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

- **Security**
  - Counterfeit
  - Identity documents

- **Medicine**
  - Lab on chip
  - Opto-fluidic circuit
How laser finds applications in industry?

Telecommunication
- 3D optical circuit
- Fibers cutting and welding

Aeronautical
- Surface texturing Fuselage

Security
- Counterfeit
- Identity documents

Medicine
- Lab on chip
- Opto-fluidic circuit

An important part is occupied by transparent materials
Many ways to machine transparent materials

**Dicing & thinning**

**Dry and wet etching**

**Laser machining**
Micro-structuration of transparent materials

Dicing & thinning

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Thinning until 1µm</td>
<td>• Thickness homogeneity&gt;1µm</td>
</tr>
<tr>
<td>• Optical roughness quality</td>
<td>• Only straight lines are possible</td>
</tr>
<tr>
<td>• Aspect ratio&gt;400</td>
<td>• Maximum channel width=100µm</td>
</tr>
<tr>
<td>• Minimum width=1µm</td>
<td></td>
</tr>
<tr>
<td>• Sidewall verticality=88°</td>
<td></td>
</tr>
<tr>
<td>• Roughness quality=4nm</td>
<td></td>
</tr>
</tbody>
</table>

June 2015 Femtosecond Laser
Dry and wet etching

<table>
<thead>
<tr>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complex and deep etching are possible</td>
</tr>
<tr>
<td>Anisotropic etching (Dry)</td>
</tr>
<tr>
<td>Controlled roughness</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low aspect ratio</td>
</tr>
<tr>
<td>Multistep process</td>
</tr>
<tr>
<td>Sidewall verticality = 80°</td>
</tr>
</tbody>
</table>
### Case: Gaussian beam Laser machining

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Fast complex and deep etching are possible</td>
<td>• Low aspect ratio</td>
</tr>
<tr>
<td>• One step etching</td>
<td>• Roughness &gt; 0.2µm</td>
</tr>
<tr>
<td></td>
<td>• Sidewall verticality = 75°</td>
</tr>
</tbody>
</table>

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

**Drawbacks**
- Low aspect ratio
- Roughness > 0.2µm
- Sidewall verticality = 75°
Nano-structuration of transparent materials

Focused ions beam

Clean room technology

- Limited aspect ratio
- Very long time processing
Limits of classical femtosecond laser machining

Opt Exp 18, 16840 (2010)

High focusing

Low aspect ratio ~ 20

Machining deep ~ µm
Our technic: Bessel beams

- Bessel beam diameter less than 1\( \mu \)m
- Bessel length reaches several hundred microns
- High stability and homogeneity
Nano-structuration by Bessel beams

Lithium niobate

Perfect circle less than 1µm of diameter

Surface nano-structuration

Depth less than 0.5µm
Nano-structuration by Bessel beams

Glass

one pulse = one channel

Aspect ratio = 100

Nano-structuration by Bessel beams

Glass

one pulse = one channel

Aspect ratio = 400

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

460nm

574nm
Nano-structuration by Bessel beams

- Lithium niobate

New record
Aspect ratio > 2000
Transparent materials laser cleaving

Glass

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

- Glass thickness range 30µm to 500µm
- Minimal micro-cracking < 1µm
- Surface roughness, Ra < 1µm
- 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

Lithium niobate

Lithium tantalate

250µm
Diamond straight cutting

Edge view

Zoom

Surface quality

300µm

Ra~100nm

Surface roughness (µm)

Scan distance (µm)
- Very high ablation rate > 30µm³
- 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

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