James Watt Institute for High Value Manufacturing

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Micro-structuring of optical surfaces

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Distinctly Ambitious
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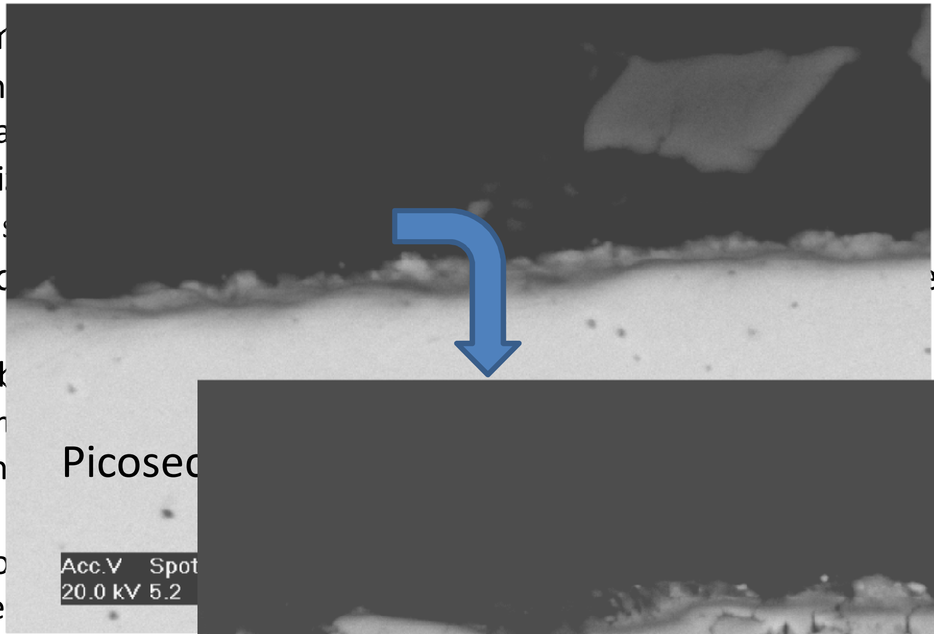
Bespoke optical components / surfaces

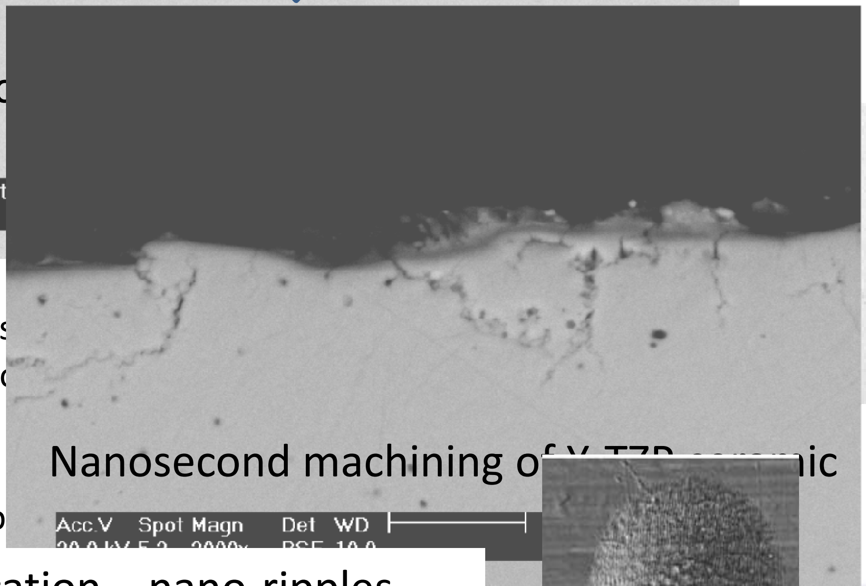
- Manufacture of optics and the integration of optics and electronics increasingly important
- Traditional optical manufacture techniques
  - suitable for high volumes
  - spherical and planar surfaces
  - not suitable for low volume, aspherical, customised components
- Lasers ideal for highly flexible structuring on a sub-micron scale but resultant surfaces can be significantly scattering for optical wavelengths
  - However by control of laser wavelength and pulse length develop processes for the manufacture of optical components

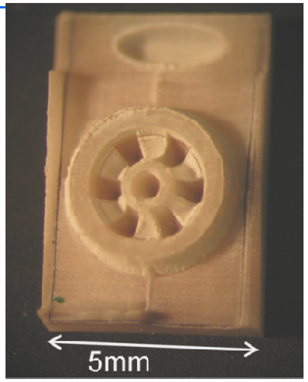
Laser machining of precision surfaces – optimal pulse length?

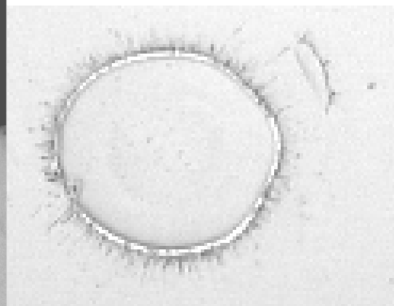
Nanosecond laser m
- widely used for m
  of various materia
- Typical features si
- Cracking problems

Ultrafast (femtoseco … ss?
- Metals
  - Absorption b
  - Delay in tran
    (electron-ph
  - Subsequent
  - Also need to
    electron the
- Transparent materials
  - Linear and non-linear abs
  - Emission of photo-electro
  - Coulomb explosion
- Impact of wavelength:
  - uv wavelengths achievab



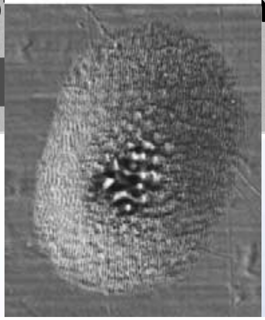






Single shot machining of BK7 glass 160 μJ, 150fs

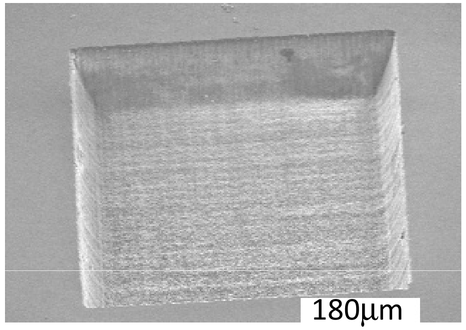
- Further complication – nano-ripples



Mannion et al, Applied Surface Science 233 (2004) 275–287

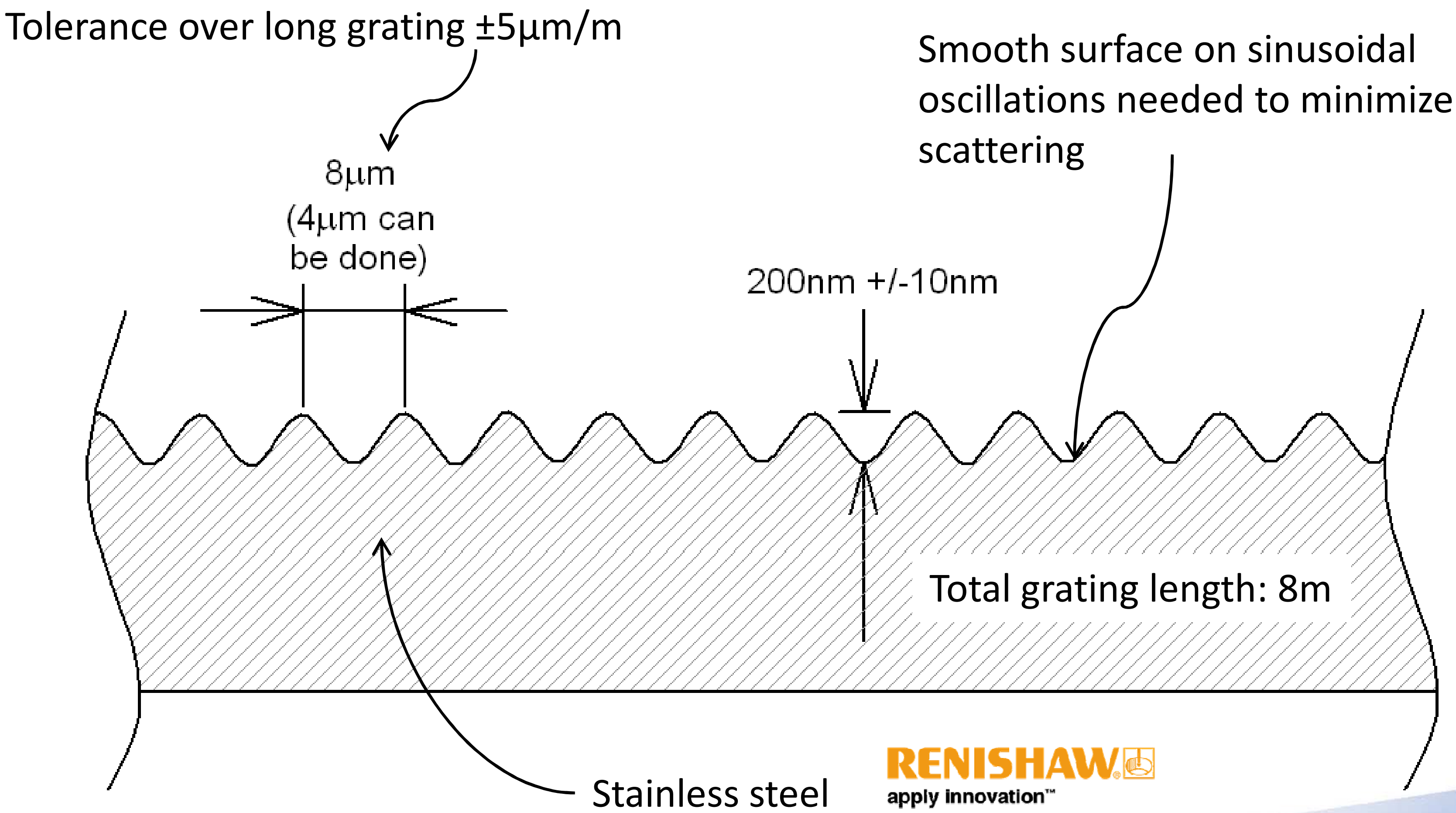
Laser machining of *optical* surfaces – optimal pulse length?

- Picosecond and femtosecond lasers give minimal heat affected zone
  - Ideal for particular materials e.g. glass, ceramics
  - Minimal cracking or other thermal damage
  - Excellent control over ablation depth
- However, lasers still relatively expensive and complex
- Also, do not generate optical quality surfaces
  - For optical surface manufacture, use longer pulses
  - Nanosecond, millisecond, microsecond
  - Controlled surface melting



Fraunhofer Institute for Laser Technology, Aachen, Germany

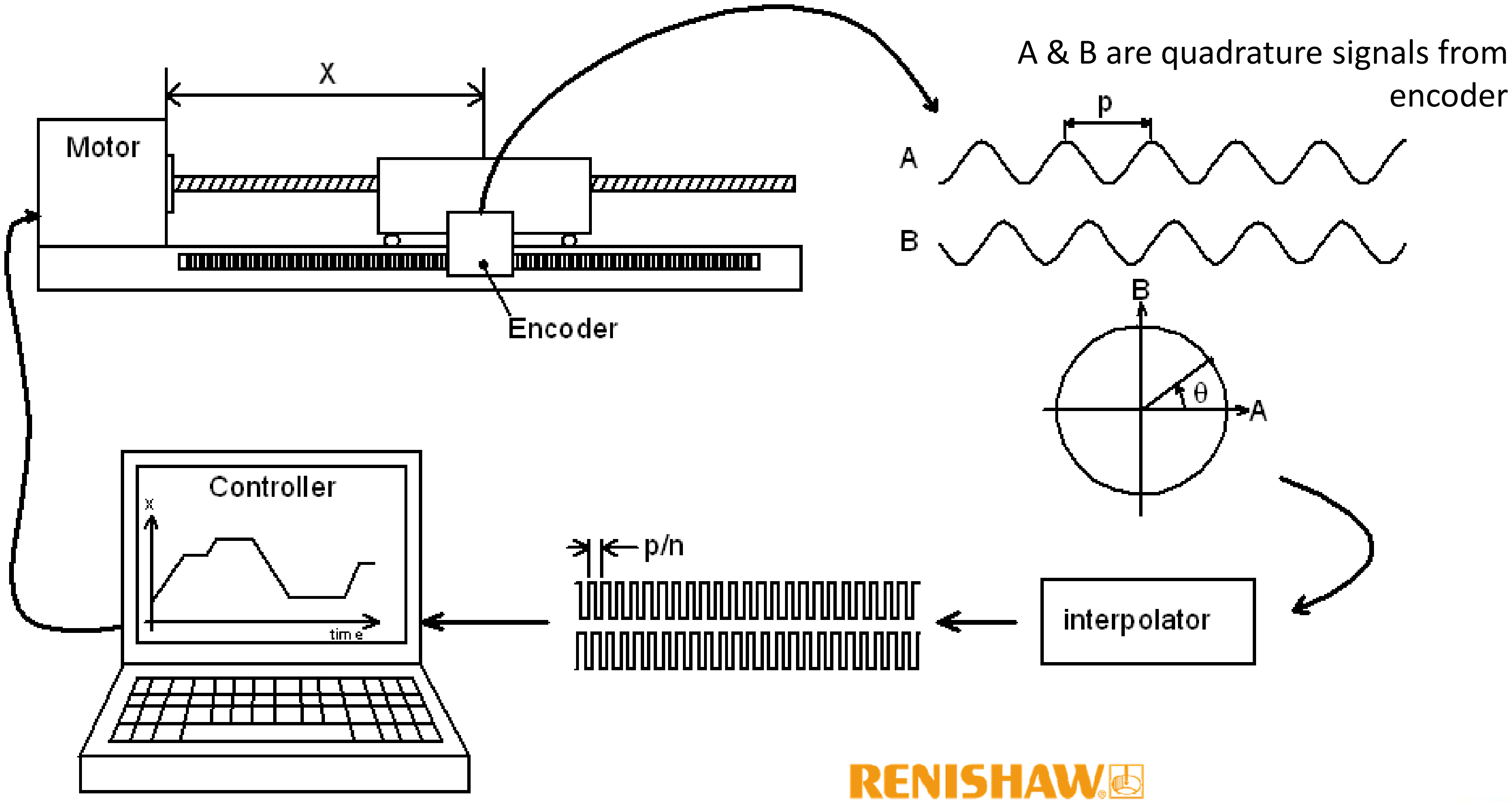
Requirement for manufacture of optical grating structure



Developed manufacturing process using ns pulses for highly localised melting

Encoders

Convert linear or rotary motion into electrical signals for feedback control

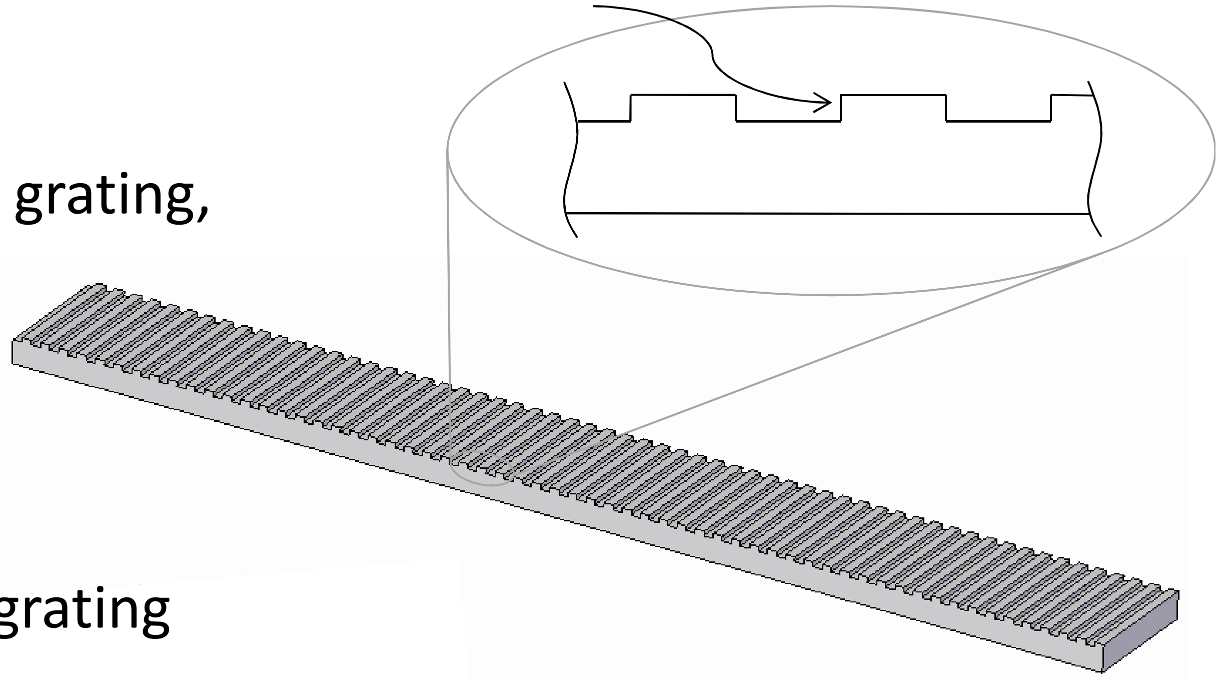


RENISHAW apply innovation™

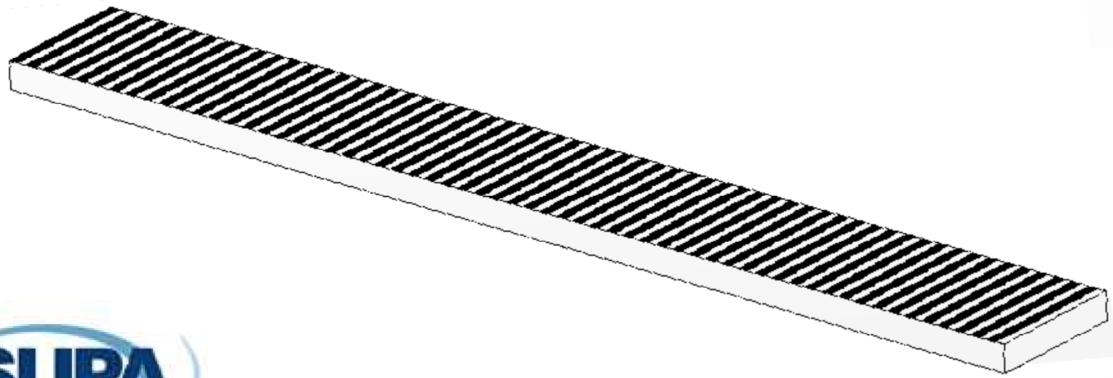
Diffraction scale

Precision encoder scale:

usually a long diffraction grating,
in this case:
a phase grating



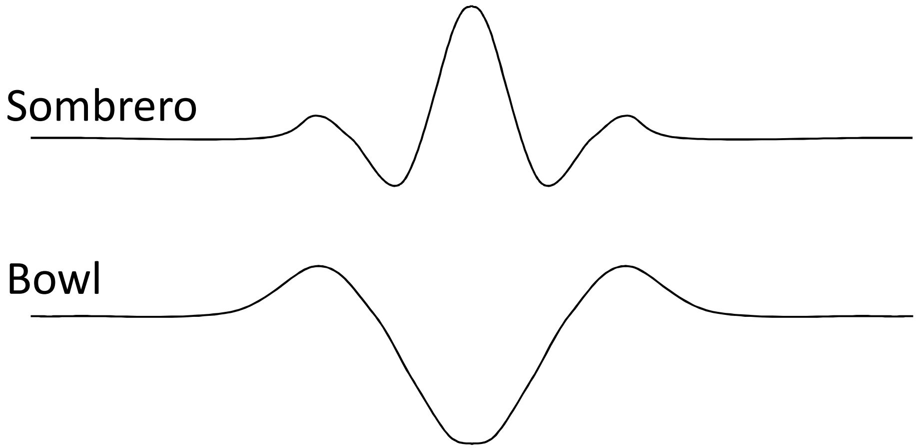
As opposed to:
amplitude (Ronchi) grating



Melted features

Experimental results

Material A	→	Single pulse per feature
Material B	→	>20 pulses per feature
CO_2	→	Sombrero
Air	→	Bowl
Ar	→	Bowl

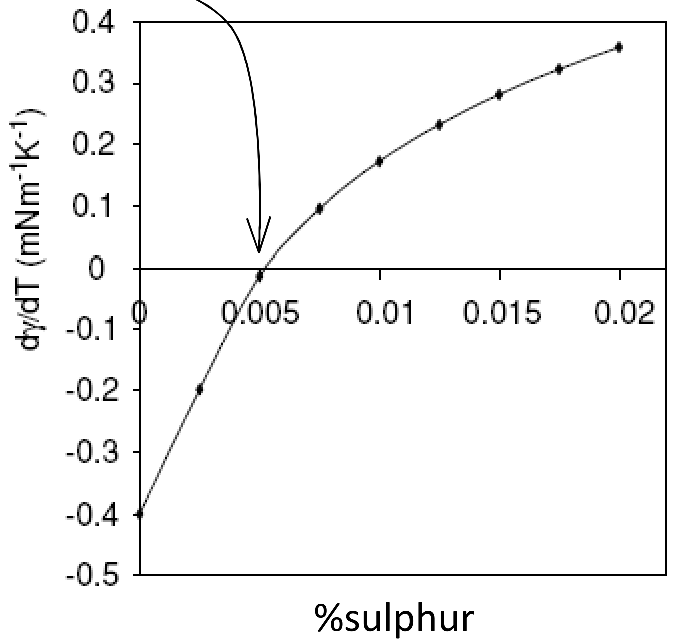


1) Marangoni effect. Surface tension forces: proportional to thermal forces divided by viscous forces
2) Thermo-capillary motion: buoyancy, density changes, thermal currents
3) Chemi-capillary motion: diffusion across surface, chemical reactions

Surfactant concentration

Materials with critical surfactant concentration can show little surface disturbance with laser pulse interaction.

Coefficient of surface tension with temperature drives surface forces

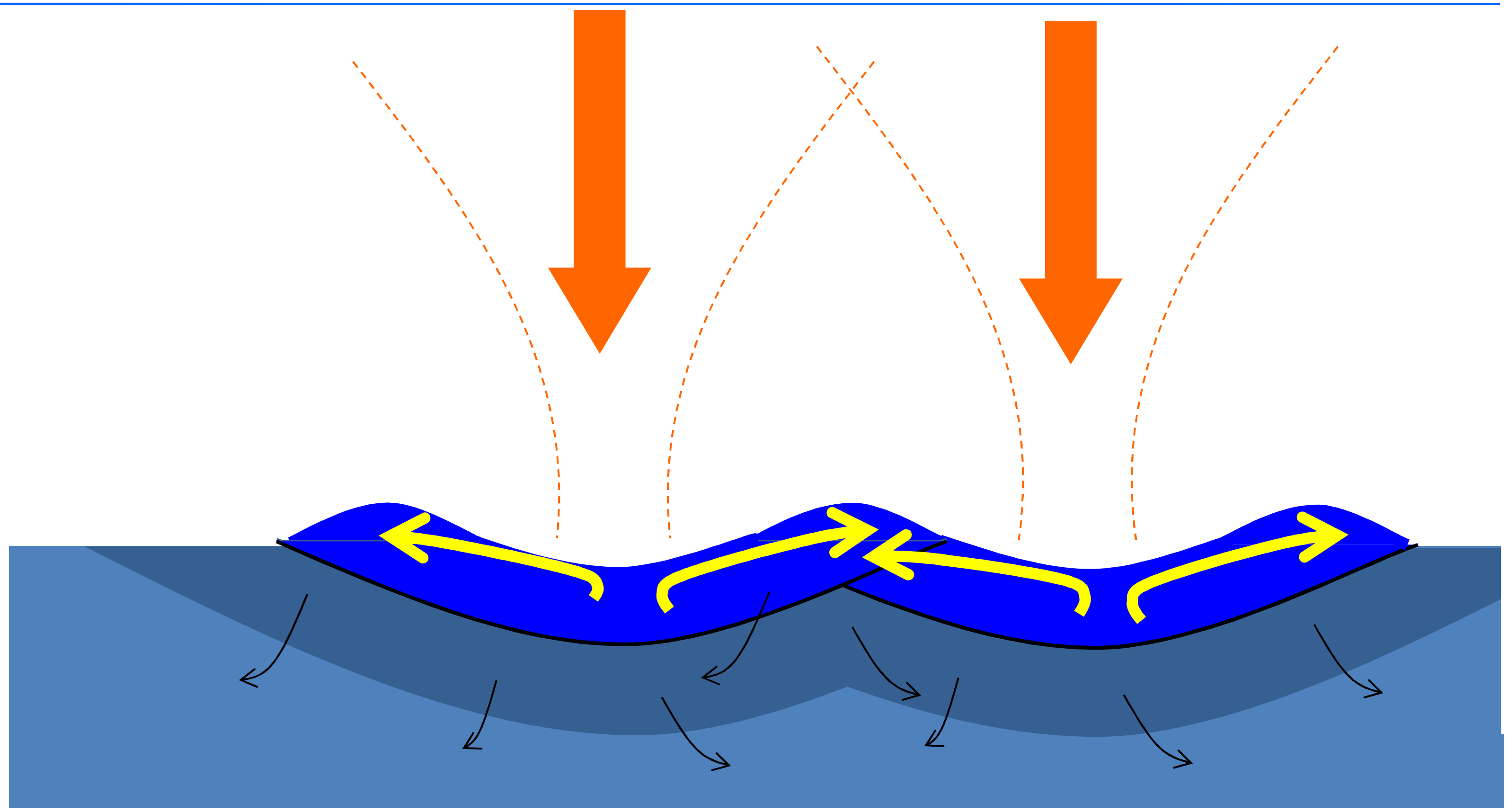


Thermal coefficient of surface tension behaviour with sulphur concentration

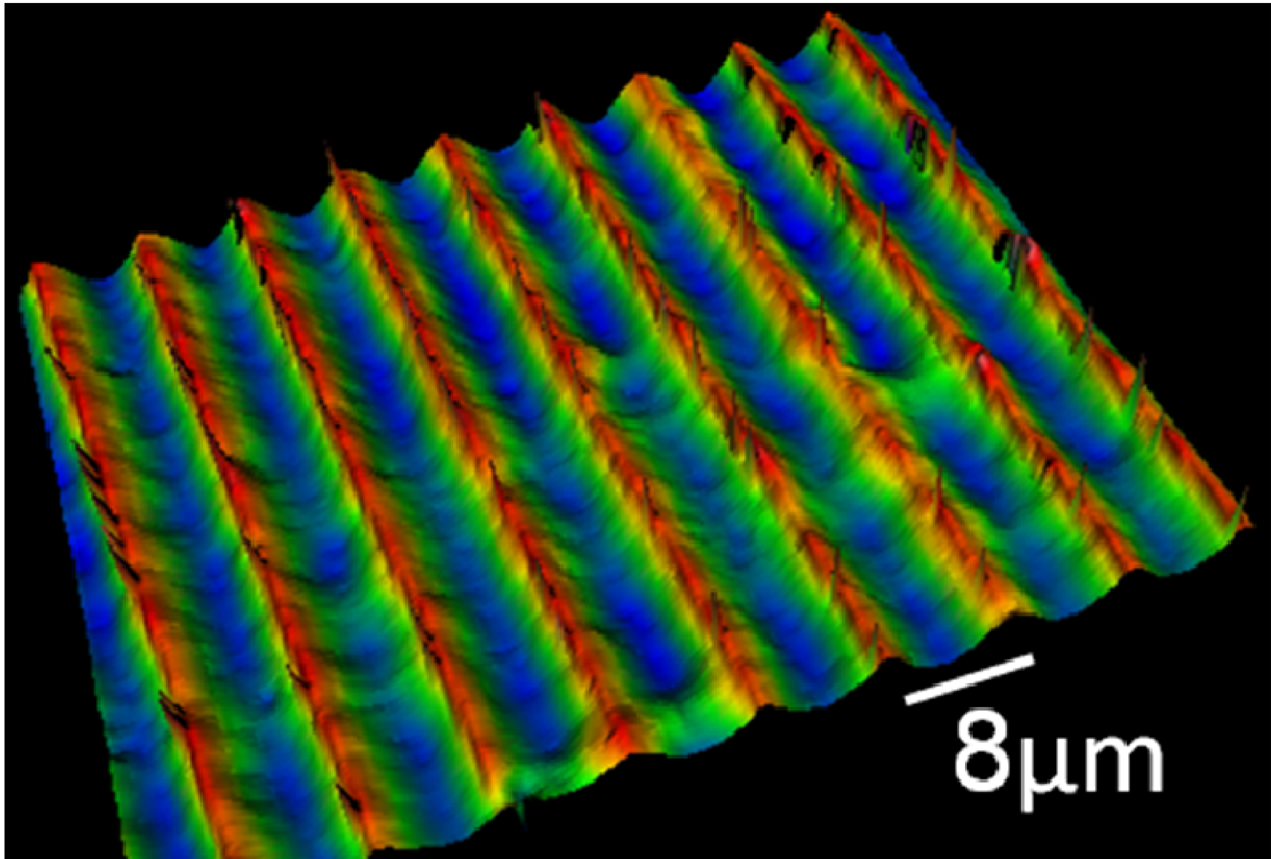
Y. Su, Z. Li, K. C. Mills
J.Mater.Sci. 40(2005)2201-2205

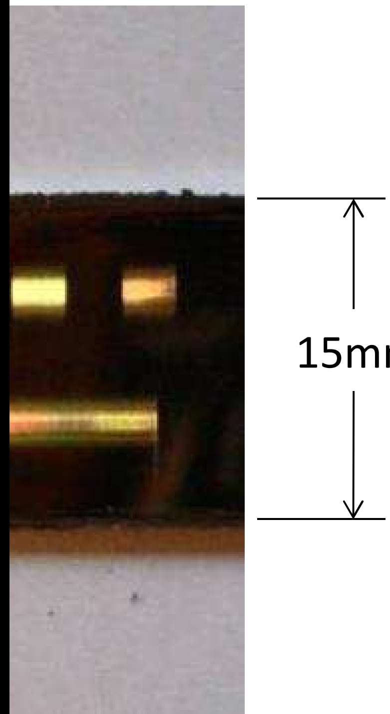
Many elements can act as surfactant:
oxygen,
sulphur,
phosphorous
and more

Generation of grating



Results: diffraction grating by laser melting



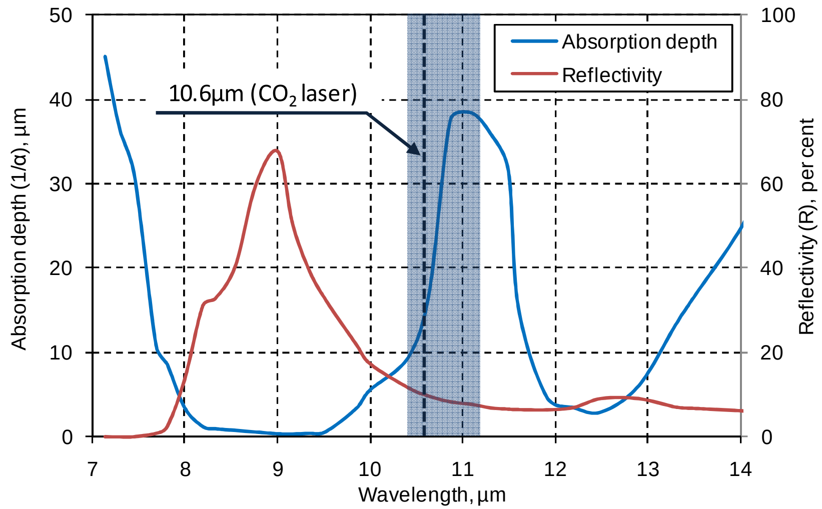


8μm period reflective phase grating
Depth of feature 200nm±10nm

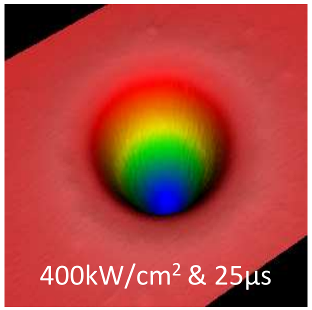
Shown illuminated by domestic tungsten filament bulb

Glass optics: CO_2 laser process

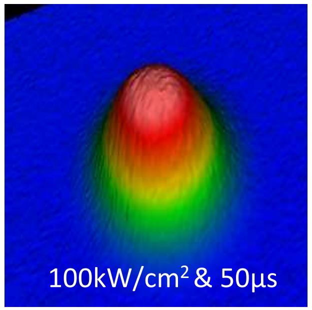
- highly transparent between 0.3 – 2.2µm wavelength (T > 90%)
- stong absorption at 10.6µm wavelength
- only optical glasses with low CTE (e.g. fused silica) can be extensively machined with a CO_2 laser at room temperature without material cracking
- single laser pulses produce deformations at the glass surface

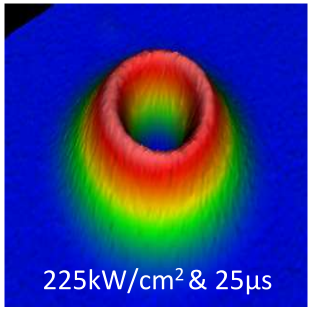


Crater generated in fused silica (HPFS®7980, Corning)

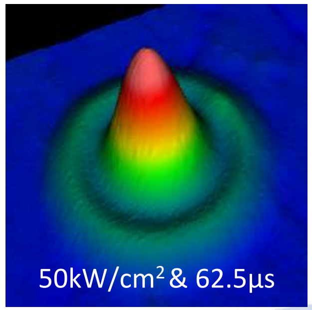


Bump and ring generated in Borofloat®33 (Schott AG)





Sombrero generated in lead-silicate glass (SF57, Schott AG)

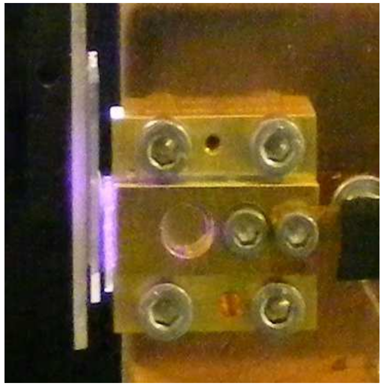


* K. L. Wlodarczyk, "*Surface deformation mechanisms in laser smoothing and micro-machining of optical glasses*," Ph.D. dissertation (Heriot-Watt University, Edinburgh, 2011).

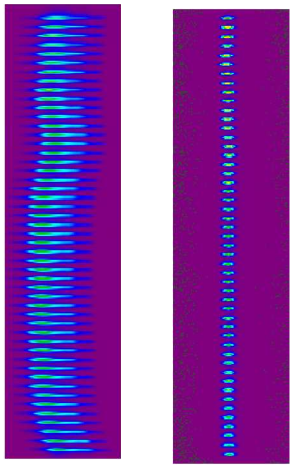
Application of CO_2 laser process

- Laser cutting and polishing for generation of optical components
  - Precision laser cutting of silica using pulsed CO_2 with optimised laser conditions
  - Smoothing of surface with optimised cw CO_2 laser re-melting

Recent example –Correction and slow axis collimation of 49 single mode diode laser on one bar



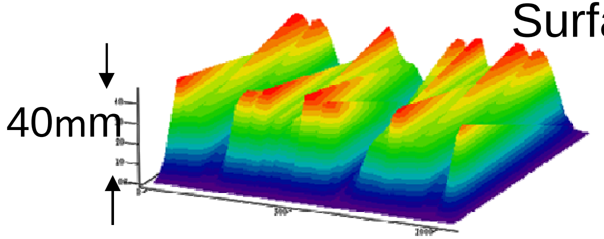
SLOW AXIS NEAR FIELD IMAGE

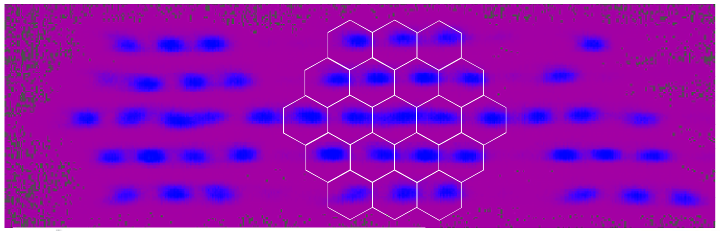


UNCORRECTED CORRECTED

Conversion of linear array into hexagonal packing

Surface design





SELEX GALILEO

CO_2 laser process – commercial exploitation

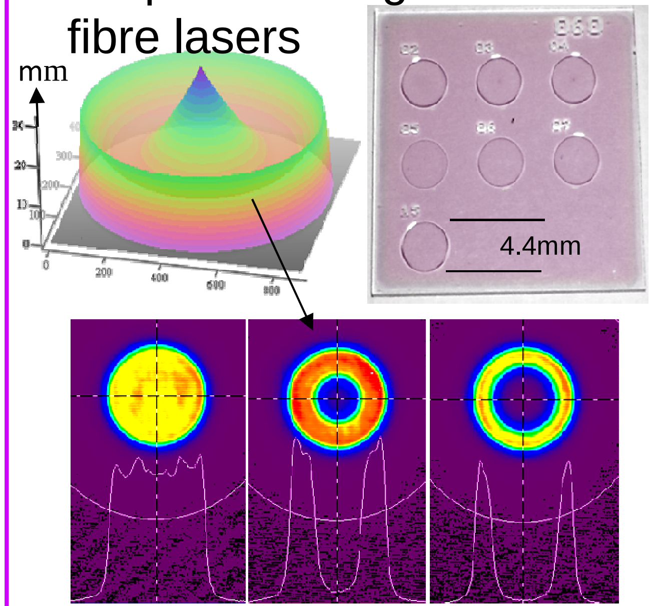
PowerPhotonic Ltd, Fife is the HWU spin-out, exploiting our original research

- Directly-written optical surfaces to 1/10 wavelength accuracy
- Wafer scale processing, using several proprietary laser tools
- Custom correction optics for improving diode laser brightness
- Collimation array optics for diode laser systems
- Beam shaping for close-packing, matching diode laser array beams into fibre optics
- Beam shaping for conventional lasers, and for optical interconnects

Currently world leading in custom refractive micro-optics, with unique products

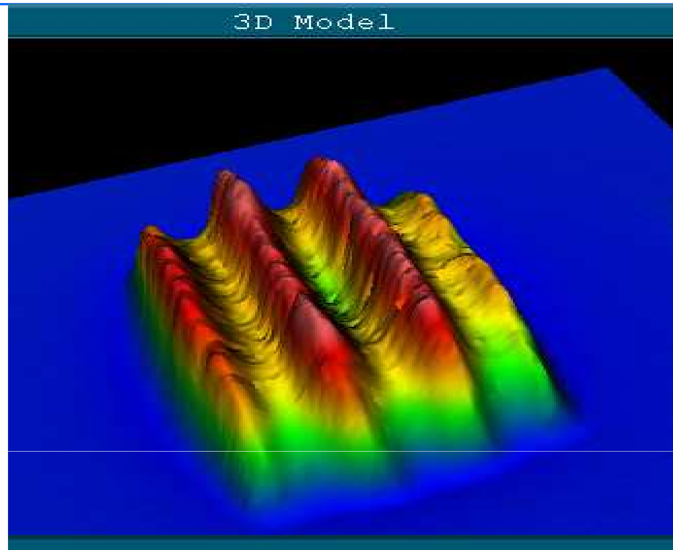
powerphotonic
enhancing beam performance

Fixed profile beam-shapers for single-mode fibre lasers

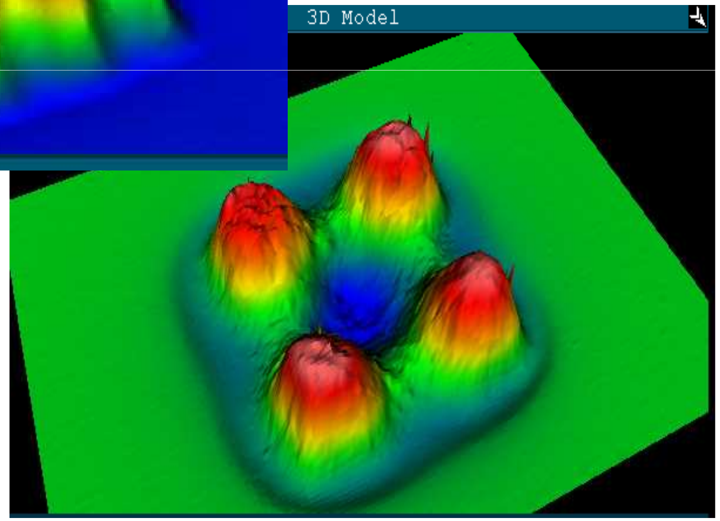


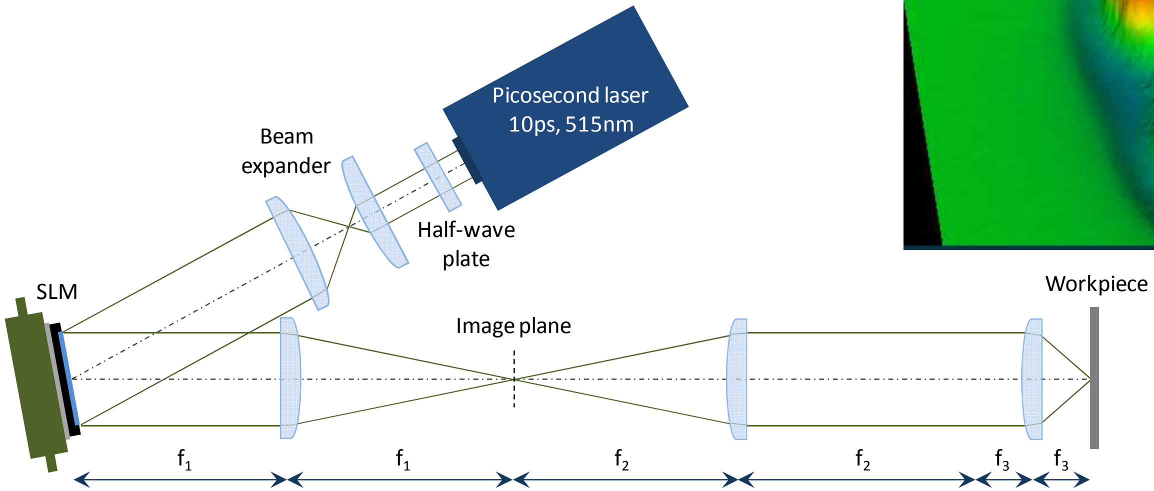
Also demonstrated surface profiling with ps laser on glass

Picosecond laser + liquid crystal spatial light modulator used with glass (with absorbing layer) – see poster P10



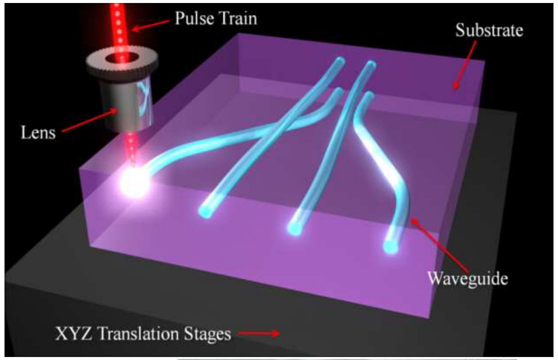
Raised structures on borosilicate glass

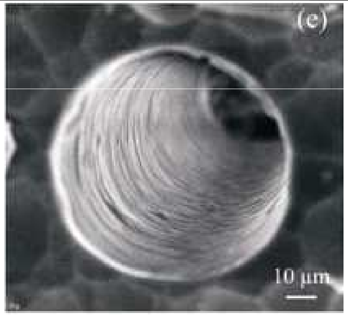


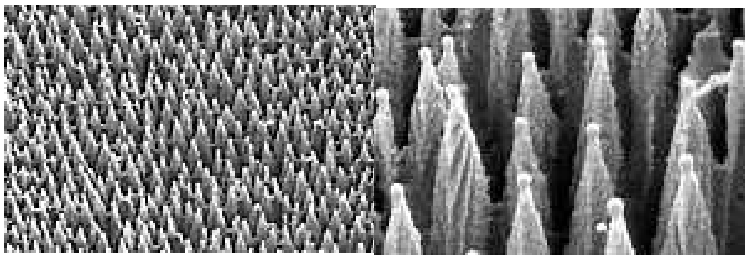


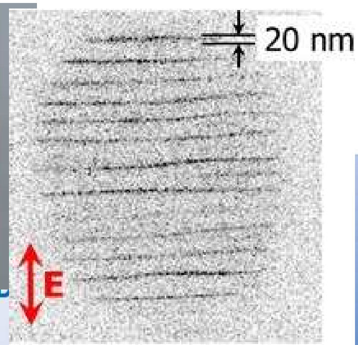
Additional optical fabrication techniques

- Refractive index modification
  - ➢ Waveguide writing
  - ➢ Grating writing
- Laser material modification + etching
  - ➢ Generation of buried channels
- Surface microstructing
  - ➢ Nano-gratings (birefringent – e.g. waveplates, Kazansky)
  - ➢ Absorbing surfaces e.g. black silicon









Summary – micro-structuring of optical surfaces

- Highly localised melting processes required to provide optically smooth surfaces
  - ➢ Nanosecond (or longer pulses) better than ultrafast
- Surface profile can be controlled by exploiting Marangoni effect
  - ➢ Encoder gratings
  - ➢ Bespoke glass optics
- Combine with other laser-based processes (RI modification, laser+etching) for complete optical fabrication process

Thank you for your attention !