

Laser micro-sculpting of metal surfaces

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High Power Laser Applications

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- Presentation of High Power Laser Applications Group
- Nano-second laser machining viable for small surface features?
- Surface sculpting and texturing of metal
- Commercial applications: diffractive gratings

Part of the
Applied Optics and Photonics group

In the
School of Engineering and Physical Sciences

Aims:

- Fundamental studies of laser/matter interaction during precision machining
- Development and optimisation of new technologies suited for commercial applications

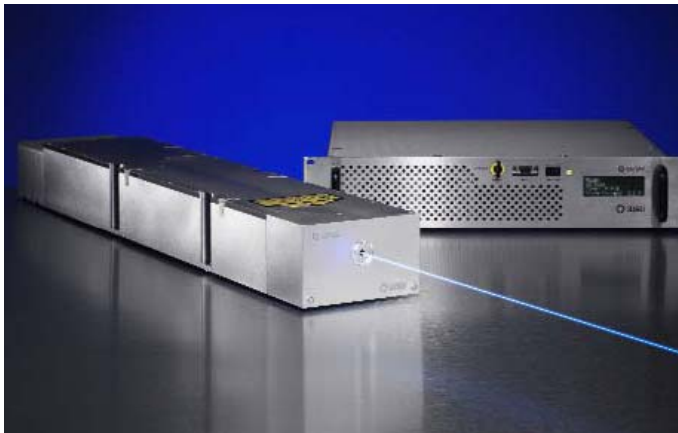
- Range of facilities and competences available to industrial partners for feasibility studies or technology development
- TSB + IMRC + EPSRC funding: industrial projects

LUMONICS Nd-YAG **ms-laser**



TRUMPF **ps-laser**

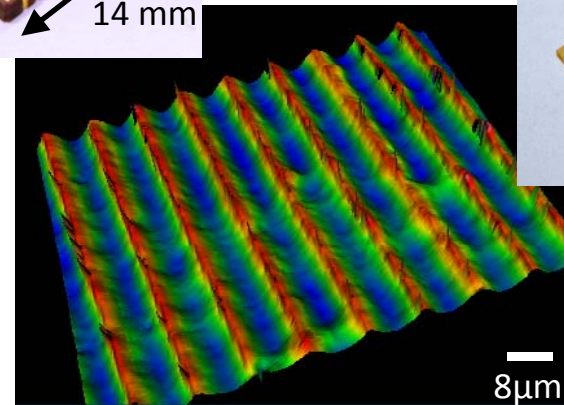
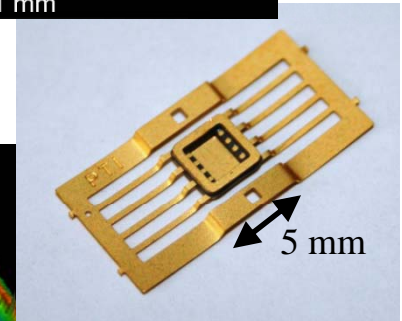
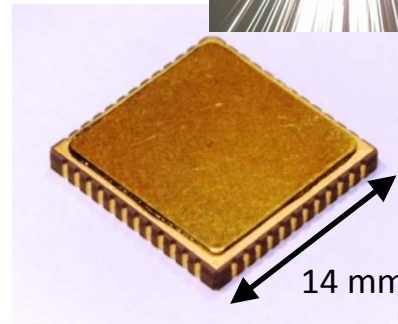
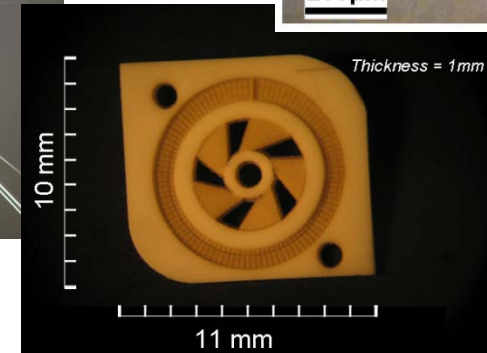
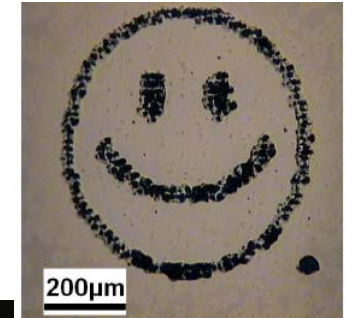
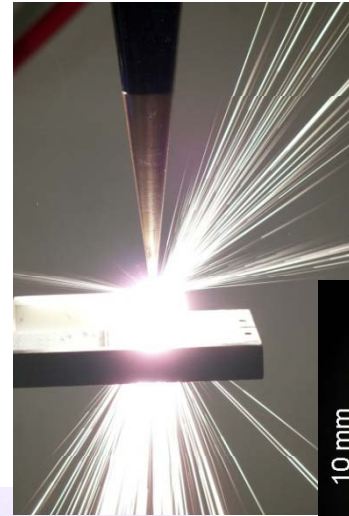
343nm, 515nm, 1030nm
50W avg power@1030nm
400kHz rep rate
<10ps pulse duration



INAZUMA + JDSU Q301 High power
Q-switched **ns-laser** – 10W at 10KHz -

Competences in:

- Adaptive optics
- High power beam fibre delivery
- Optical diagnostics
- Laser precision machining
- Materials
- Packaging
- Laser bonding
- ...



Requirement for small surface features

Short-pulse laser

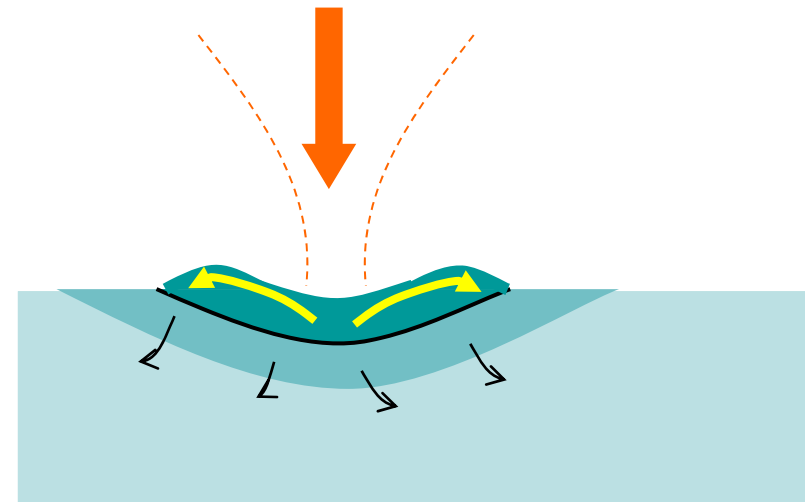
Nano-second laser

- No/small heat affected zone
- High precision
- High accuracy
- High repeatability for commercial applications
- High reliability of technology
- Cost effective - value for money



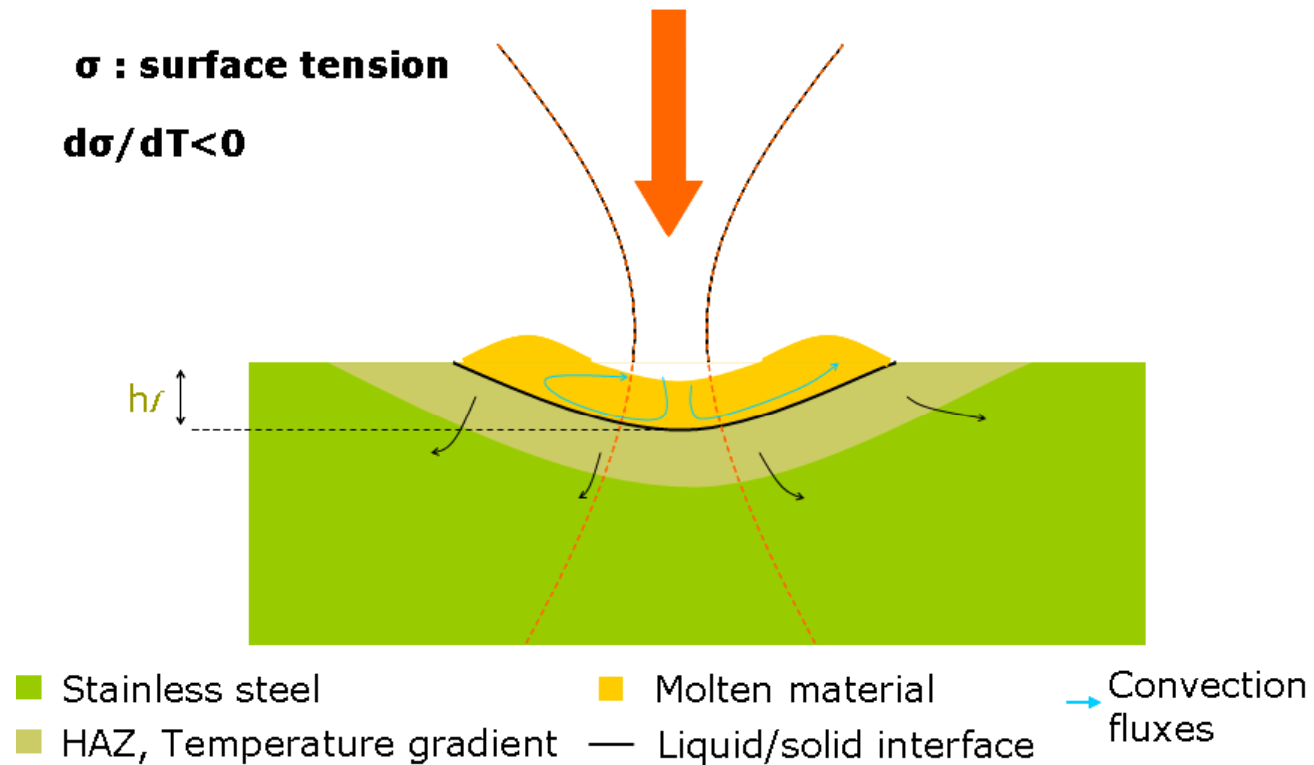
True of ablative technique

- Based on laser-matter interaction in melting regime
- No ablation
- Nano-second laser-based process
- Direct write method
- Sub-micron texturing of metallic surfaces
- Based on laser-induced Marangoni effects



Requirements:
Sinusoidal profile
8 μ m period,
200 \pm 20nm deep grooves

- Based on Marangoni convections



- Marangoni flows;
- Thermo-capillary motions;
- Chemical-capillary motions;


James Watt Institute for High Value Manufacturing

Diffractive feature formation on metal

Marcus Ardron

HERIOT WATT UNIVERSITY

Single feature made on polished stainless steel surface



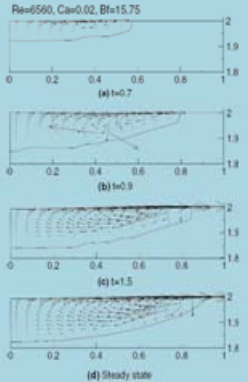
Marangoni effect: surface tension due to thermal gradient

$$Mg = -\frac{\partial\sigma}{\partial T} \frac{h}{\eta \cdot \alpha} \Delta T$$

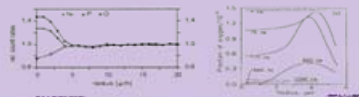
Where: σ = surface tension
 h = length in temp. grad.
 η = viscosity
 α = thermal diffusivity
 ΔT = temp. difference

Thermo-capillary motion: buoyancy, density changes, thermal currents

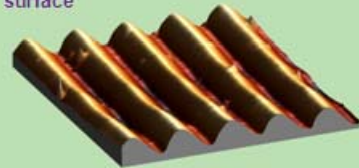
Re=6500, Ca=0.02, Bt=15.75



Chemi-capillary motion: diffusion across surface, chemical reactions



Periodic structure formed in plated surface




Period of 8μm
Height excursion of ≈ 125nm

IMRC

James Watt Institute for High Value Manufacturing - Edinburgh

EPSRC
Engineering and Physical Sciences Research Council

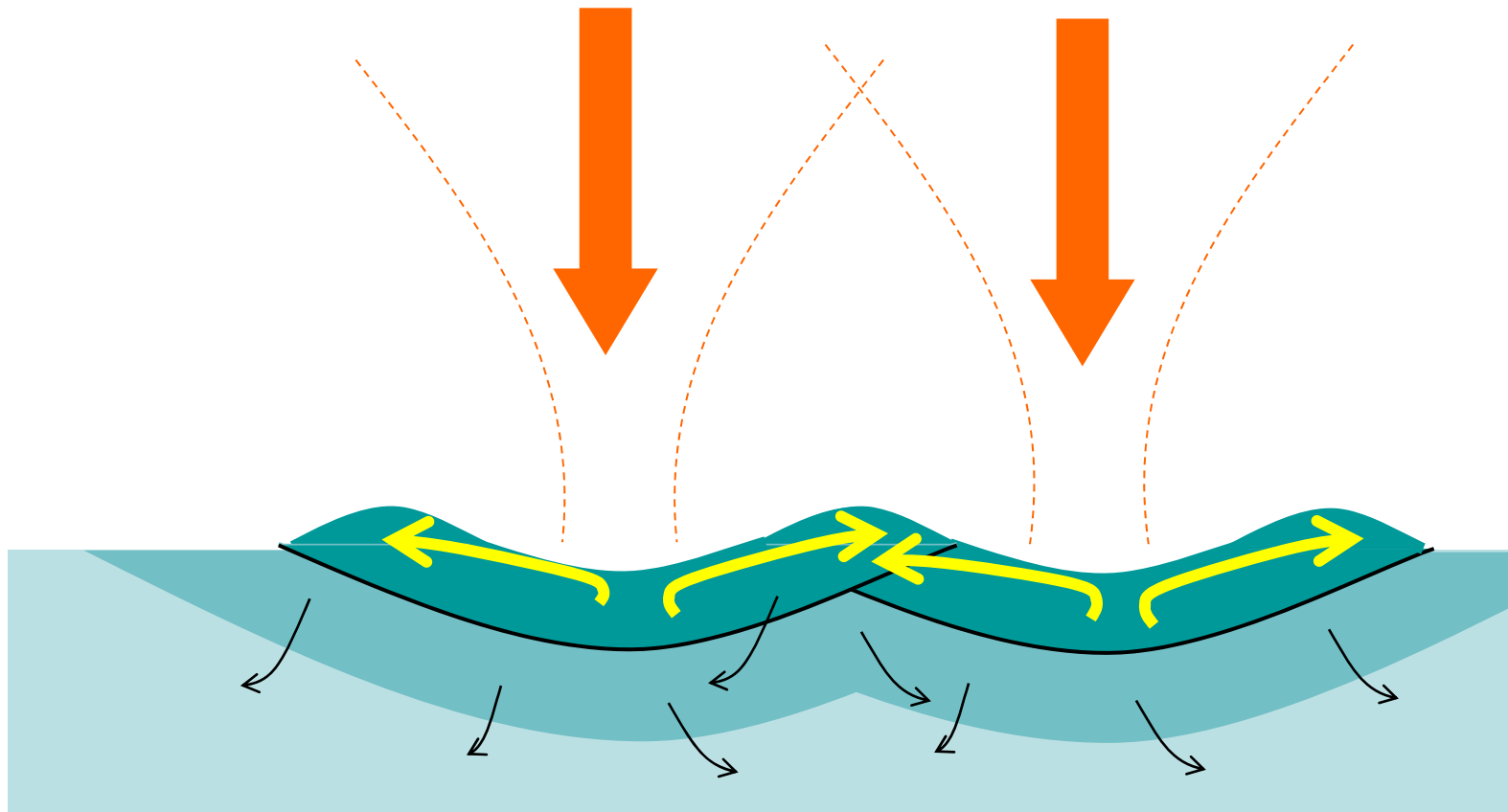
- Laser micro-sculpting: harnessing surface deformations
- Suited for surface deformations on metal surfaces
- Range: 100s nanometer depth
- Based on laser-matter interaction, melting regime, no ablation
- Deformations are function of:
 - Thermal gradient across irradiated area
 - Composition of material + machining atmosphere
 - Type and amount of chemical reactions occurring in the melt pool
 - Surface tensions gradients

- Mission:
 - Create a diffractive grating
 - Sinusoidal profile 
 - $8 \pm 0.2 \mu\text{m}$ period
 - Peak-to-trough $\sim 200 \pm 20 \text{nm}$

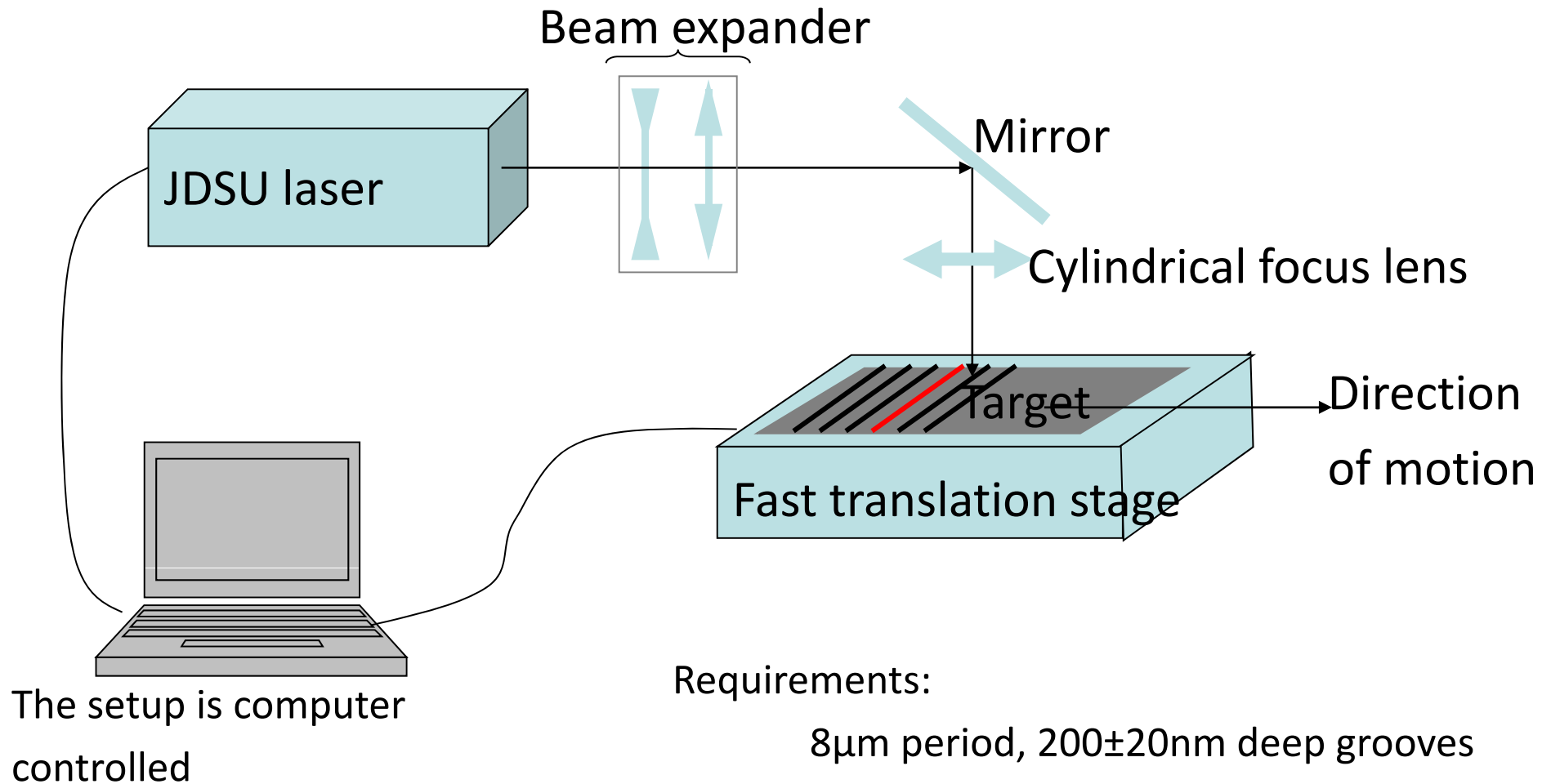
- Aim:
 - Integrate laser-machined diffractive gratings in Optical Position Encoders



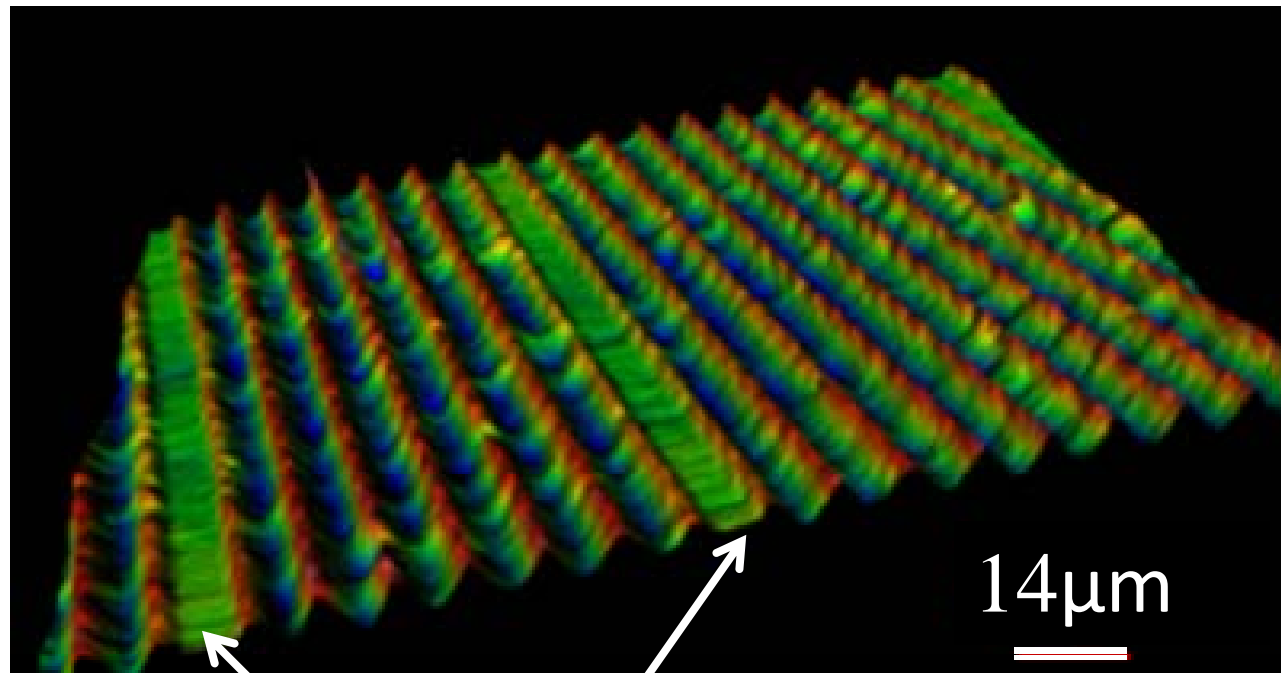
- Use of laser texturing technology for production of diffractive scales machined on metals



- Stainless steel
- Molten material
- Convection fluxes
- HAZ, Temperature gradient
- Liquid/solid interface



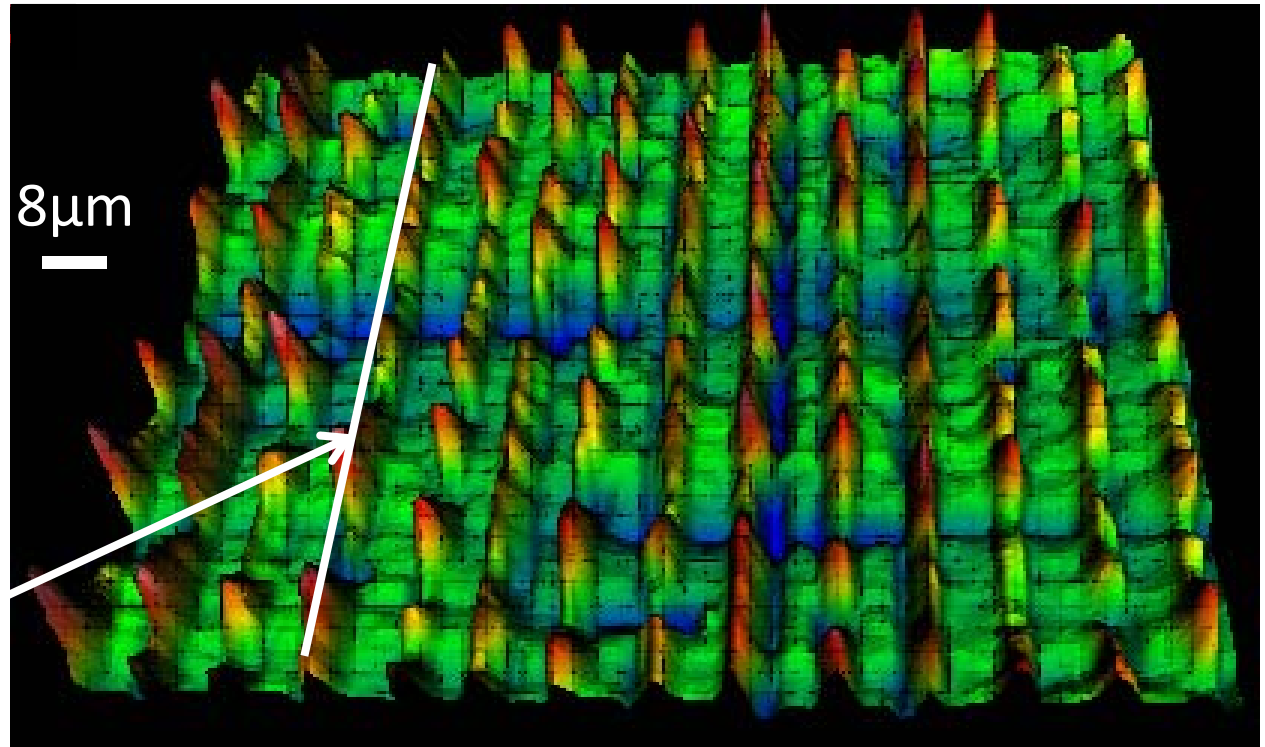
- $8\mu\text{m}$ period
sinusoidal profile
- Peak to trough:
 $\sim 200\pm 10\text{nm}$
- 20 pulses, 5KHz
- $210\pm 20\mu\text{J}$ per pulse



Reference marks

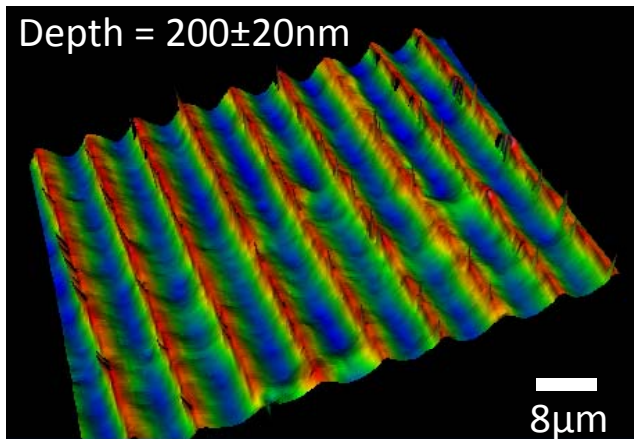
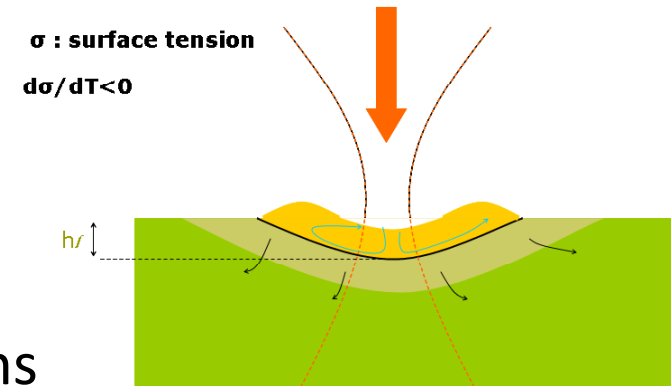
- stainless steel
- 10 pulses, 25KHz
- $400 \pm 12 \mu\text{J}$ per pulse
- Peak-to-trough: 170nm

Laser machined area



Laser line focus → material protrusion

- Laser-based micro-sculpting technique
- Based on thermal and chemical effects
- Lead to successful commercial applications
- Cost-effective, versatile and programmable alternative to some precision surface laser-machining techniques

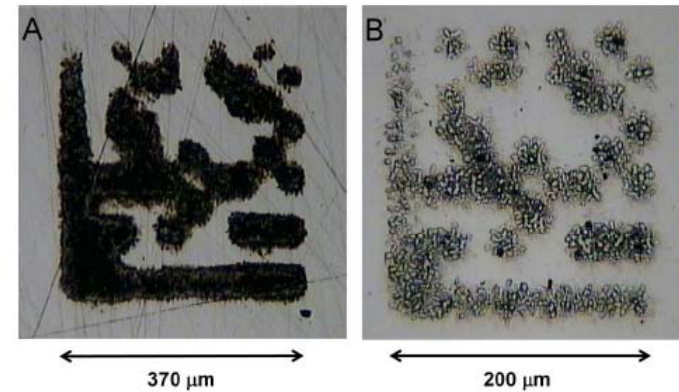


Use Laser Texturing IP as the basis of
→ process for direct-write of complex
surface patterns

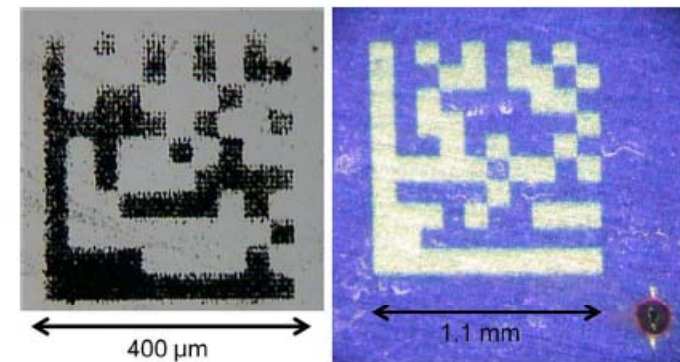
IMRC (EPSRC)-funded project agreed
(with support from Renishaw)

→ Direct write of Diffractive
Optical Elements (DOEs) onto
metal surfaces

→ e.g. for security tagging /
identification
alternative to stick-on tags



Metals



A
Metal

B
Polymers

*Application of a liquid crystal spatial light modulator to
laser marking*, J.P. Parry, R.J. Beck, J.D. Shephard,
D.P. Hand, April 2011 / Vol. 50, No. 12 / Applied Optics

ACKNOWLEDGMENTS



High Power Laser
Applications Group



Technology Strategy Board
Driving innovation

- Reliable high-accuracy location feedback
- Measuring and recording displacements of moving parts
- Automatic positioning in machine tools
- Correction of errors in the relative motion of machine tool parts



- Depth: $200 \pm 20 \text{ nm}$
- Width: $8 \mu\text{m}$
- $600 \mu\text{J}$ energy pulse
- 15 pulses
- Automated marking

