High power Adaptable Laser beams for materials processing

HALO

Project overview presentation

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www.halo-project.eu
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
• 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.
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)

Gooch & Housego

Laser technology development

• ORC Southampton
• Fraunhofer ILT
• Lulea University

Industrial systems suppliers and end users

• Synova
• Laser Expertise
• Trumpf Laser
• Trumpf Werkzeugmaschinen

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 Metamodell → Solution in Design Space.
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.
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\textsuperscript{th} and 1\textsuperscript{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.
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.
Demo-Sheet metal cutting

- Currently CO₂ lasers offer state-of-the-art edge quality
  - E.g. 12 mm stainless steel

- 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
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
• 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.
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.
Key results to date: Cutting process analysis

• 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.

• High-speed video can be used to make streak analysis
  • Viewing the video through a vertical slit at the front vertex (t → x-axis)
Key results to date: Brittle material cutting

- Results published in (Photonics West 2013)
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.
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”
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.
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

- 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.
Thanks for your attention!

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