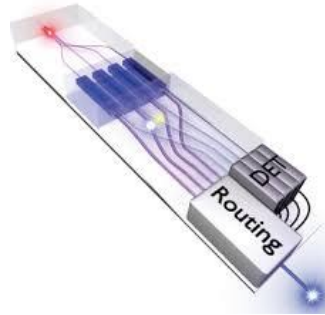


Micro- and nano-machining of transparent materials using Bessel beams

Jassem SAFIOUI, Gwenn ULLIAC, Pierre-Ambroise LACOURT and François COURVOISIER

- jassem.safioui@femto-st.fr
- 03 63 08 23 89

How laser finds applications in industry?



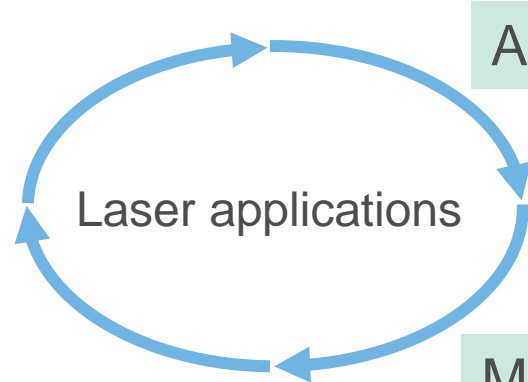
Telecommunication

3D optical circuits
Fibres cutting and welding



Aeronautical

Surface texturing
Fuselage



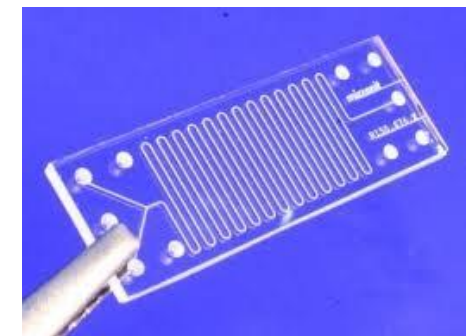
Laser applications

Medicine

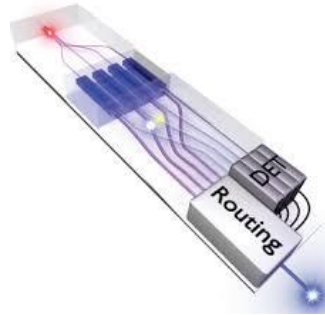
Lab on chip
Opto-fluidic circuit

Security

Counterfeit
Identity documents



How laser finds applications in industry?



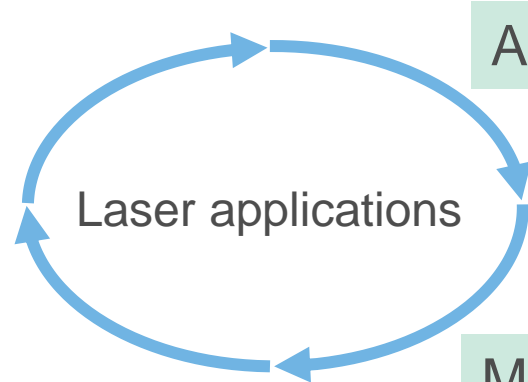
Telecommunication

3D optical circuit
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Surface texturing
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Laser applications

Medicine

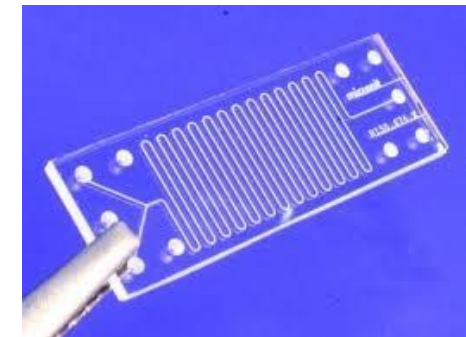
Lab on chip
Opto-fluidic circuit

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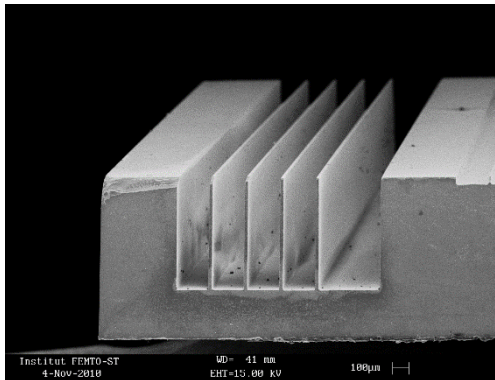
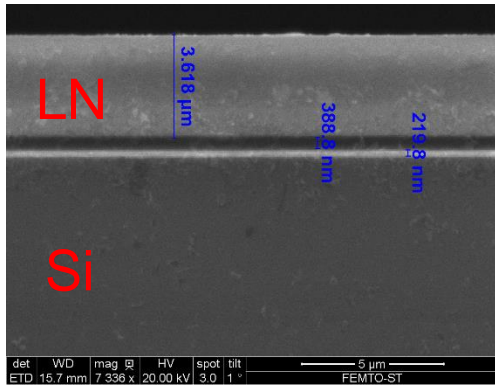
An important part is occupied by transparent materials



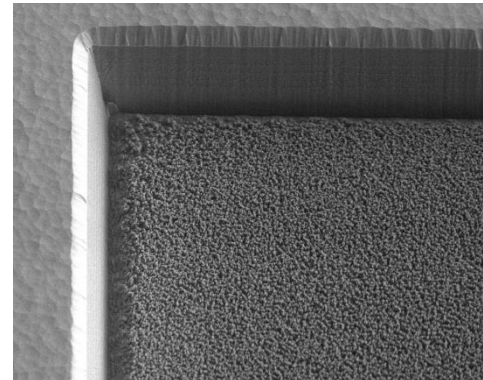
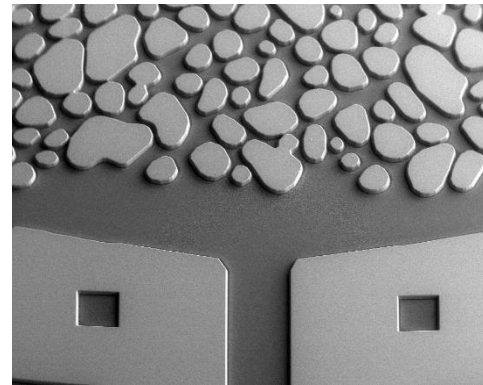
Many ways to machine transparent materials



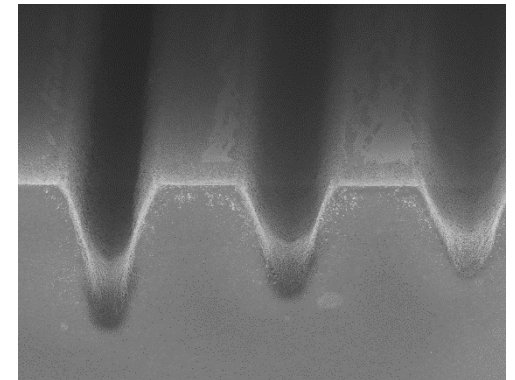
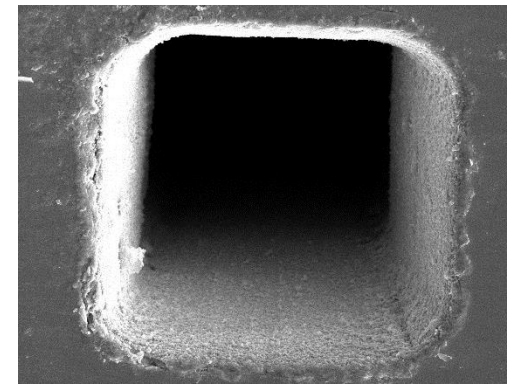
Dicing & thinning



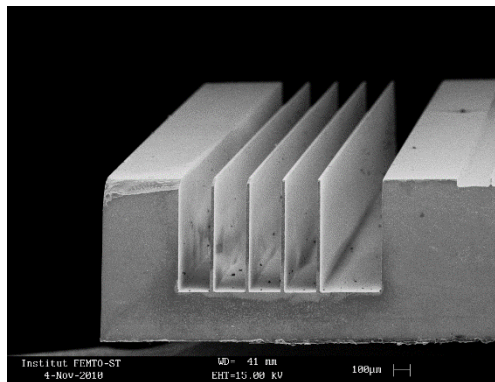
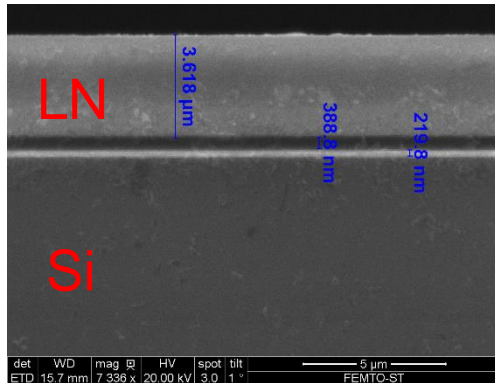
Dry and wet etching



Laser machining



Dicing & thinning



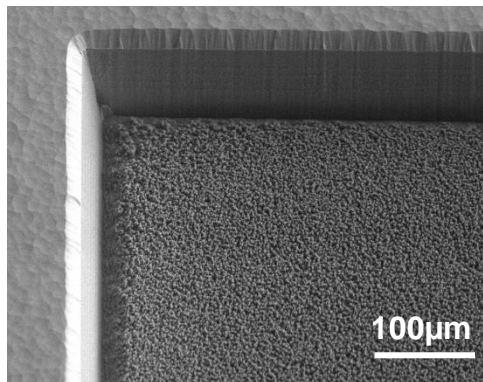
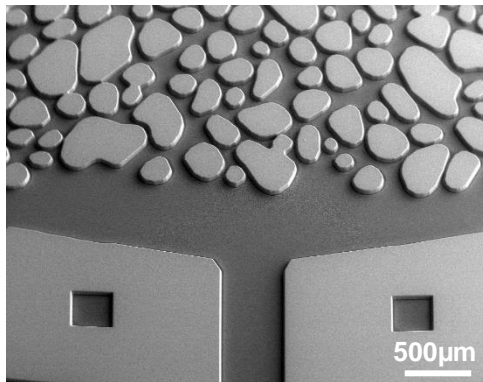
Advantages

- Thinning until $1\mu\text{m}$
- Optical roughness quality
- Aspect ratio >400
- Minimum width $=1\mu\text{m}$
- Sidewall verticality $=88^\circ$
- Roughness quality $=4\text{nm}$

Drawbacks

- Thickness homogeneity $>1\mu\text{m}$
- Only straight lines are possible
- Maximum channel width $=100\mu\text{m}$

Dry and wet etching



Advantages

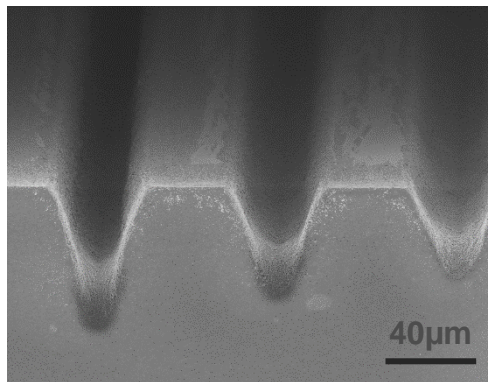
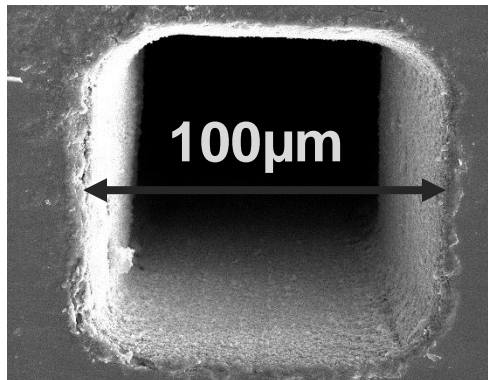
- Complex and deep etching are possible
- Anisotropic etching (Dry)
- Controlled roughness

Drawbacks

- Low aspect ratio
- Multistep process
- Sidewall verticality=80°

Case : Gaussian beam

Laser machining



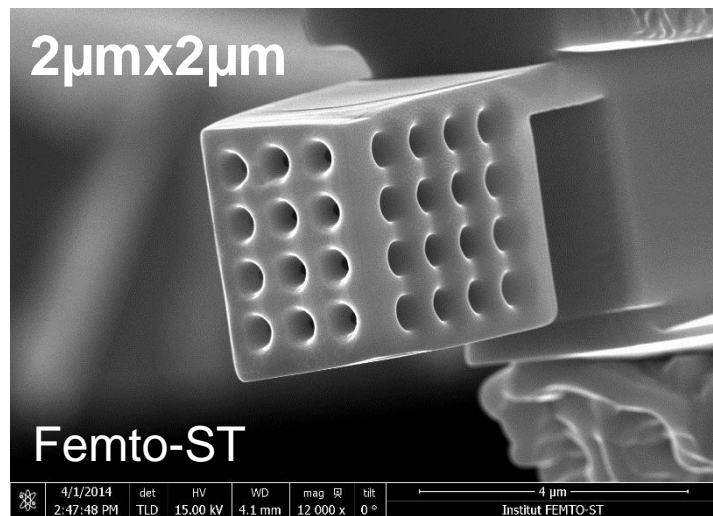
Advantages

- Fast complex and deep etching are possible
- One step etching

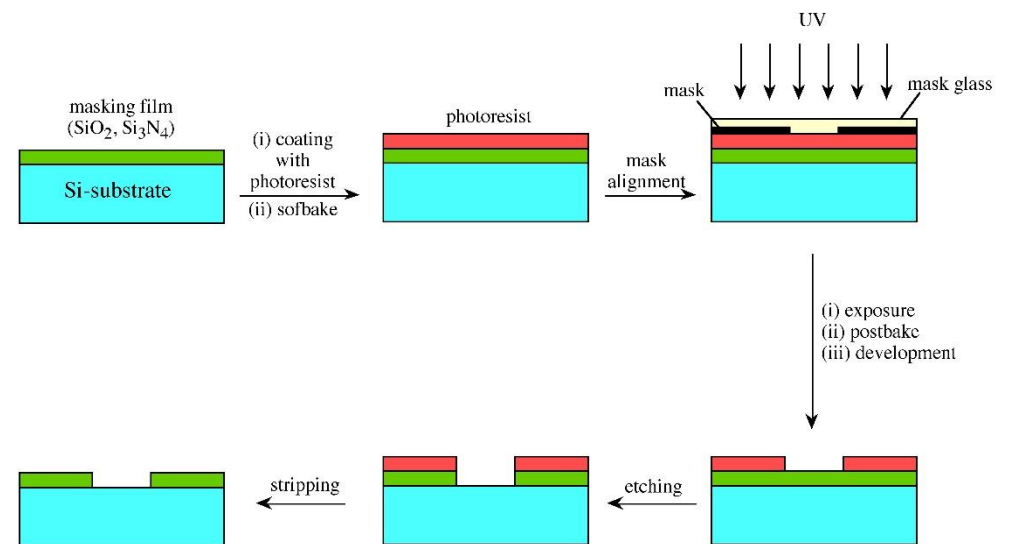
Drawbacks

- Low aspect ratio
- Roughness > 0,2µm
- Sidewall verticality = 75°

Focused ions beam



Clean room technology

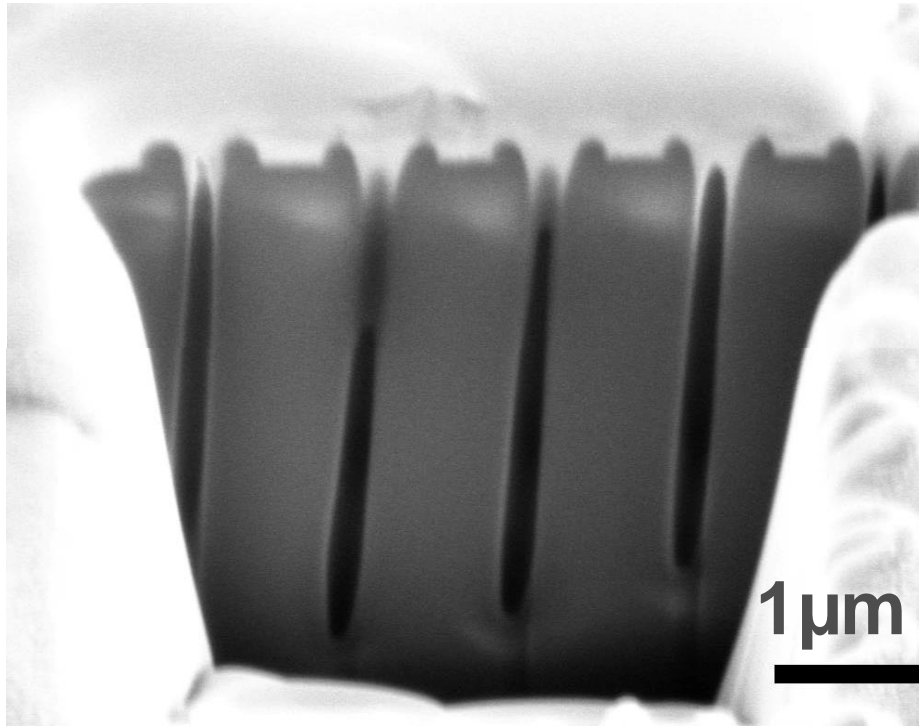


- **Limited aspect ratio**
- **Very long time processing**

Limits of classical femtosecond laser machining



Opt Exp 18, 16840 (2010)

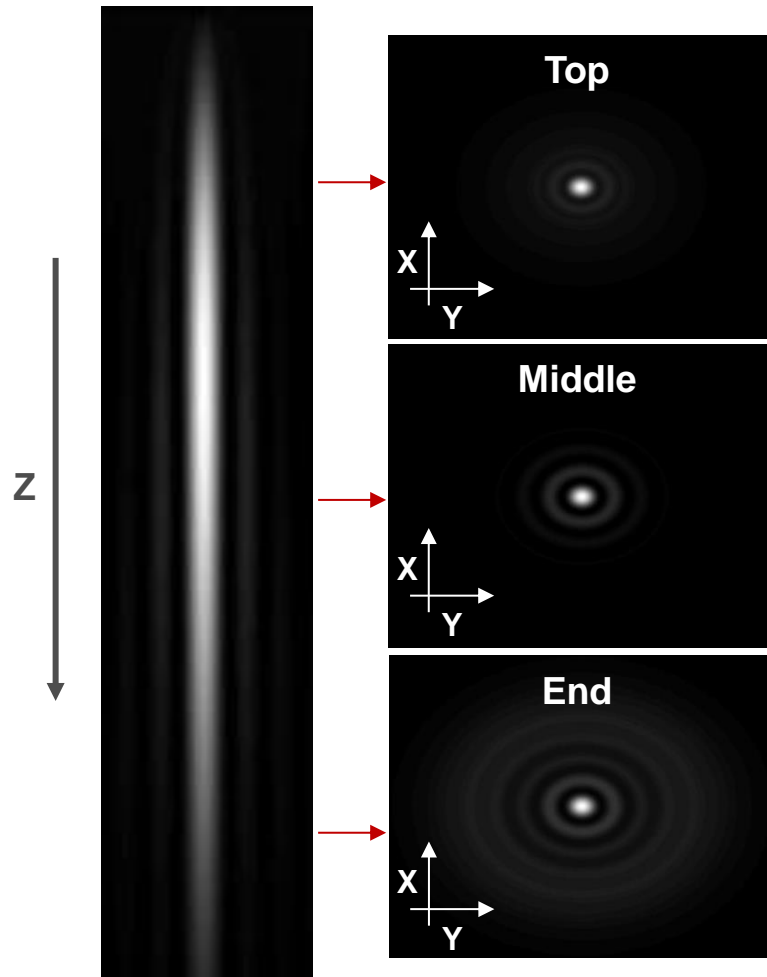


Low aspect ratio ~20

High focusing



Machining deep ~ μm



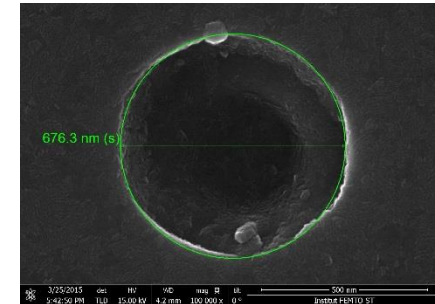
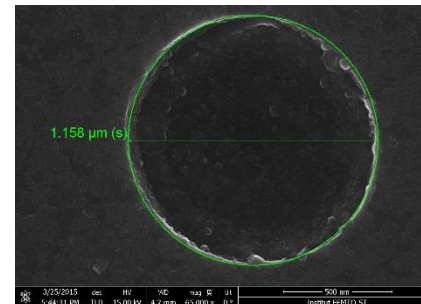
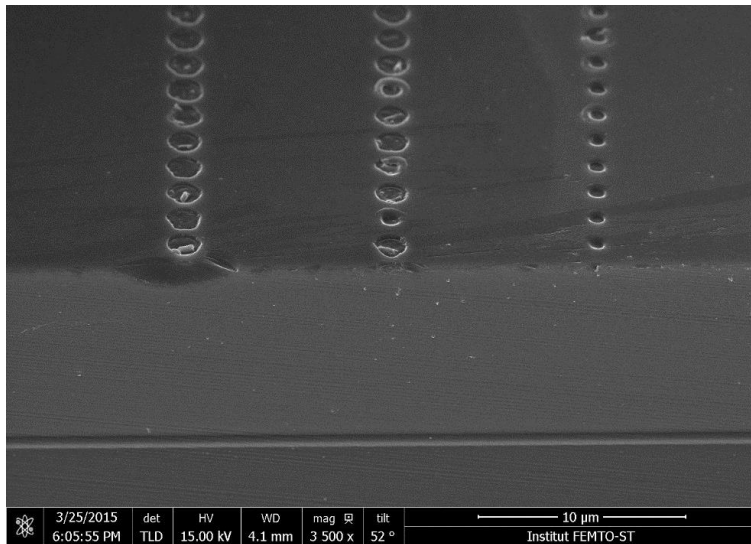
- Bessel beam diameter less than $1\mu\text{m}$
- Bessel length reaches several hundred microns
- High stability and homogeneity

Nano-structuration by Bessel beams

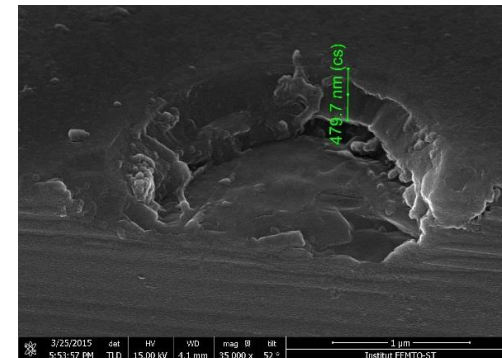


➤ Lithium niobate

Perfect circle less than $1\mu\text{m}$ of diameter



Surface nano-structuration

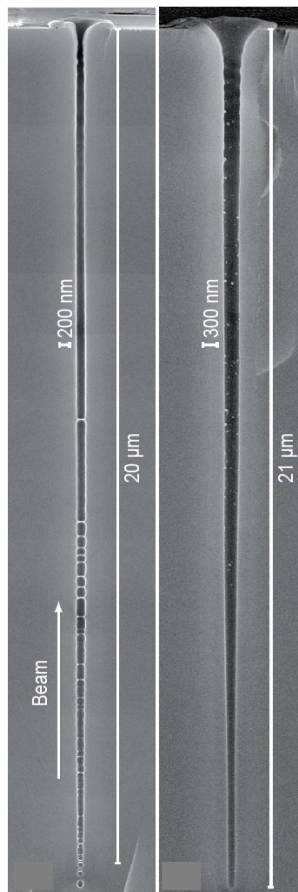


Depth less than $0,5\mu\text{m}$

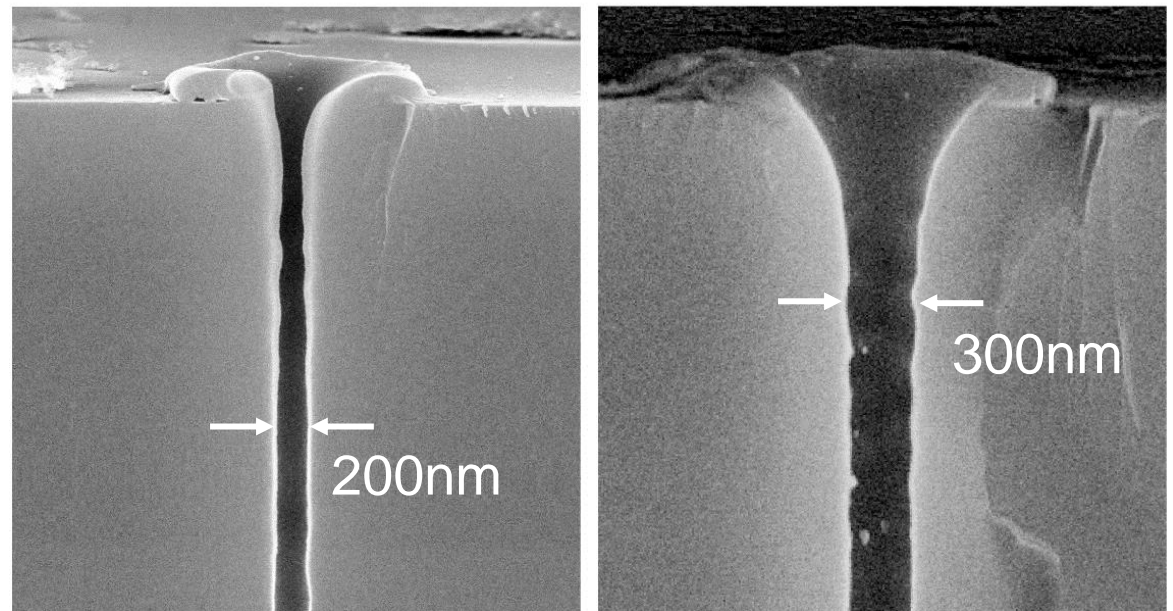
Nano-structuration by Bessel beams



➤ Glass



one pulse=one channel



Aspect ratio =100

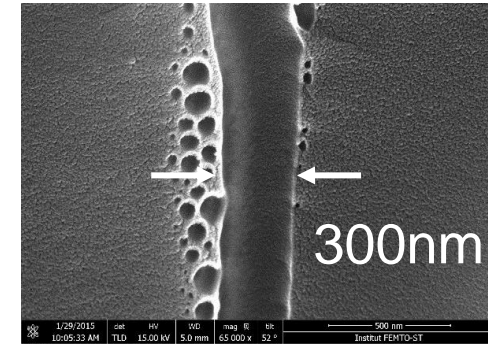
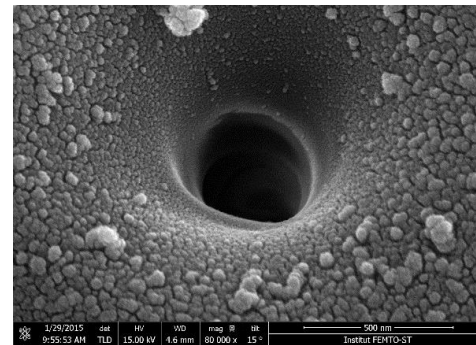
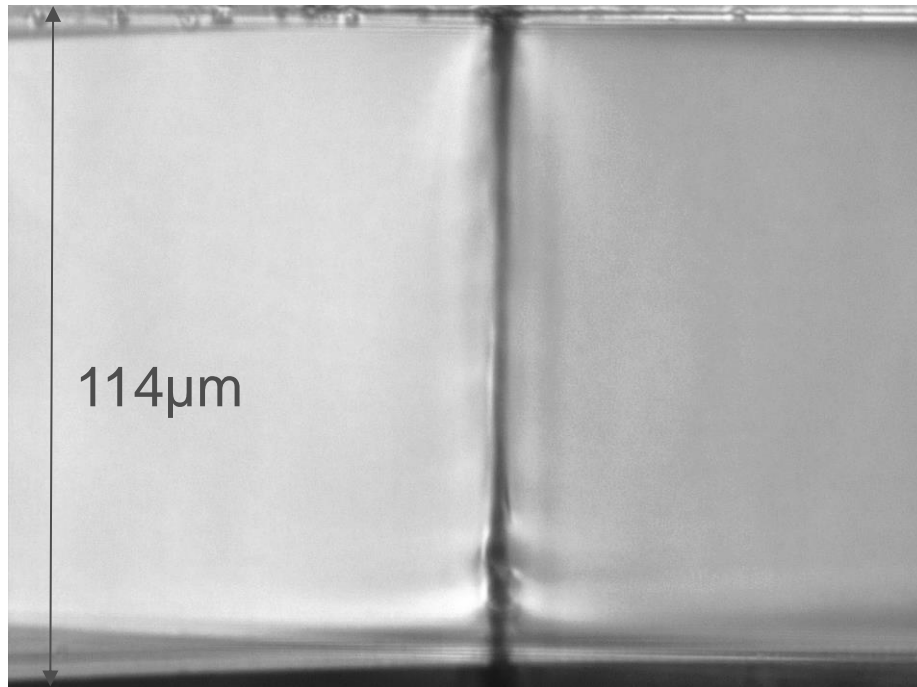
Bhuyan *et al*, Appl. Phys. Lett., **97**, 081102 (2010)

Nano-structuration by Bessel beams



➤ Glass

one pulse = one channel



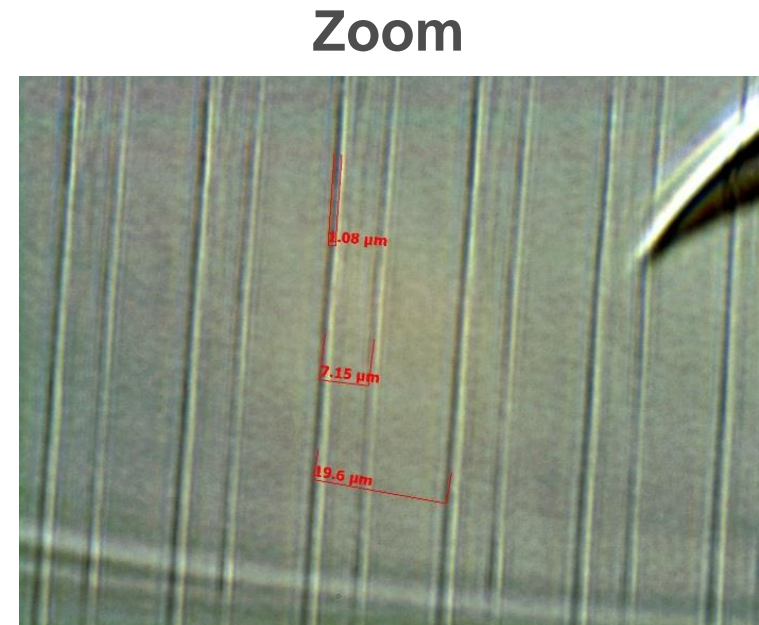
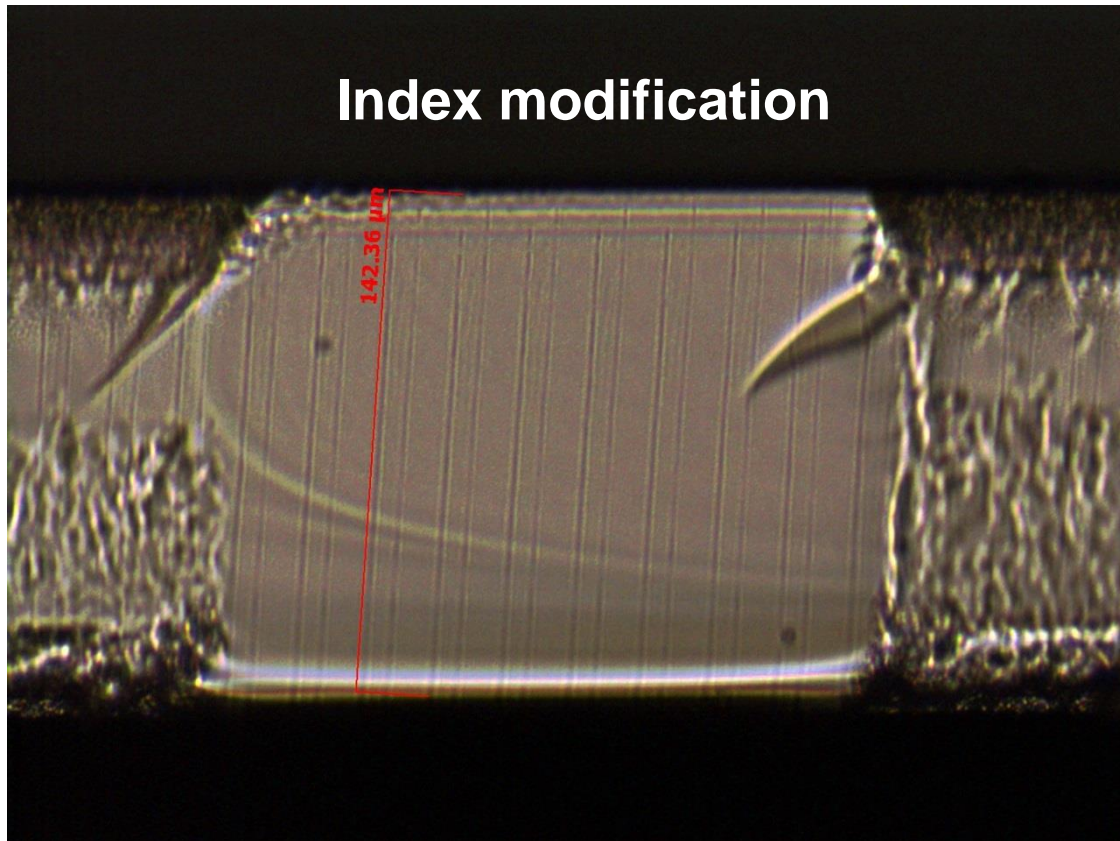
Aspect ratio=400

- The ablation rate per pulse is greater than $32\mu\text{m}^3$
- Gaussian beam $< 2\mu\text{m}^3$

Nano-structuration by Bessel beams



➤ Glass



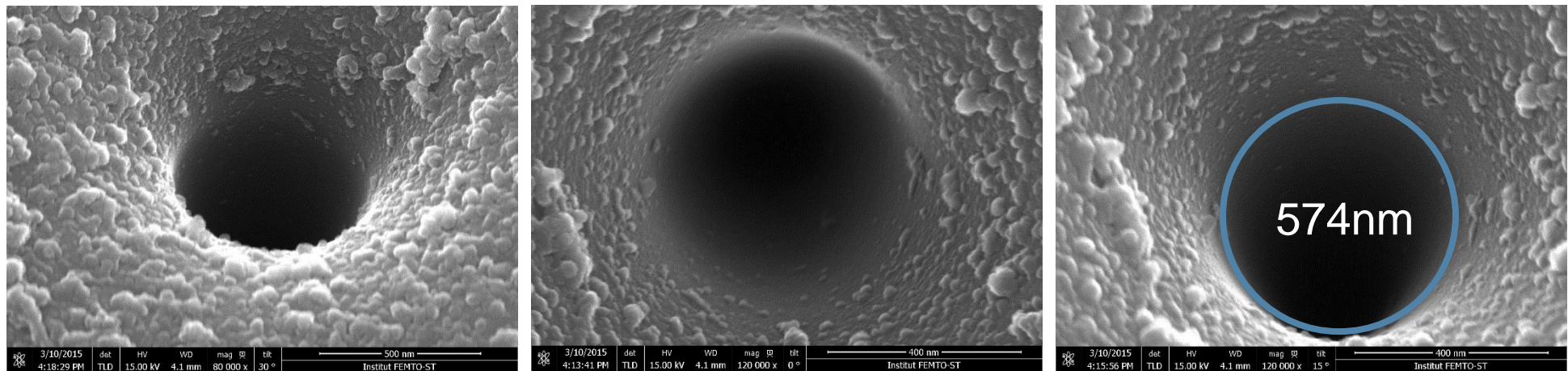
➤ Index modification can be done until 2mm depth

Nano-structuration by Bessel beams

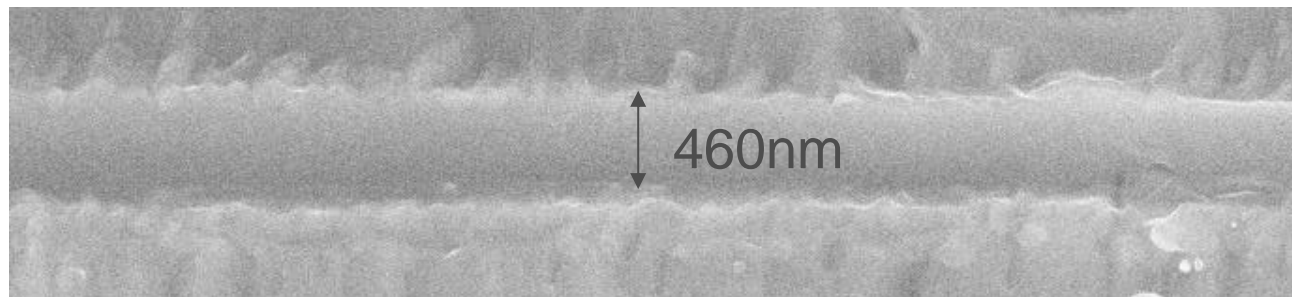


➤ Lithium niobate

Excellent surface quality : optical quality



Top view

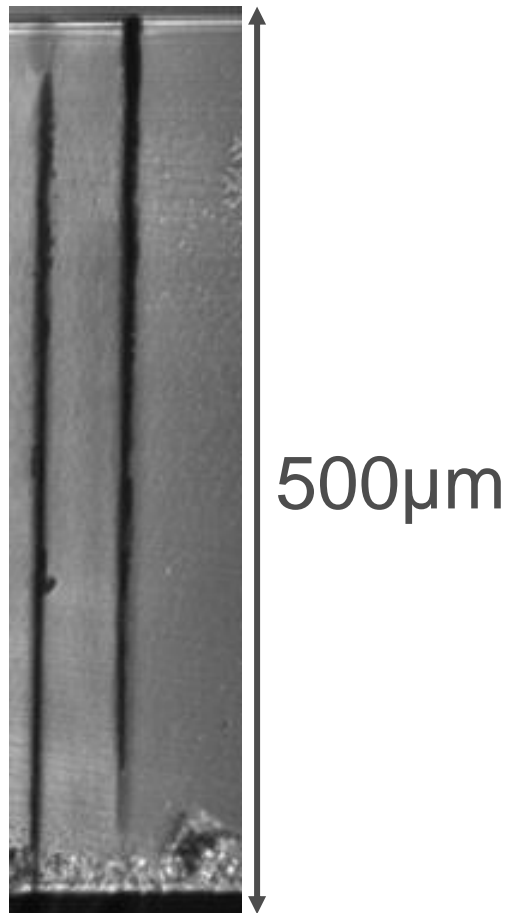


Inside channel view

Nano-structuration by Bessel beams

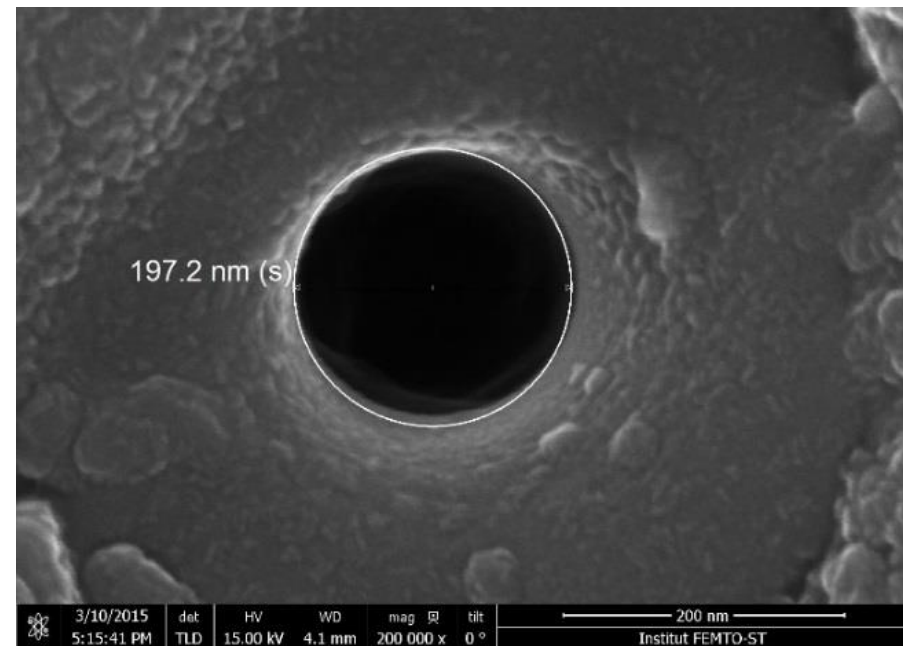
➤ Lithium niobate

OM picture



Side view

SEM picture



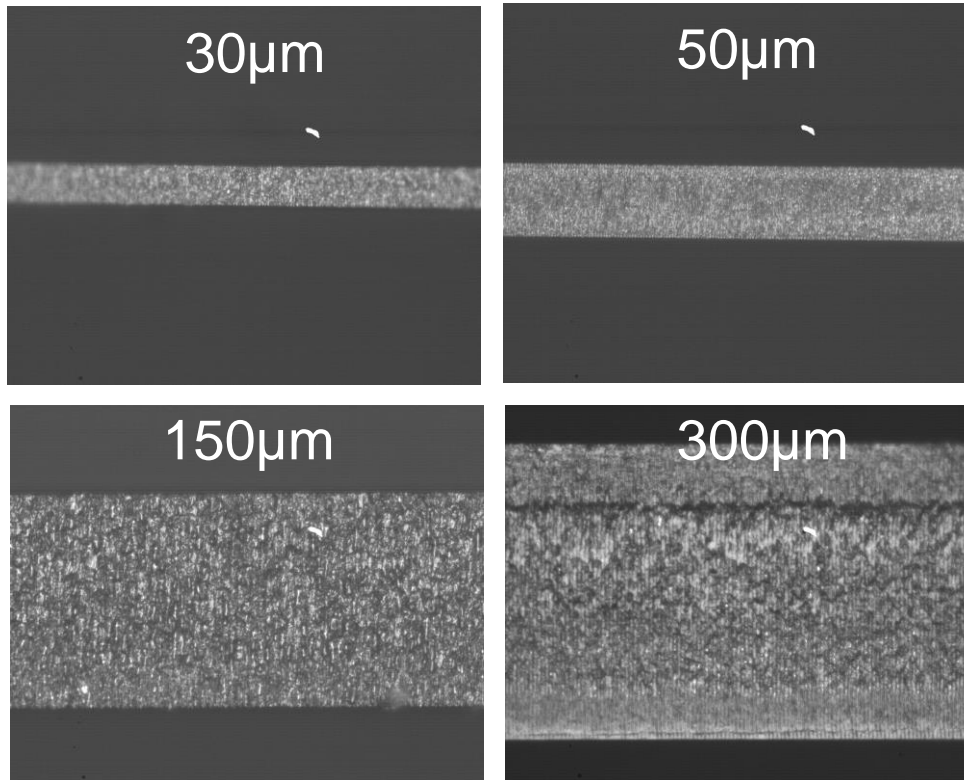
New record
Aspect ratio > 2000

Transparent materials laser cleaving



➤ Glass

$V_{\max}=100\text{mm/s}$ at low repetition rate

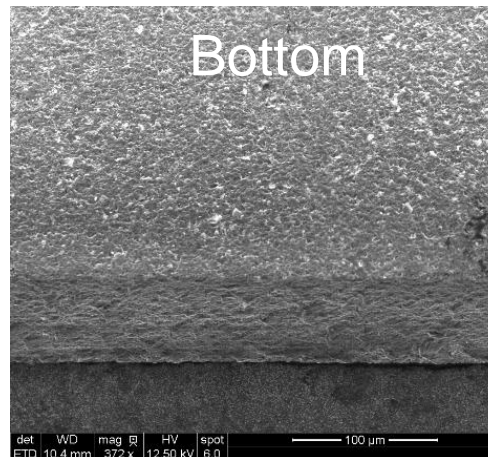
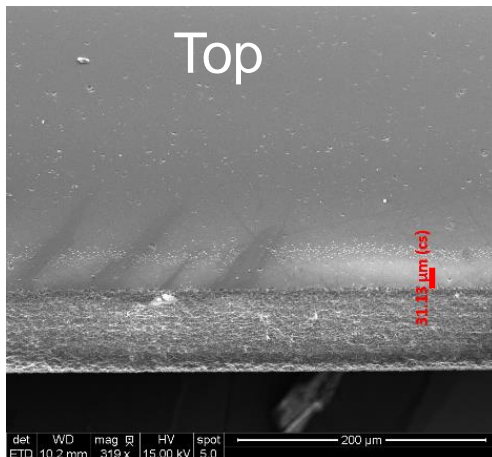
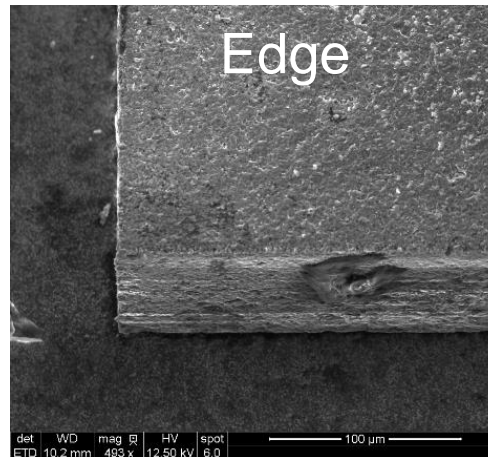
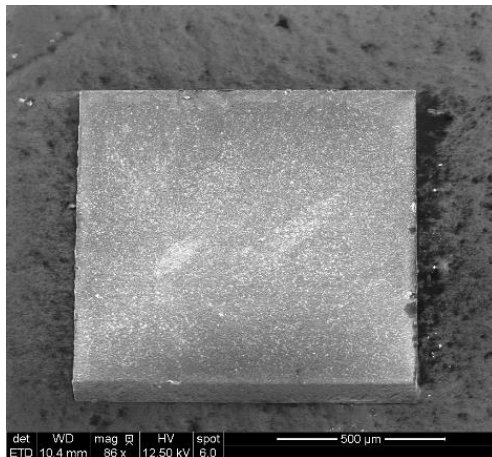


- Glass thickness range 30µm to 500µm
- Minimal micro-cracking < 1µm
- Surface roughness, $R_a < 1\mu\text{m}$
- **Speed cutting more than 1m/s is expected at high repetition rate**

Transparent materials laser cleaving



➤ Quartz



Quartz high speed cutting

- Quartz thickness range 80μm to 500μm
- Very good surface quality
- Very good edge verticality
- Surface roughness, Ra < 2μm

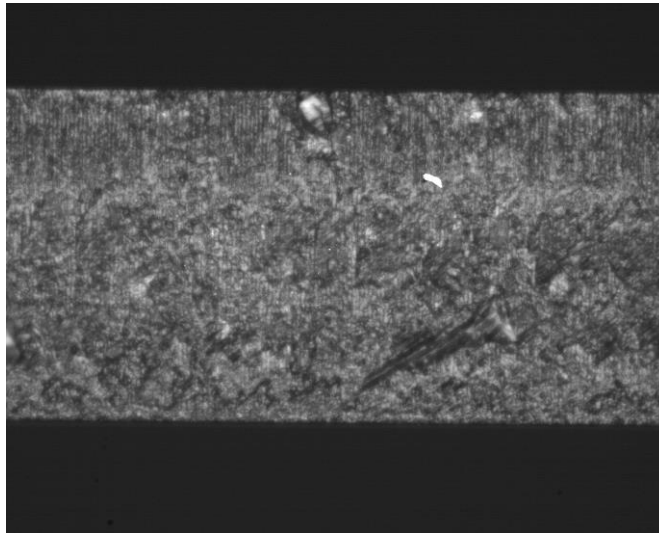
Transparent materials laser cleaving



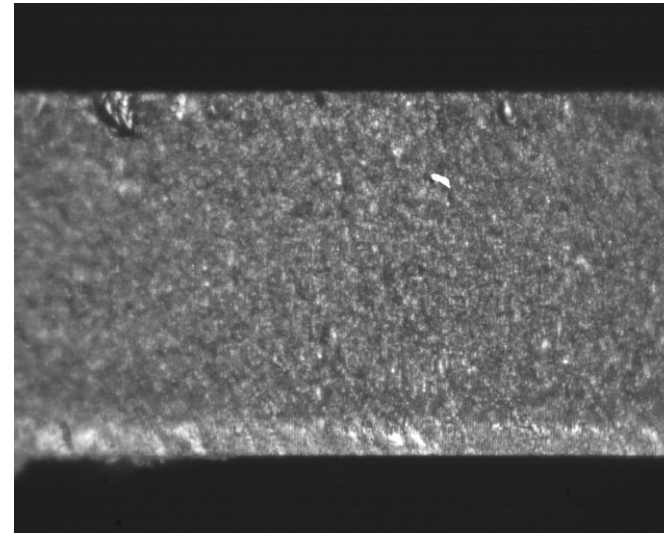
- Lithium niobate & Lithium tantalate

High speed crystals cutting

250μm



Lithium niobate



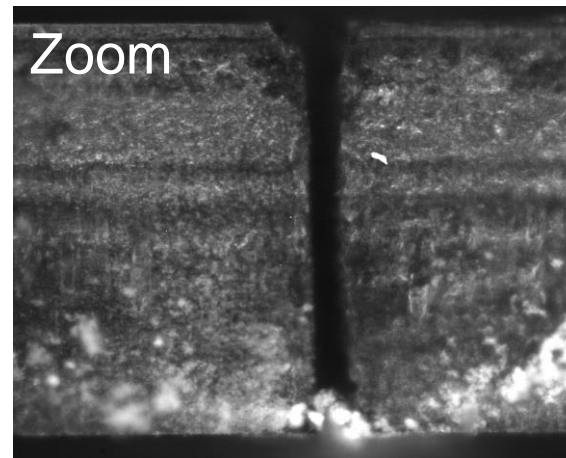
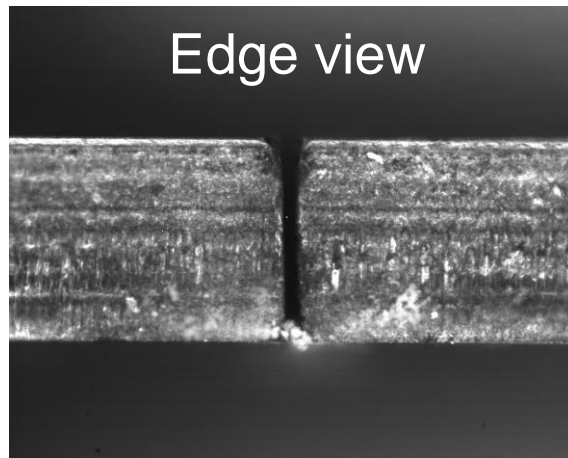
Lithium tantalate

Transparent materials laser machining

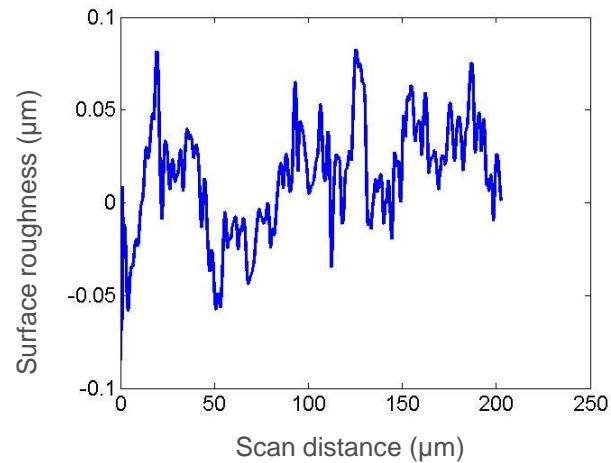
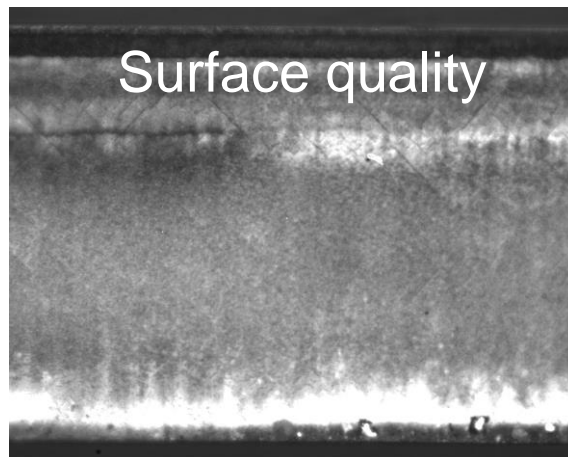


➤ Diamond

Diamond straight cutting



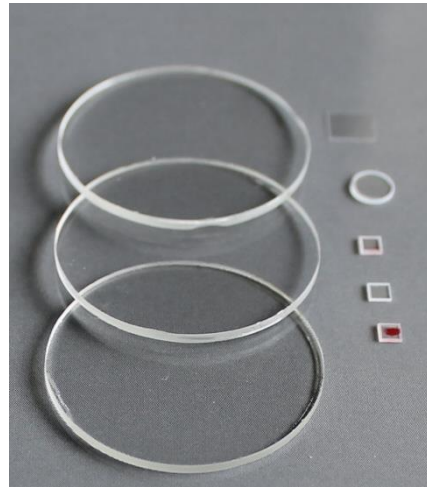
300 μ m



Ra~100nm



- Very high ablation rate $> 30\mu\text{m}^3$
- New aspect ratio record >2000
- Possibility to nano-machine different kind of glass and crystals
- High speed laser glass and crystals cleaving



Thank you for your attention

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➤ 03 63 08 23 89