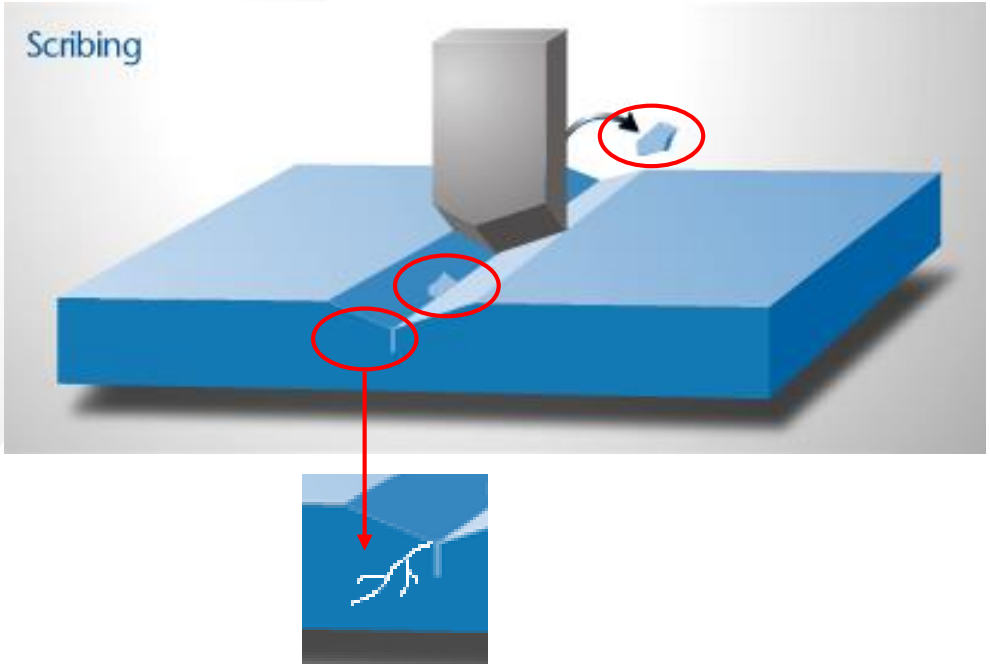
The Breaking Process

- The glass is now weakened along the scribe line and the glass sheet is ready to be “broken” in two.

3 Cutting with Wheels – Scribe & Break

A Two-Stage Process

- Step 1: Scribing



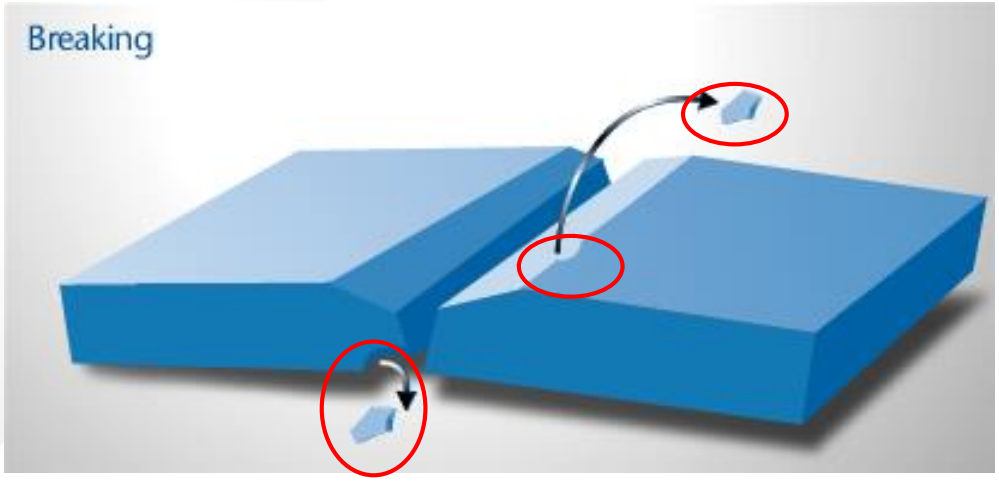
Disadvantages

> Broken out glass fragments and chippings
> Micro cracks
> Fragments left in cut path
> Edge chips
> The cut is not perpendicular to glass surface

3 Cutting with Wheels – Scribe & Break

A Two-Stage Process

- Step 2: Breaking



Disadvantages

> Fragmentation on the under side of glass
> Break is not occurring along cut path
> necessity of second step is costly and time-consuming

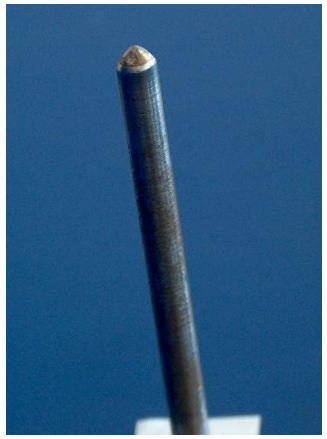
3 Cutting with Wheels – Products

Depending on glass thickness (t), according wheel angles (V) should be used.
Example:

- Diamond pin / wheel t = 50µm to 200µm V = 105° or 110°
- Diamond wheel t ≥ 200µm V = 110°
- Diamond wheel t ≥ 400µm V = 110° or 115°
- Carbide wheel t ≥ 600µm V = 115° or 120°

Cutting tool by Mitsuboshi

Cutting tool by Bohle



Diamond pin by Lach

3 Cutting with Wheels – Machines

Automatic float glass cutting machine

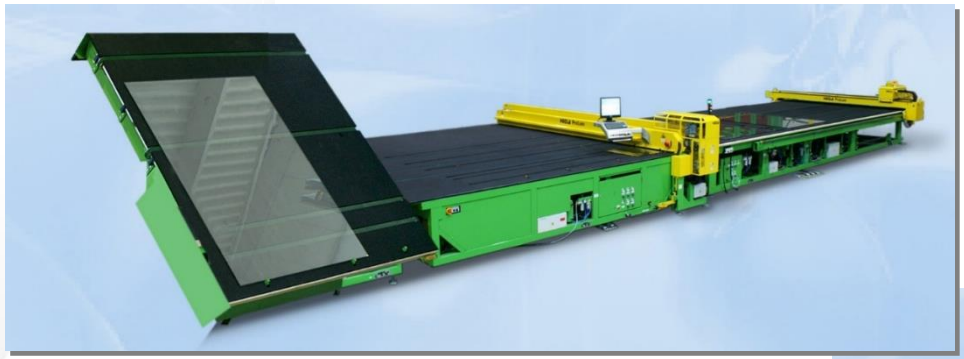
State-of-the-Art technology with magnetic linear drives

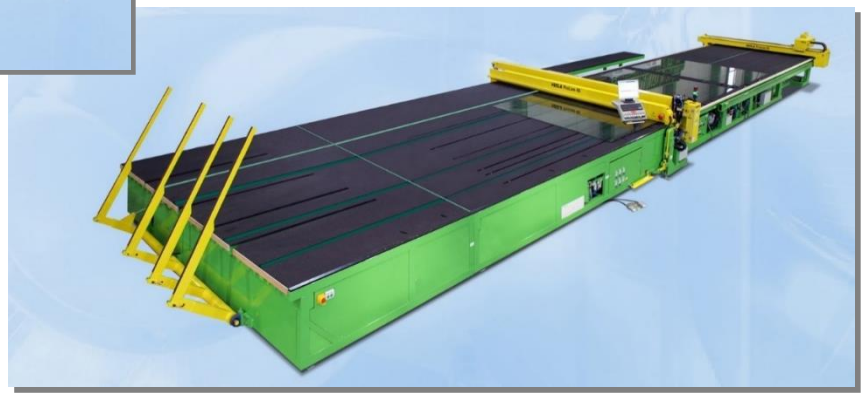
- Dynamic
- Precise
- Minimal wear

3 Cutting with Wheels – Machines

Laminated glass cutting machine

Cutting of laminated glass and float glass for maximum workload and flexibility

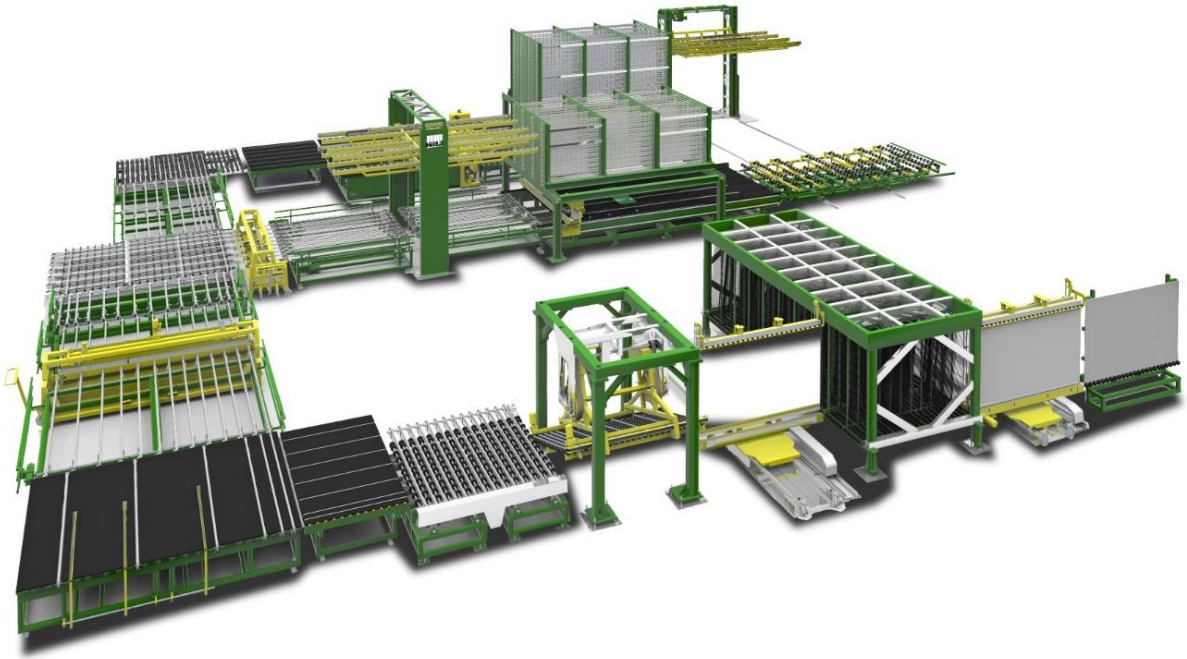




3 Cutting with Wheels – Machines

Glass processing line

High performance in glass cutting and handling



3 Cutting with Wheels – Penett®

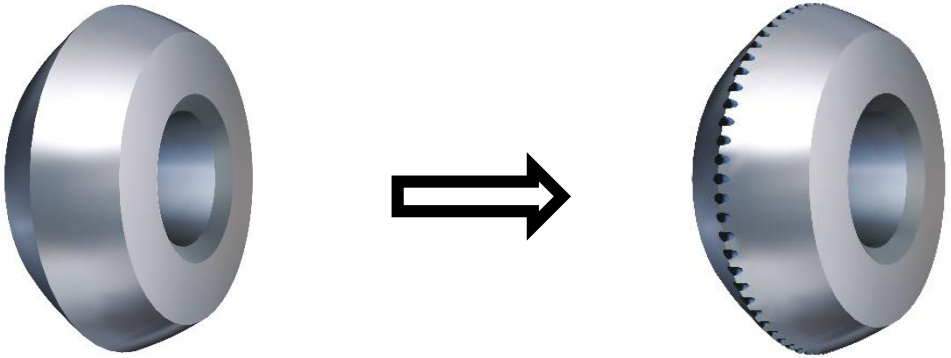
Breakthrough in FPD market

- Due to the demands in consumer electronics, glass was getting thinner and handling got a bigger importance
- To overcome disadvantages of normal wheel cutting, the development of structured wheels started in the 1990th
- **Targets:**
  > simplify or even eliminate no breaking process
  > increase edge strength

3 Cutting with Wheels – Penett®

A new technology

- The deep penetration cutting wheel was invented in 1998 by MDI; breakless separation of FPD (Flat Panel Displays) became possible
- Consecutive hitting caused by the unique wheel structure (notches) creates very deep median cracks up to 90% of the glass thickness



Conventional cutting wheel

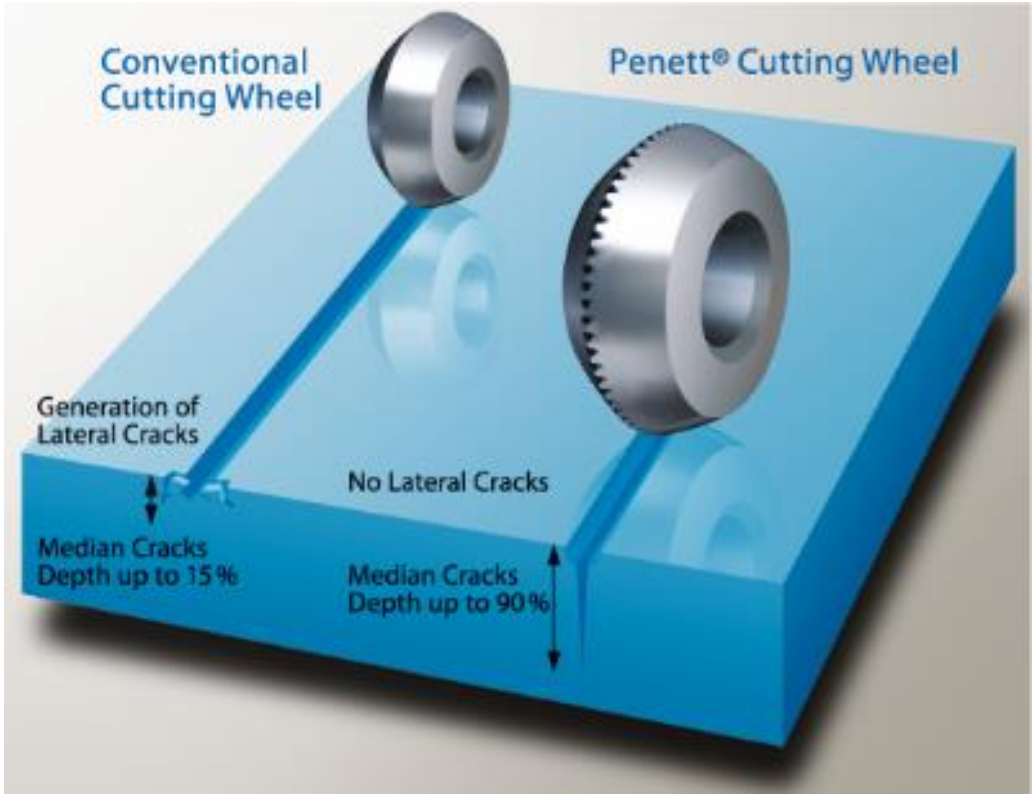
Penett® cutting wheel by MDI

3 Cutting with Wheels – Penett®

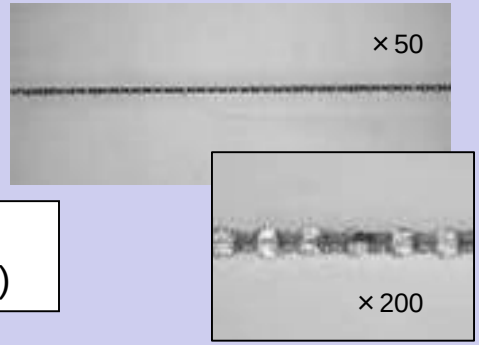
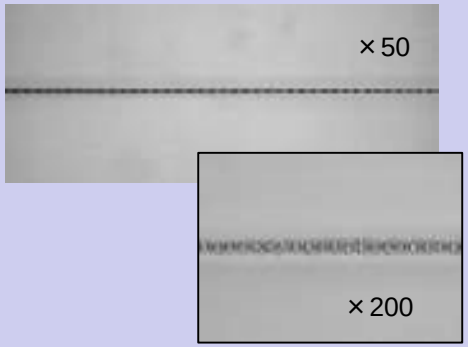
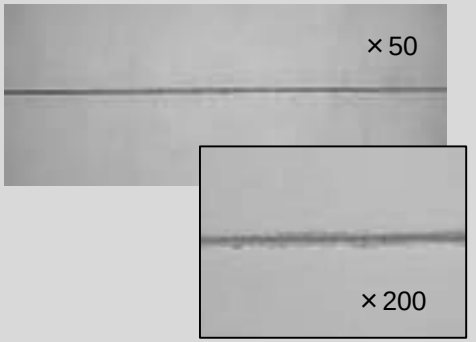
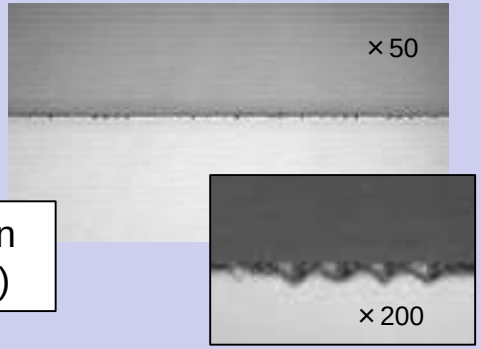
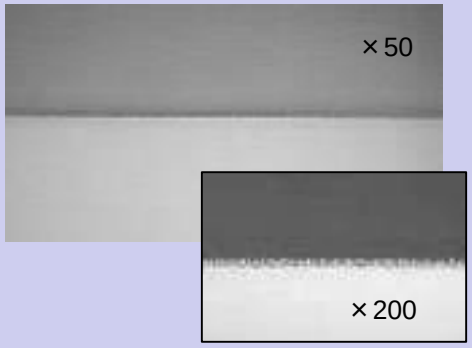
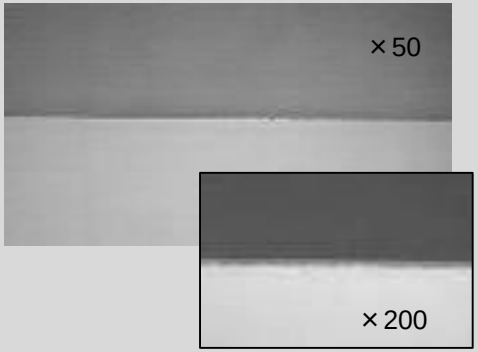
Comparison: conventional wheel cut vs. Penett® wheel cut

Essential advantages of deep penetration cutting wheels such as Penett®:

- No lateral cracks
- Median cracks depth up to 90% enables easy breaking process



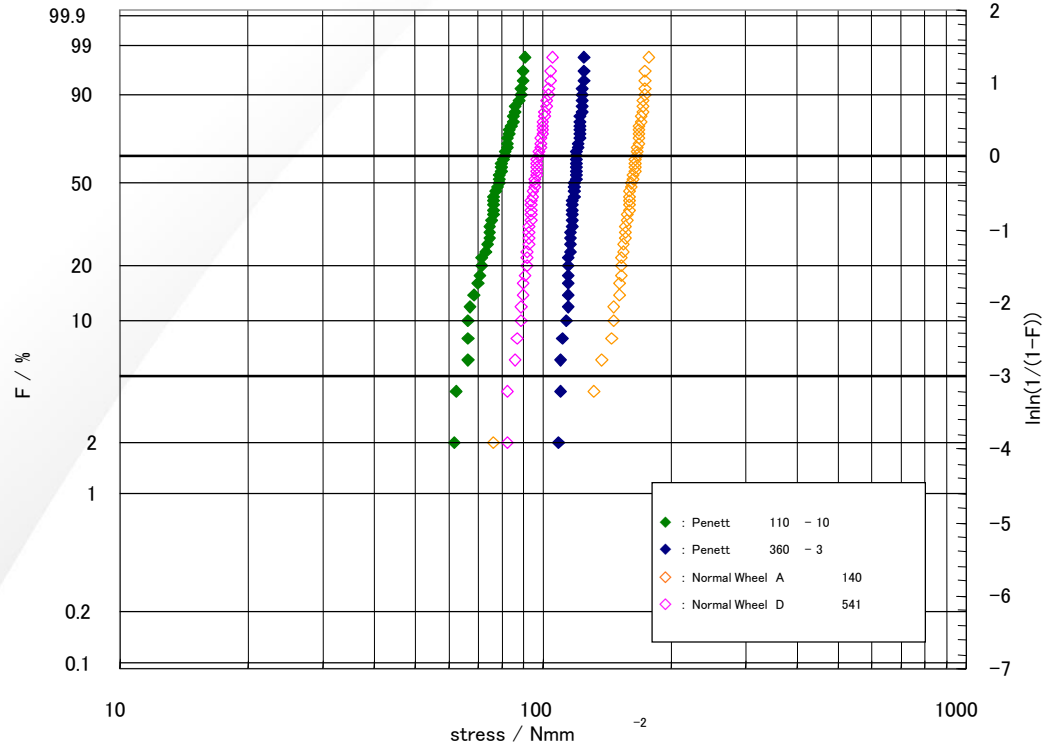
3 Cutting with Wheels – Penett®

	Penett® wheel		Conventional wheel
	110 notches – 10µm depth	360 notches – 3µm depth	Grinding A140
Scribe line (glass surface)			
After separation (glass surface)			

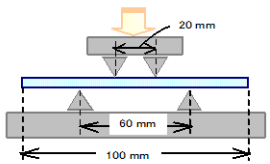
3 Cutting with Wheels – Penett®

Weibull distribution

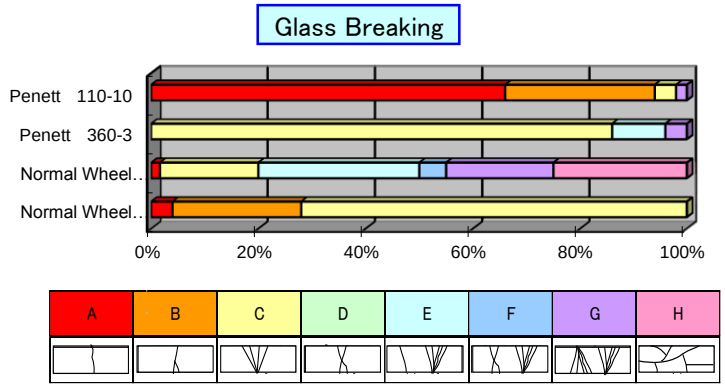
Edge strength comparison: conventional wheel cut vs. Penett® wheel cut



Glass bending strength test conditions



Test equipment	Shimadzu Ez Test / CE
Test method	4-point bending
glass	Eagle2000 0.63t
Specimen dimensions	100 × 15 mm
Upper fulcrum distance	20 mm
Lower fulcrum distance	60 mm
Test speed	0.5 mm/min
Arrangement	rib mark 100 μm Cutting surface is positioned below.



3 Cutting with Wheels – Machines

Automatic glass scriber

MS Series with single cutting head

MM Series with multiple cutting heads

3 Cutting with Wheels – Machines

Inline glass separation systems

Separation of super-large liquid-crystal panels

- Simultaneous separation of both upper and lower side of panels

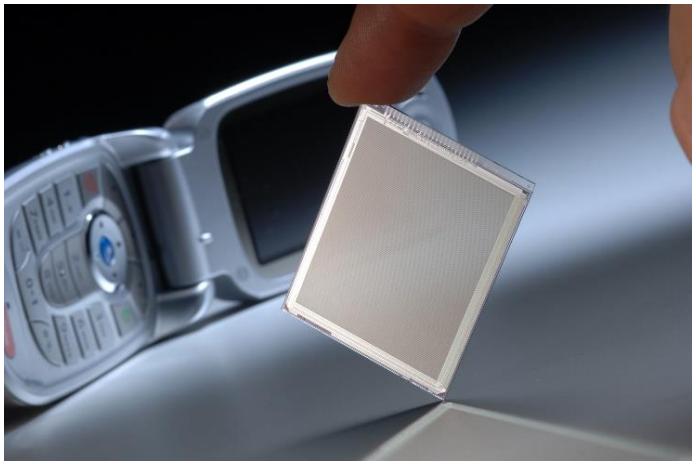
VSS Series

MPL Series

4 Cutting with CO_2 Laser

Advancements in laser technology opened new doors

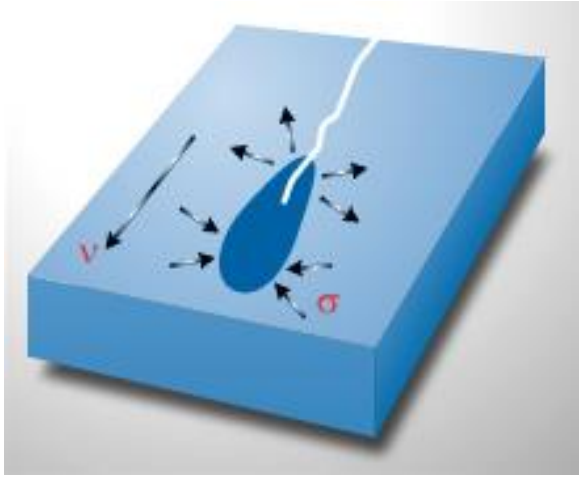
- Structured wheels improve breakability of glass, but no improvement regarding edge strength and chipping
- To overcome disadvantages of Penett wheels, CO_2 laser technology entered glass production in year 2000
- **Targets:**
  > increase cutting edge strength (especially cell phones, later on touch panels for smartphones)
  > reduce or even eliminate chippings

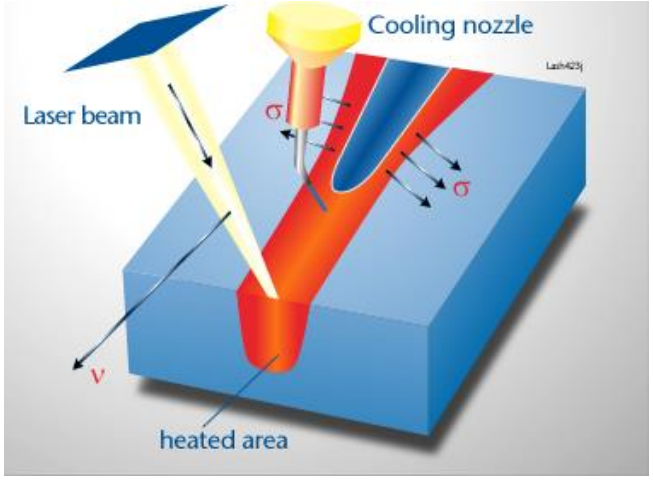


4 Cutting with CO_2 Laser

Principle of thermal stress cutting – a contactless process

- Focused laser beam heats up a specific line on the glass, followed by a cold jet of air / liquid mixture from cooling nozzle
- This thermally induced tension causes precise fissuring of glass



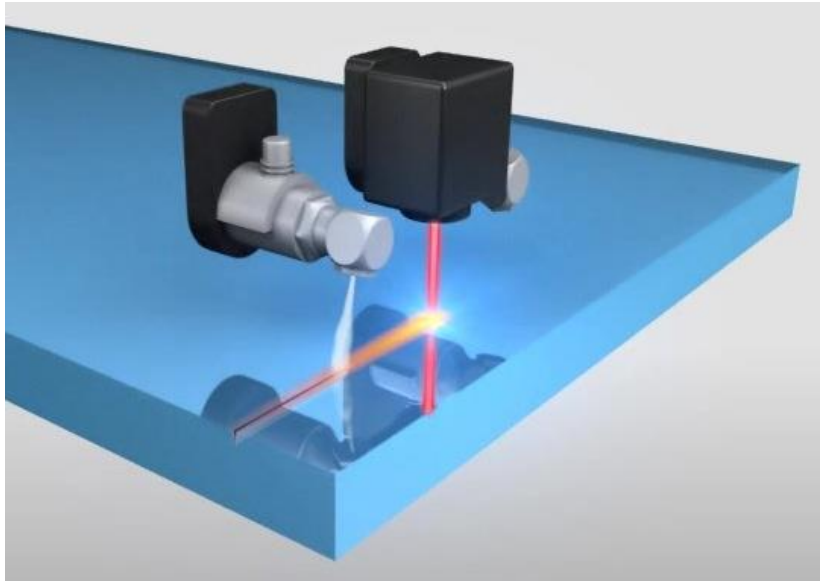


4 Cutting with CO_2 Laser

Principle of thermal stress cutting – a contactless process

Advantages:

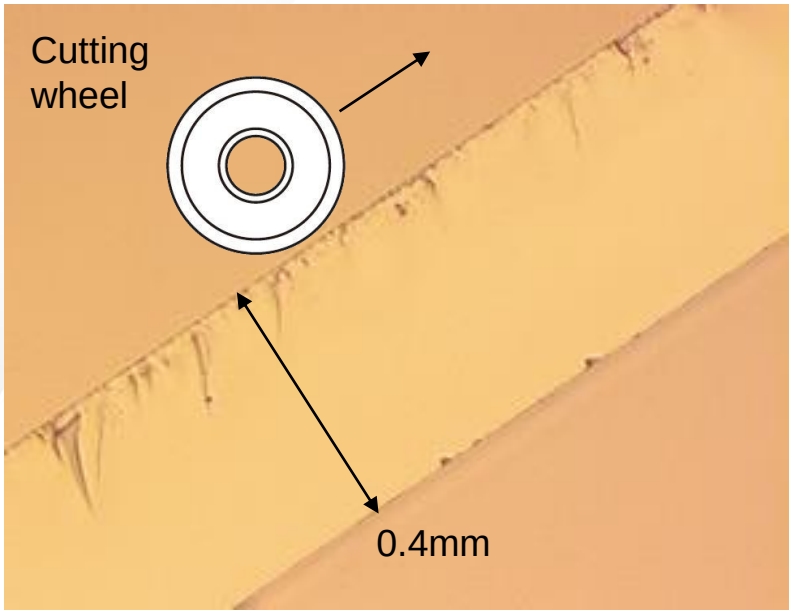
- no further processing like grinding or polishing needed
- no micro cracks / chipping
- no material loss
- for cleanroom applications



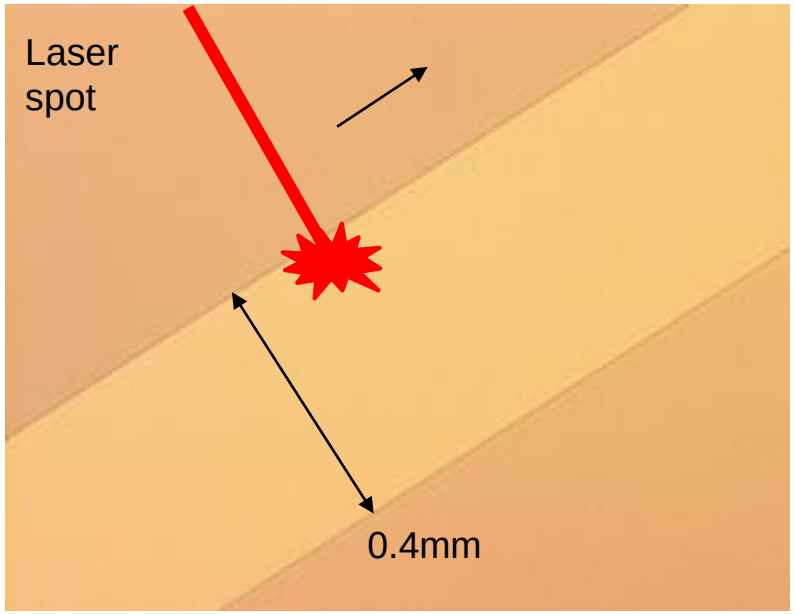
4 Cutting with CO_2 Laser

Comparison: conventional wheel cut vs. laser cut

- Glass D263, thickness t=0.4mm



Conventional wheel cut edge

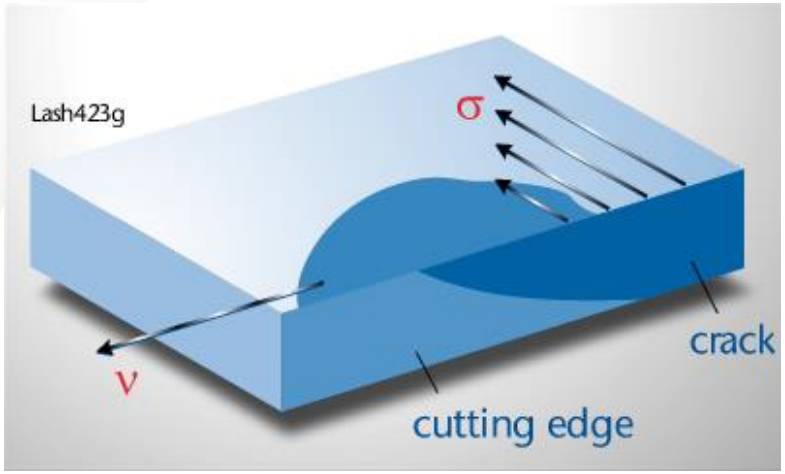


Laser cut edge

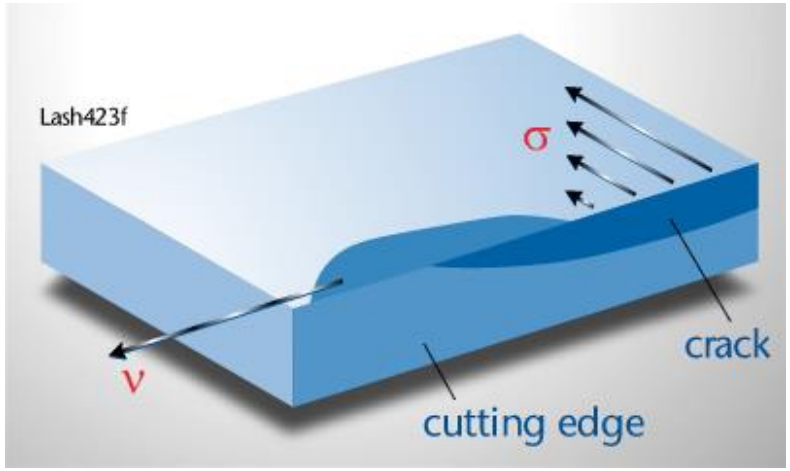
4 Cutting with CO_2 Laser

Laser full cut or laser scribe

- Laser full cut: completely cuts the glass using only laser process
- Laser scribing: requires a further breaking process for separation



Laser full cut d < 1mm

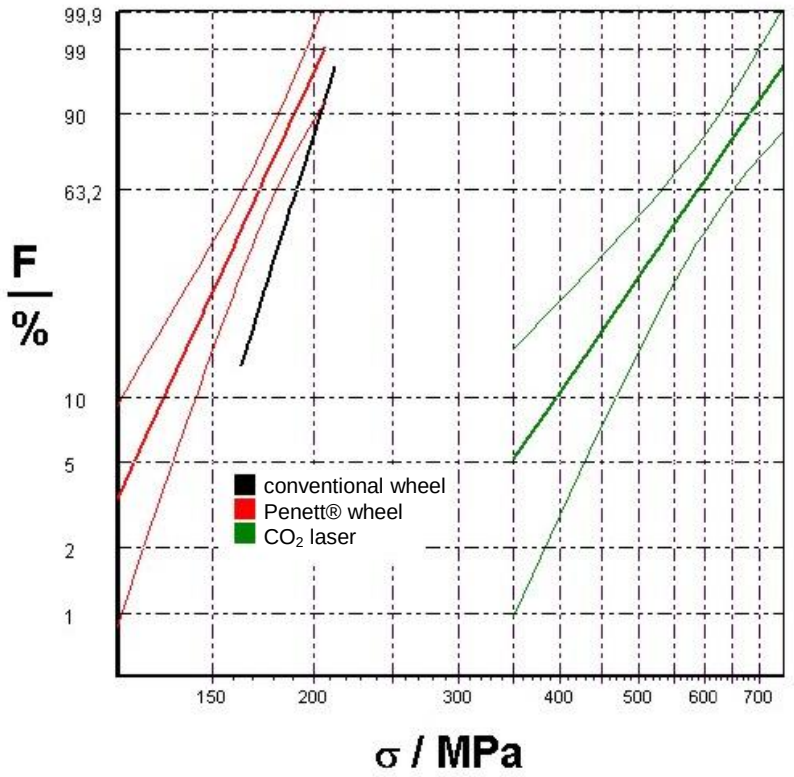


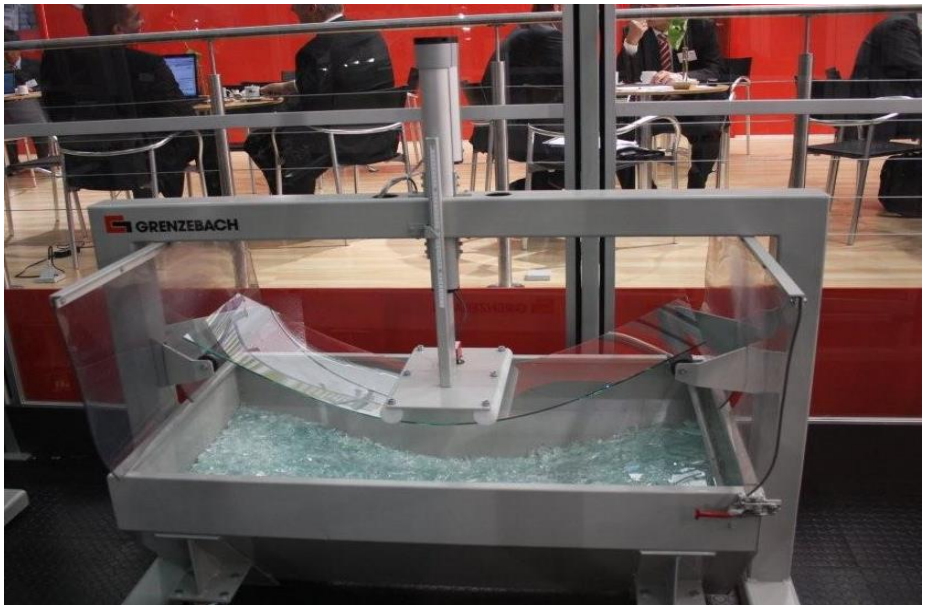
Laser scribe d ≥ 0.3 mm

4 Cutting with CO_2 Laser

Weibull distribution

Edge strength comparison: wheel cut (conventional and Penett®) vs. CO_2 cut



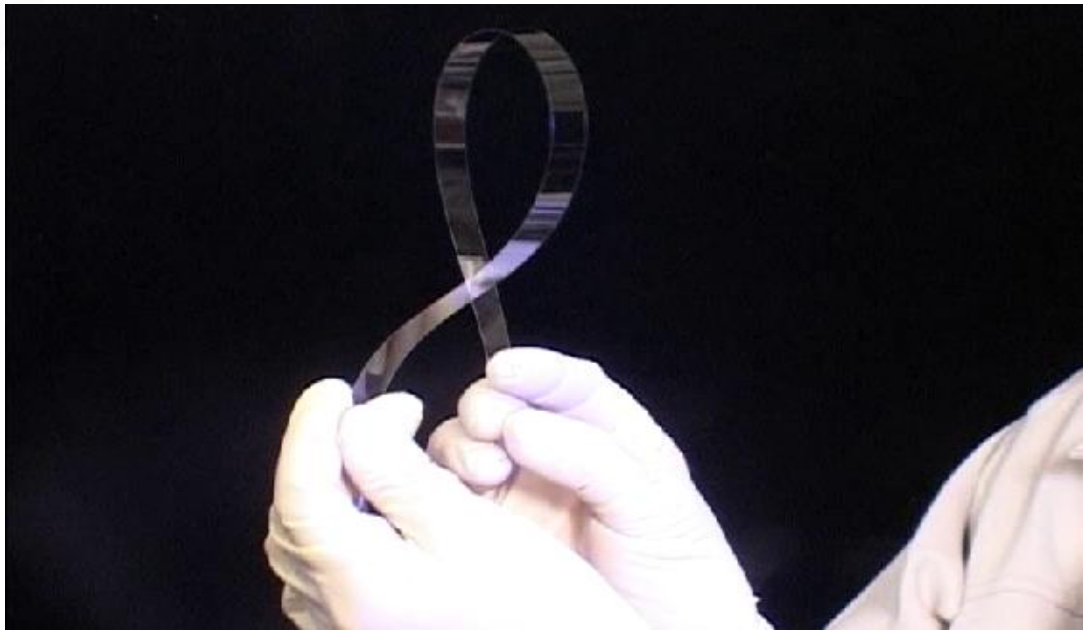


Source: Grenzebach GmbH

4 Cutting with CO_2 Laser

Cutting of ultra thin glass (thickness 30 – 300µm)

- Highest edge strength due to cutting by CO_2 laser without micro cracks



Ultra thin glass with highest edge strength (Source: SCHOTT AG)

4 Cutting with CO_2 Laser – Machines

TGC Series (Thin Glass Cutter)

- High edge strength up to 1000MPA
- Glass bendable up to r = 2mm
- Laser cut enables easy handling
- Special beam guiding also for free shape cutting

TGC1350

5 Cutting by Ablation

Next step: laser shape cutting

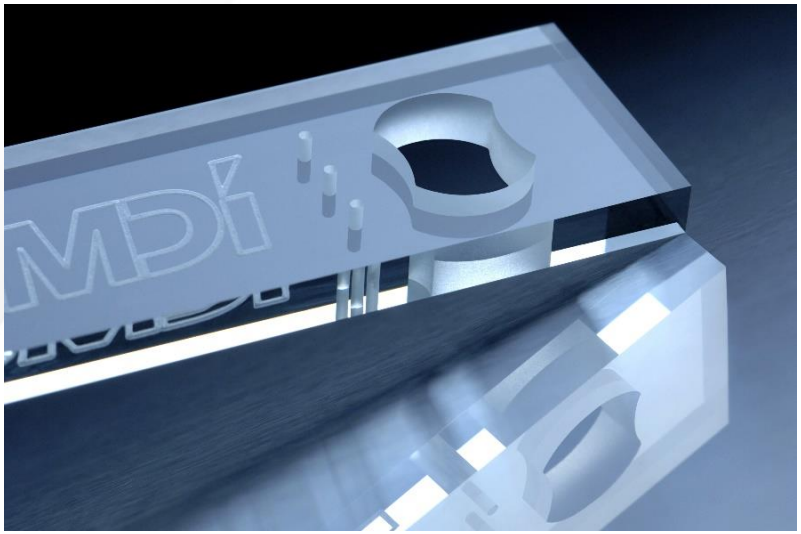
- CO_2 Laser cutting improves glass edge strength and reduces chippings, limitation in free shape cutting
- Around 10 years ago the question popped up how to cut out shapes inside the glass without destroying it
- **Target:**
  > cutting of flexible shapes
  > cutting out shapes inside the glass using laser technology

Source: SCHOTT AG

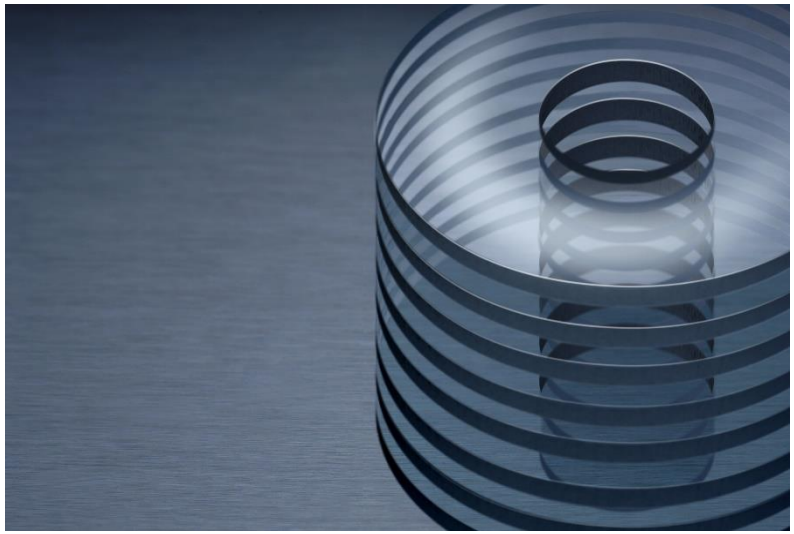
5 Cutting by Ablation

Micro processing by green laser (532nm) or UV laser

- Drilling, grooving, marking, patterning and coating



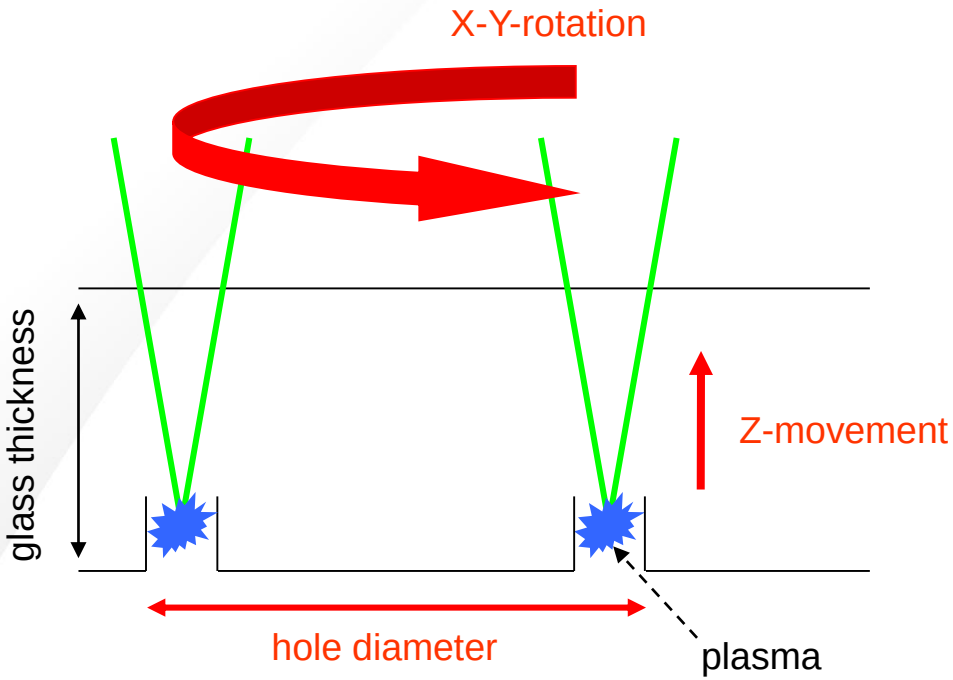
Company logo in glass

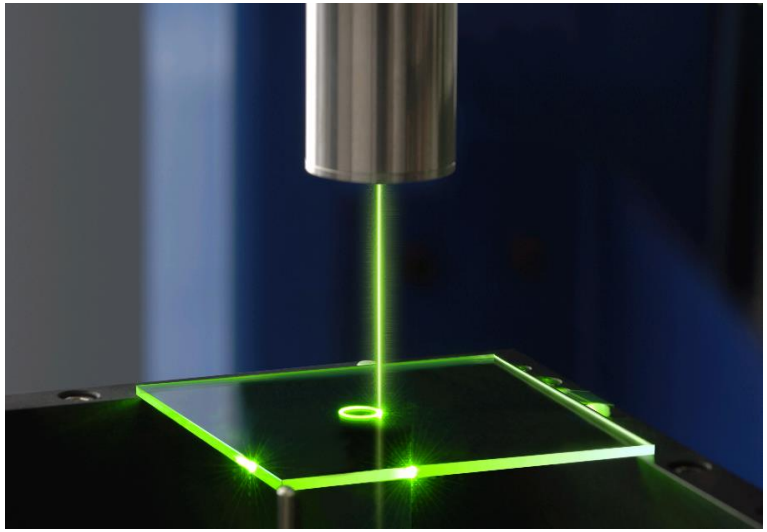


Encoder Disks

5 Cutting by Ablation – Drilling

Drilling with green laser technology



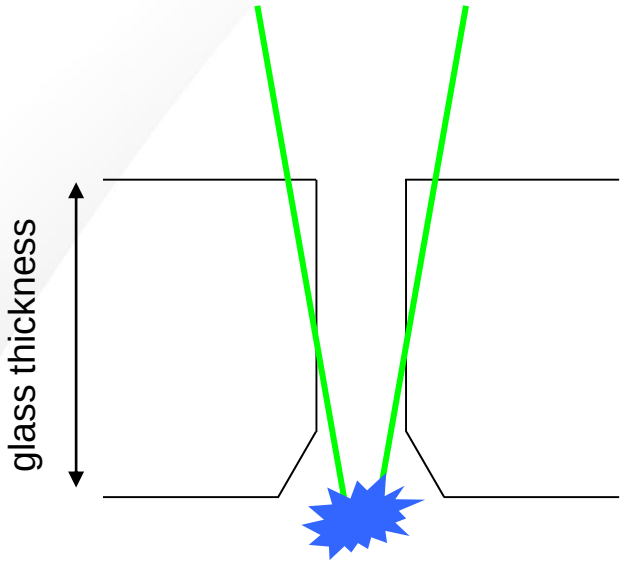


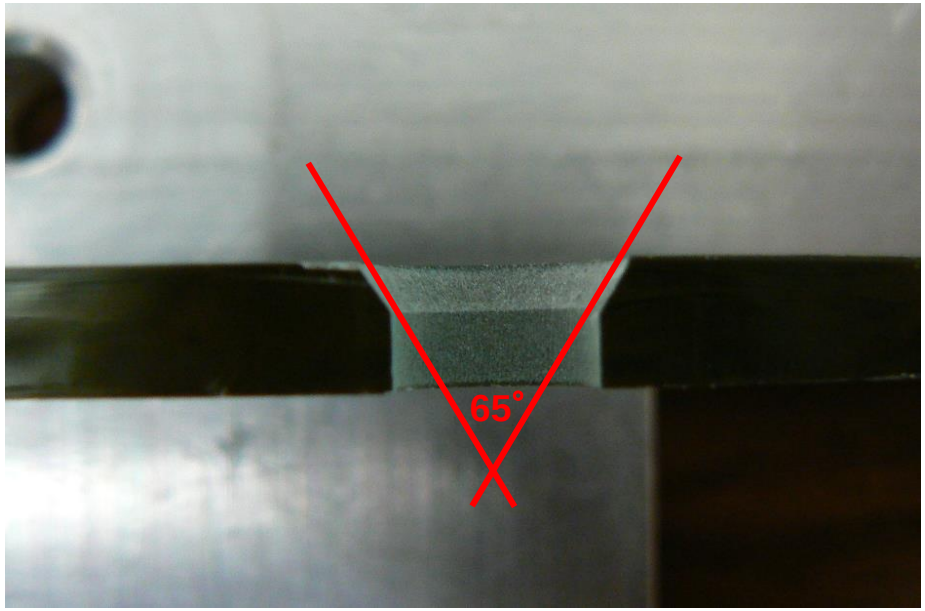
Drilling process

5 Cutting by Ablation – Chamfering

Chamfering with green laser technology

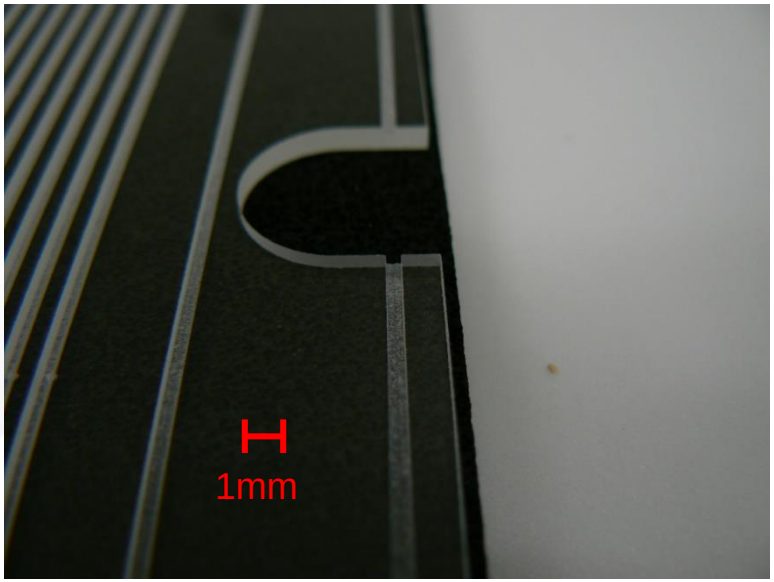
- Green laser processing enables edge chamfering on the opposite side of the optic device



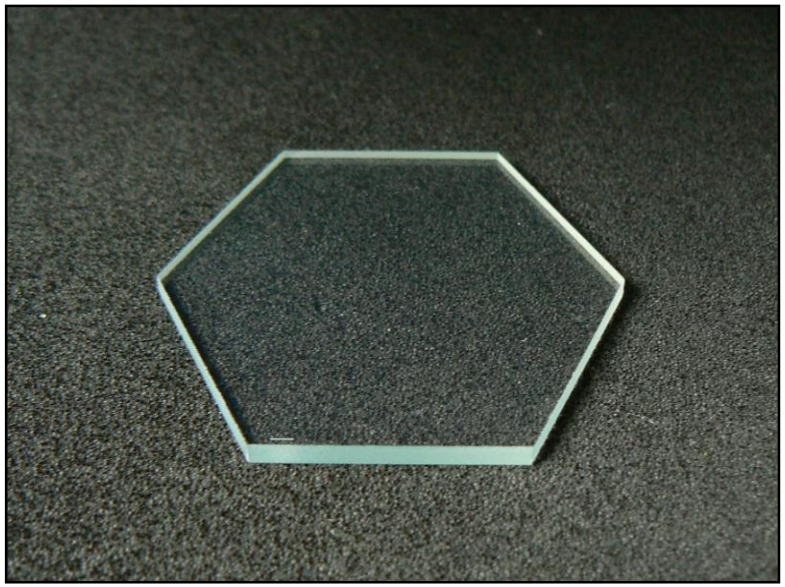


5 Cutting by Ablation – Applications

Green laser 532nm – DPSS SHG



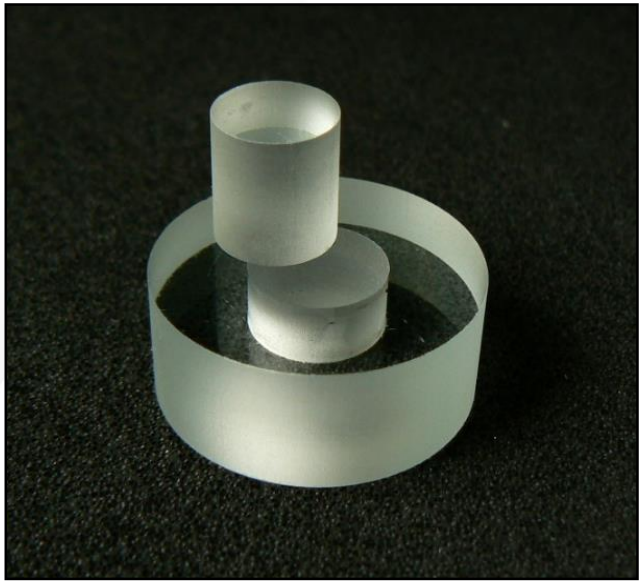
Combination of drilling and marking



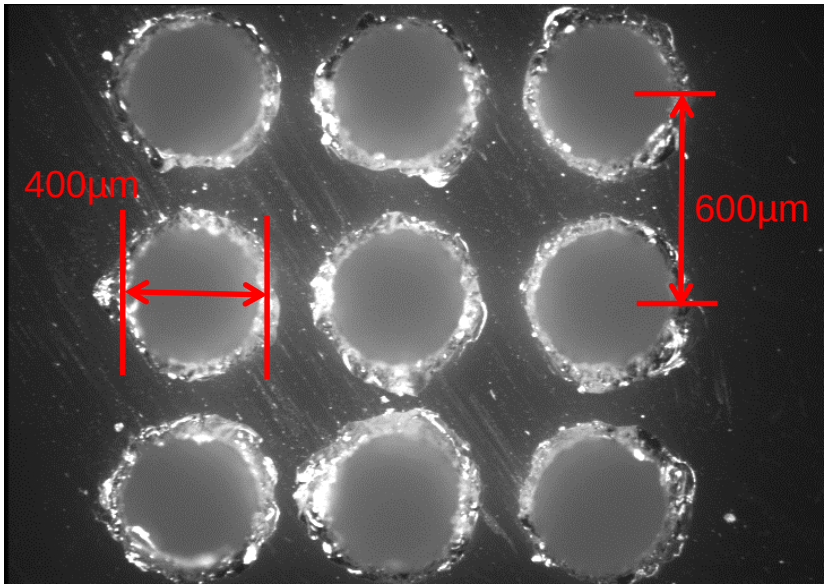
Flexible layouts with high shape accuracy

5 Cutting by Ablation – Applications

Green laser 532nm – DPSS SHG



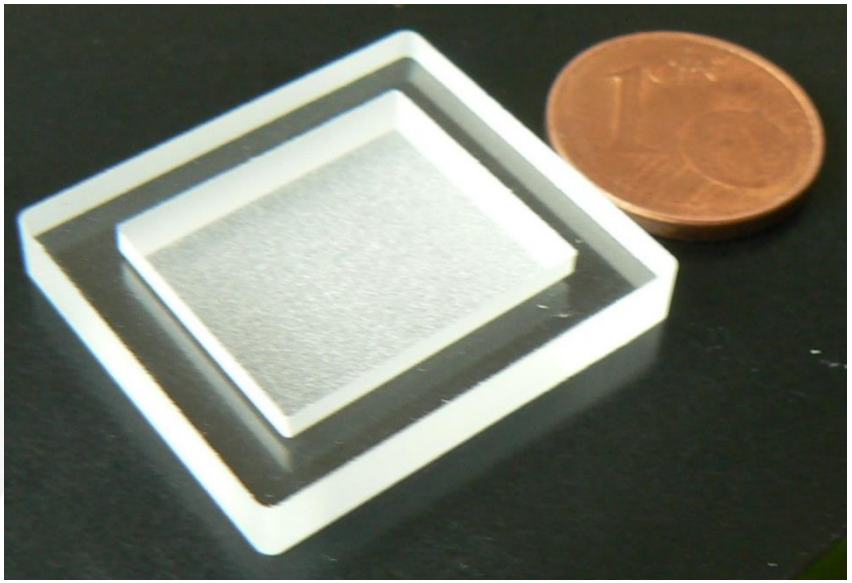
Glass thickness 10mm



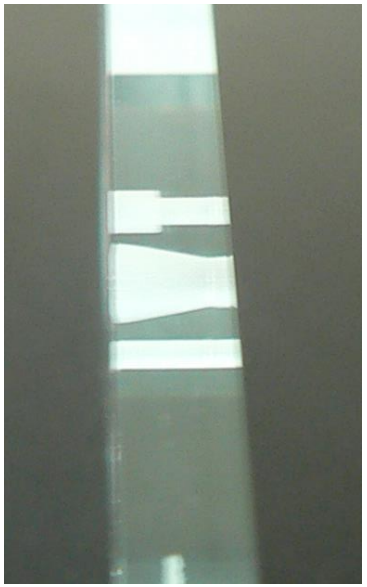
Ø 0.4mm holes in 10mm sodalime glass

5 Cutting by Ablation – Applications

Green laser 532nm – DPSS SHG



Sagging 2mm depth in 3mm sodalime glass

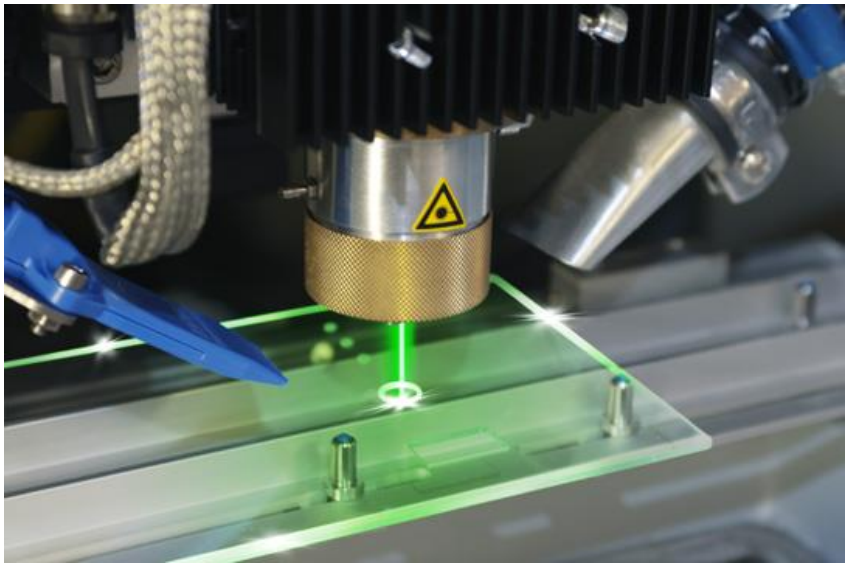


1mm drilling (straight, conical and counterbore)

5 Cutting by Ablation – Machines

Laser driller LD Series

Laser driller LD600

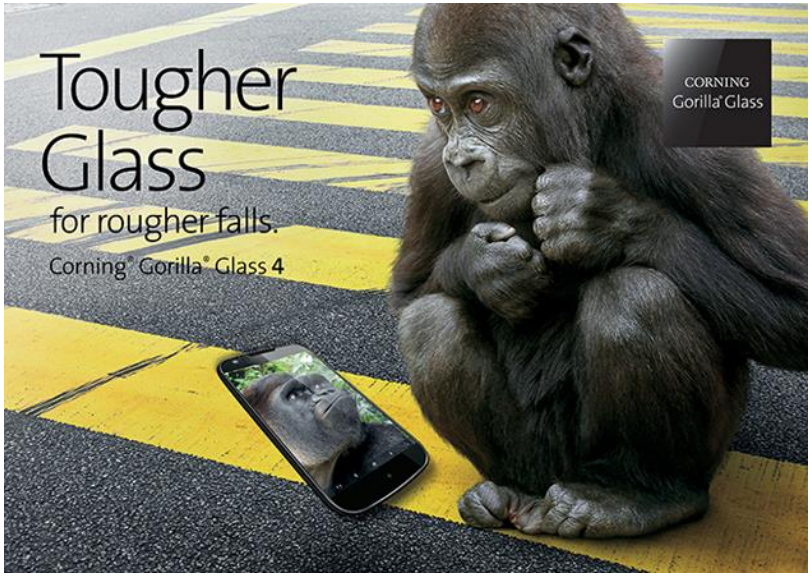


Drilling process

6 Filament Cutting

Latest development

- Since a couple of years a new technology entered the market: Filament Cutting
- The technology was pioneered by Prof. Dr. Peter Herman and Dr. Abbas Hosseini, University of Toronto
- **Target:**
  > free shape cutting for products with strengthened glass



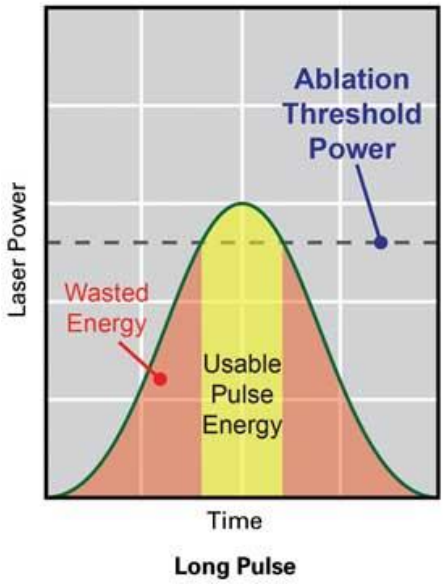
Gorilla glass by Corning Inc.

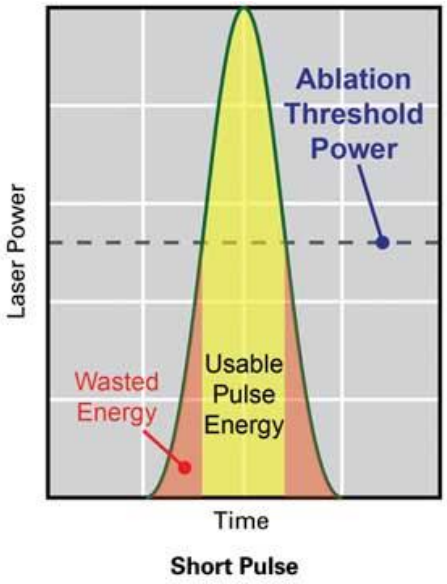
6 Filament Cutting

Effect of pulse width on processing with nanosecond lasers

- **Longer pulses:**
  much of the pulse energy contributes only to heating

  Heat can spread into surrounding material and cause damage known as heat-affected zone (HAZ)



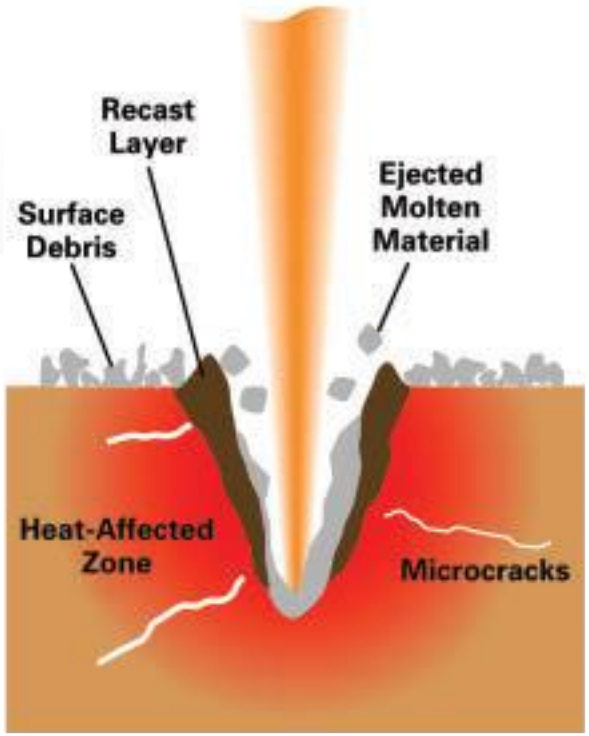


- **Shorter pulses:**
  higher proportion of pulse energy is delivered above the threshold power level, maximizing processing while minimizing HAZ

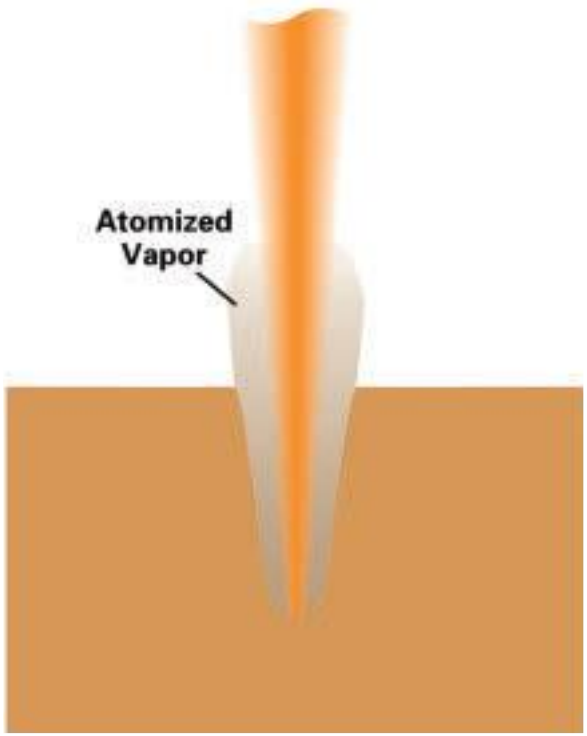
Source: Coherent, Inc.

6 Filament Cutting

Comparison: laser micro machining vs. filament cutting



Laser micro processing



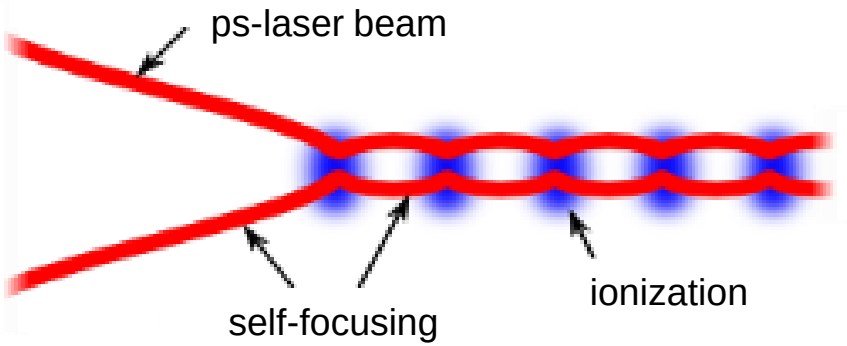
Filament cutting

Source: Coherent, Inc.

6 Filament Cutting

Technology:

- ps-laser pulses are focused within transparent material
- High local intensity gives rise to self focusing
- Different from ablative process – no debris
- Hot free-electrons damage / melt material
- Filament creates a defect channel up to 3mm long
- Moving the beam and / or the material creates a curtain of fractures

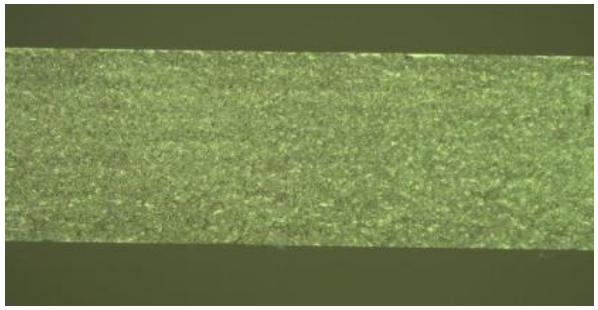


Source: Coherent, Inc.

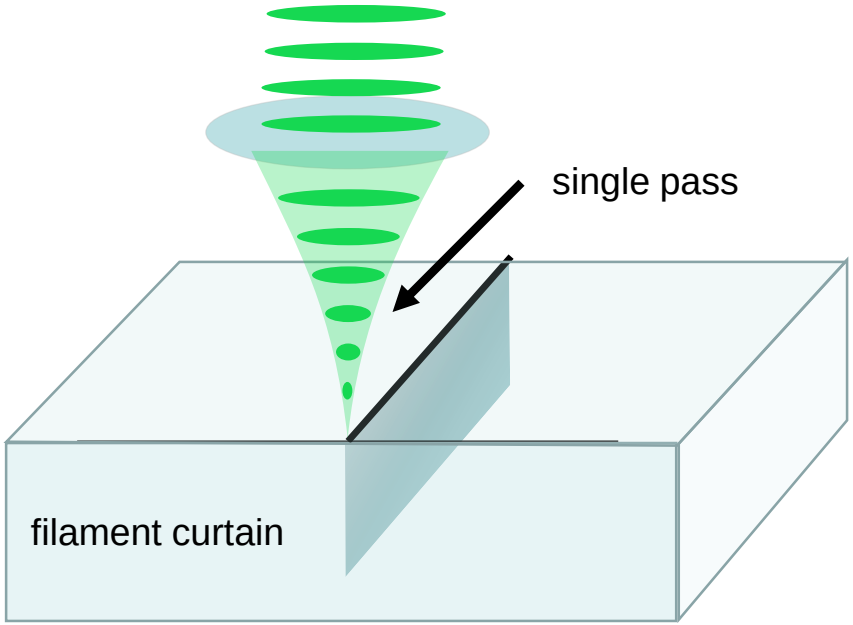
6 Filament Cutting

Advantages:

- After breaking glass has ground-like surface
- Good bend strength
- Filaments extend through glass
- Minimal micro cracks
- No surface mark or debris
- Curved cuts possible



Gorilla glass t=700µm, at 500mm/sec



Source: Coherent, Inc.

7 Conclusion

- **Wheel cutting:**
  Market introduced and investment is low,
  but chips (not clean) and poor edge strength require post processing.

- **CO_2 laser:**
  Offers high edge strength and is clean,
  but limited capability in geometry and rectangular edges are disadvantageous.

- **UV and green laser (ablation):**
  Higher invest than wheel machines, advantages in “glass inside“ (holes, any kind of shape).

- **Filament cutting / ps laser:**
  Good for strengthened glass, capability for free shapes, medium edge strength. Economical benefit not clear; more R&D is needed.

7 Conclusion

Cutting of glass is a very old technology, with which mankind has dealt with for a long time.

The mechanical methods are still dominating the industry, but laser based methods develop and enter market very fast.

What will be the next process technology ?

I am pretty sure:
It will be a laser but we have to find a way to overcome rectangular edges (cut and chamfer in one step).

Reference Material

- Literature:
  > Overview of Strength Tests for LCD Substrates and Panels
  from Corning Inc.
  > Short-Pulse Lasers Enable Transparent Materials Processing
  from Coherent, Inc. for Industrial Photonics article
  > Shorter Pulse Widths Improve Micromachining
  from Coherent, Inc.
  > Filament Propagation
  from Wikipedia

- Videos on Youtube:
  > Corning® Gorilla® Glass Ball Drop Test
  > MDI: Edge Strength Comparison (Laser Cut Glass)

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  SCHOTT AG
- Ms. Christine Stahl
  MDI Advanced Processing GmbH

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