Extending the Process Limits of Laser Polymer Welding with High-brilliance Beam Sources – POLYBRIGHT Project Overview

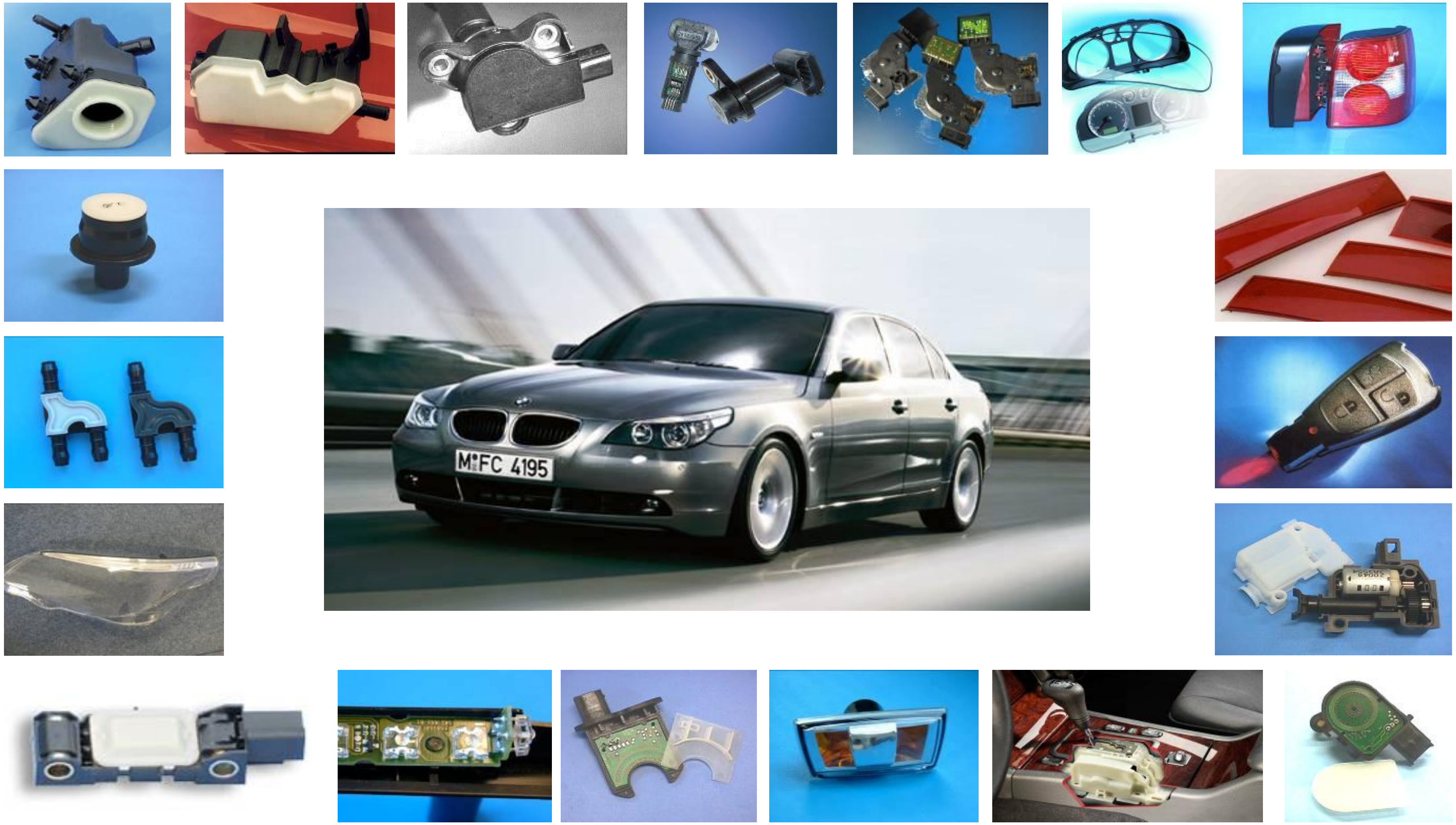
Laser Polymer Welding: From Research to High Volume Industrial Applications

May 9, 2012   Alexander Olowinsky

Outline

- Introduction
    - Motivation and aims
    - Process requirements
- The POLYBRIGHT Project
    - The consortium
    - Expected POLYBRIGHT breakthrough
    - Project impact
- Experimental results –current status
    - Computer simulation of the polymer welding process
    - New laser sources
    - Welding results using material adapted laser wavelengths
- Development of optical elements for tailored laser beam profiles
- Summary and Outlook

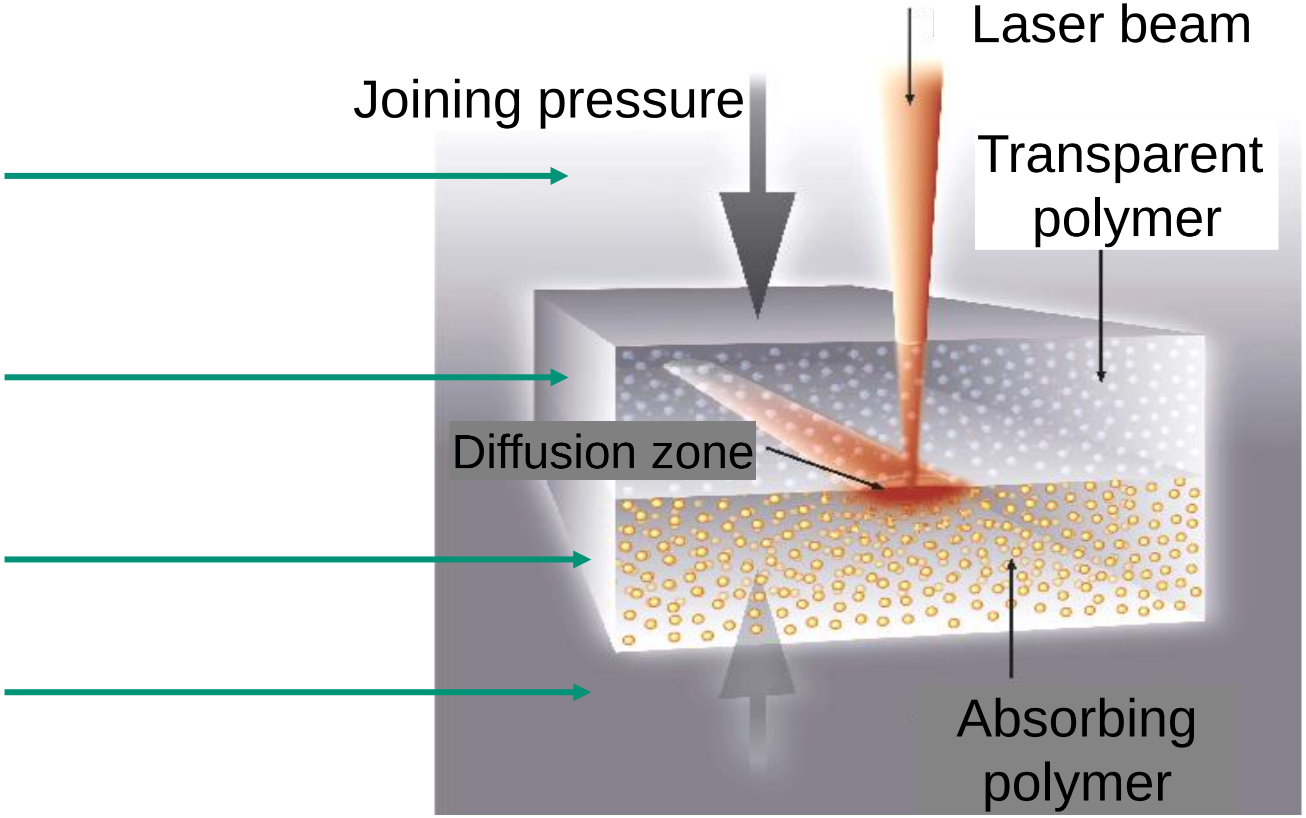
Laser Polymer Welding
Industrial Applications in Automotive



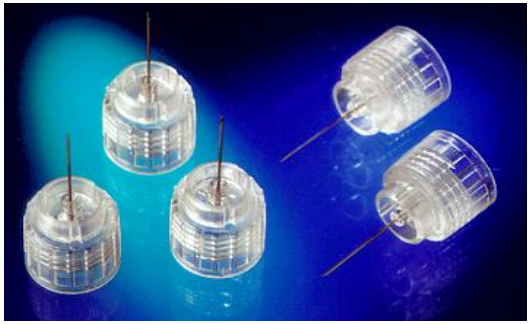
Laser beam transmission welding

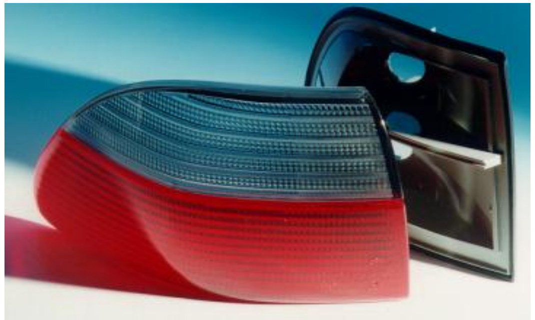
Process basics

- Wavelength
- Intensity distribution
- Beam quality
  - Reflection coefficient
  - Transmission coefficient
  - Scattering
  - Material thickness
- Optical penetration depth
- Thermal properties
  - Polymer compatibility
  - Surface contact



Motivation and aims



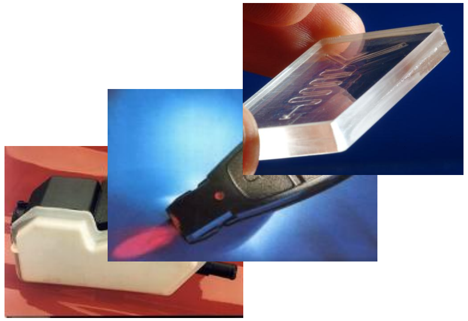


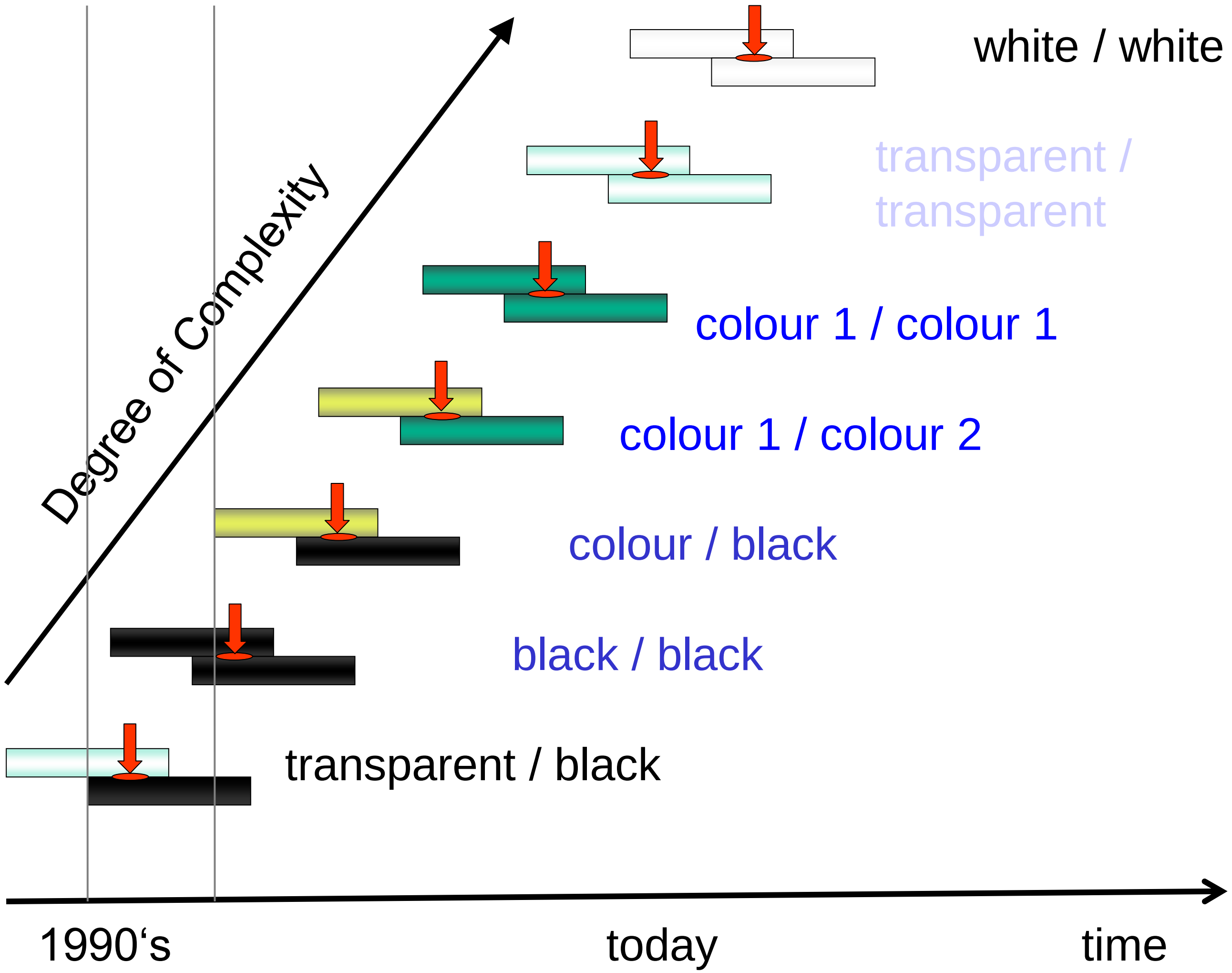
Process related disadvantages

- Material limitations – requirement to match the optical properties of the joining partners for the laser welding process . Furthermore, only few materials combinations are possible for welding dissimilar plastics
- Shape limitations – currently most of the welding contours are restricted to flat, 2D surfaces
- High investment – the cost for complete laser welding systems is still high for many applications compared to other joining methods
- Lack of know-how or conservative attitude in the product development process

Degree of Complexity

- Transparent / black standard configuration
- Changing colours influencing the process:
  - Transmission
  - Absorption
- Additives (GF etc.)





Degree of Complexity

white / white

transparent / transparent

colour 1 / colour 1

colour 1 / colour 2

colour / black

black / black

transparent / black

1990‘s

today

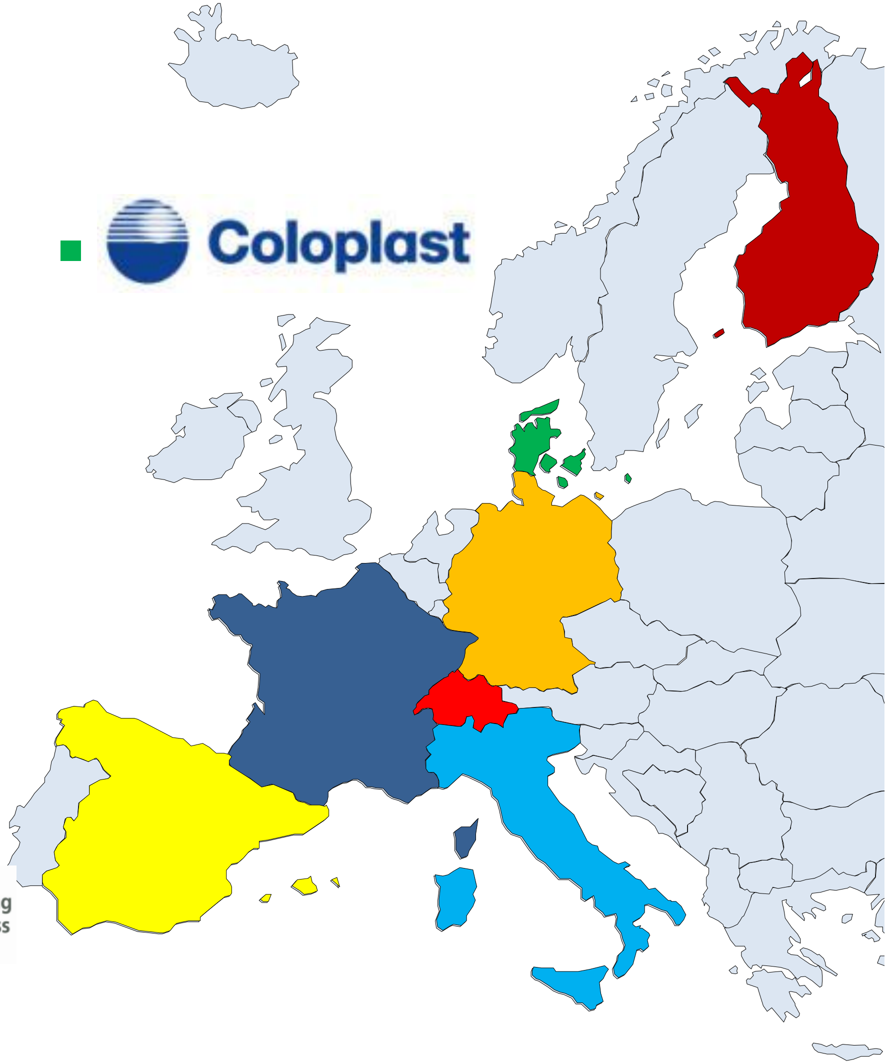
time

Motivation and aims - Project objectives

- Development of high power high brilliance lasers with new wavelengths in the range of 1500 - 1900 nm. Laser power up to 500W
- Innovative beam manipulation systems for optimum energy deposition in the welding area
- New laser polymer joining processes based on advanced thermal management concepts
- New machine concepts for the high speed and flexible laser manufacturing
- Enabling new applications for laser polymer welding by enhancement of the process performance and new joint configurations

The POLYBRIGHT Project

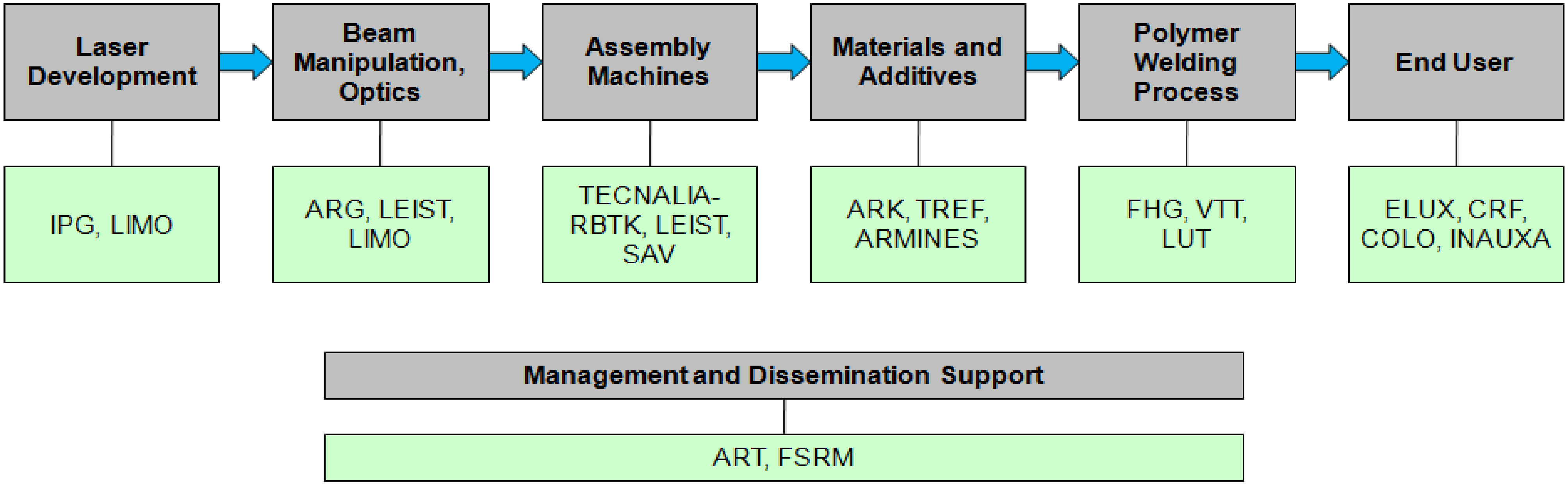
- 🟧 Fraunhofer ILT
- 🟧 Fraunhofer LBF
- 🟧 TREFFERT®
- 🟧 IPG LASER THE POWER TO TRANSFORM™
- 🟧 LIMO Lissotschenko Mikrooptik
- 🟧 ARGES
- 🟦 ARMINES
- 🟦 ARKEMA The world is our inspiration
- 🟦 ARTTIC INTERNATIONAL MANAGEMENT SERVICES
- 🟨 tecnalia Inspiring Business
- 🟨 inauxa



- 🟩 Coloplast
- 🟥 SAVCOR
- 🟥 VTT
- 🟥 LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
- 🟥 LEISTER
- 🟥 fsrm CROSSROADS OF MICROTECHNOLOGY
- 🟦 Electrolux Thinking of you
- 🟦 CRF CENTRO RICERCHE FIAT

The POLYBRIGHT Project - The consortium

Process Chain Plastic Part Welding



Laser Development
IPG, LIMO

Beam Manipulation, Optics
ARG, LEIST, LIMO

Assembly Machines
TECNALIA-RBTK, LEIST, SAV

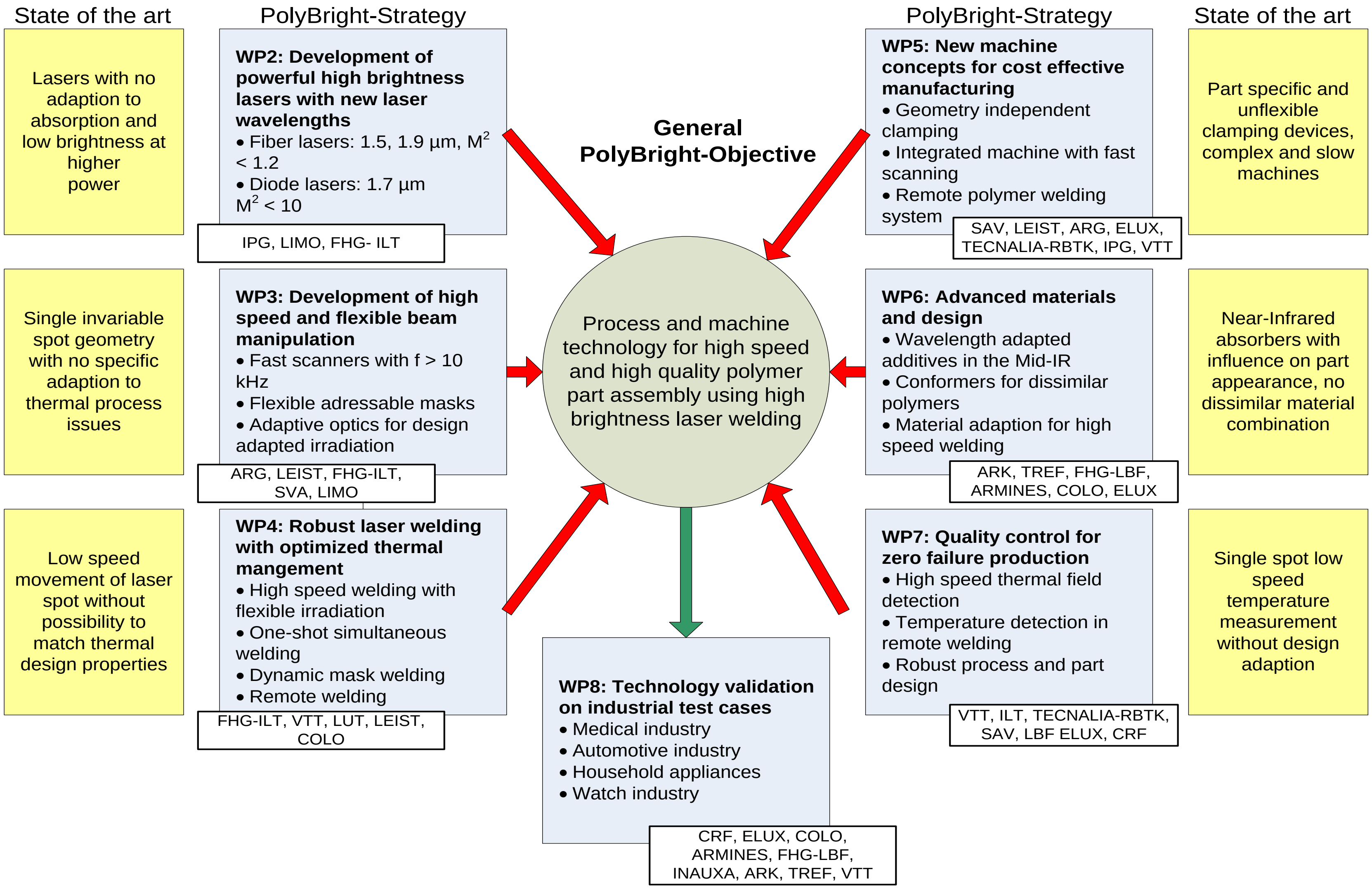
Materials and Additives
ARK, TREF, ARMINES

Polymer Welding Process
FHG, VTT, LUT

End User
ELUX, CRF, COLO, INAUXA

Management and Dissemination Support
ART, FSRM

The POLYBRIGHT Project - Expected POLYBRIGHT breakthrough



State of the art

Lasers with no adaption to absorption and low brightness at higher power

PolyBright-Strategy

WP2: Development of powerful high brightness lasers with new laser wavelengths
- Fiber lasers: 1.5, 1.9 µm, $M^2 < 1.2$
- Diode lasers: 1.7 µm $M^2 < 10$

IPG, LIMO, FHG- ILT

Single invariable spot geometry with no specific adaption to thermal process issues

WP3: Development of high speed and flexible beam manipulation
- Fast scanners with f > 10 kHz
- Flexible adressable masks
- Adaptive optics for design adapted irradiation

ARG, LEIST, FHG-ILT, SVA, LIMO

Low speed movement of laser spot without possibility to match thermal design properties

WP4: Robust laser welding with optimized thermal mangement
- High speed welding with flexible irradiation
- One-shot simultaneous welding
- Dynamic mask welding
- Remote welding

FHG-ILT, VTT, LUT, LEIST, COLO

General PolyBright-Objective

Process and machine technology for high speed and high quality polymer part assembly using high brightness laser welding

PolyBright-Strategy

WP5: New machine concepts for cost effective manufacturing
- Geometry independent clamping
- Integrated machine with fast scanning
- Remote polymer welding system

SAV, LEIST, ARG, ELUX, TECNALIA-RBTK, IPG, VTT

State of the art

Part specific and unflexible clamping devices, complex and slow machines

WP6: Advanced materials and design
- Wavelength adapted additives in the Mid-IR
- Conformers for dissimilar polymers
- Material adaption for high speed welding

ARK, TREF, FHG-LBF, ARMINES, COLO, ELUX

Near-Infrared absorbers with influence on part appearance, no dissimilar material combination

WP7: Quality control for zero failure production
- High speed thermal field detection
- Temperature detection in remote welding
- Robust process and part design

VTT, ILT, TECNALIA-RBTK, SAV, LBF ELUX, CRF

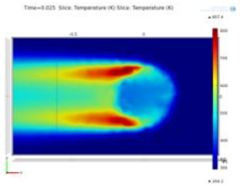
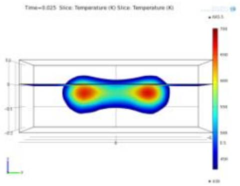
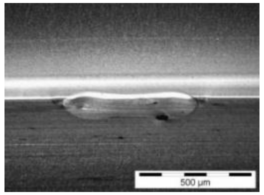
Single spot low speed temperature measurement without design adaption

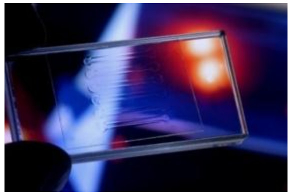
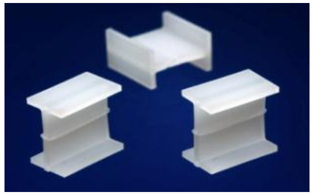
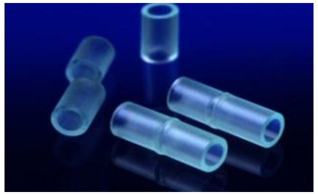
WP8: Technology validation on industrial test cases
- Medical industry
- Automotive industry
- Household appliances
- Watch industry

CRF, ELUX, COLO, ARMINES, FHG-LBF, INAUXA, ARK, TREF, VTT

Flexible, robust and fast-adapting laser beam welding

- Development of a computer model for the investigation of various thermal management concepts
- Realization of an intelligent power control for welding of polymers in order to enable a larger process window
- Investigation of new laser welding processes with higher quality and higher speed such as Transmission Welding by an Incremental Scanning Technology (TWIST), Remote Welding for polymeric components or Quasi-simultaneous welding with advanced power control
- Welding of transparent polymers with new laser wavelengths and new weld joint configurations relevant for developments of new products

TWIST®- Concept

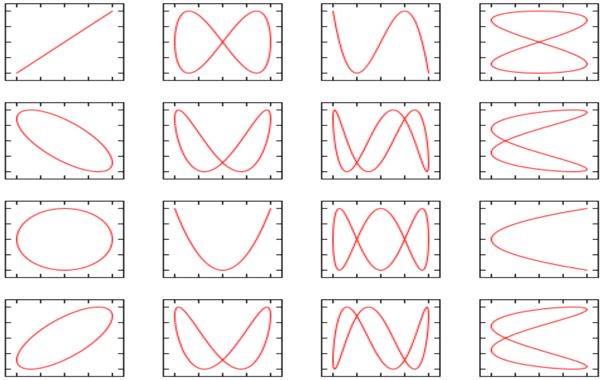
Transmission

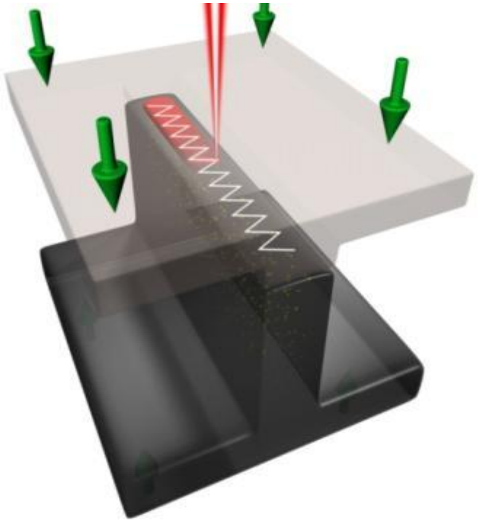
Welding

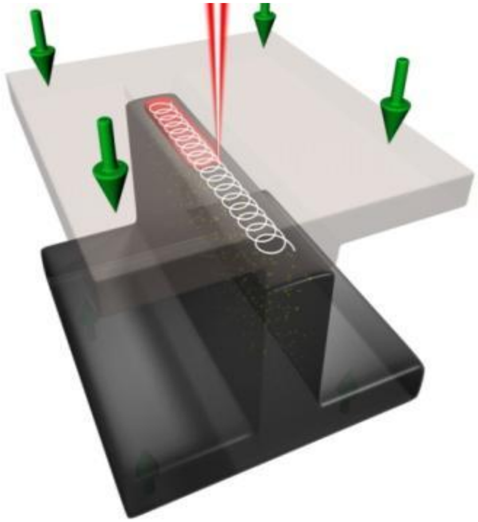
Incremental

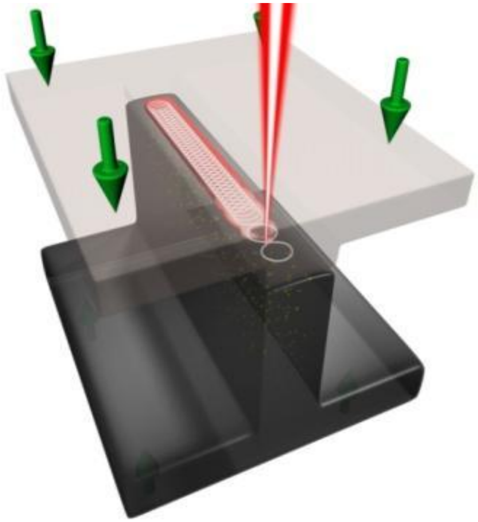
Scanning

Technique









TWIST®- Concept

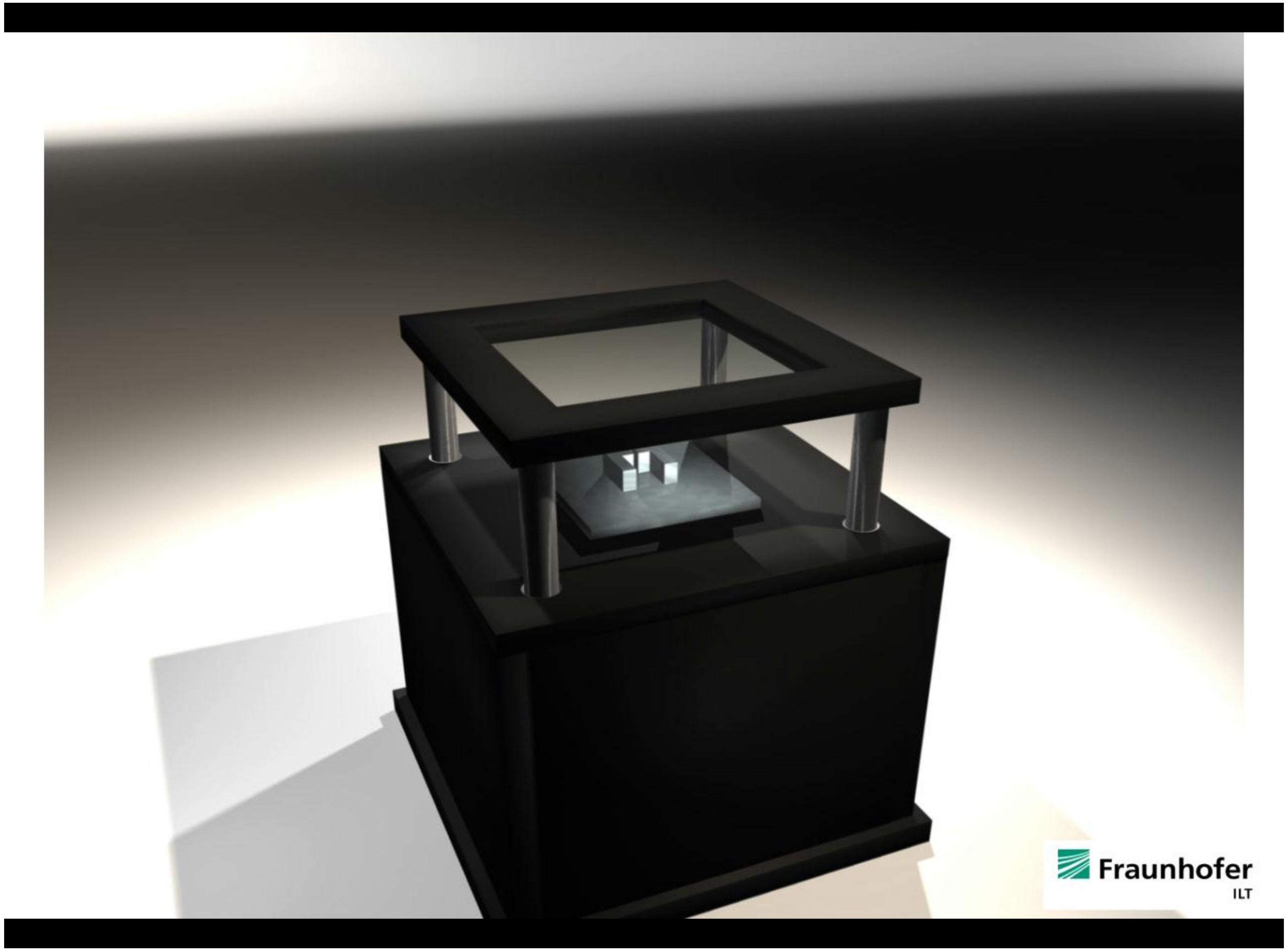
Transmission

Welding

Incremental

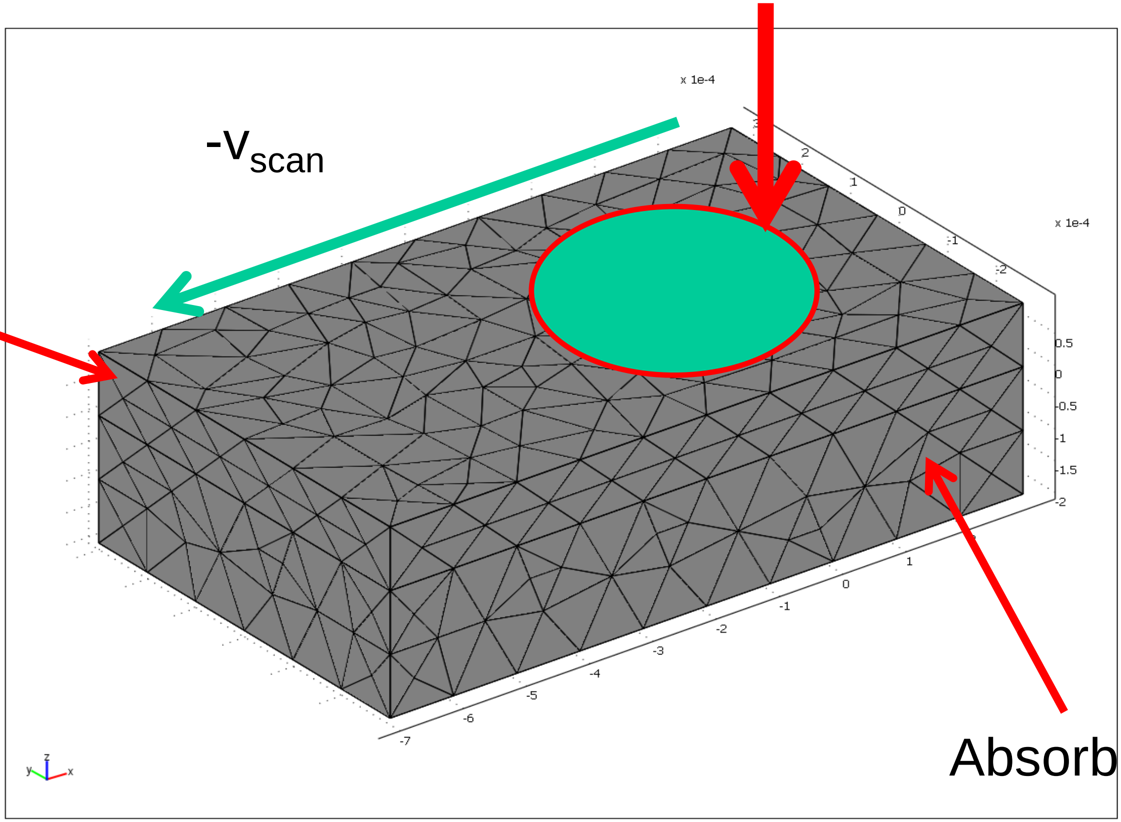
Scanning

Technique



Computer simulation of the polymer welding process

Absorbent and transparent joining partners (dabs= 200 µm, dtra= 100 µm) in thermal contact

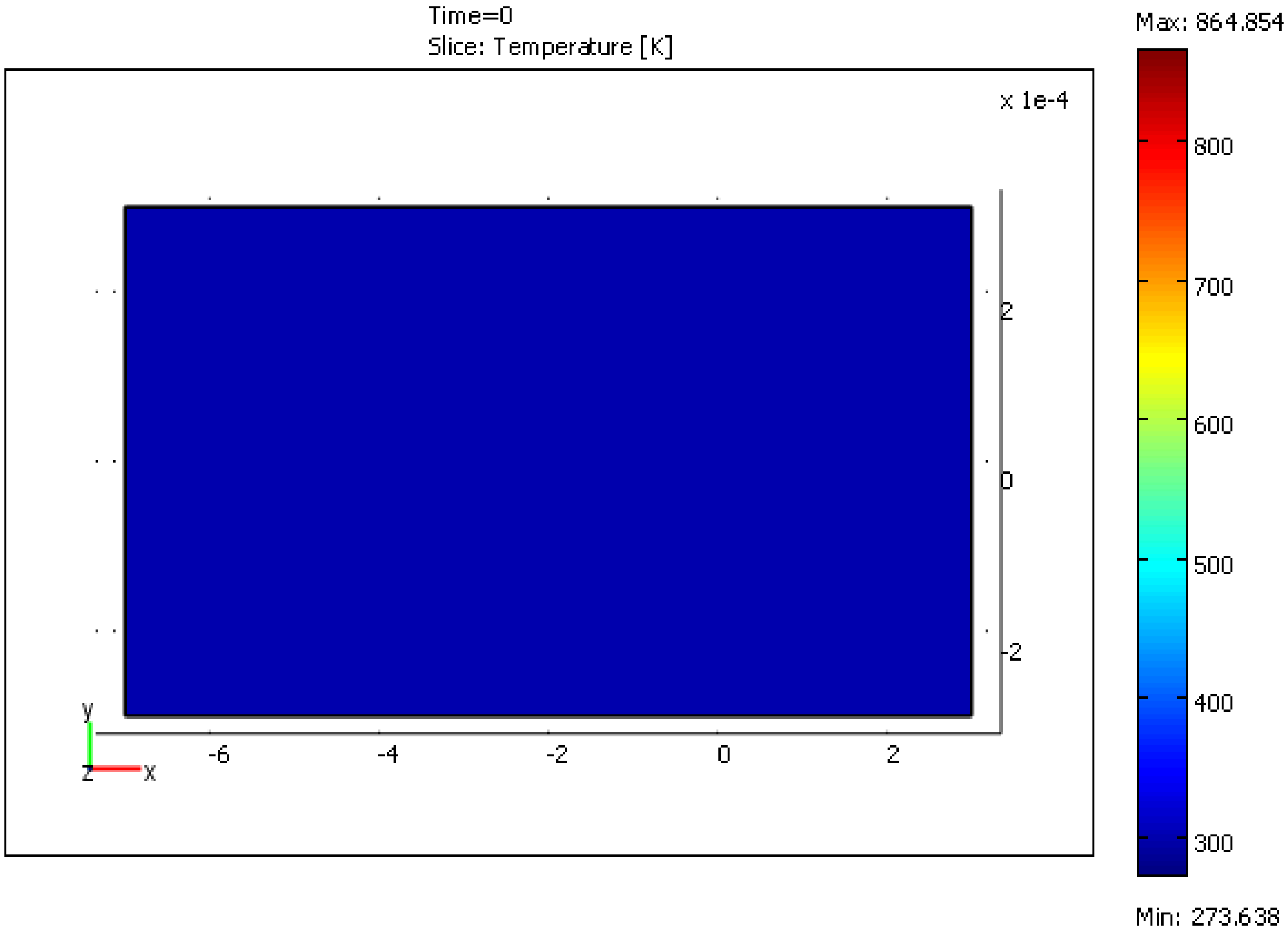


$-v_{scan}$

Transparent part

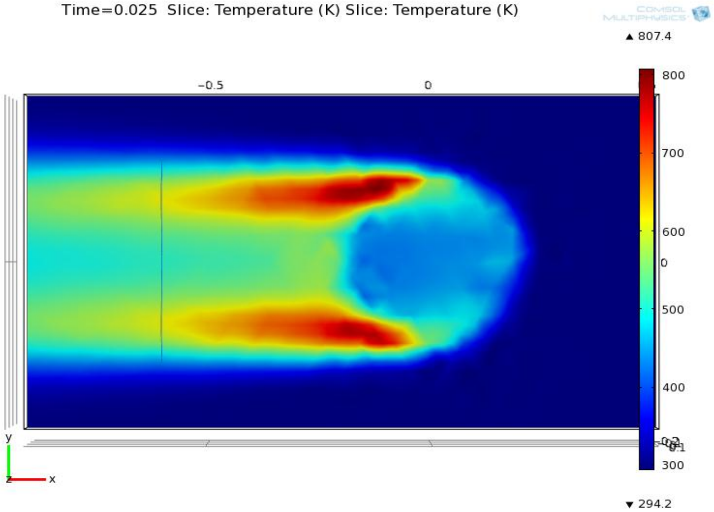
Absorbent part

Computer simulation of the polymer welding process

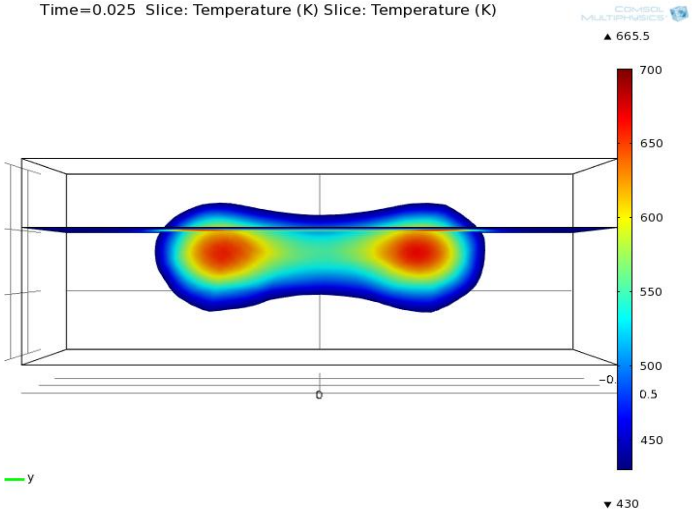


Computer simulation of the polymer welding process

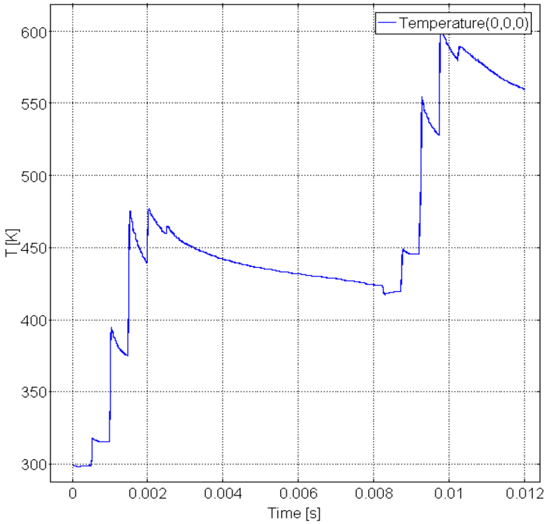
Top view - welding area



HAZ in cross section



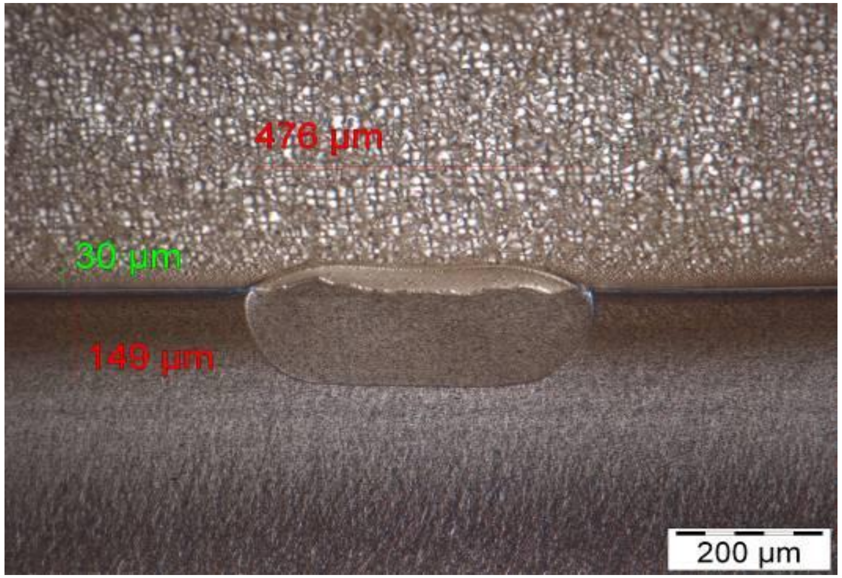
Temperature profile

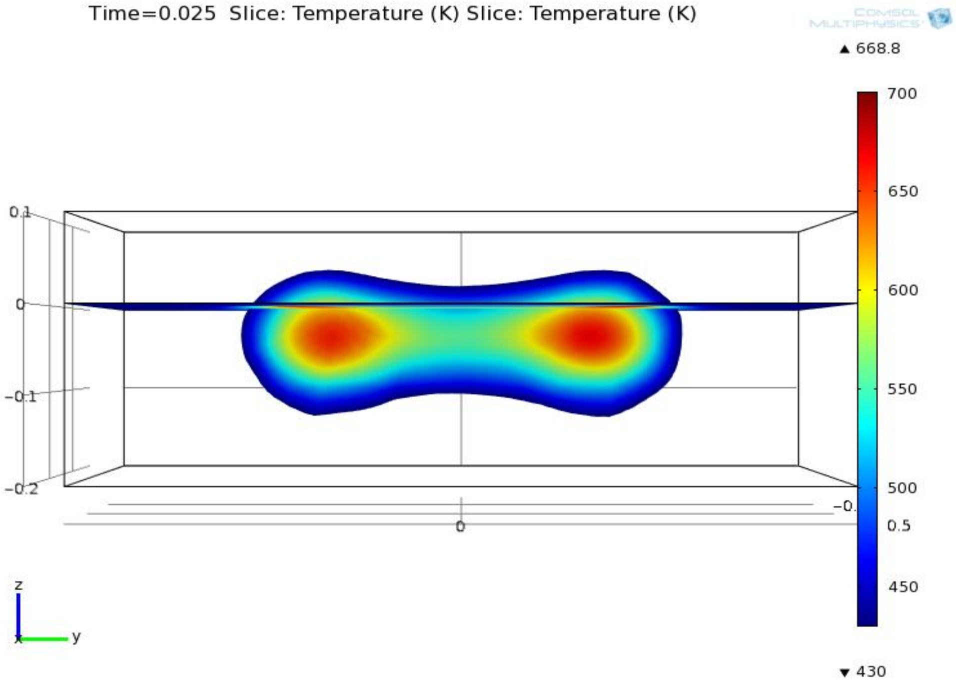


Computer simulation of the polymer welding process

Process parameters:

PP; 2w0=80µm; P=4W; v=50mm/s; f=1000Hz; r=0.2mm

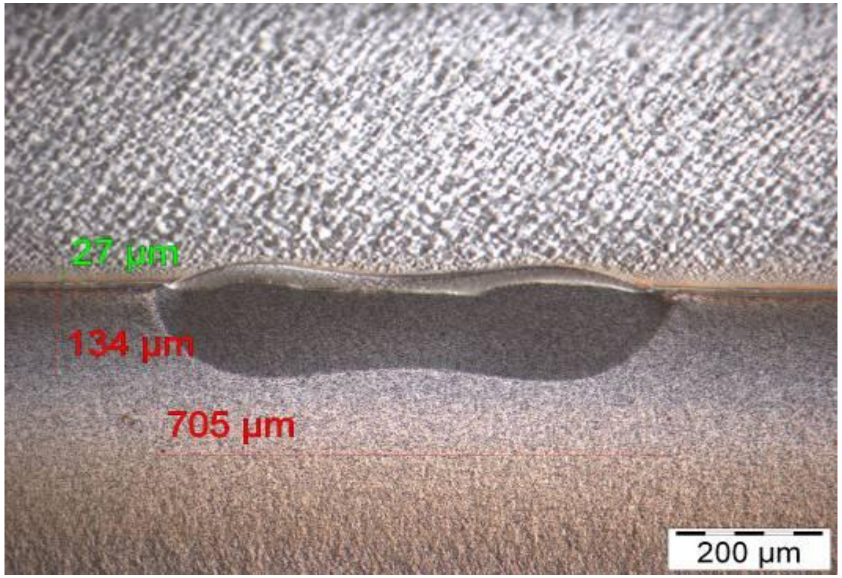


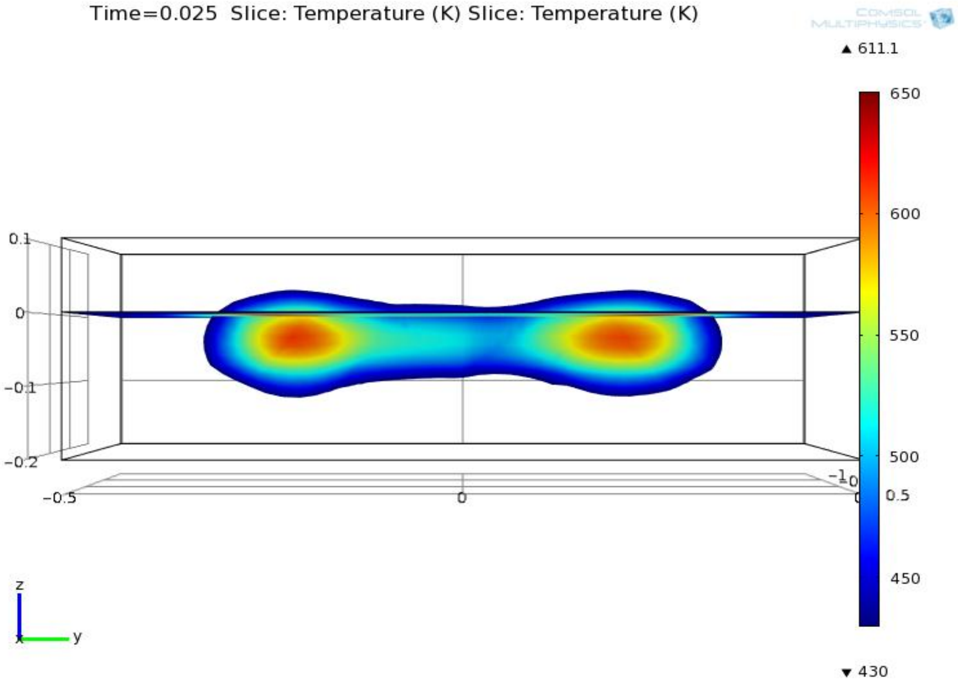


Computer simulation of the polymer welding process

Process parameters:

PP; 2w0=230µm; P=5W; v=50mm/s; f=2000Hz; r=0.3mm

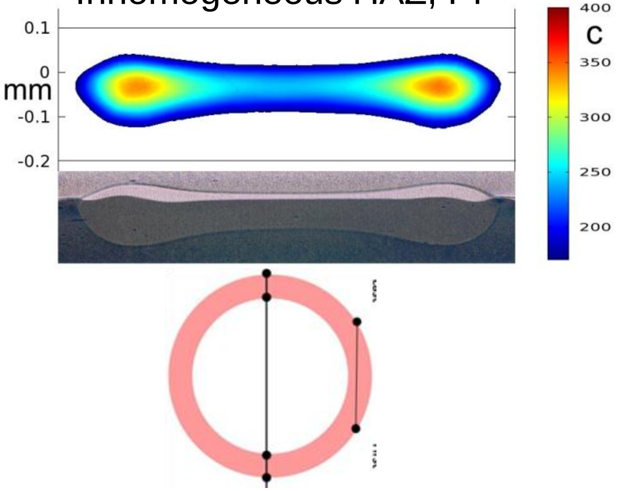




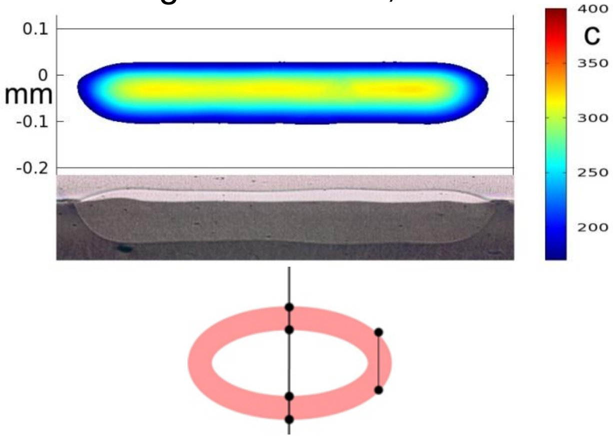
Computer simulation of the polymer welding process

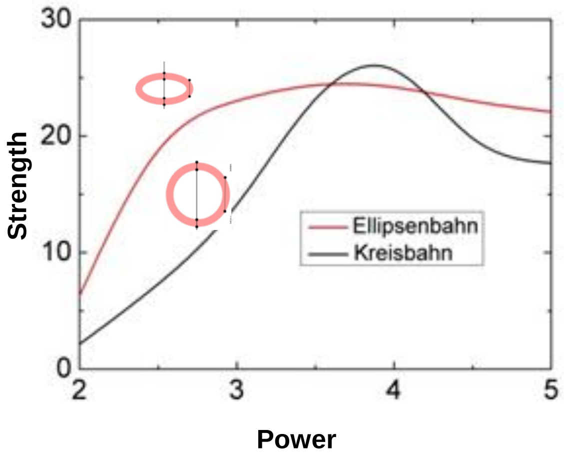
Comparison between circular and elliptical modulation

TWIST Circle 0,8mm
Beam 80 µm
Feed 50 mm/s
Rotation 2000 Hz
Inhomogeneous HAZ, PP



TWIST Ellipse 0,8/0,2mm
…
…
…
Homogeneous HAZ, PP

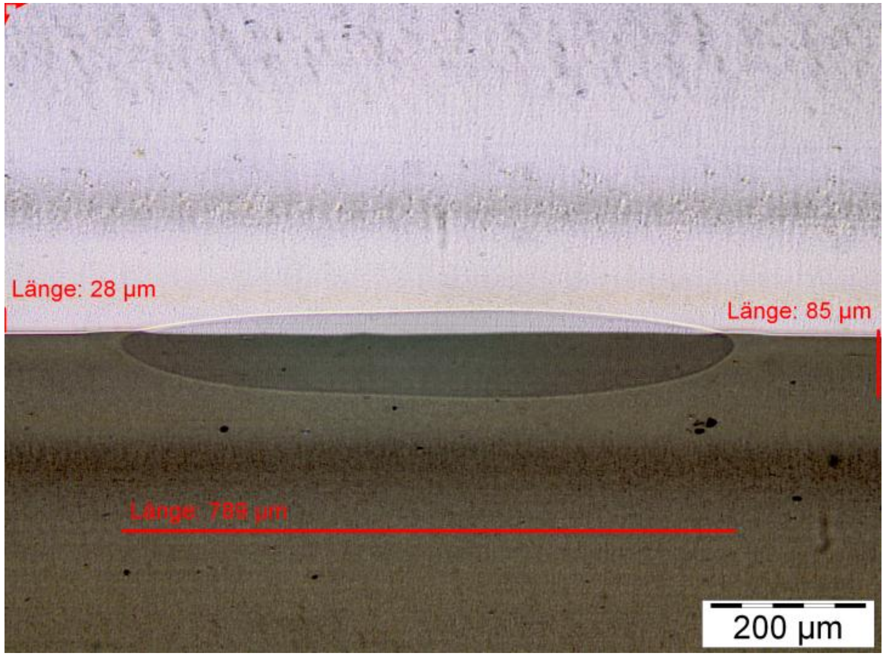




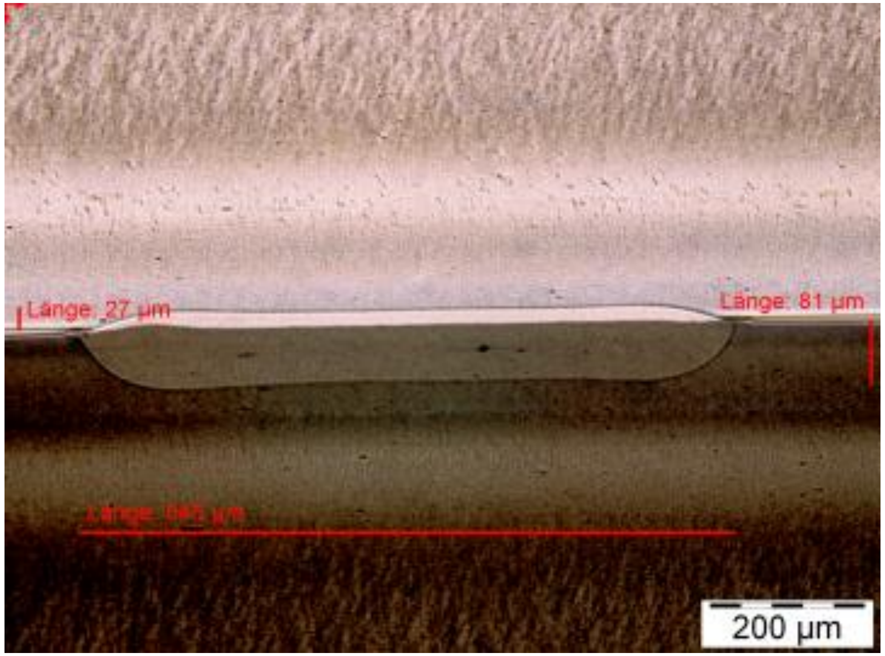
Experimental verification of simulation

Comparison Contour welding - TWIST welding

Contour v=ct.



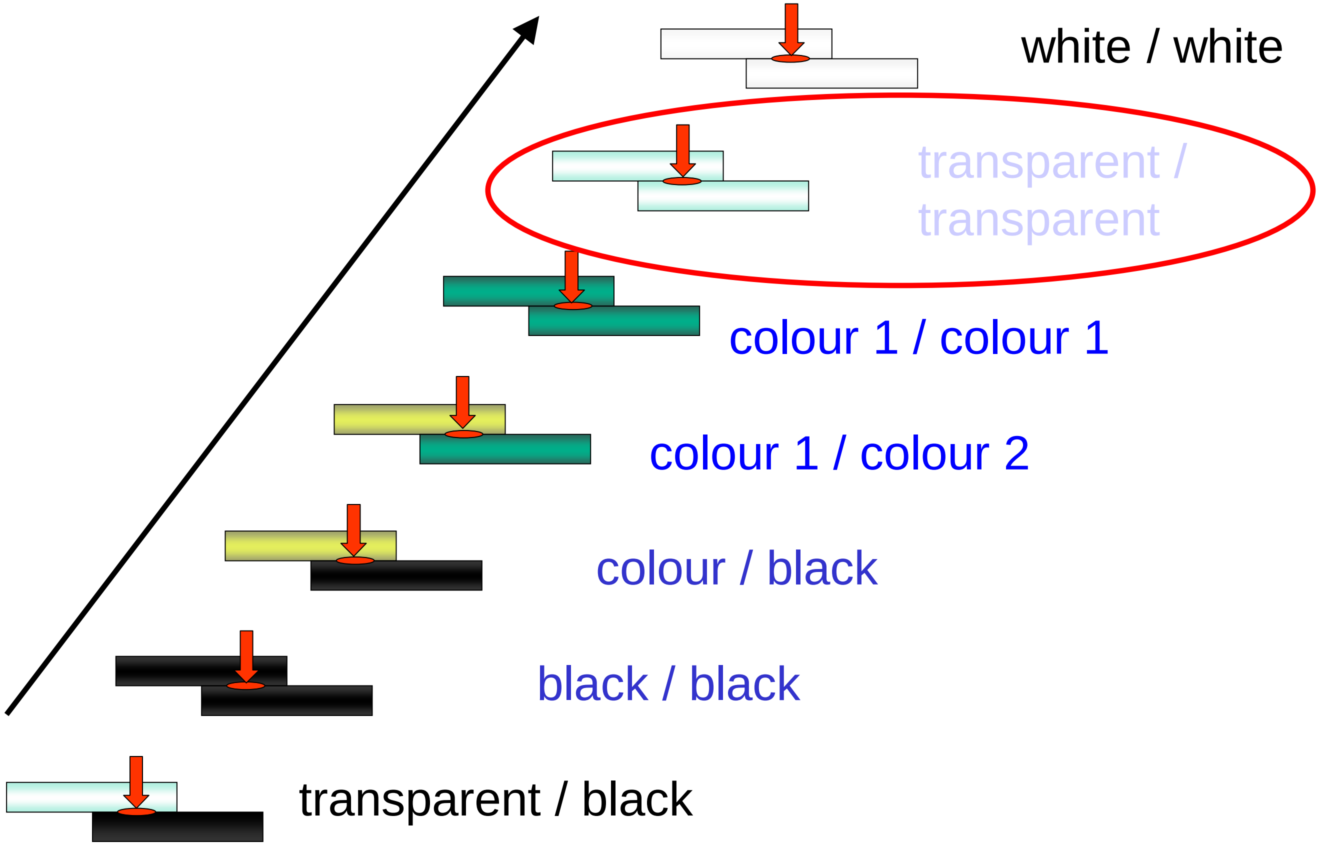
Elliptical shape v=ct.



TWIST welding: heat effective zone is homogeneous

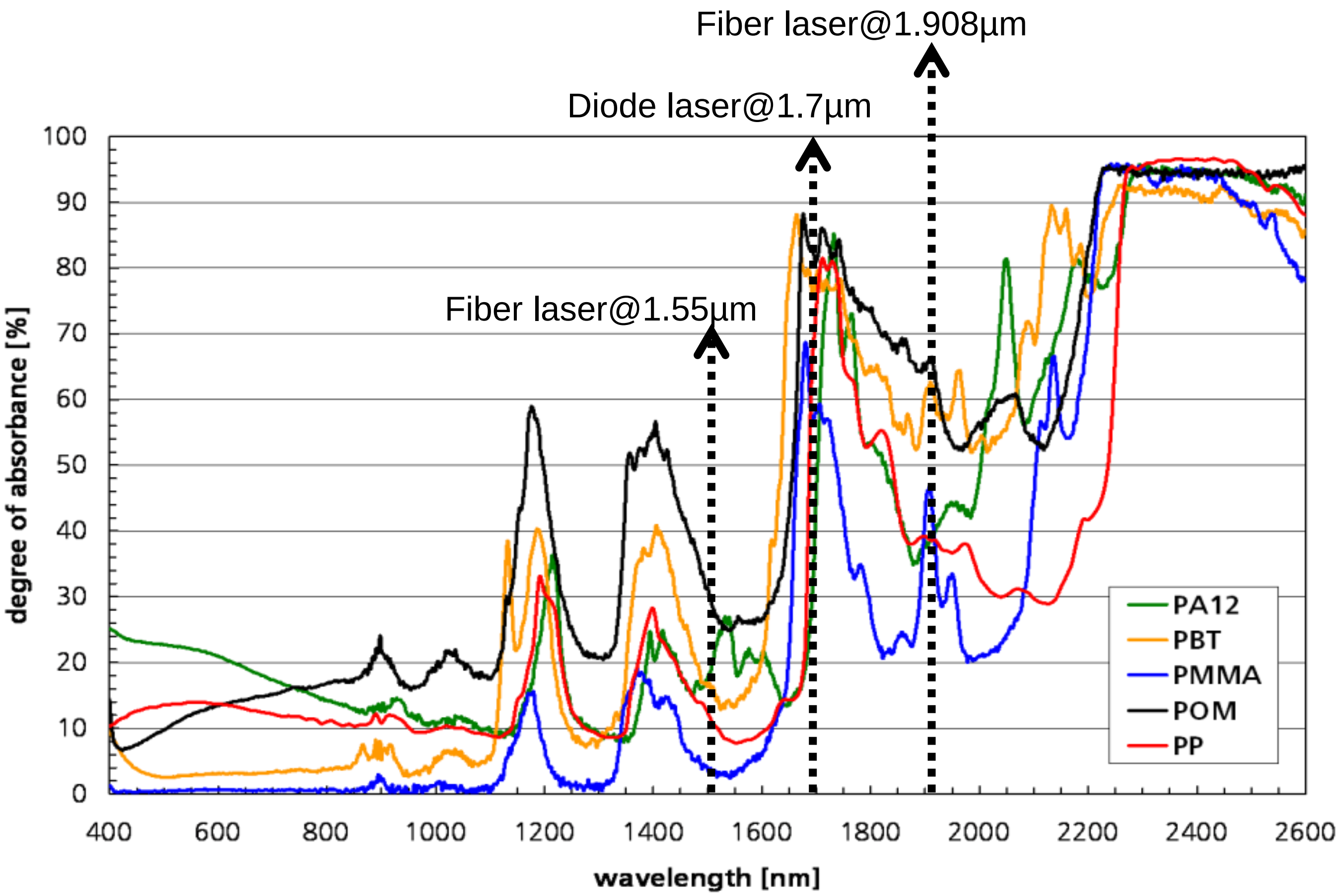
Welding results using material adapted laser wavelengths

- Transparent / black standard configuration
- Laser transparent additives allow colourisation of upper joining partner
- IR-absorber allow coloured lower joining partner
- No additional additive needed



Welding results using material adapted laser wavelengths

- Transparent in VIS
- Intrinsic absorption in infra-red
- Absorption band aroused by harmonic oscillation of molecular groups of the polymer chains
- Optical properties of thermoplastics highly dependent from wavelength in IR-Area and molecular structure


Fiber laser@1.908µm

Diode laser@1.7µm

Fiber laser@1.55µm

Material thickness d = 2mm

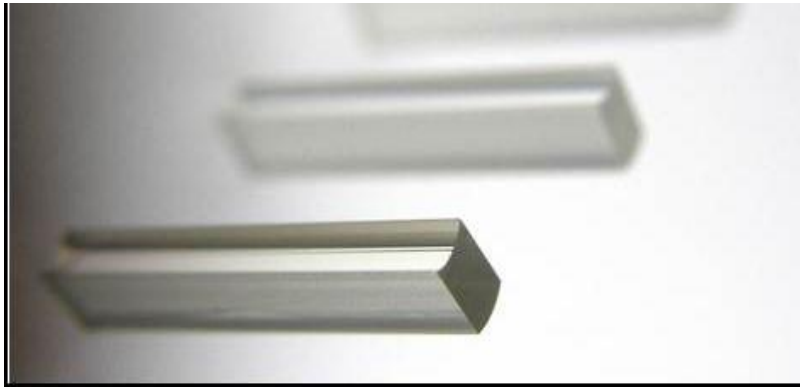
Available new laser sources

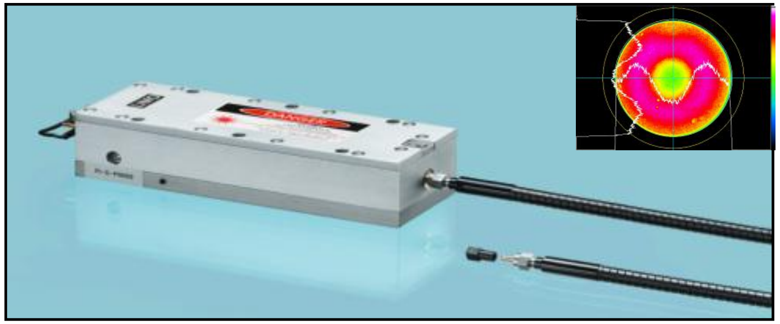
IPG:

- 120 W Erbium doped Fiber Laser (1.5 µm wavelength)
- 120 W Thulium doped Fiber Laser (1.9 µm wavelength)

LIMO:

- 20 W diode laser (1550 nm wavelength) with 400 µm fibre
- 80 W diode laser (980 nm wavelength) with 400 µm fibre with M-shape beam profile





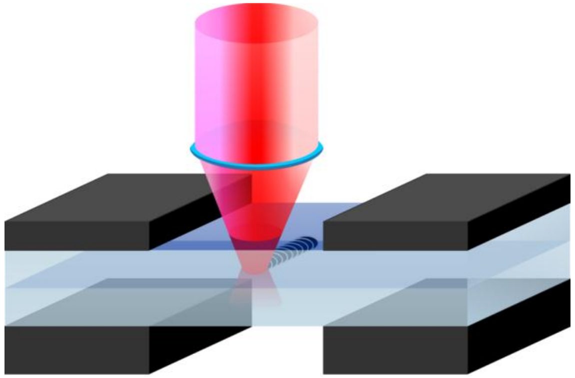
Welding results using material adapted laser wavelengths

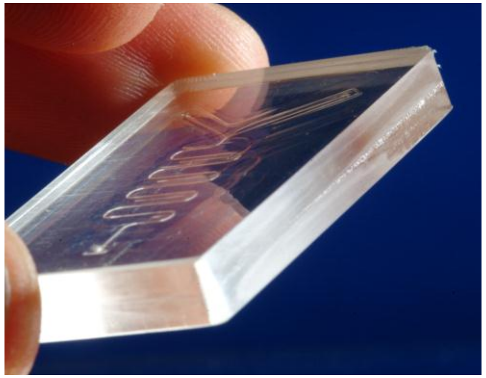
Concept

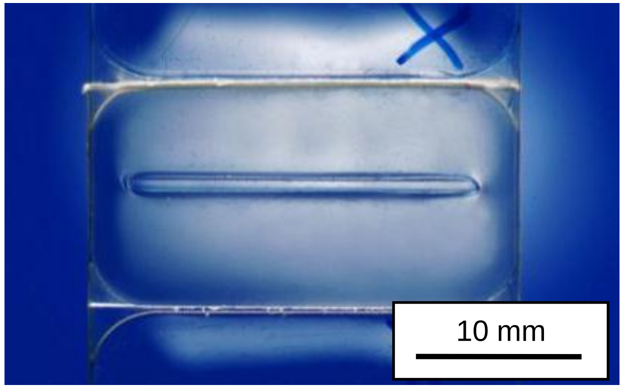
- Adjusted wavelength of laser source
- High numerical aperture optics

Result

- Low intensity on surface but high intensity in welding area
- Temperature exceeds melting point only in welding area



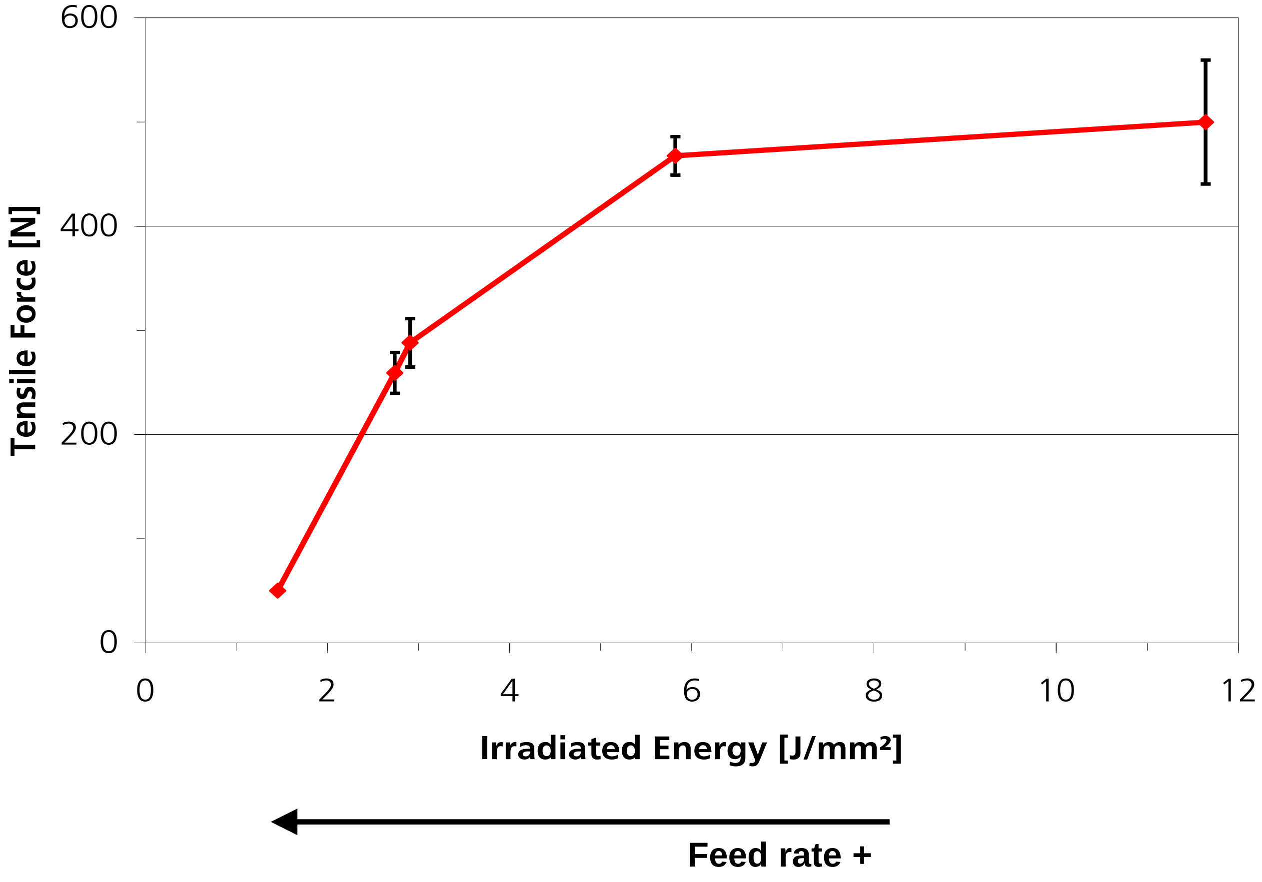


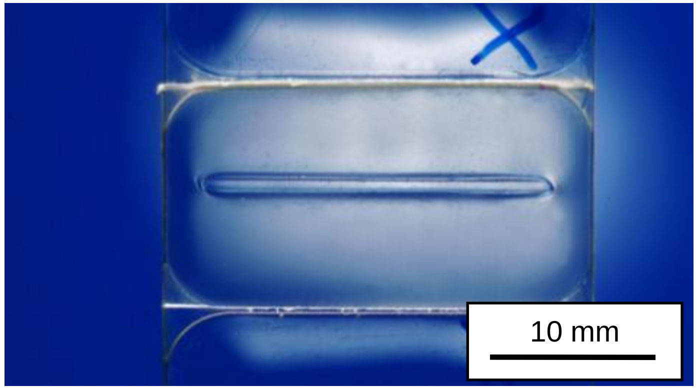


Material thickness d = 2mm

Welding results using material adapted laser wavelengths

- Laser power up to 100W@1.55µm
- Feed rate:
  0.5 m/min - 4 m/min
- No characteristic curve at high irradiated energies
- Wider Weld seam for higher energy levels





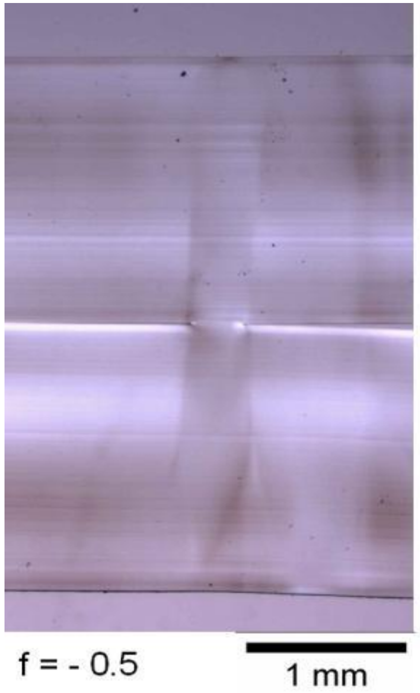
Welding results using material adapted laser wavelengths

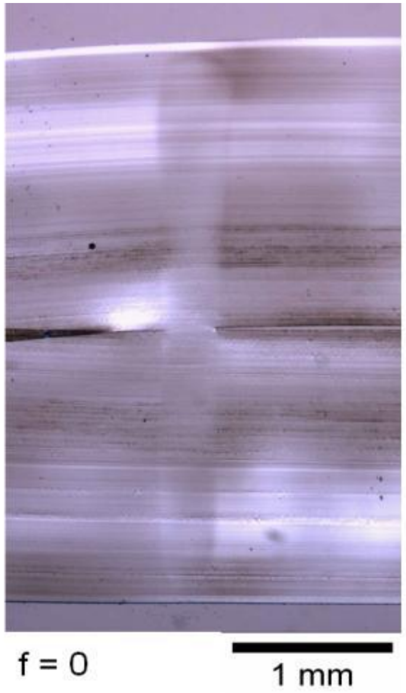
Variation of focal position

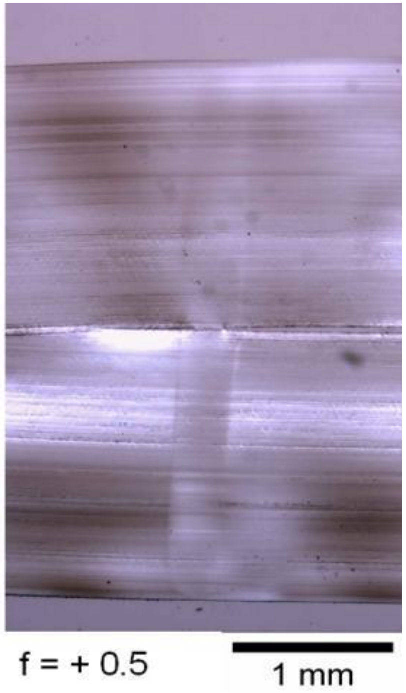
- Fiber laser @1.55µm
- Laser power: P= 100 W
- Feed rate: v= 2 m/min

Results:

- Optimal setting prevents melting of surface and deliver smallest width of heat affected zone
- No further limitation of depth of heat affected zone

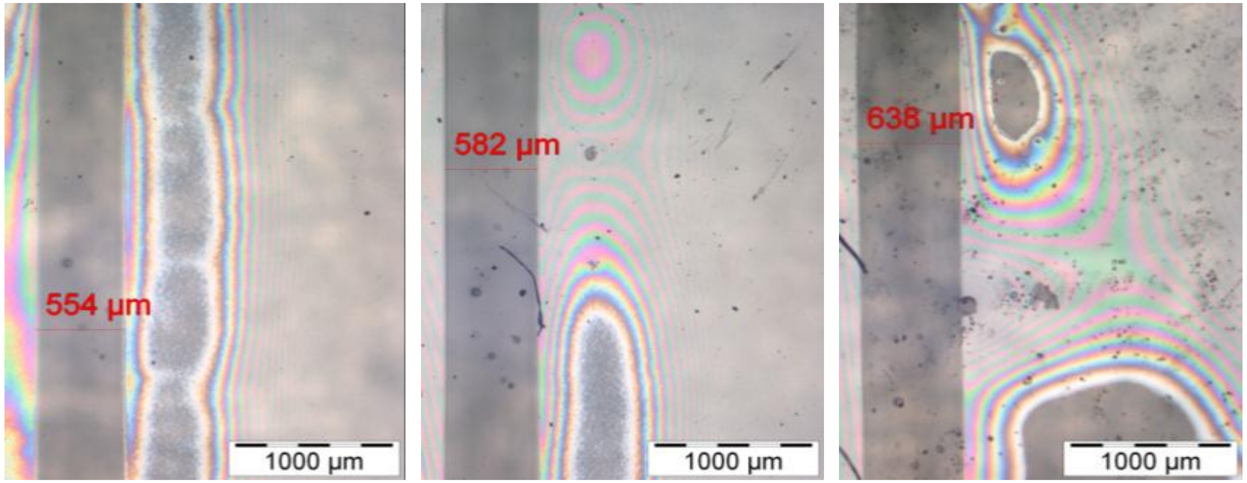

f = - 0.5

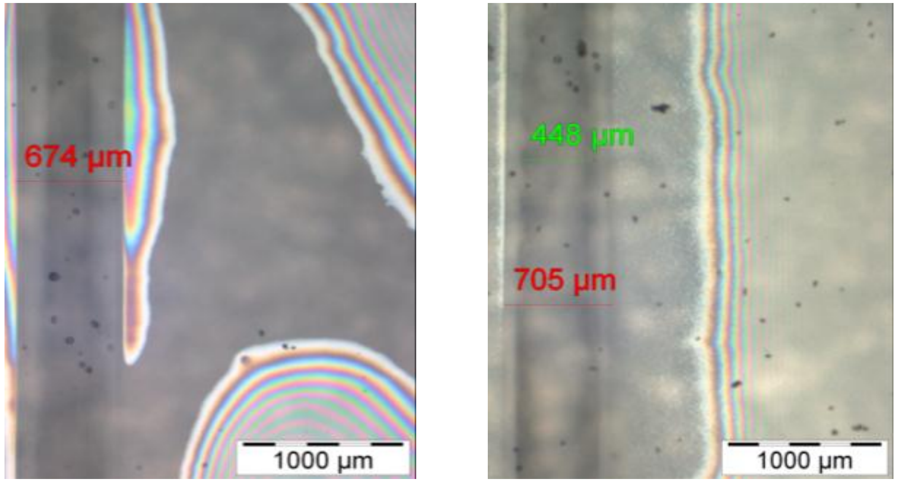

f = 0

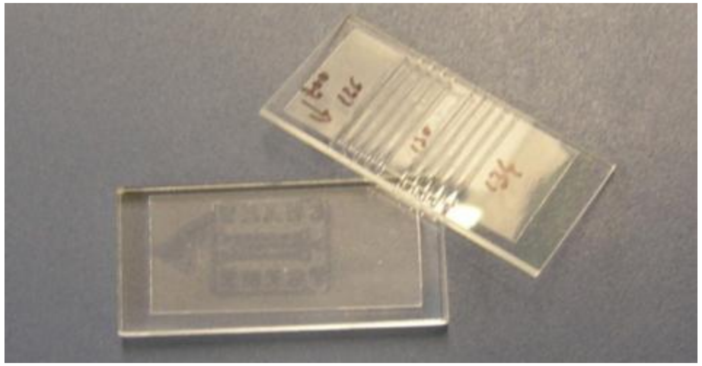

f = + 0.5

Welding results using material adapted laser wavelengths

- Diode laser @1.7µm
- Material - PMMA
- Laser power:
  P=20/ 22.5/ 27.5/ 32.5/35W
- Feed rate: v= 1.5 m/min

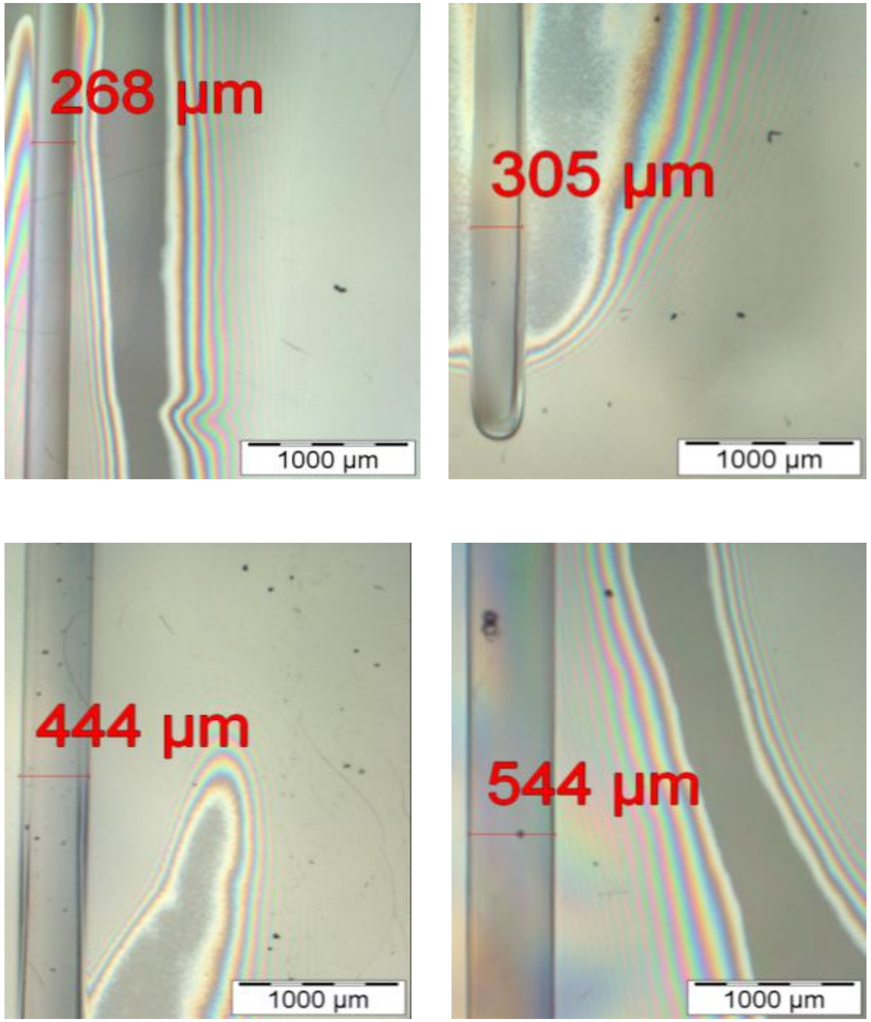


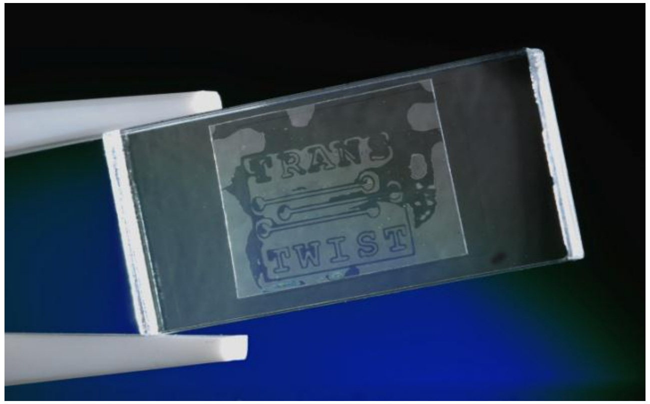




Welding results using material adapted laser wavelengths

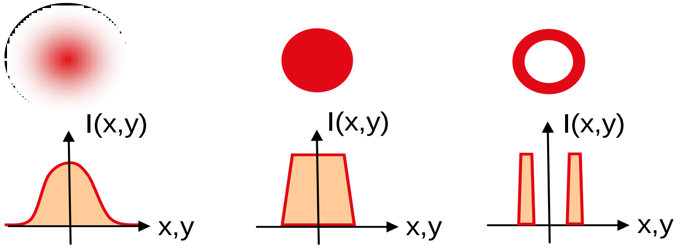
- fiber laser @1.908µm
- Material - PMMA
- Laser power: P= 16.6/ 25/ 25/ 33.3 W
- Feed rate: v= 3 m/min
- Oscillation parameters:
  f= 2000 Hz
  A= 0.075/ 0.1/ 0.15/ 0.2mm

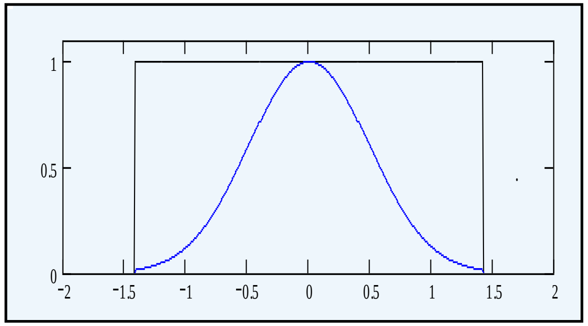


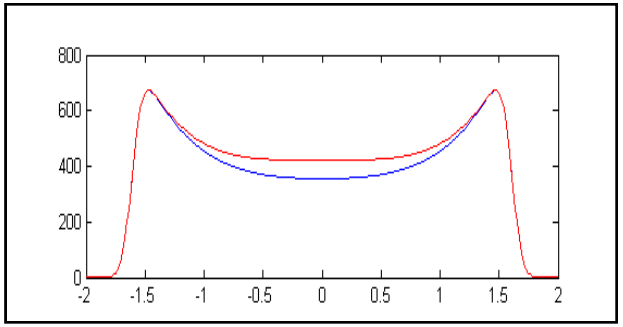


Development of optical elements for tailored laser beam profiles

- Using diffractive or refractive optical elements an alternative to the TWIST® approach can be achieved.

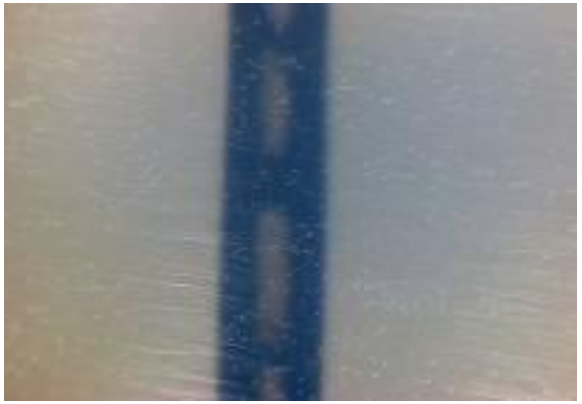


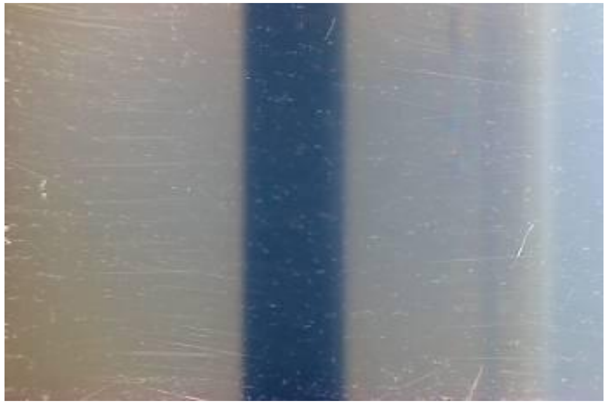




Gaussian beam

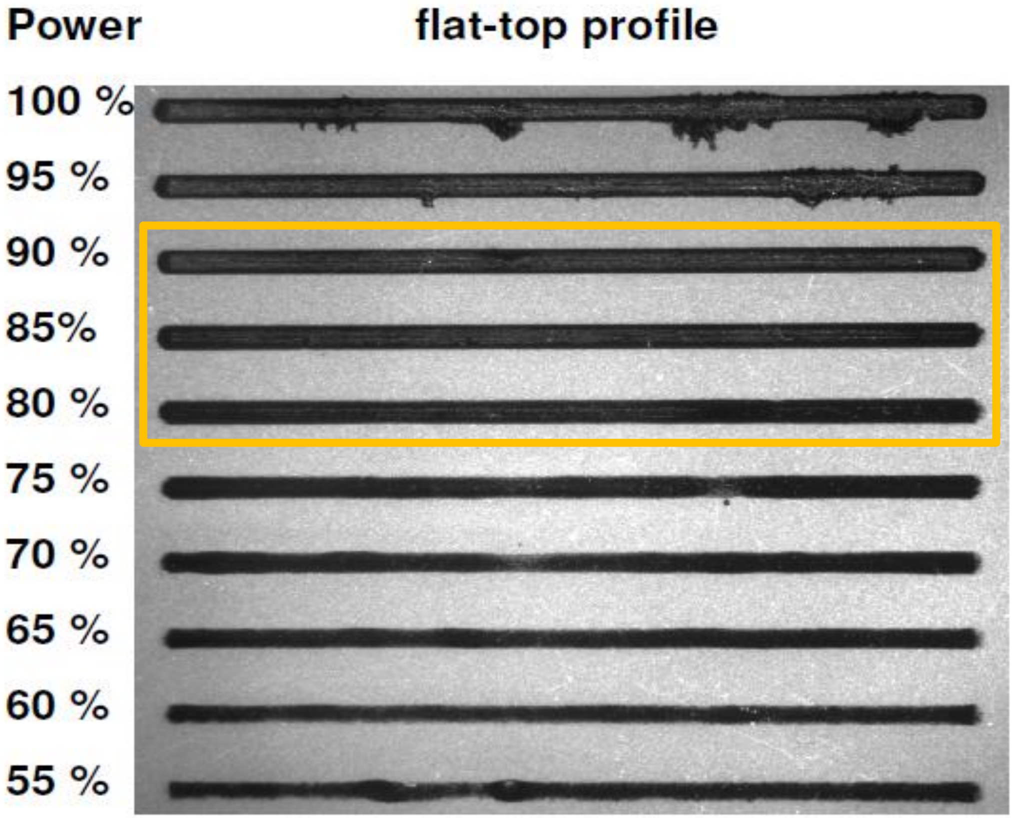
M-shaped beam





Development of optical elements for tailored laser beam profiles

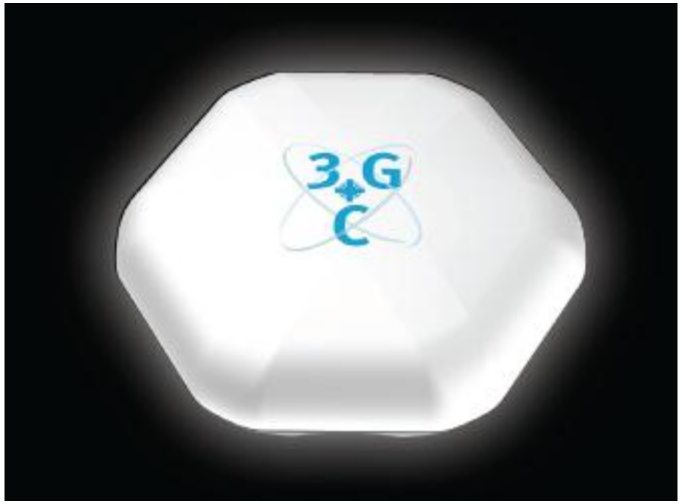
Welding tests with DOEs generating an M-shaped beam profile and a spot diameter of 1 mm (material PC)

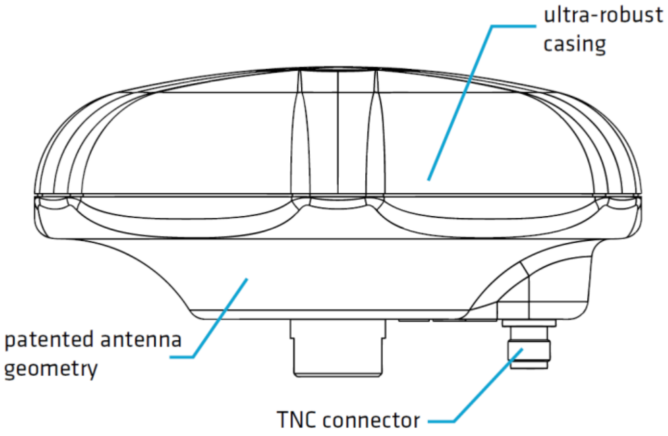


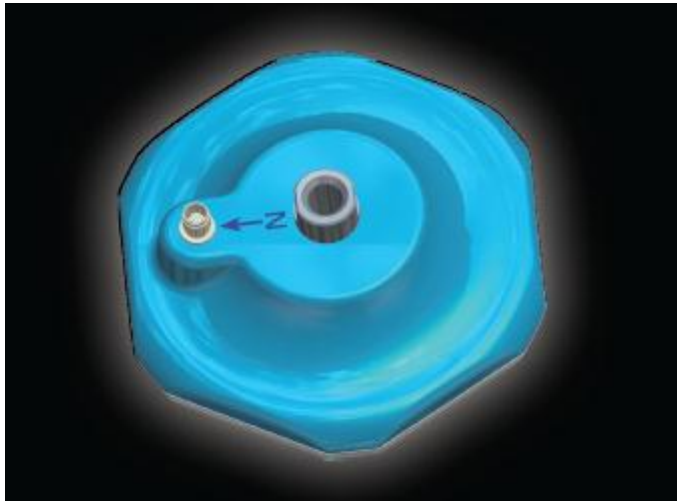
Contour welding: 100% Power = 53 Watt (fiber laser @ 1070nm)

From research to market – an industrial application example

- Four constellation GNSS antenna
- Galileo | GPS | Glonass & Compass
- Rugged housing
- Hermetic sealing needed
- Varying colours







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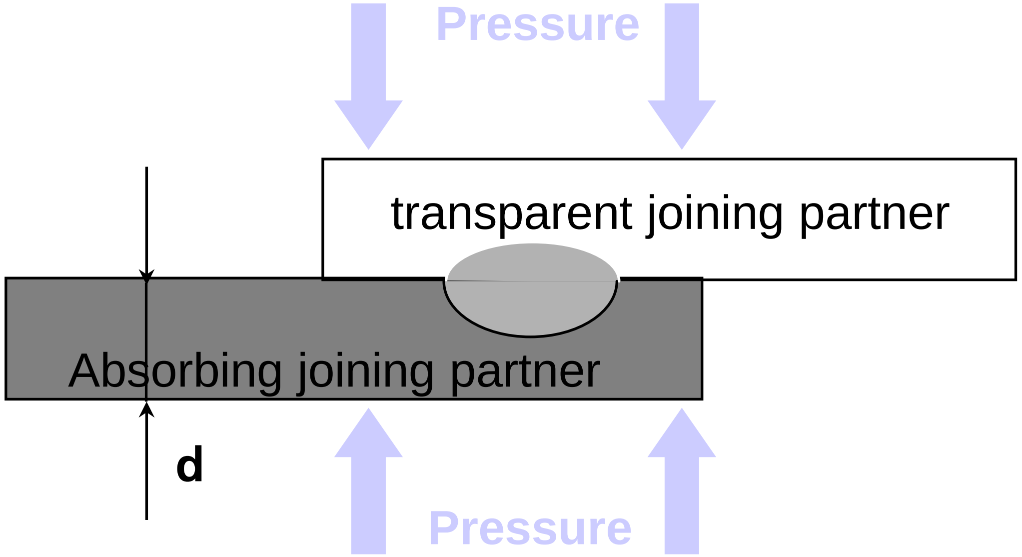
Requirements on optical properties – overlap weld

Transparent joining partner:

- Transmission high
- Reflexion low
- d low

Absorbing joining partner:

- dopt << d
- Reflexion low
- d not important



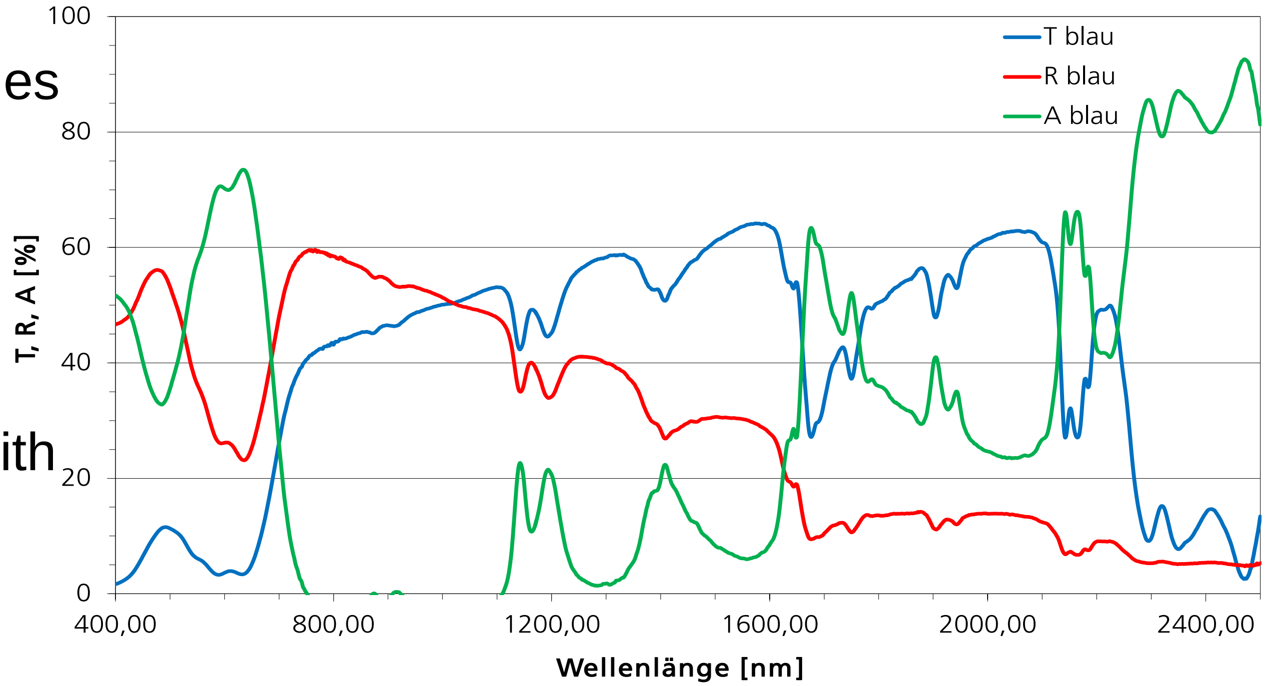
Optical properties ASA blue laser transparent

- Strongly wavelength dependent optical properties
- Reflexion decreases with increasing wavelength:

  53% @ 940 nm
  30% @ 1550 nm
- Transmission increases with increasing wavelength:

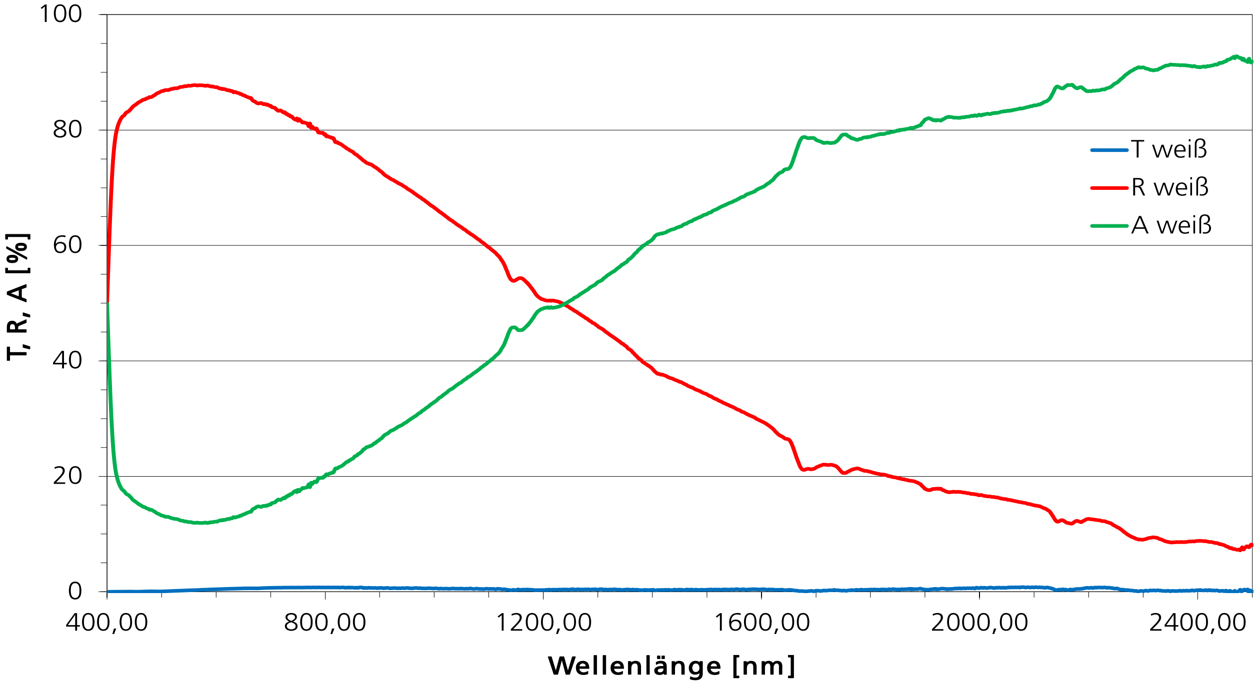
  48% @ 940 nm

  63% @ 1550 nm



Optical properties ASA white laser absorbing

- Wavelength depending properties determined by filler additives
- Very high reflectivity in the visible spectrum
- Strong decrease of reflectivity with increasing wavelength:
  71% @ 940 nm
  32% @ 1550 nm
- Optical penetration depth:
  222 µm @ 940 nm
  176 µm @ 1550 nm

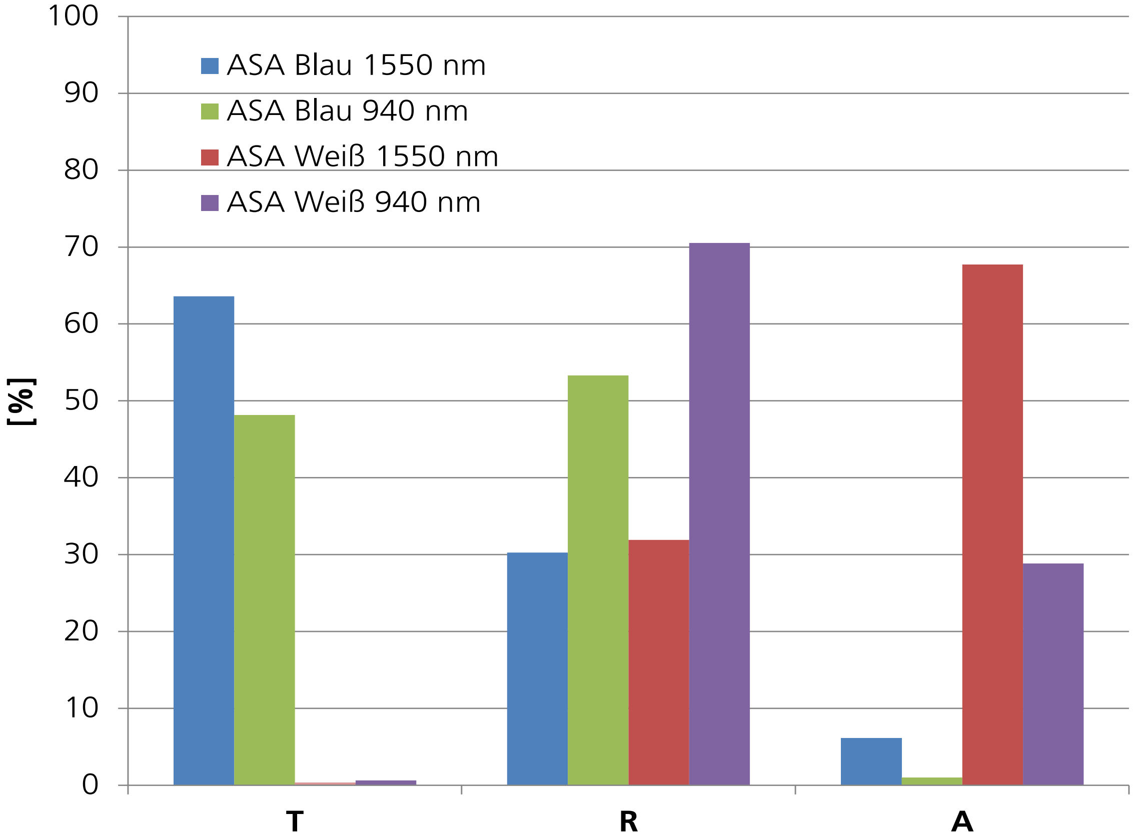


Comparison of optical properties @ 940 nm and 1550 nm

Advantages of 1550 nm:

- Higher transmission and lower reflexion of blue material
- Considerably more radiation reaches the joining interface
- Lower reflexion and higher absorption of the white material
- More energy transfered into heat

→ Significant improvement of the weld quality



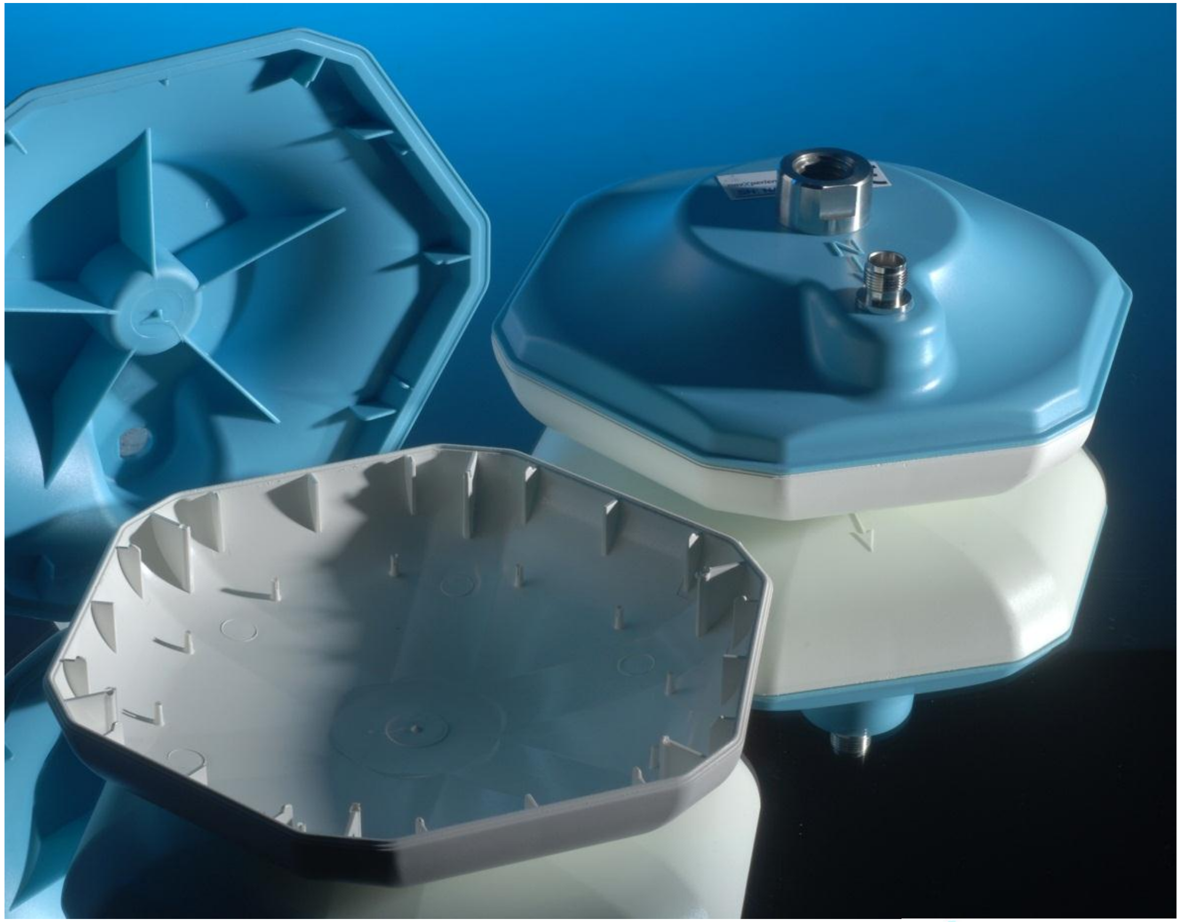
Welding of GPS antenna housings

Requirements:

- Invisible weld seam
- Hermetic sealing
- No thermal and mechanical load of the antenna components inside
- Burst pressure 2.5 bar

Result:

- Fiber laser 1550 nm
- TWIST-welding with:
  Laser power: 25 W
  Feed rate: 25 mm/s
  Frequency: 2000 Hz
  Amplitude: 0,2 mm
  4-times multi-pass welding



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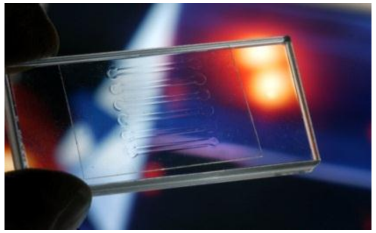
Summary and Outlook



Industrial applications require:

- **High Quality** – through robust polymer assembly with high reproducibility and minimum waste
- **Flexibility** – by minimizing time and investment for product change on the manufacturing line
- **Productivity** – by high speed processes with joining times < 1 second
- **Cost reduction** - reconfigurable machines and high yield production, new laser systems and peripherals
- **New products** - simplified product design and highly integrated products , material independent welding processing, new designs

Thank you for your attention!

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We gratefully acknowledge the support for the described work through the EU funded 7th framework project: POLYBRIGHT

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Dr.-Ing. Alexander Olowinsky
Fraunhofer Institute for Laser Technology
Steinbachstraße 15
D-52074 Aachen, Germany

Phone: +49 (0) 241 89 06 -491
Email: alexander.olowinsky@ilt.fraunhofer.de

More information : www.polybright.eu