High power Adaptable Laser beams for materials prOcessing
HALO

Project overview presentation

Version C; 28-Jan-2014

HALO is supported by the European Commission through the Seventh Framework Programme (FP7)

Project number 314410

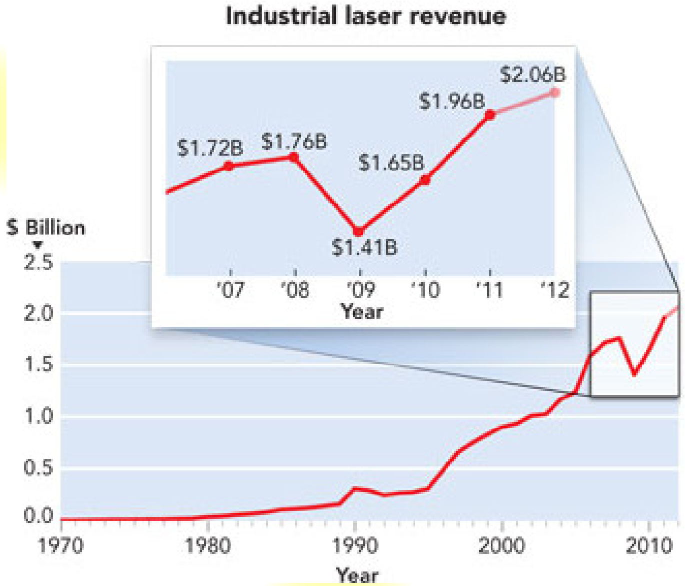
Materials processing with lasers

- Laser technology is already well established in manufacturing
- Materials processing with lasers covers many techniques
  - Cutting and drilling
  - Welding and brazing
  - Marking and engraving
  - Surface treatment
  - Laser additive manufacturing
- The next generation of lasers offers key manufacturing technology for the "Factory of the Future"
  - Faster, cheaper, better processes!
- HALO will improve
  - Efficiency, adaptability and sustainability of manufacturing systems
  - Integration into business processes.

Images courtesy of Trumpf Laser GmbH and Fraunhofer ILT

Market size

- Industrial laser market has shown robust growth for thirty years
  - Double-digit annual growth
  - Strong rebound from global crash in 2008/9
- Europe
  - Makes up almost one third of the world market (2012)
    - Industrial lasers ~1.5 M€*
    - Industrial laser systems (integrated tools based on lasers) ~5.5 M€*
  - Is a power base for laser system manufacture and development
- HALO will help to maintain Europe's leading role in industrial laser technology.

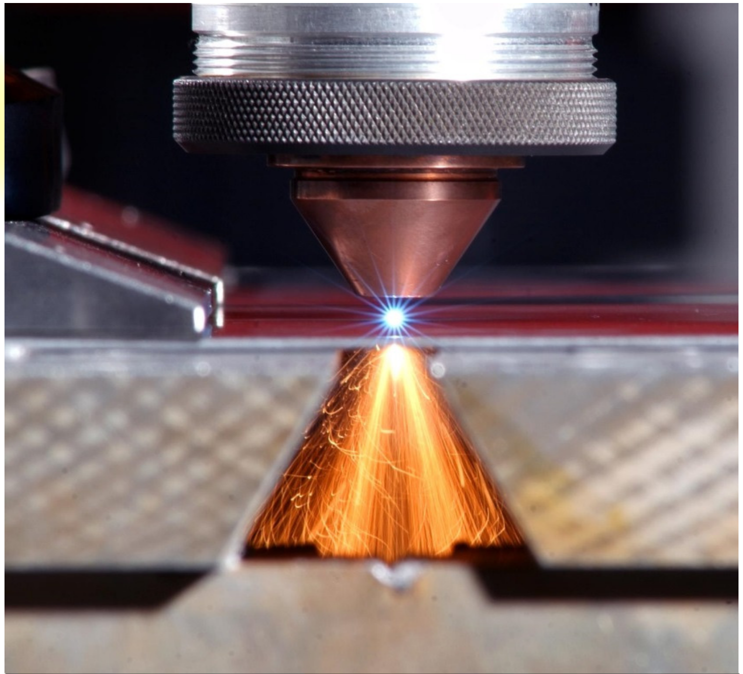


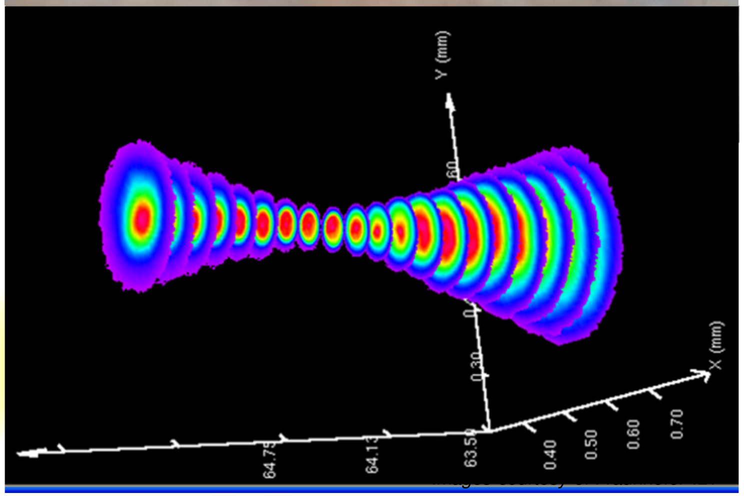
Graph and figures from David Belforte; Industrial Laser Systems (Jan-2012)

Image courtesy of Trumpf Laser GmbH

Technology advances

- The next generation of materials processing lasers will have adaptable beams to optimise efficiency
- HALO will investigate:
  - Adaptable beam profiles
    - Gaussian
    - Top hat
    - Ring modes
    - Polarisation distribution
  - Modelling of laser cutting processes
    - Beam & pulse propagation
    - Absorption
    - Phase transition and material removal
  - Novel cutting processes
    - Brittle materials cutting
    - Advanced sheet metal cutting
    - Liquid jet cutting.





Consortium

Components

Coordinator

- **G&H (Torquay)**

Industrial systems suppliers and end users

- **Synova**
- **Laser Expertise**
- **Trumpf Laser**
- **Trumpf Werkzeugmaschinen**

Laser technology development

- **ORC Southampton**
- **Fraunhofer ILT**
- **Lulea University**

Admin & management

- **Vivid Components**

Meta-modelling

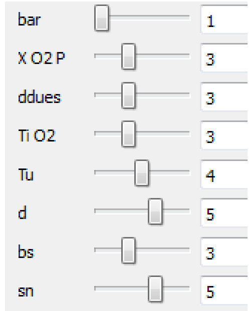
- Mathematical model of complex multi-dimension relationships
  - “Pure“ mathematical functions
  - Often without any physical meaning
- Links many parameters and criteria quickly and efficiently
  - Fast visual exploration
  - Multi-criterion optimisation
  - Sensitivity analysis
  - Machine integration/ control/ set-up
  - Direct comparison with experimental data.

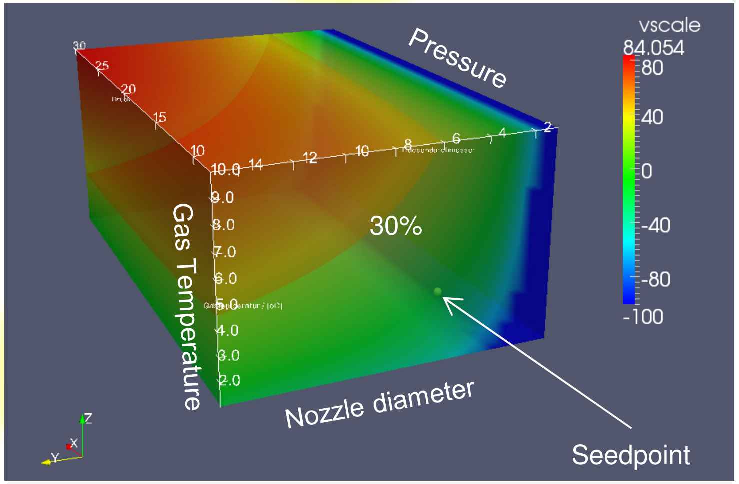
→Parameters = Model Input

→Explorable quantitative 8-dimensional Cutting Process Map

→Design Tool Metamodel → Solution in Design Space.

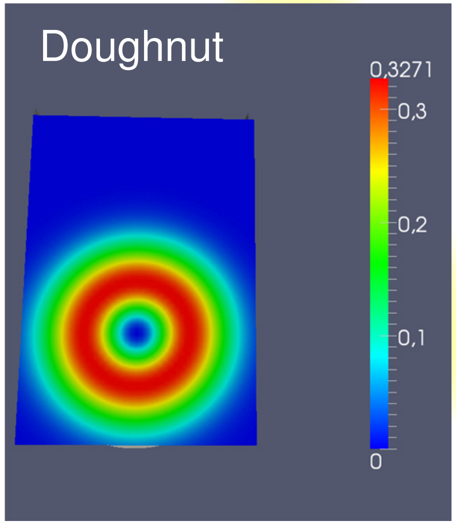
Images courtesy of Fraunhofer ILT

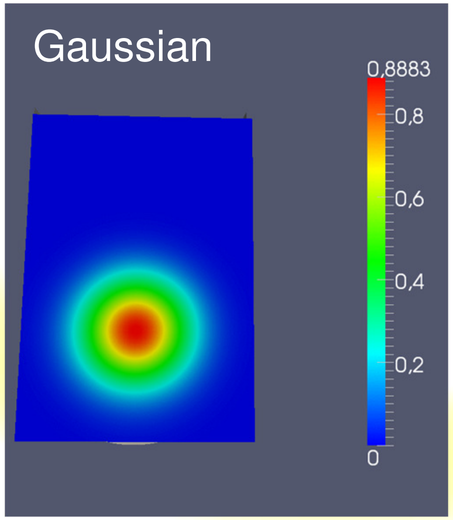


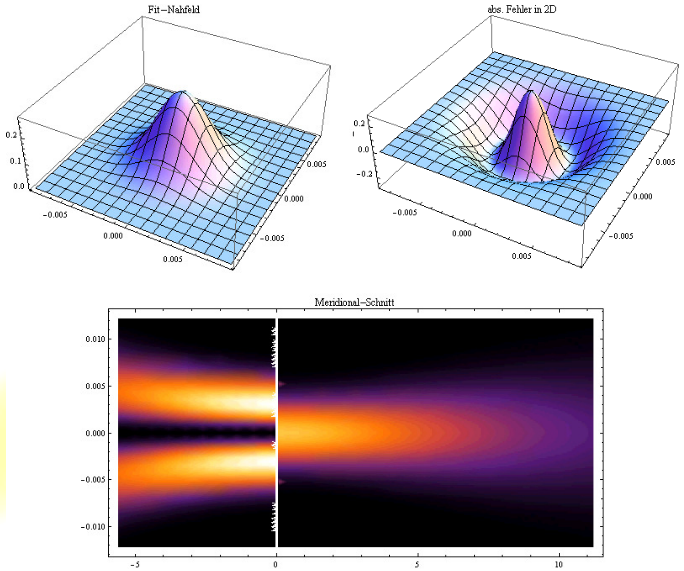


Beam forming

- Beam shape has a large influence on cutting efficiency and quality
- Optimum shape depends on precise process details
  - Dozens of variables
  - Highly sensitive optimisation
  - Non-intuitive!
- HALO will
  - Develop adaptable lasers to optimise beam shape to the process
  - Identify ideal beam parameters for real processes through meta-models.



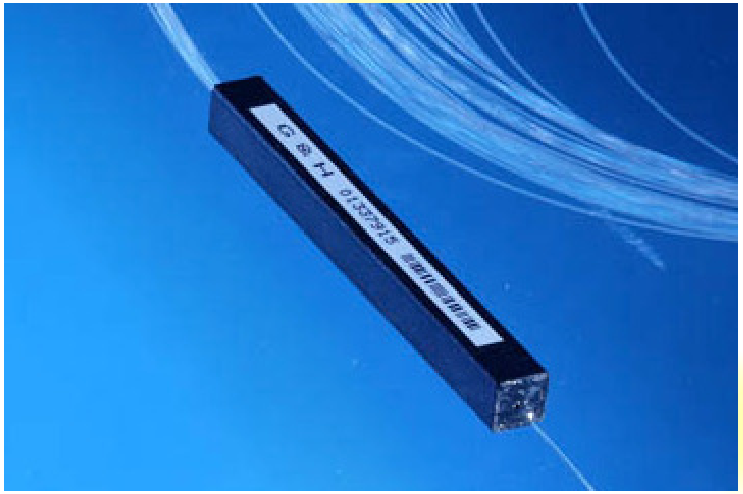




Images courtesy of Fraunhofer ILT

Novel passive components

- Optical isolators
  - Novel designs to permit the unusual beam polarisations used in HALO
  - Comprehensive modelling to understand thermal and optical effects resulting from novel beam shapes
  - Materials for use in high power operation will be investigated

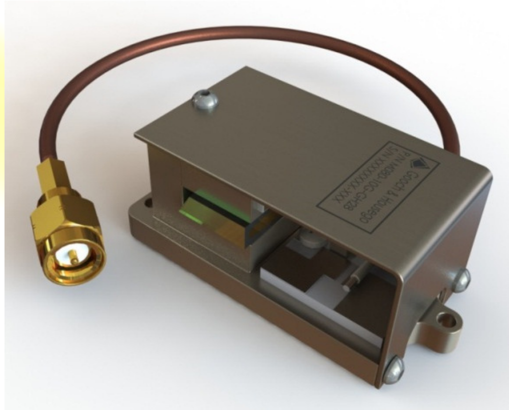


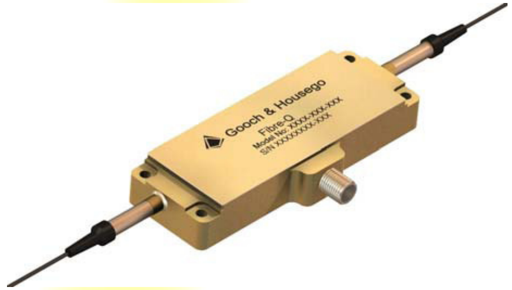
- Fused fibre devices
  - Novel hollow core fibre tapers will provide ring-shaped pump beam for selecting desired LG mode
  - Customised MM pump combiners will be built for high power thulium pump sources.

Images courtesy of Gooch and Housego (Torquay) Ltd.

Novel acousto-optic components

- Acousto-optic devices
  - Low insertion loss
  - Good power handling
- Fast & controllable beam deflectors
  - RF signal applied to crystal
  - Induces temporary diffraction grating
  - Rapidly switches beam between 0^{th} and 1^{st} order
- Applications
  - Q-switching
  - Pulse picking
  - Frequency shifting
- HALO advances
  - Fibre-coupled polarisation insensitive AO Q-switches
  - First of their kind polarisation selecting and control AO devices
  - LG “doughnut modes” preserved in free-space devices.



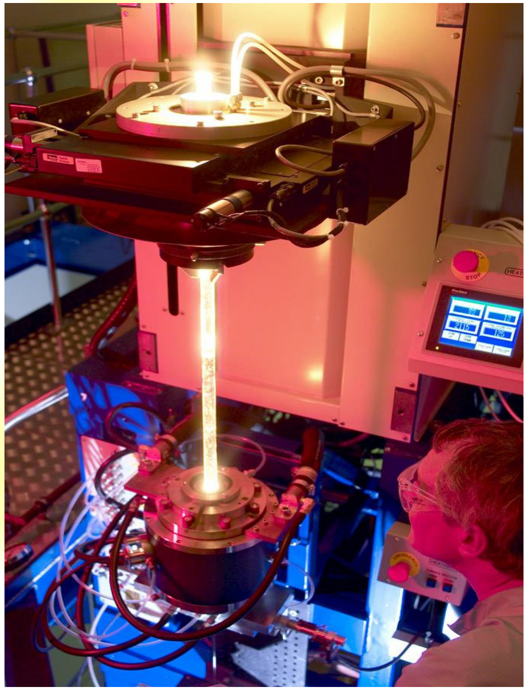


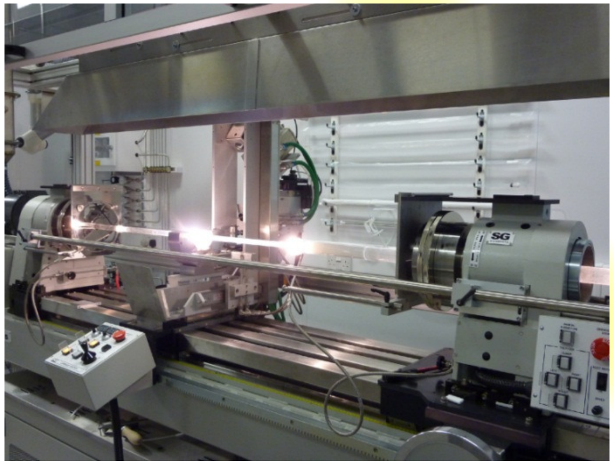
Images courtesy of Gooch and Housego Ltd.

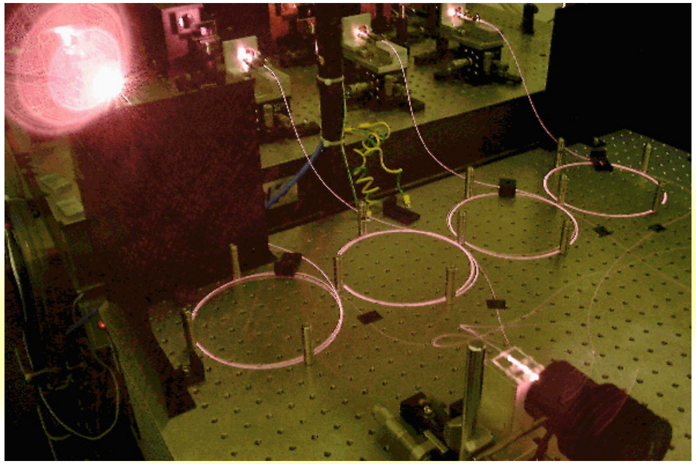
Adaptable beam 2 µm laser-1

- Holmium-doped hybrid (fibre laser-pumped) solid-state laser
  - Generation of high average power laser output at ~2 µm
  - Adaptable output beam profile (doughnut shape to a quasi-top hat)

- Novel technique for direct generation of required beam profile
  - Components located within the laser resonator
  - Architecture compatible with high power operation
    - Continuous-wave (CW)
    - High peak power pulsed modes.



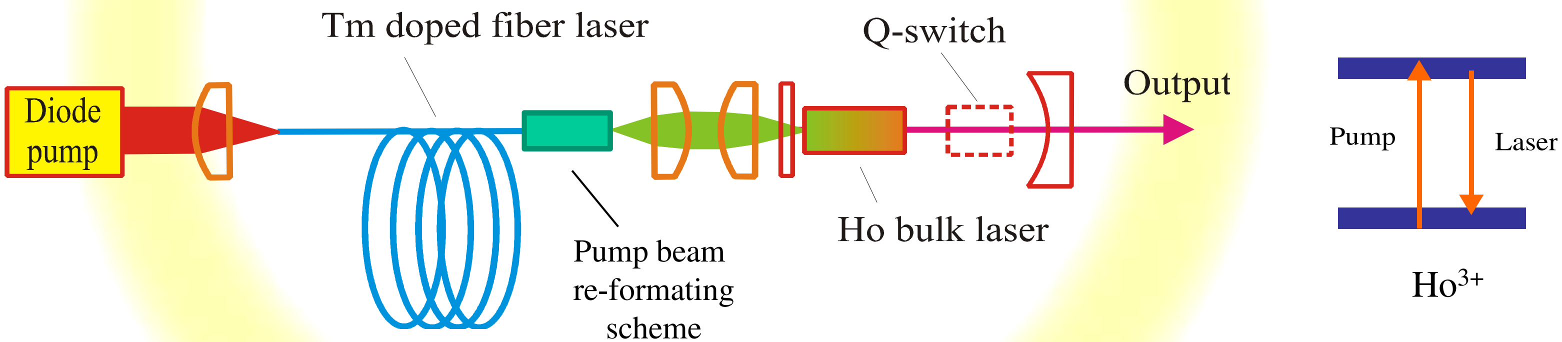


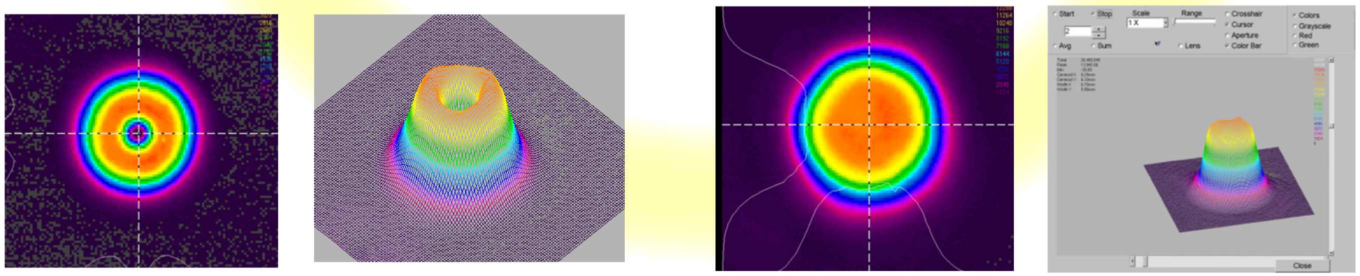


Images courtesy of ORC, University of Southampton

Adaptable beam 2 µm laser-2

- Hybrid laser development comprises three stages:
  - High-power cladding-pumped Tm fibre laser pump source
  - Low-loss fibre-based pump beam shaping and delivery scheme
  - High-power Ho:YAG laser at ~2.1 µm
    - Adjustable near-field and far-field intensity profile
    - Doughnut or top hat
- Hybrid laser will be evaluated in various laser processing trials.

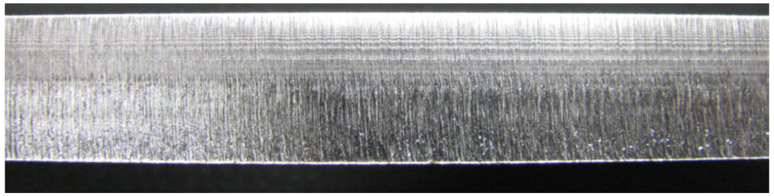




Images courtesy of ORC, University of Southampton

Demo-Sheet metal cutting

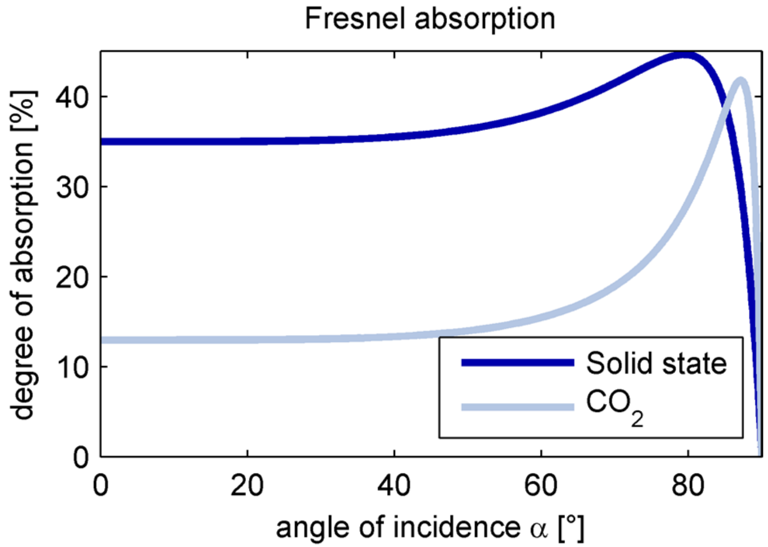
- Currently CO_2 lasers offer state-of-the-art edge quality
  - E.g. 12 mm stainless steel



CO_2 laser, 6 kW

Solid state laser, 5 kW

- In principle solid state lasers offer a much more efficient process
  - 3x higher absorption



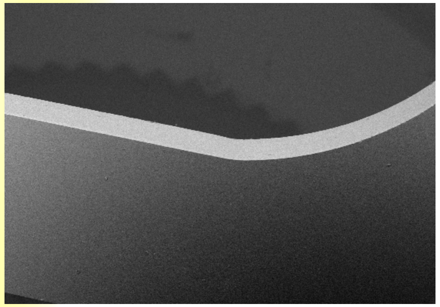
- HALO objectives
  - Improve cutting with solid state lasers
  - Increase cutting quality and productivity
  - Use of extra-cavity beam converters
  - Quality criteria
    - roughness of edges
    - dross length.

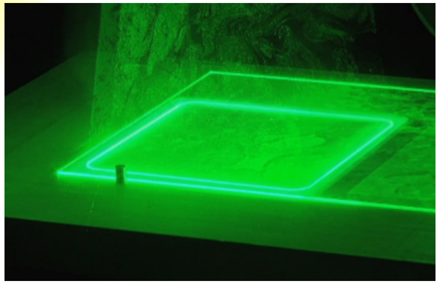
Images courtesy of Trumpf Laser GmbH

Demo-Brittle materials cutting

- HALO will investigate the cutting of brittle materials using ultra-short pulsed lasers
  - Glass
  - Ceramics
  - Sapphire
- Effect of spatial and temporal beam shaping
- Understanding laser-material interactions
  - Absorption and ablation mechanics
  - Thermal behaviour

- HALO objectives
  - Reduce material damage
    - Roughness, micro-cracks and chipping
    - Improved bending strength
  - Increase process efficiency, quality and throughput
    - Ablation rate and cutting speed
    - Edge sharpness kerf width.



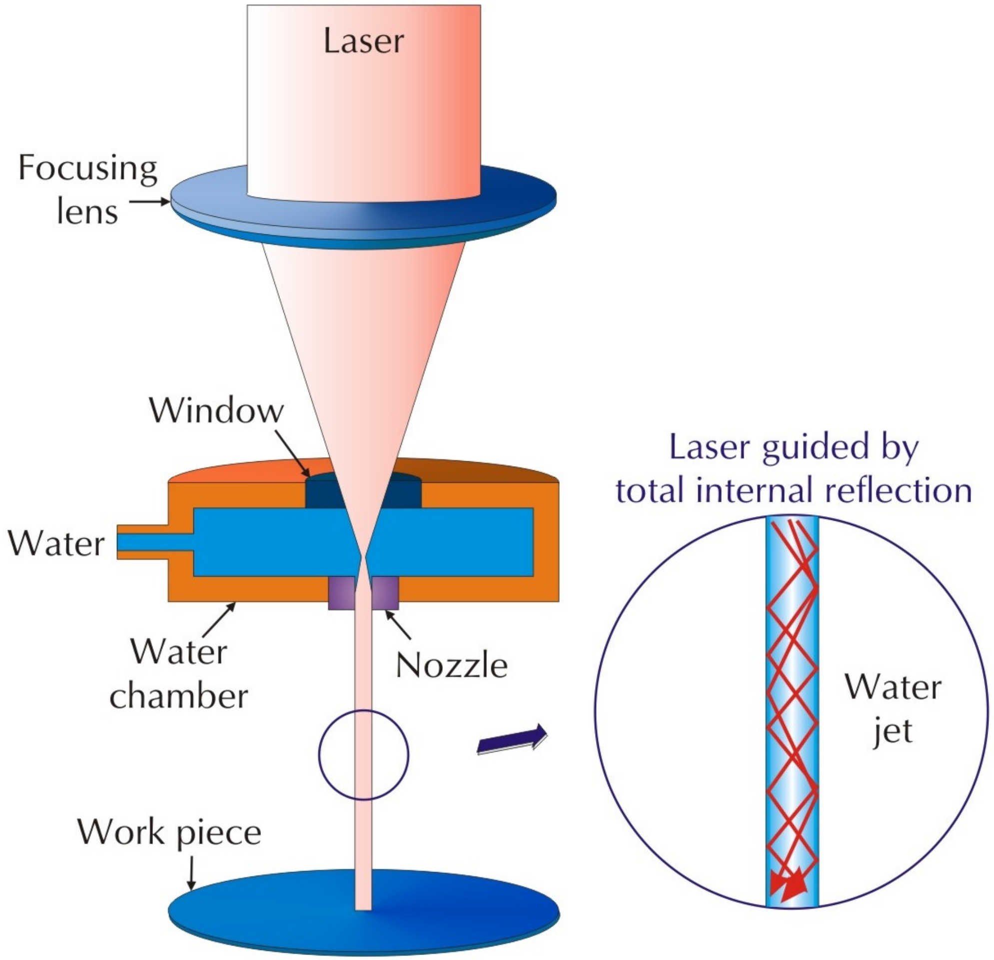


Images courtesy of Trumpf Laser GmbH

Demo-Water jet cutting 1

Laser micro-jet cutting

- Utilizing the difference in the refractive indices of air and water, the technology behind Laser MicroJet® creates a laser beam that is completely reflected at the air-water interface
- The laser beam is entirely contained within the water jet as a parallel beam, similar in principle to an optical fibre
- This allows improved cutting with reduced heat damage, contamination and deformation.



Images courtesy of Synova SA

Demo-Water jet cutting 2

- HALO will demonstrate:
  - Cutting of delicate materials including glass and sapphire
  - End user trials in an industrial environment
    - Brittle materials
      - Glass & sapphire

- HALO targets:
  - Cut precision <15 µm
  - 20% bending strength increase for glass cutting
  - Cut precision from reduced nozzle diameter <15 µm.

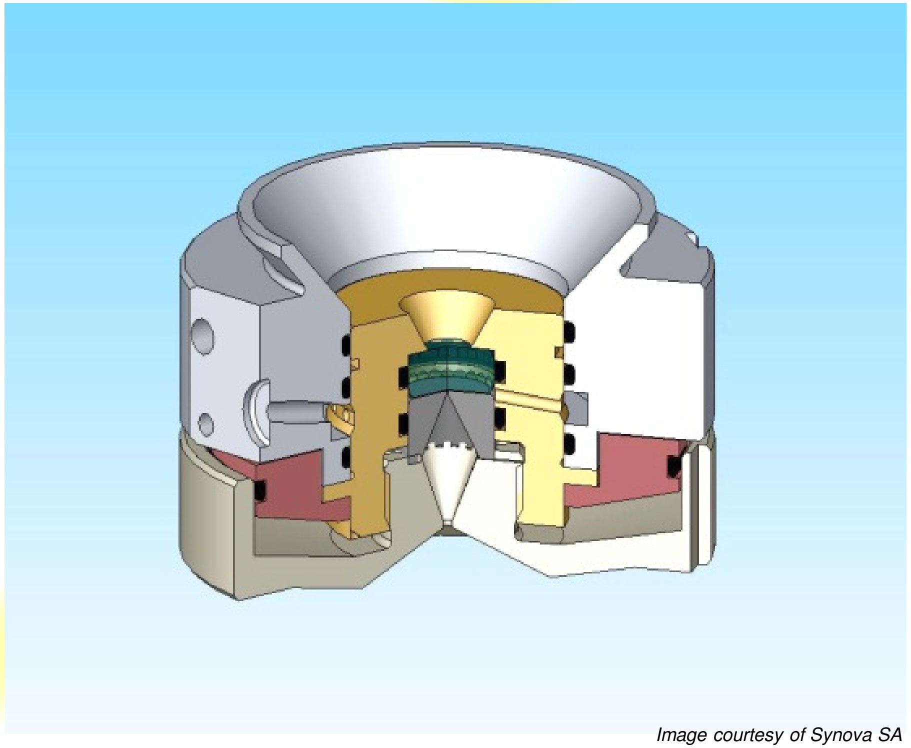
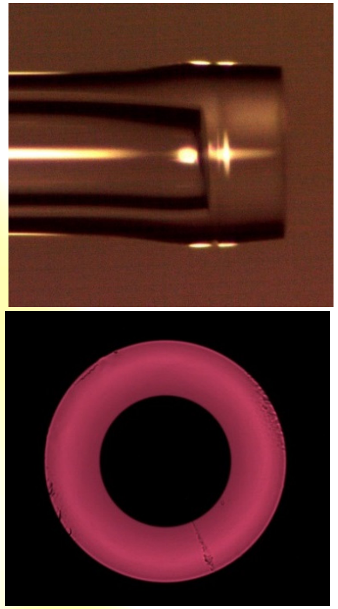


Image courtesy of Synova SA

Key results to date: Components & laser

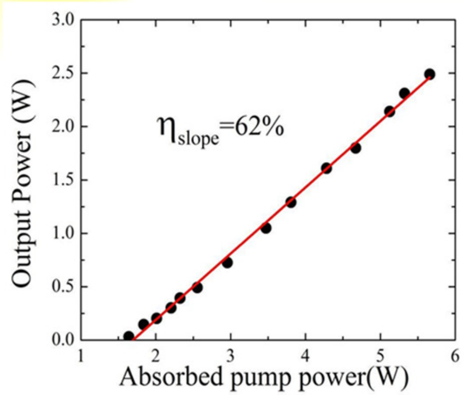
- Optical component development
  - Fibre pump beam shapers for doughnut beams
  - Optical isolators for Laguerre-Gaussian beams
  - Beam combiners for adaptable beam lasers
  - AO deflectors for dynamic beam shaping
- 2 µm hybrid laser
  - Demonstration (low power) of hybrid Ho:YAG doughnut mode laser at 2.1 µm.

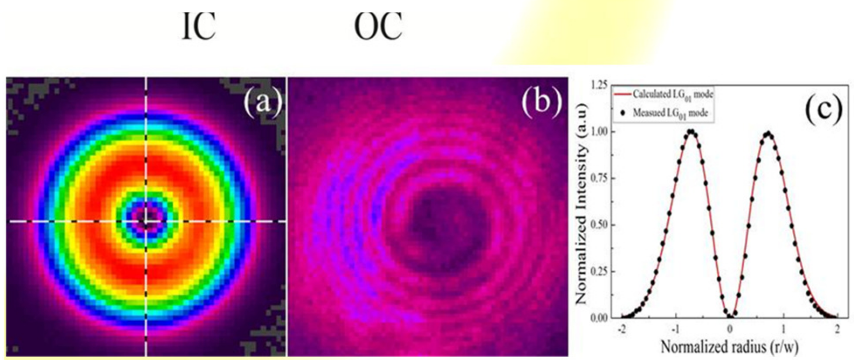
Gooch & Housego



G&H beam shaper (above) and output (below)

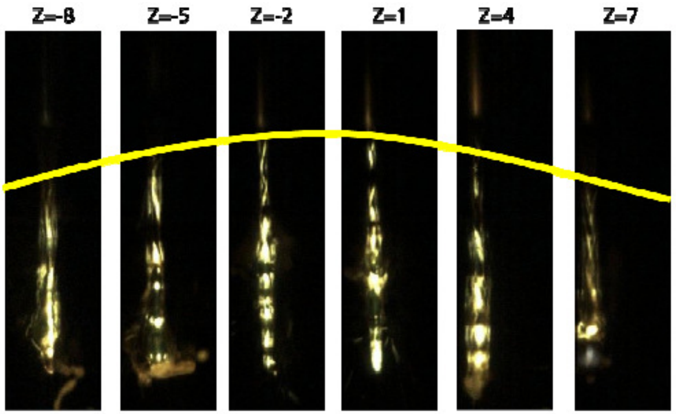
UNIVERSITY OF Southampton
Optoelectronics Research Centre





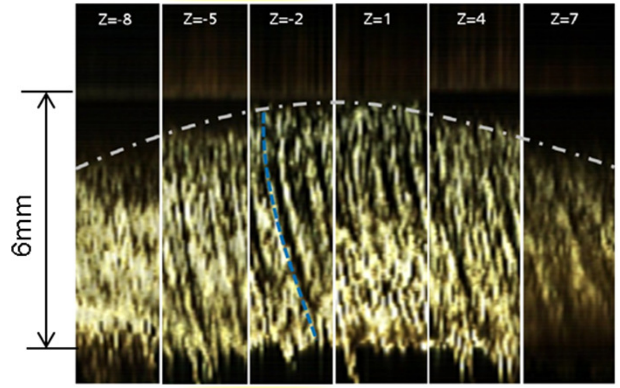
(a) Laser beam profile in LG_{01} mode and
(b) Interferogram showing phase handedness

Key results to date: Cutting process analysis

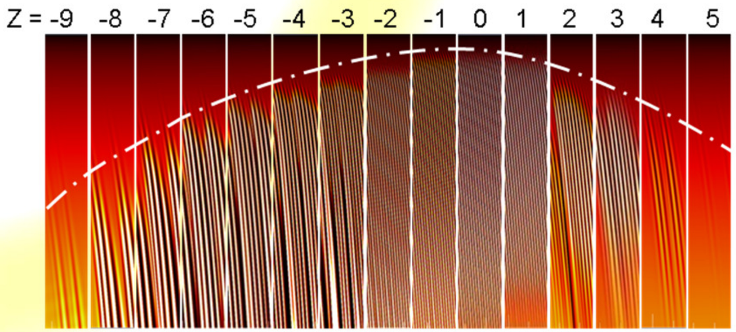


- High-speed video can be used to make streak analysis
  - Viewing the video through a vertical slit at the front vertex (t ⟶ x-axis)

Experiment – streak images



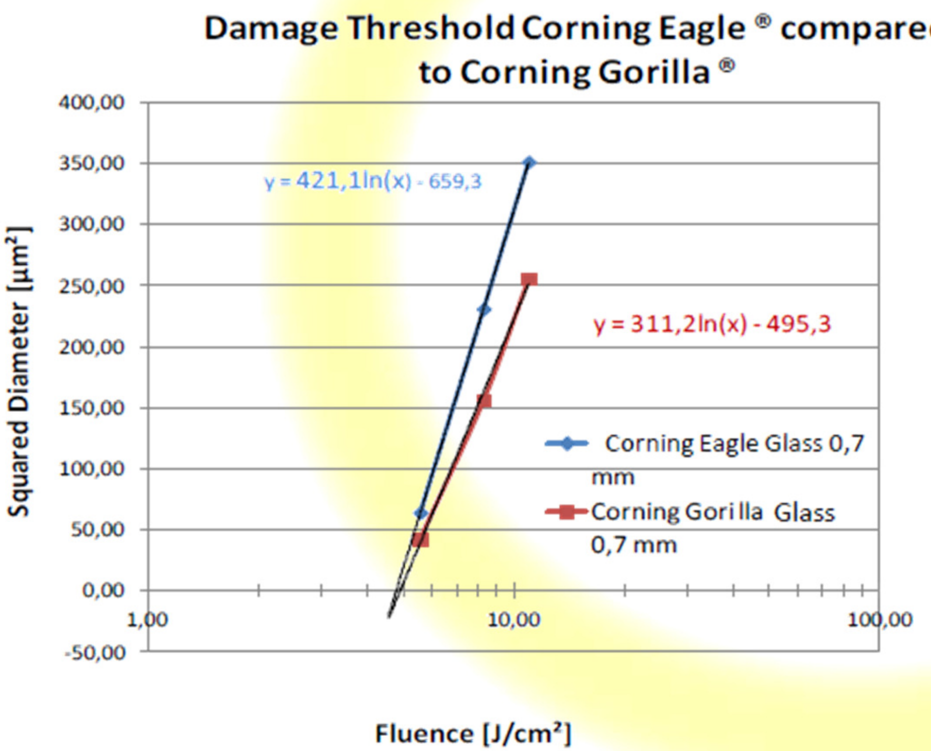
- Some typical features of melt film dynamics (e.g. onset of waves) have been very well reproduced with the 2D-simulation tool QuCut
- Even some quantitative measures seem to be within acceptable ranges
- Minor deviations in scale of focal position due to
  - Model reduction
  - Beam diagnostics uncertainties.

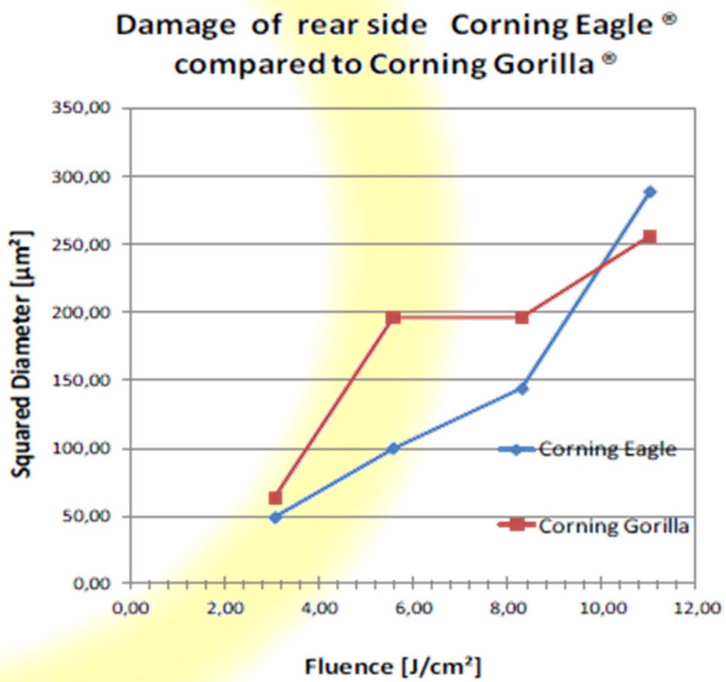


Simulation with QuCut– virtual streak images

Key results to date: Brittle material cutting

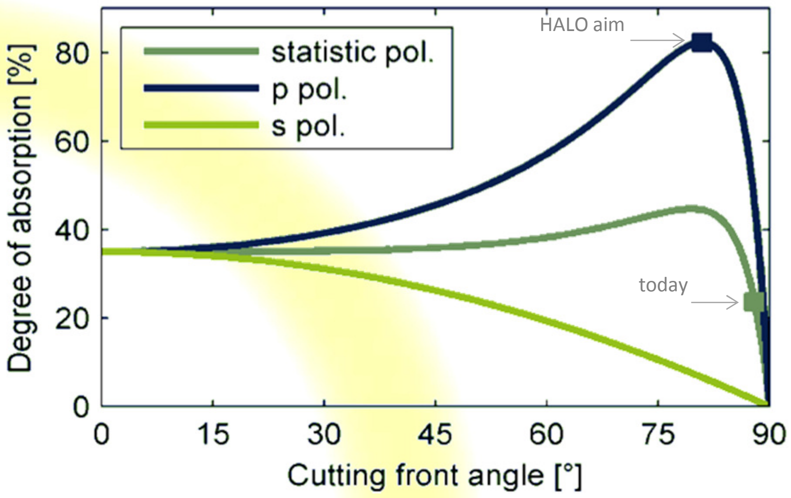
- Results published in (Photonics West 2013)
- *“Picosecond laser ablation of transparent materials”* Proc. SPIE **8608** (2013)
  - S. Russ, C. Siebert, U. Eppelt, C. Hartmann, B. Faißt, W. Schulz.

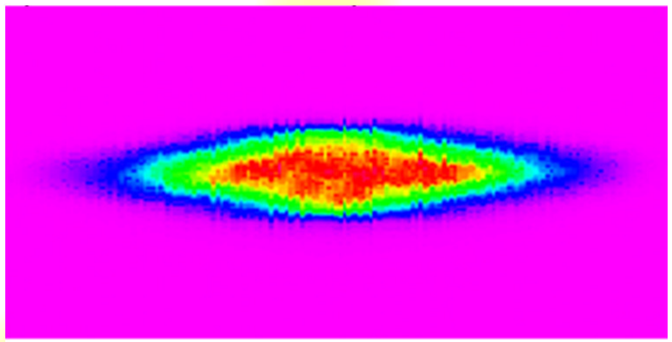




Key results to date: Sheet metal cutting

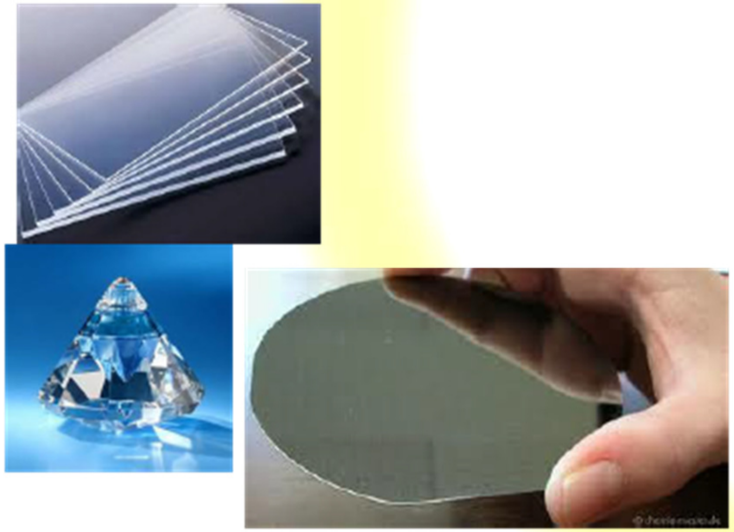
- Absorption of solid state lasers is far from the theoretical maximum
  - HALO aims to improve on the state-of-the-art in two ways
- Polarisation
  - Change laser beam to p polarisation
  - Electric field of the beam is parallel to each particular plane of incidence
  - This will require segmented waveplates for tailored polarisation
- Beam profile
  - Decrease cutting front angle to 79° (Brewster Angle)
  - To avoid larger kerf width, an elliptic focus will be used.





Key results to date: Liquid jet cutting

- Liquid-jet cutting of sapphire demonstrated
  - Green high power laser
- Process variables guided by meta-modelling
  - Previously unidentified parameter space revealed
  - Good results: groove free of chipping.



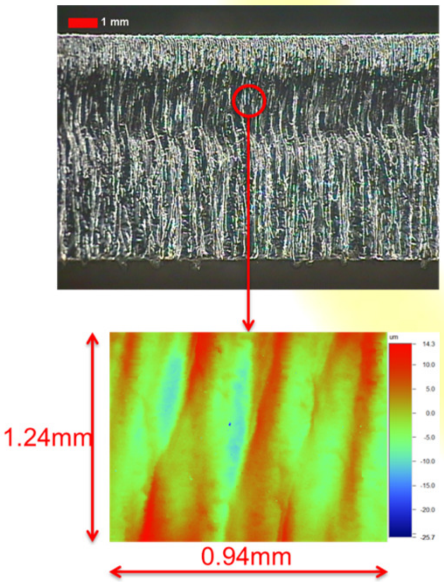
Glass, sapphire, silicium

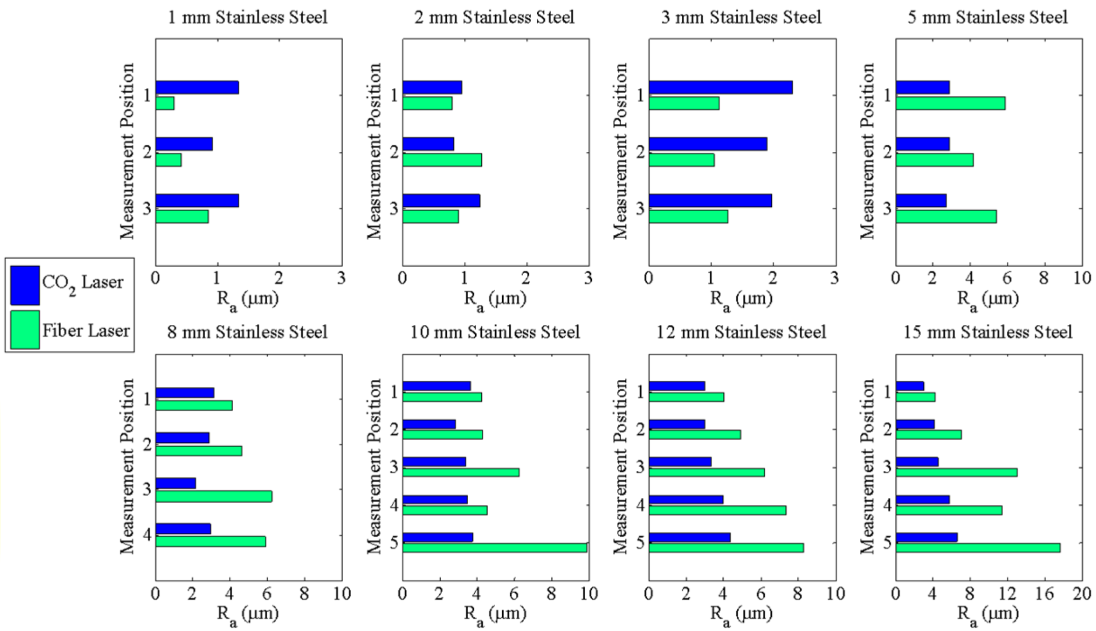
Laser, process parameters:
Wavelength
Rep rate
Power
Pulse energy
Nozzle diameter
Pump preassure

Process material parameters:
Depth of groove
Line width
Strength

Key results to date: Benchmarking

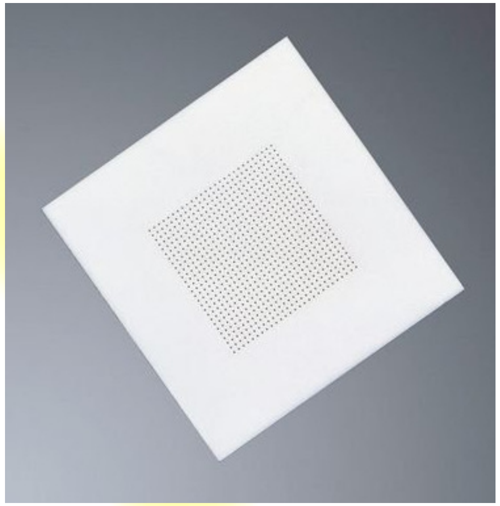
- Experimental benchmarking evaluation
  - Comprehensive measurement of the state-of-the-art in progress
  - High speed videography
- Surface roughness measurement method
  - Past: measurements in straight lines
  - HALO advance: optical surface roughness colour-coded surface map
- See *"Measuring the state-of-the-art in laser cut quality"*
  - J.K. Pocorni, J. Powell, T. Ilar, A. Schwarz and A.F.H. Kaplan; NOLAMP 2013.

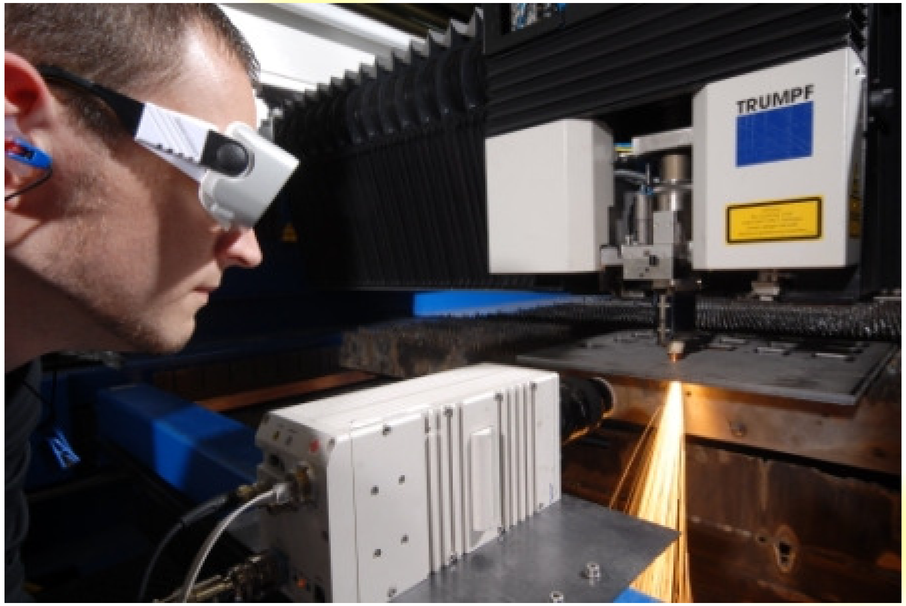




HALO summary

- HALO will develop technology for adjustable lasers for materials processing
  - Active and passive components
  - Novel adaptable beam solid-state lasers
  - Adaptable beam optics
  - Simulation of adjustable beam laser cutting
  - Process optimisation





- HALO hardware and processes will offer measureable efficiency and quality improvements
- Validation and demonstration for key cutting applications
  - Brittle material
  - Sheet metal
  - Liquid-jet.

Images courtesy of Trumpf Laser GmbH

HALO Industrial Group (HIG)

- HALO will establish a group of interested parties to:
  - Guide HALO research
  - Develop new exploitation routes
  - Identify novel applications

- Target organisations:
  - End users
  - Research organisations
  - Universities
  - Industrial companies.

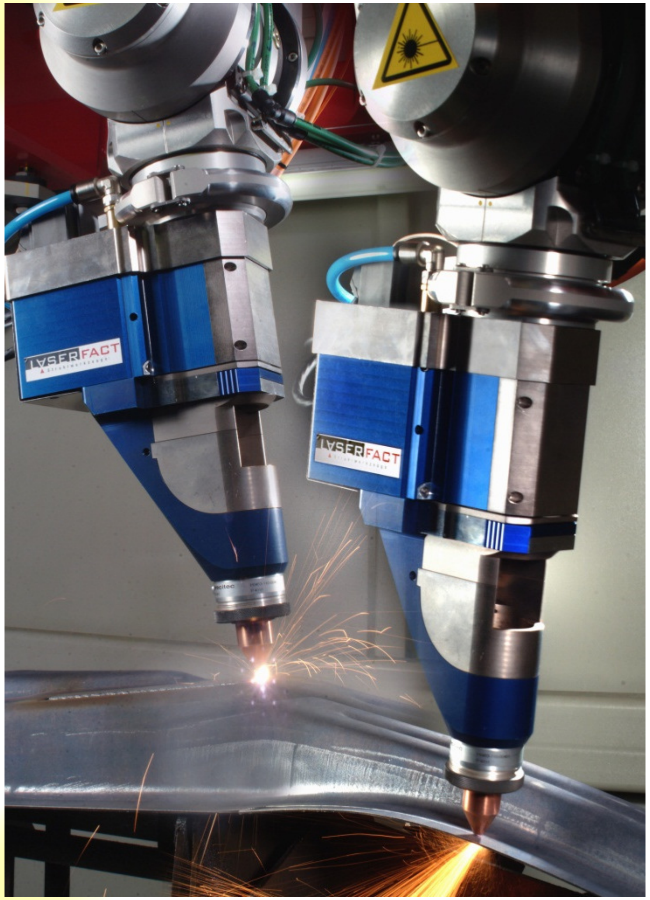


Image courtesy of Fraunhofer ILT

Project info

- HALO is funded under the European Commission's Seventh Framework Programme
  - Programme acronym FP7-ICT
  - http://cordis.europa.eu/fp7/ict/home_en.html
- Area: Smart Factories
  - Energy-aware, agile manufacturing and customisation (FoF-ICT-2011.7.1)
- Project Reference 314410
- Project cost 5.71 M€
- Project funding 3.86 M€
- Start date 01-Sep-2012
- End date 31-Aug-2015
- Duration 36 months.

Further information

Thanks for your attention!

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