Laser welding of polymers

State of the art and innovative trends - Part I

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15 - 16 March 2011

1st Internal Workshop
Laser welding - a versatile process for the high performance production of polymeric components

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Outline

- Introduction
- Basics of laser welding of polymers
- Innovative approaches for the polymer welding
  - TWIST® - a new welding process
  - Welding of transparent polymers
- Applications examples
- Summary and Outlook

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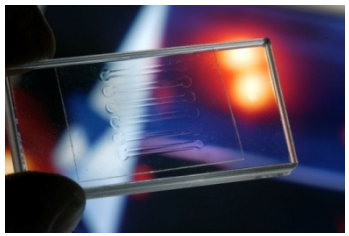
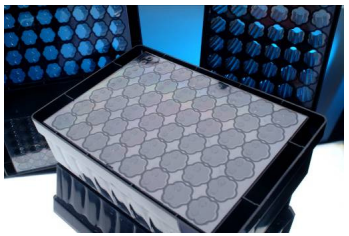
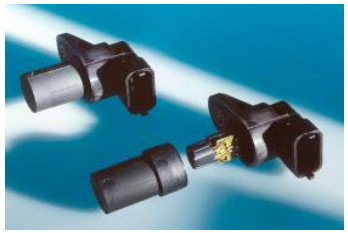
Introduction

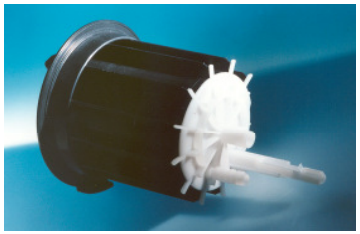
Broad application range for the laser polymer welding

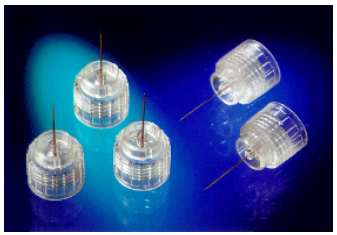
Process characteristics

- Precise control of the energy deposition
- Reduced mechanical and thermal load of the joining partners
- Contactless processing
- High weld seam strength
- Hermetical sealing
- No particle release
- High valuable optical appearance of the weld seam







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Introduction

Classifications

- Configuration of the joining partners:
  - Butt joint
  - Overlap Joint – Transmission welding
- Irradiation strategy:
  - Contour welding
  - Quasi-simultaneous welding
  - Simultaneous welding
  - Mask welding
- Type of polymers:
  - Similar materials
  - Dissimilar materials
- Dimension of the joining partner or of the weld seam:
  - Micro-welding
  - Macro-welding

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Introduction

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

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Introduction

Challenges and future trends

- Process enhancement towards a material independent laser welding of thermoplastics using material adapted laser wavelengths to avoid the use of IR absorbers
- Further development of advanced irradiation strategies for a thermally optimized processing and increased process speed
- Reduction of the weld seam width to meet the challenges resulting from the increased components miniaturization

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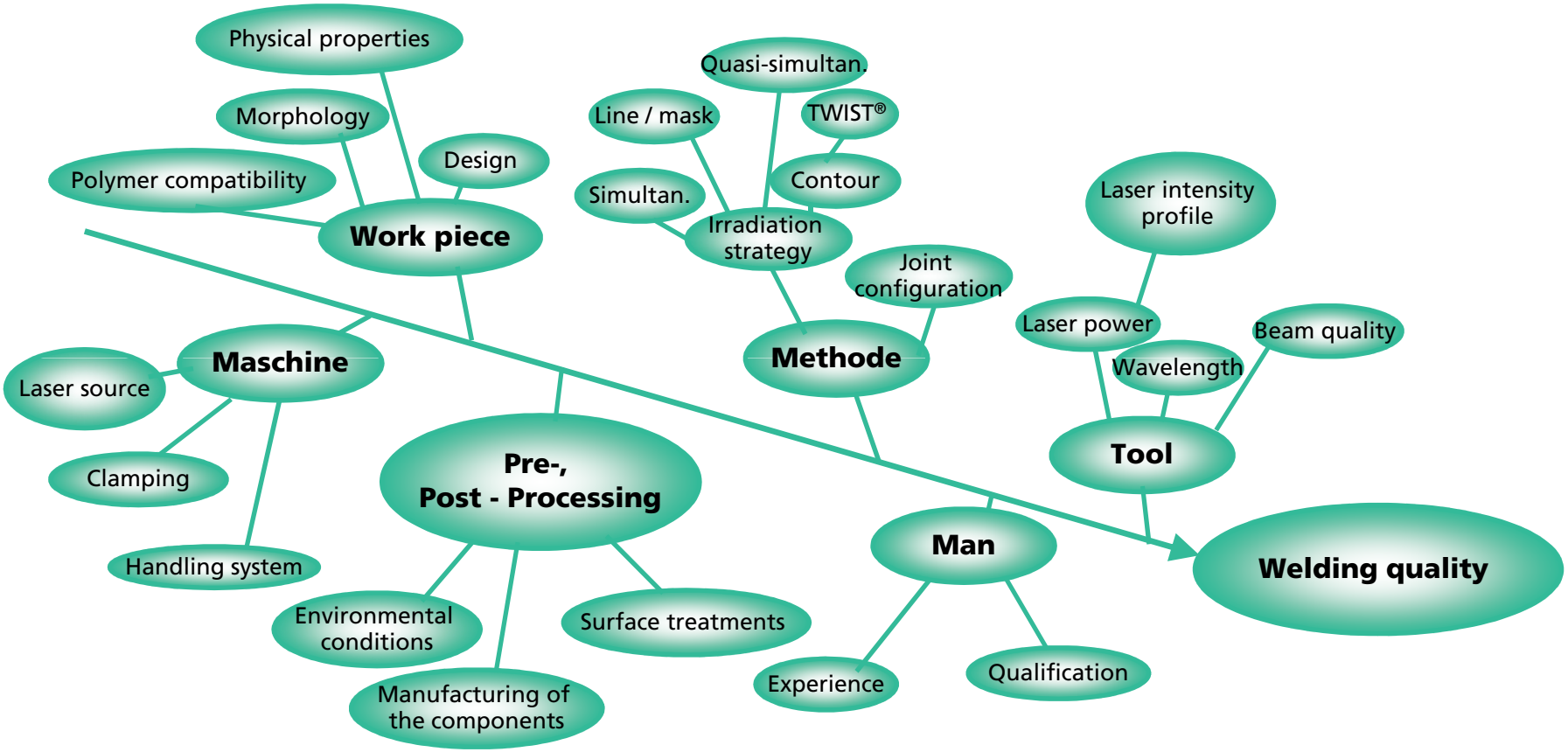
Basics of laser welding of polymers

Process influencing factors – Ishikawa diagram



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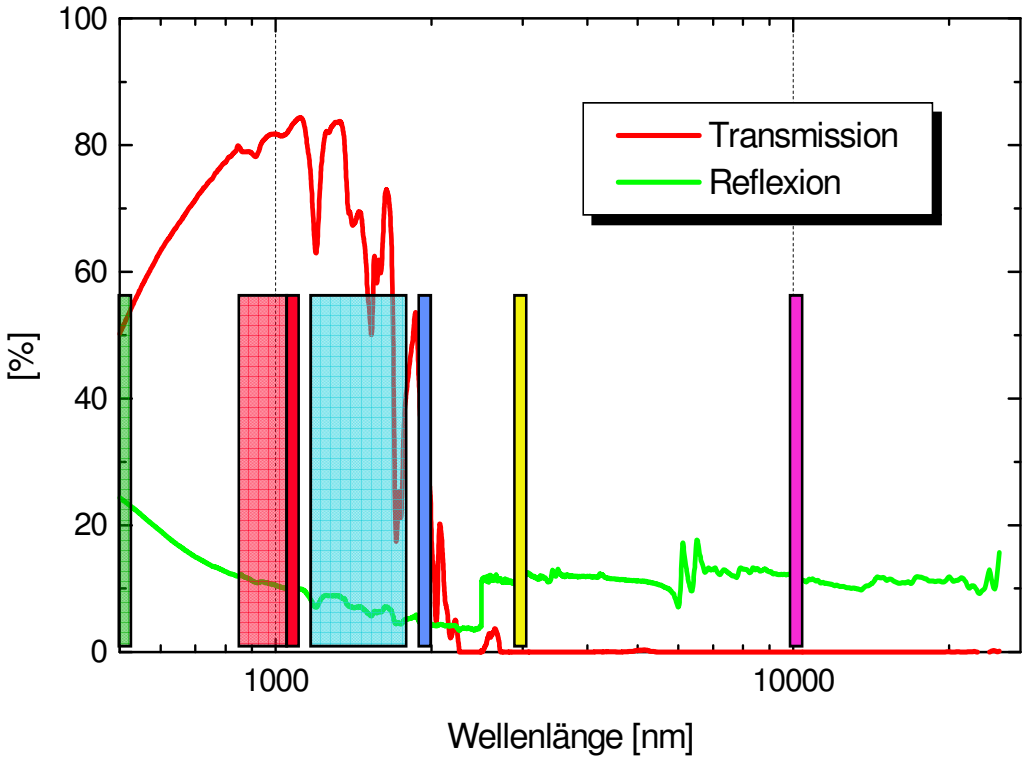
Basics of laser welding of polymers

Tool – Laser source

Emission wavelength of available laser sources

- Neodym:YAG second harmonic
- GaAs Diode laser
- Neodym:YAG
- InP Diode laser
- Holmium YAG
- Erbium:YAG
- CO2-Laser

Typical transmission and reflection degree of polymers vs. laser wavelength



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Basics of laser welding of polymers

Tool – Laser source

20 W Faserlaser der Firma IPG

40 W DIOLAC Diodenlaser

Laser source	Nd:YAG	Diode	Fiber
Wavelength [µm]	1.06	0.8-1.0	1.06-1.09
Beam quality - M^2	1,1	47	1,05
Efficiency	3-10%	30%	20%
Beam delivery	Optical fiber	Optical fiber	Optical fiber
Compactness	-	+	++
Scan head (suitability)	+	(+)	+
Spot diameter (min.) [µm]	20	~ 200	10

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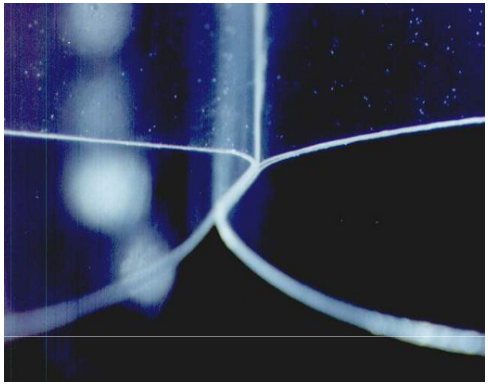
Basics of laser welding of polymers

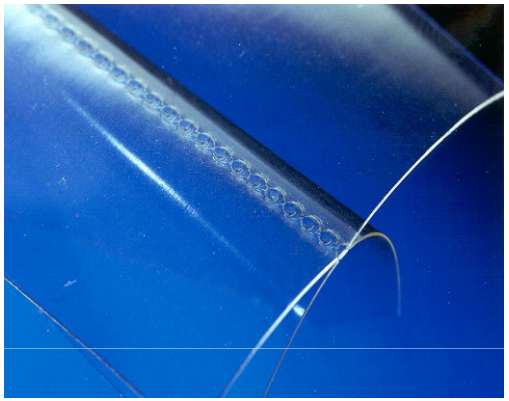
Method – joining partner configuration

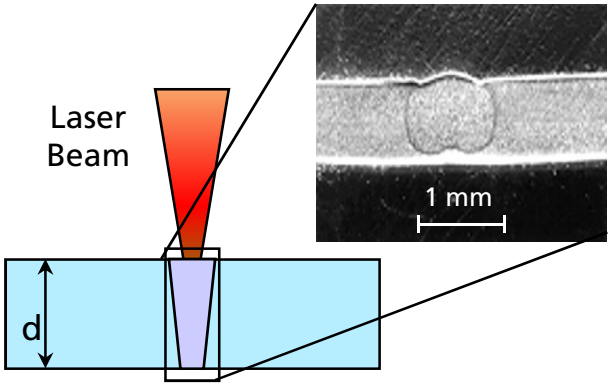
Butt joint

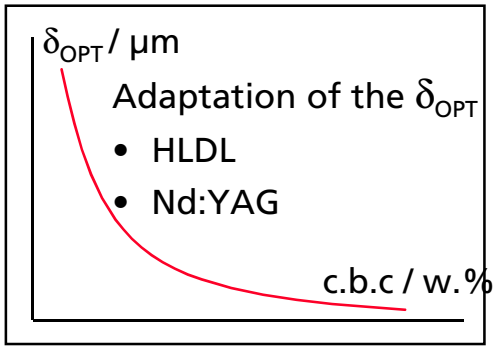
Optical penetration depth

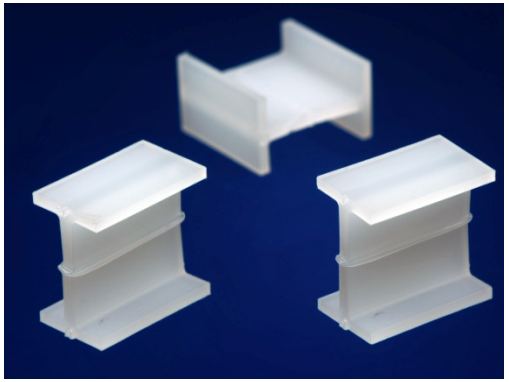
$\delta_{opt} \approx d$











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Basics of laser welding of polymers

Method – joining partner configuration

Overlap joint

Optical penetration depth:

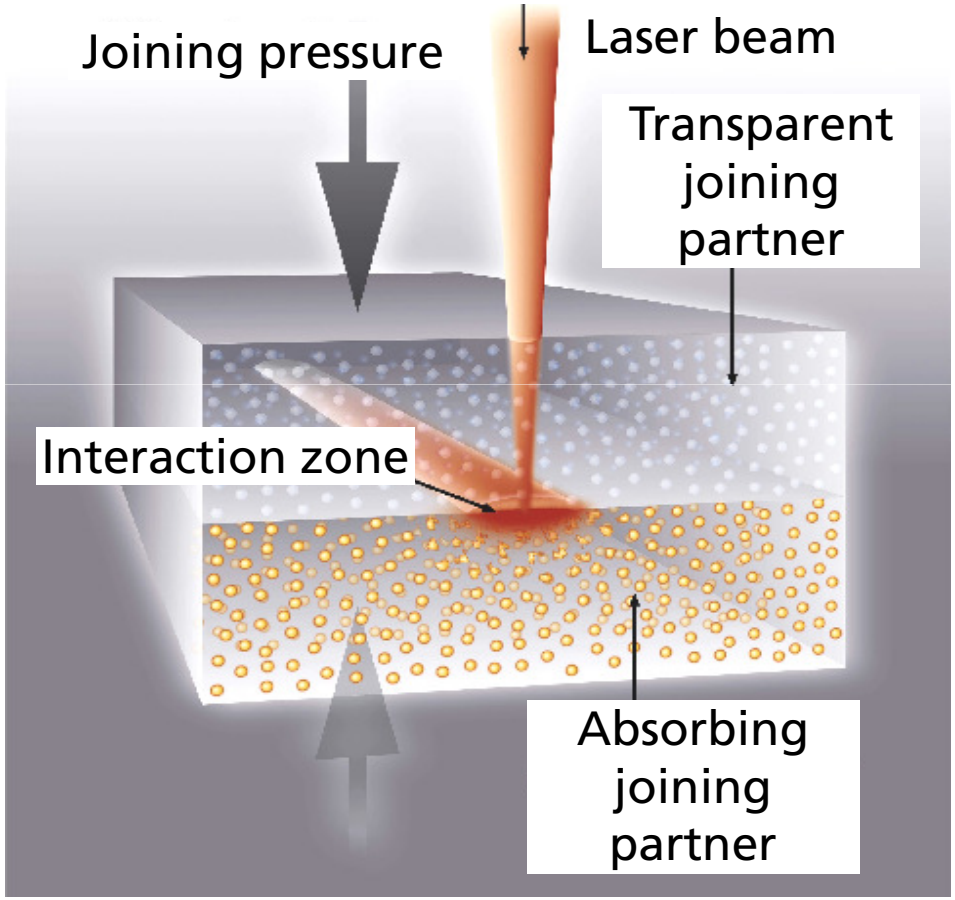
for the transparent joining partner

$\delta_{opt} >> d$

for the transparent joining partner

$\delta_{opt} << d$

d – thickness of the polymeric part



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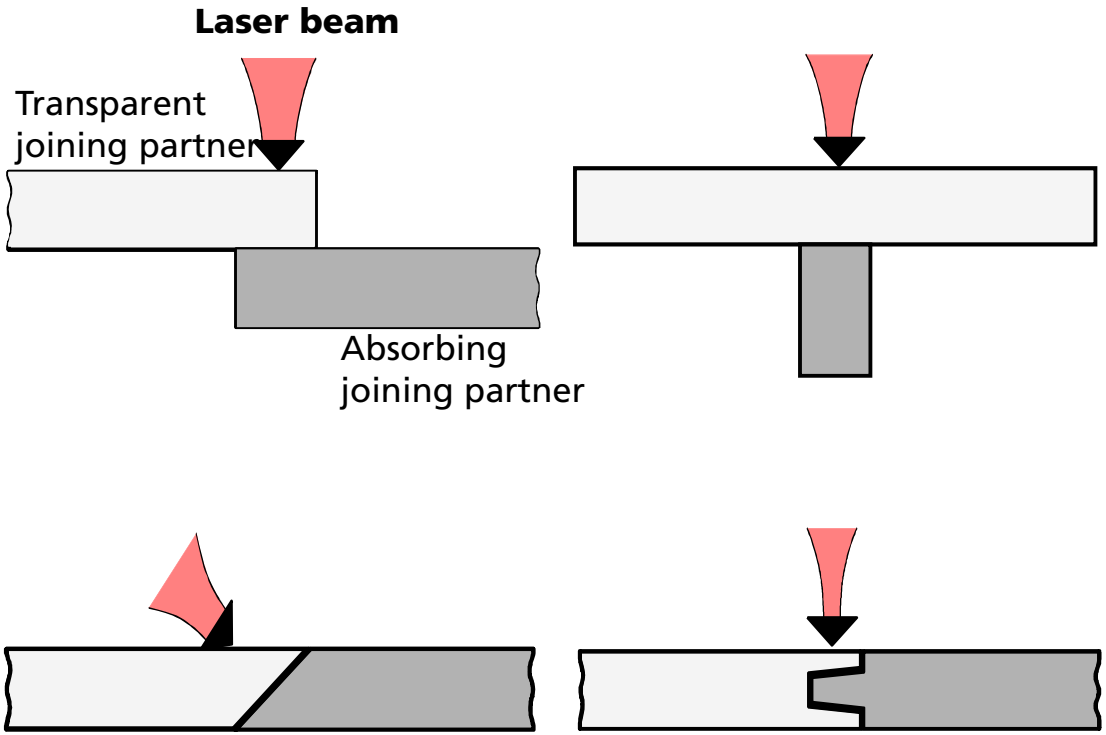
Basics of laser welding of polymers

Method – joining partner configuration

Typical joint configurations for the transmission welding of polymers



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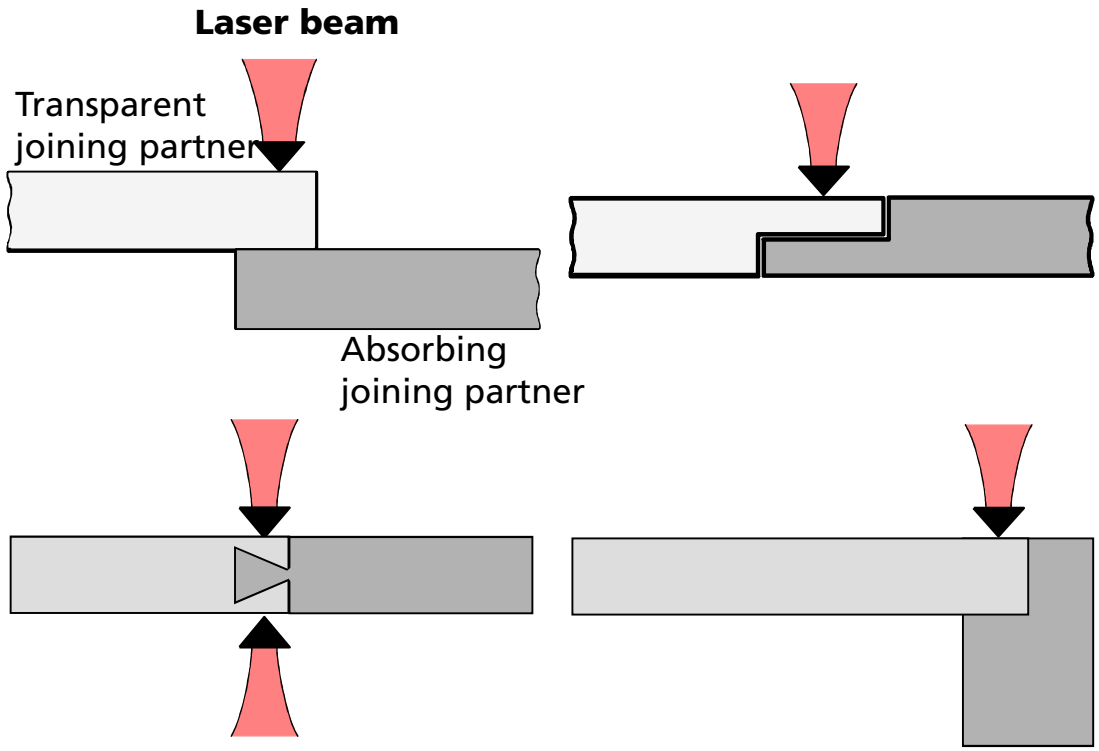
Basics of laser welding of polymers

Method – joining partner configuration

Typical joint configurations for the transmission welding of polymers



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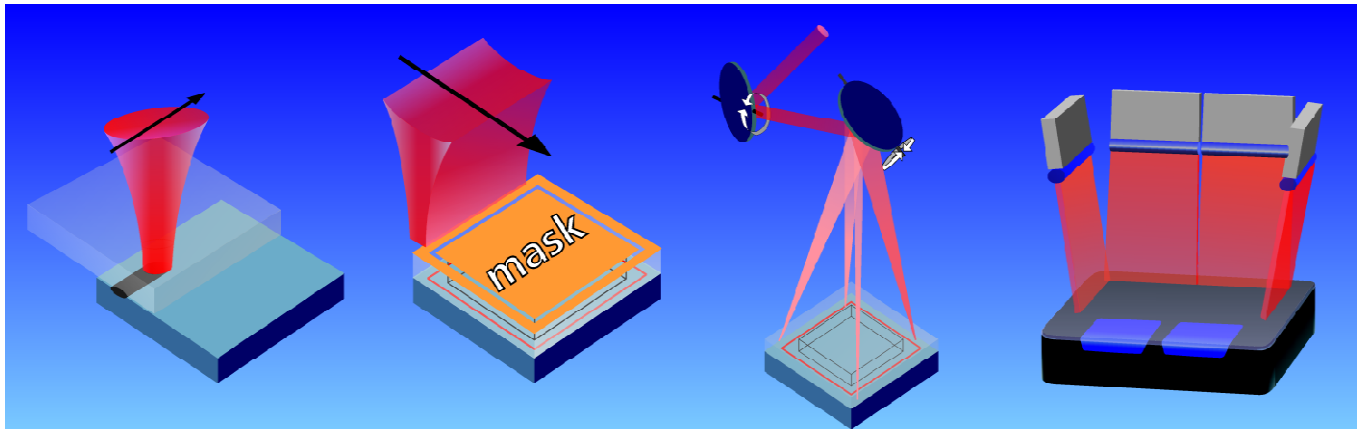
Basics of laser welding of polymers

Method – Irradiation strategy



	Konturschweißen	Maskenschweißen	Quasisimultanschweißen	Simultanschweißen
Laserquelle	HPDL / YAG / Faserlaser	HPDL	HPDL / YAG / Faserlaser	HPDL
Spotdurchmesser [µm]	> 200 / 20 / 10	50 x 40000	> 200 / 20 / 10	-
Laserleistung [W]	< 200	< 300	> 200	> 200
Vorschub-geschwindigkeit [m/ min]	< 25	< 10		-
Wechselwirkungszeit [ms]	> 1	> 2,5	> 0,002	> 50

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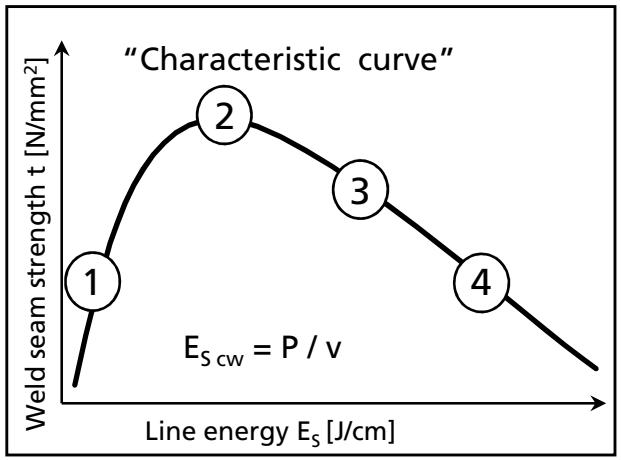
Basics of laser welding of polymers

Method – process parameters

Line energy (Energy deposition , interaction time)

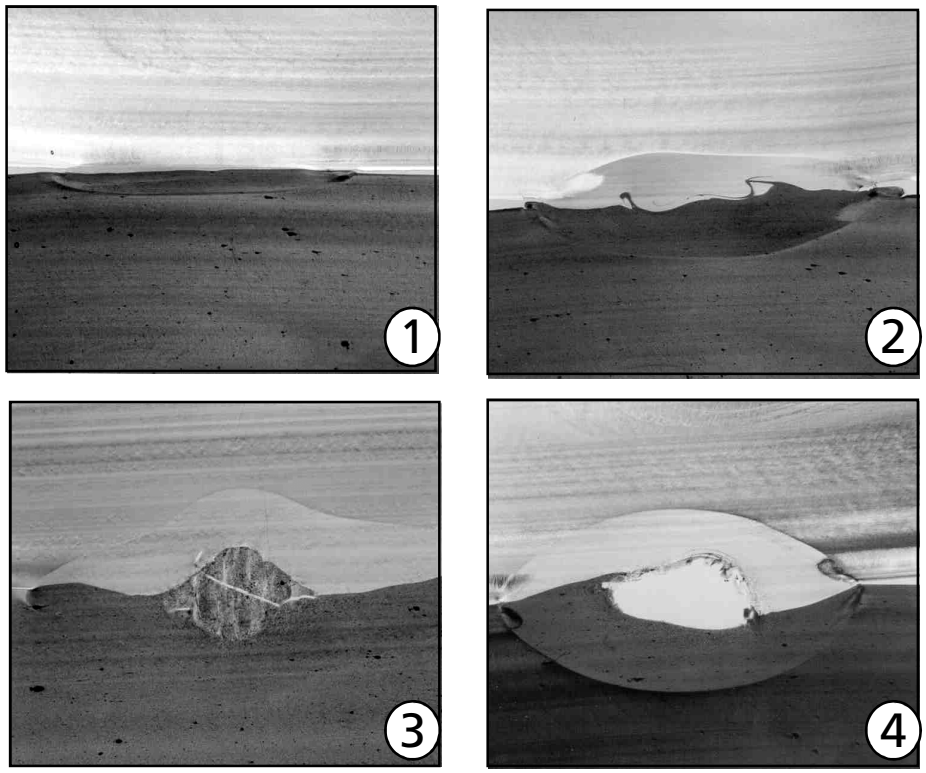


1 Low adhesion

2 Optimal welding

3 Pore formation

4 Thermal degradation



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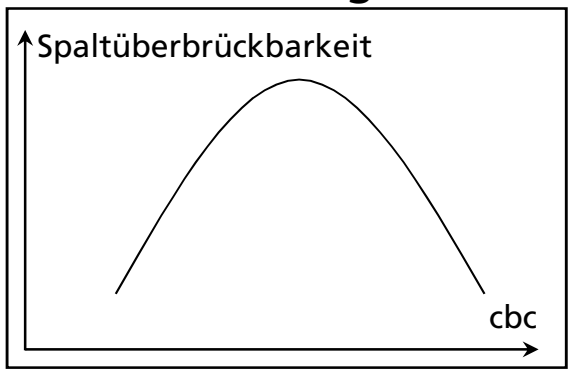
Basics of laser welding of polymers

Work piece – physical properties

- Optical Properties:
  - Reflection - Fresnel-Equations
  - Transmission - reduced energy deposition
  - Absorption - energy conversion, optical penetration depth
  - Scattering - energy distribution, forward /back scattering
- Thermal Properties:
  - Melting and degradation temperature
  - Thermal conductivity, specific heat
  - Thermal expansion, etc.
- Mechanical properties



Influencing factors on the physical properties of the joining partners

- Material fillers and additives
- Morphology, crystallization degree
- Production conditions, thickness or surface condition

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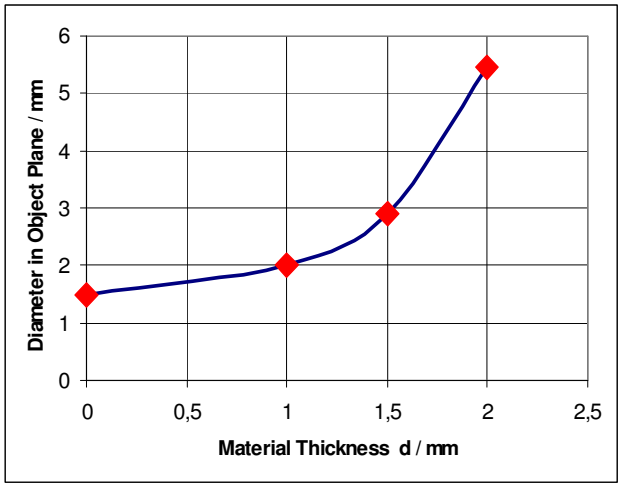
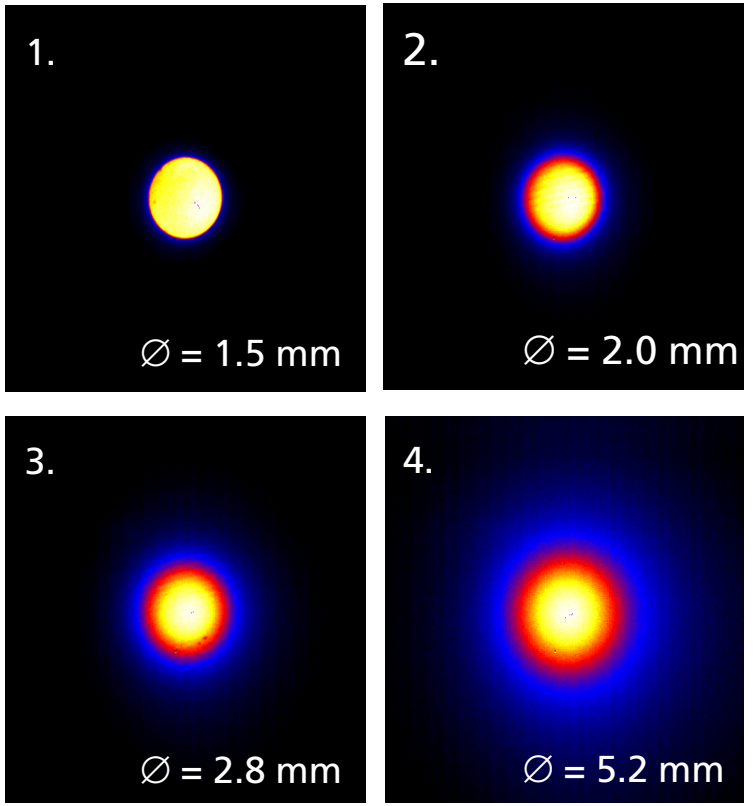
Basics of laser welding of polymers

Work piece – physical properties

Scattering effect for a radial symmetric laser intensity distribution

1. Reference beam
2. POM (t= 1.0 mm)
3. POM (t= 1.5 mm)
4. POM (t= 2.0 mm)





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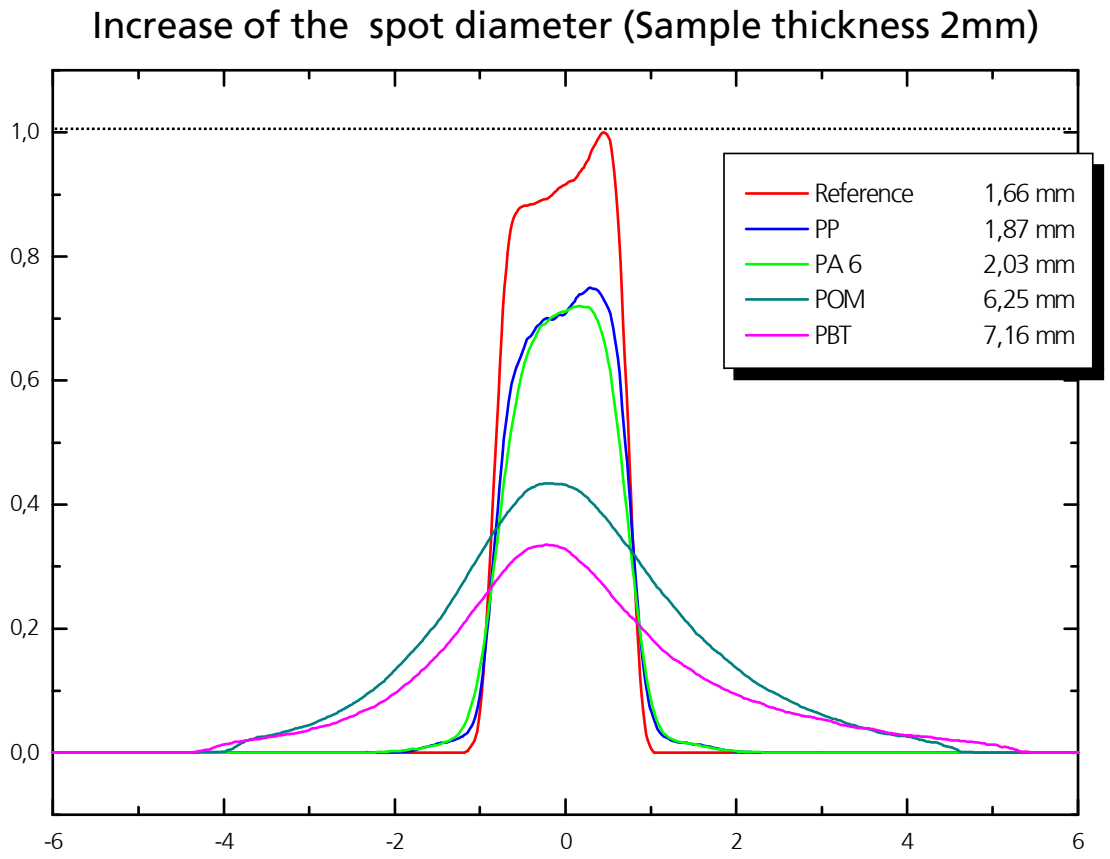
Basics of laser welding of polymers

Work piece – physical properties

Scattering effect for a radial symmetric laser intensity distribution

Scattering leads to an increase of the laser spot diameter in the welding area and therefore to the need to increase the laser power



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Basics of laser welding of polymers

Work piece – polymer compatibility

Compatible heterogeneous material combinations:

ABS - PC
ABS - PMMA
ABS - PBT
PBT - PC
PMMA - SAN
PP - PE
…

	ABS	PA 6 (tk)	PA 66 (tk)	PC	PE-HD (tk)	PE-LD (tk)	PMMA	POM (tk)	PP (tk)	PS	PBT (tk)	SAN	TPE	PPS
ABS	■			■	O	O	■	■	O	O	■	■	■	
PA 6 (tk)		■			~	~			~	■	■			
PA 66 (tk)			■	~	~	~			~	■	■			
PC	■		~	■	O	O			O	O	■	■		■
PE-HD (tk)	O	~	~	O	■	■	~	~	O	O	O	O		
PE-LD (tk)	O	~	~	O	■	■	~	~	■	O	O	O		
PMMA	■				~	~	■	■	~	■		■		
POM (tk)	■				~	~	■	■	~	O				
PP (tk)	O	~	~	O	O	■	~	~	■	O	O	O	■	
PS	O	■	■	O	O	O	■	O	O	■	O	O	O	
PBT (tk)	■	■	■	■	O	O			O	O	■	■		
SAN	■			■	O	O	■		O	O	■	■		
TPE									■				■	
PPS				■										■

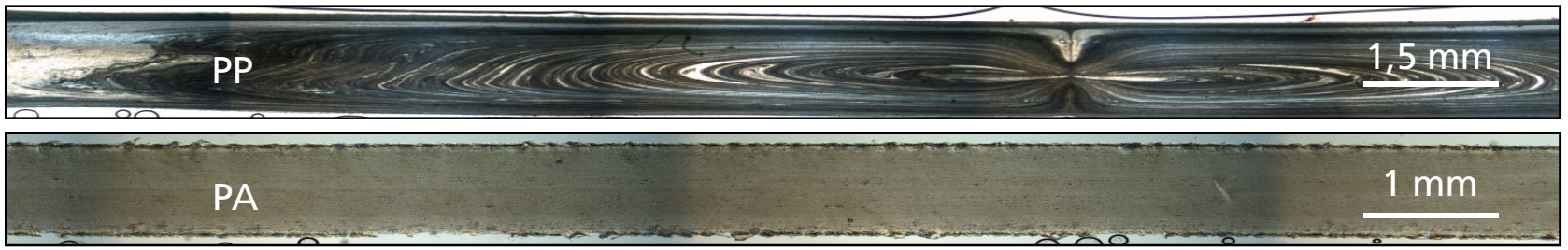
Legend

■ Very good welding
■ Good welding
■ Accelptable welding
~ Low adhesion
O No welding possible

Basics of laser welding of polymers

Pre- and post-processing of the joining partners

- Manufacturing conditions – influence on the mechanical and optical properties (homogeneity of the absorber centers)
- Thermal pre or post processes (Flame treatment, Plasma treatment)
- Coating (UV filtering, protective coatings)
- Electrostatic charges (attraction of dust particles)
- Environmental conditions (Humidity, chemical aggressive environment)



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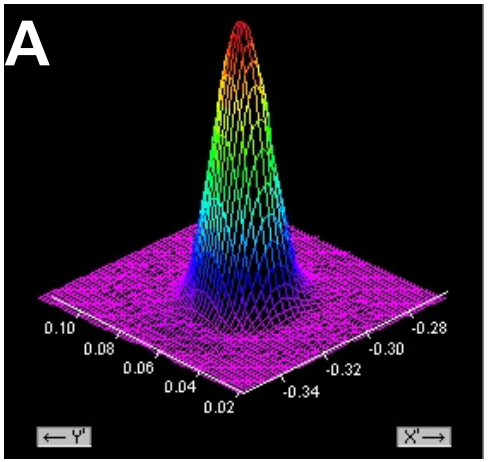
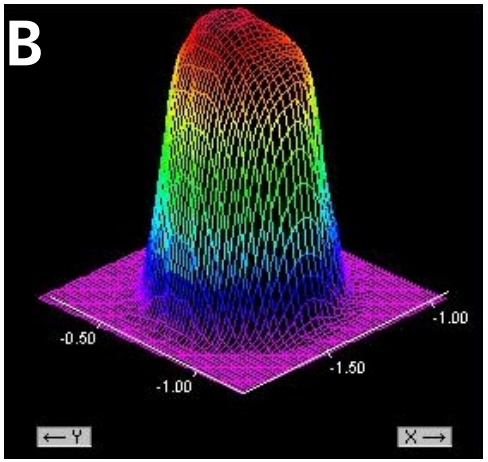
Innovative approaches for the polymer welding

TWIST® - a new welding process

A) Faserlaser
$2w_0$= 38 µm
P= 3 W
I ~ 260.000 W/ cm²

B) Diodenlaser
$2w_0$= 600 µm
P= 3 W
I ~ 1.000 W/ cm²





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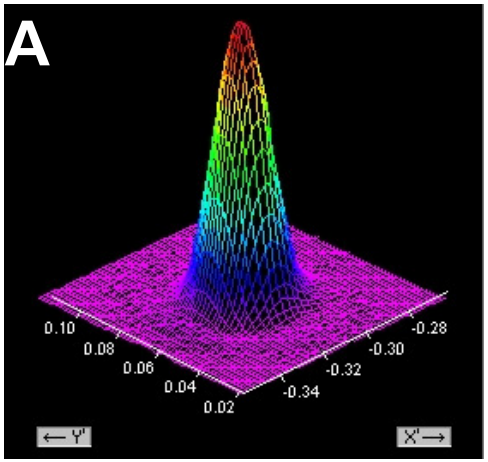
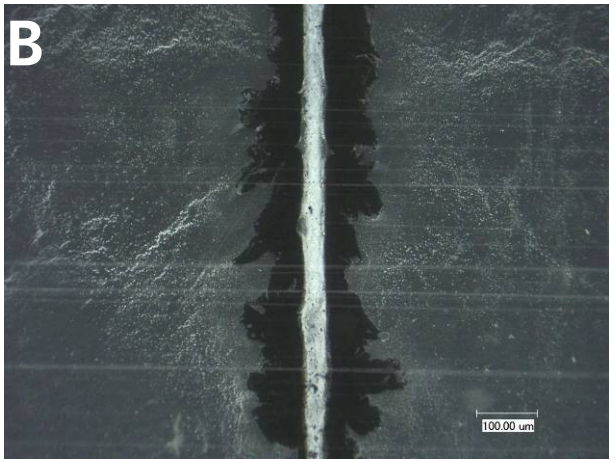
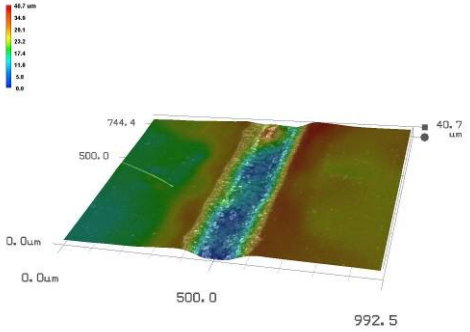
Innovative approaches for the polymer welding

TWIST® - a new welding process

B) $2w_0$= 38 µm
P= 3 W
v= 200 mm/ s
I= 264.523 W/ cm2







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Innovative approaches for the polymer welding

TWIST® - a new welding process

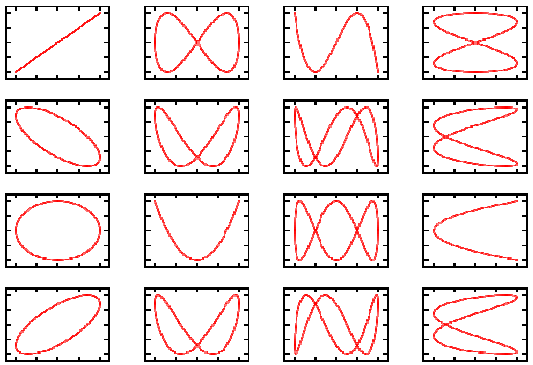
Transmission

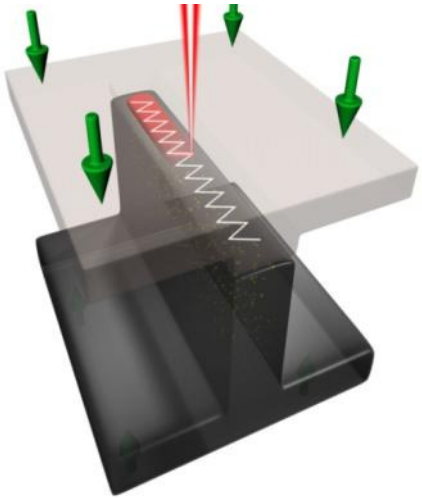
Welding

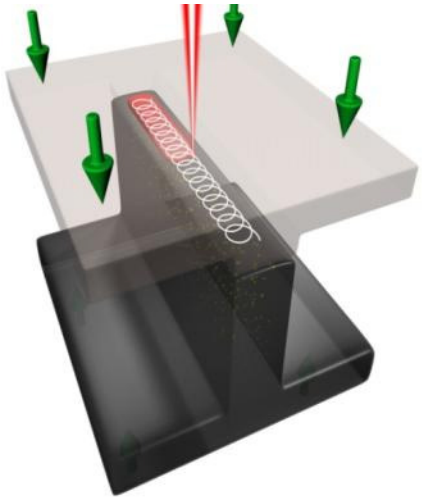
Incremental

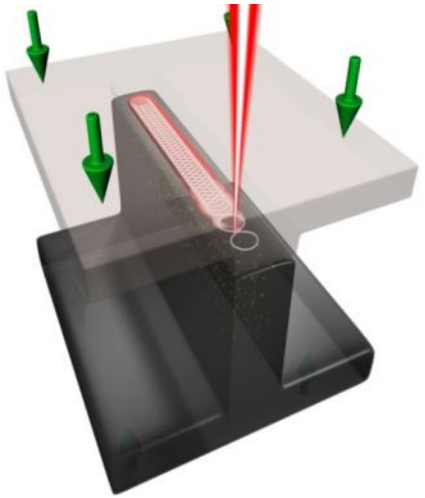
Scanning

Technique









Innovative approaches for the polymer welding

TWIST® - a new welding process

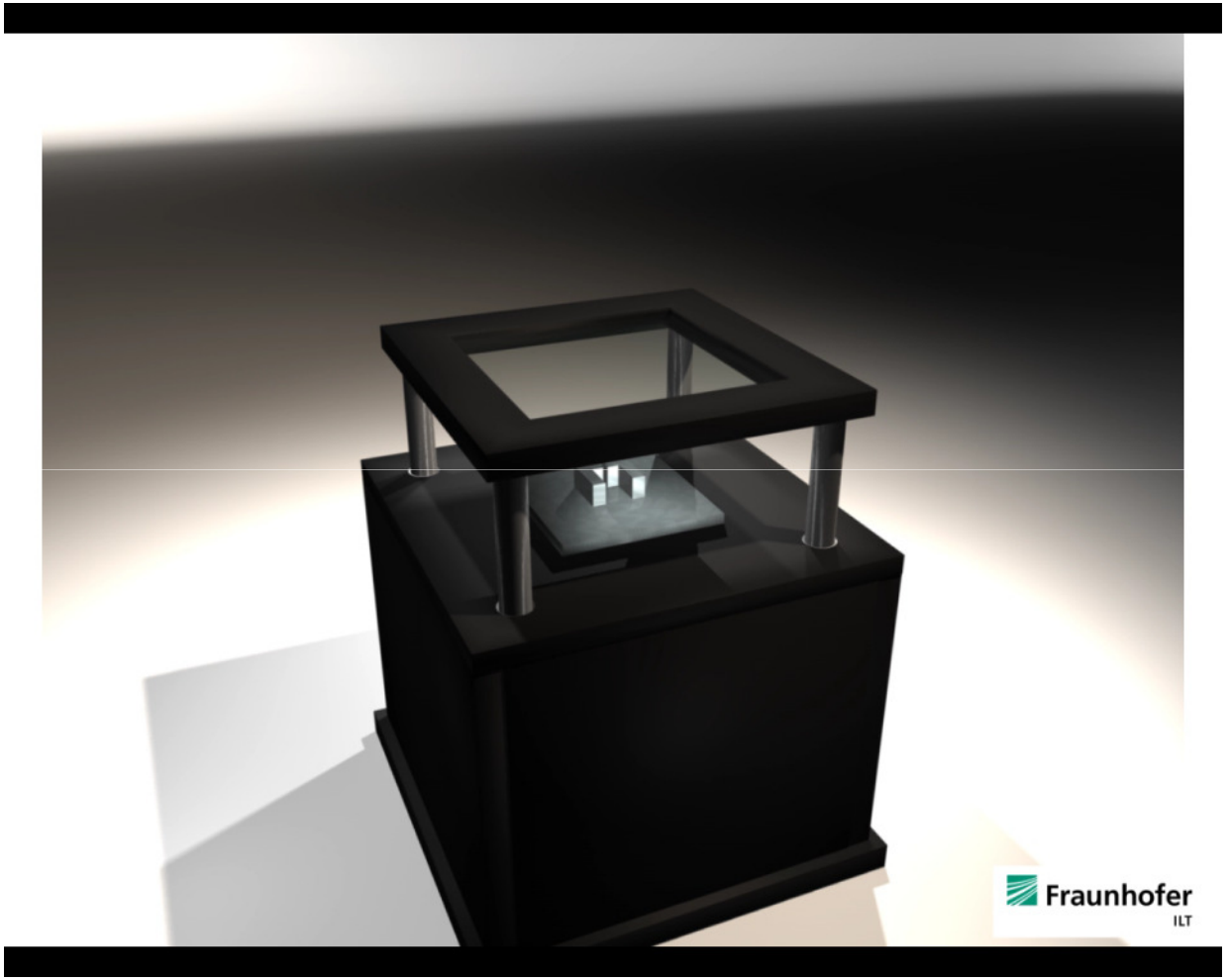
Transmission

Welding

Incremental

Scanning

Technique



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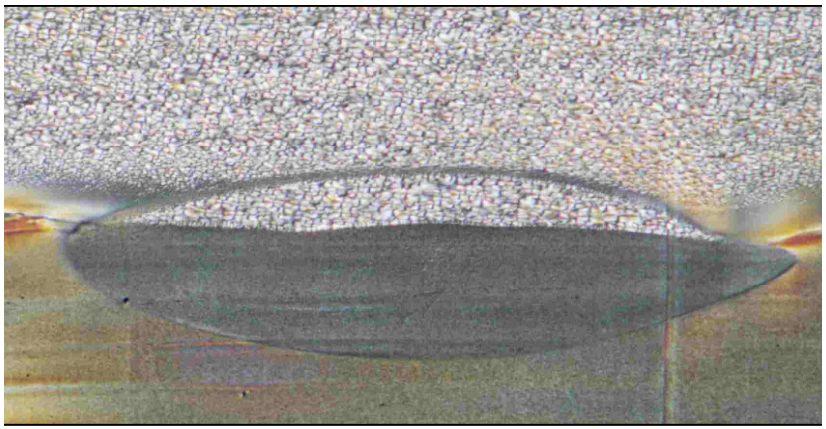
Innovative approaches for the polymer welding

TWIST® - a new welding process

- More homogeneous energy distribution across the weld seam width
- Higher processing speed possible
- Flatter Heat Affected Zone



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Innovative approaches for the polymer welding

TWIST® - a new welding process

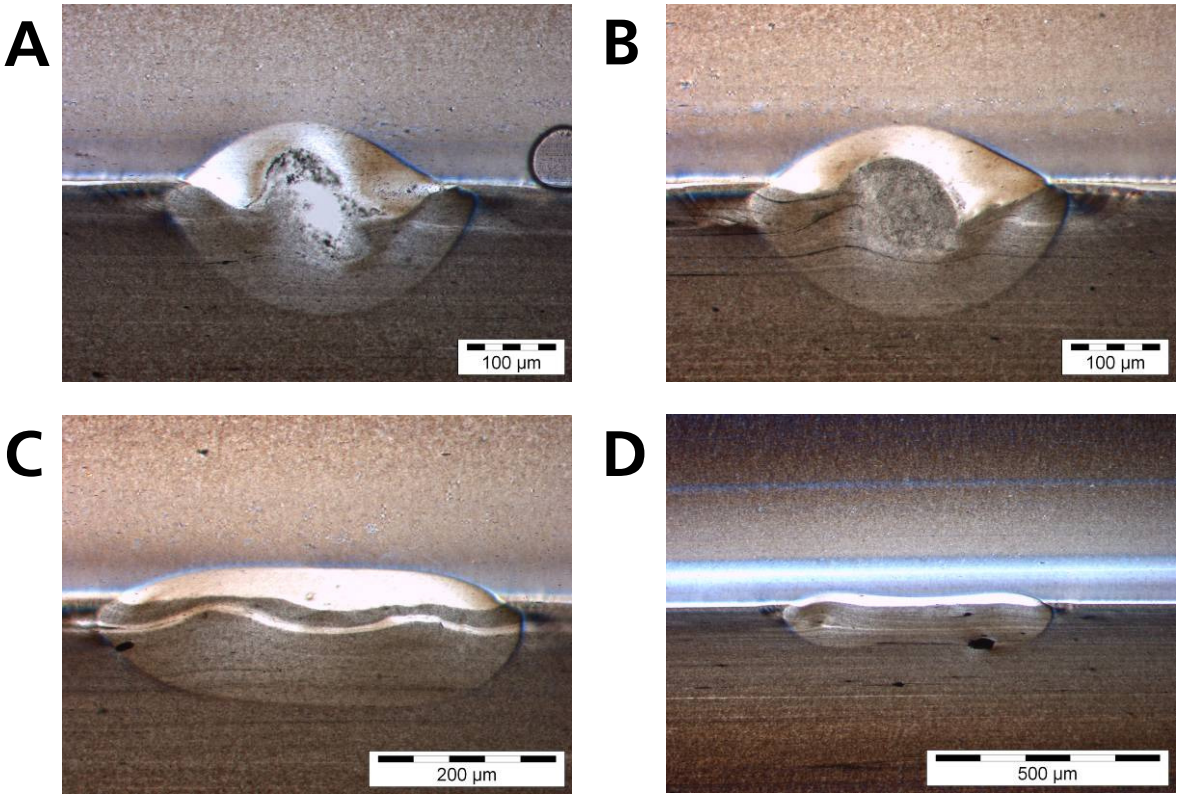
Process parameters

A) P= 4 W
f= 2500 Hz
A= 0,05 mm
v= 50 mm/s

B) A= 0,1 mm

C) A= 0,2 mm

D) A= 0,3 mm



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Innovative approaches for the polymer welding

TWIST® - a new welding process

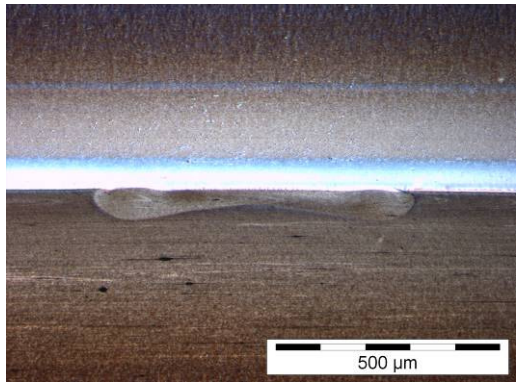
Process parameters

A) P= 3 W
f= 2500 Hz
A= 0,4 mm
v= 50 mm/s

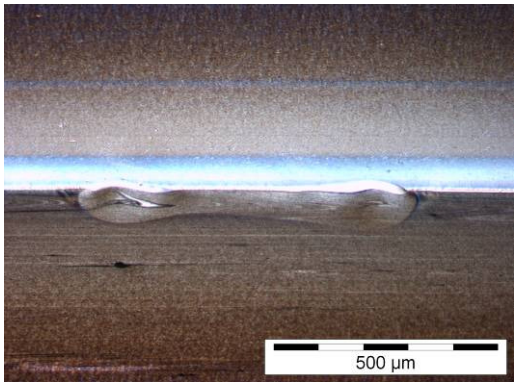
B) P= 4 W

C) P= 5 W

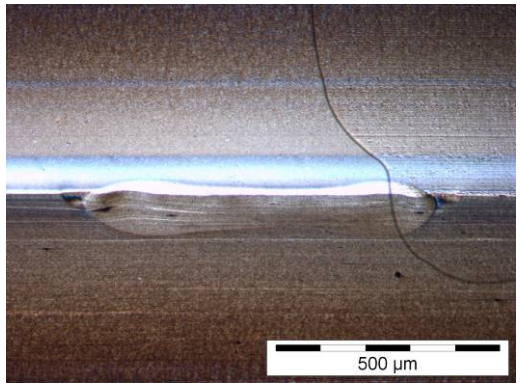
A



B



C



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Innovative approaches for the polymer welding

TWIST® - a new welding process

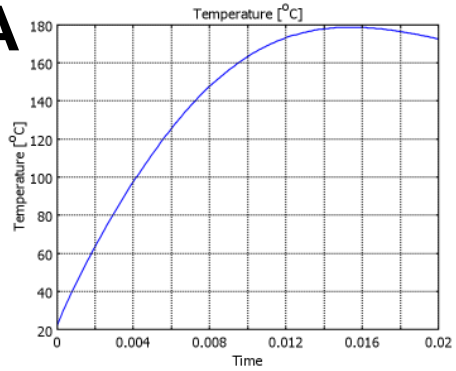
Process parameters

A) Line
P= 6,5 W
v= 50 mm/s

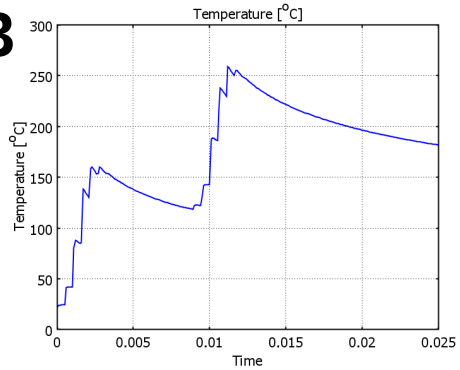
B) Circles
P= 3 W
v= 50mm/s
r= 0,225
f= 1800 Hz

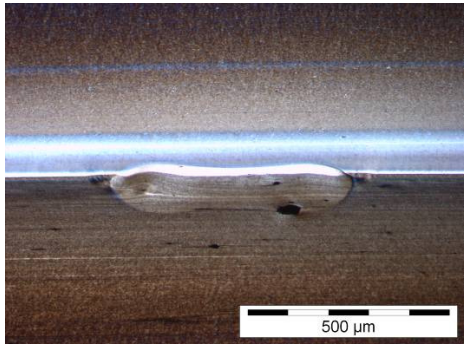
C) Eight shapes
P= 3 W
v= 150 mm/s
r= 0,250 mm
f= 2000 Hz

A

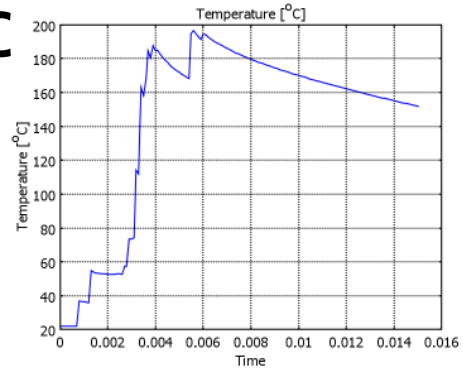


B





C



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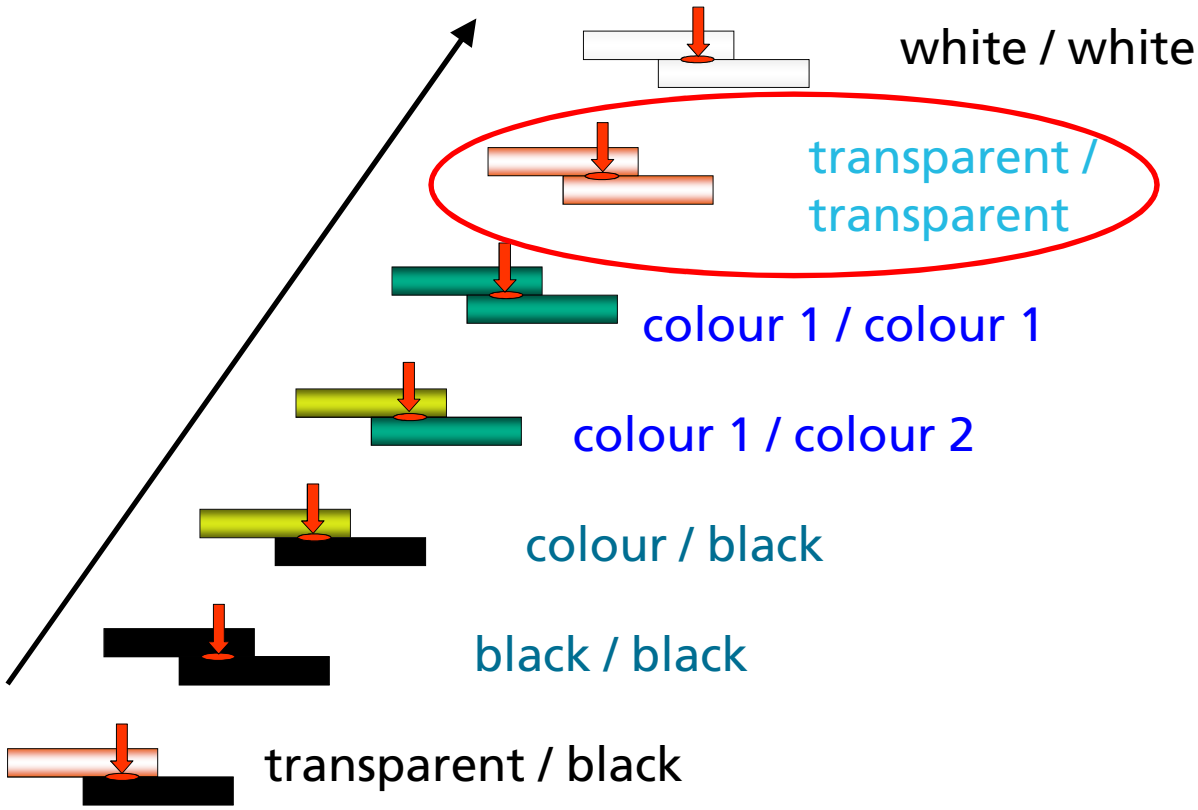
Innovative approaches for the polymer welding

Welding of transparent polymers

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



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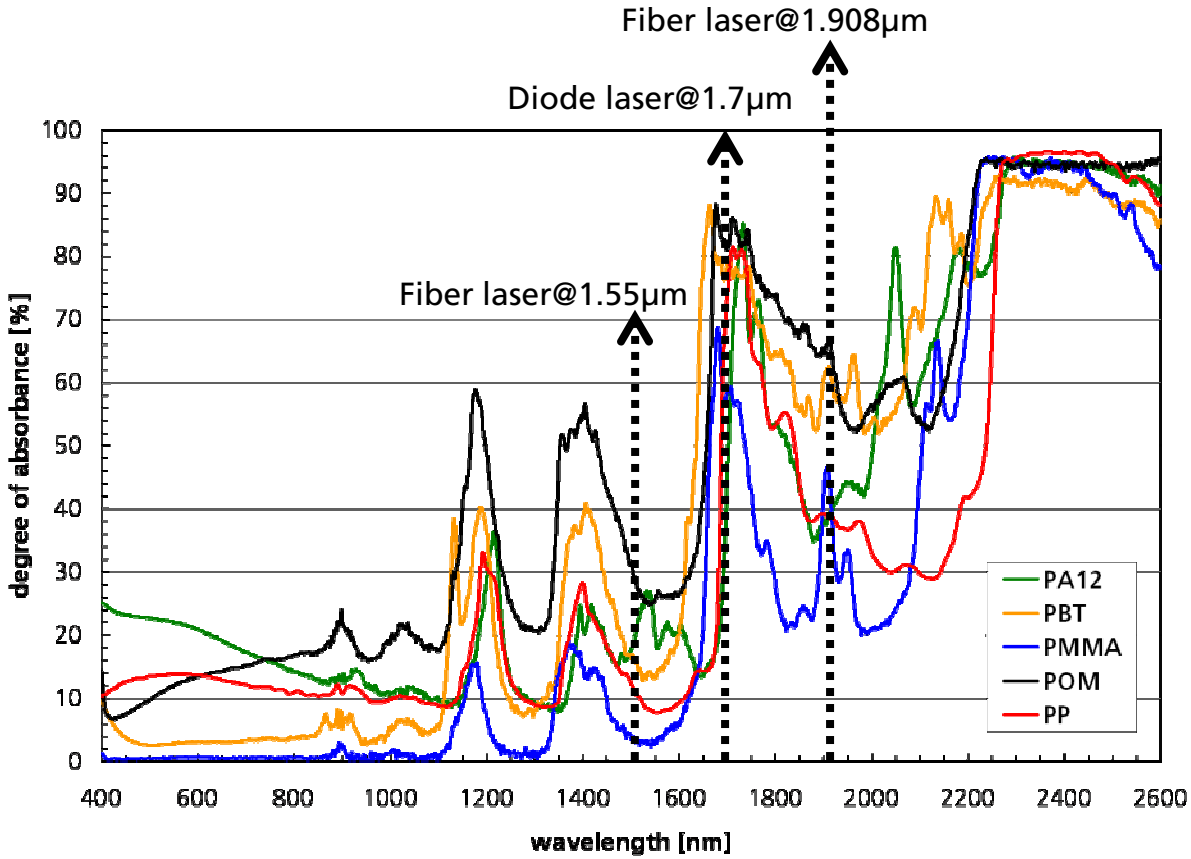
Innovative approaches for the polymer welding

Welding of transparent polymers

- 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



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Innovative approaches for the polymer welding

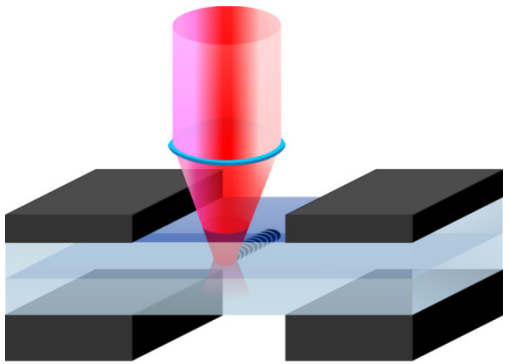
Welding of transparent polymers

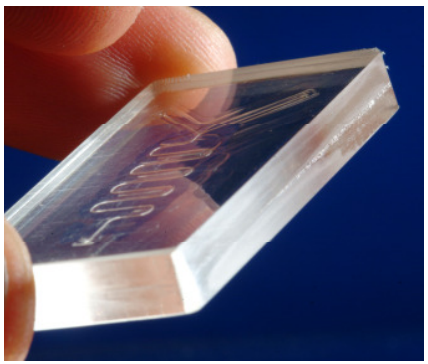
Concept

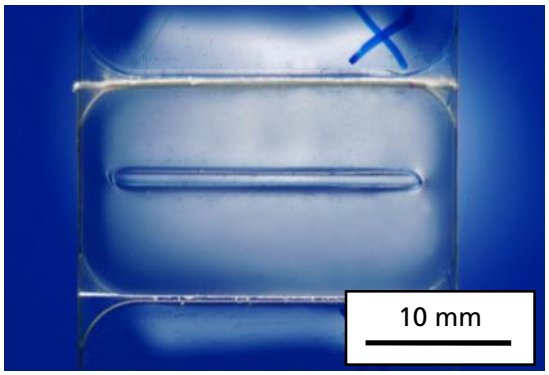
- Adjusted wavelength of laser source
- High numerical aperture optics

Result

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







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Innovative approaches for the polymer welding

Welding of transparent polymers

Variation of focal position

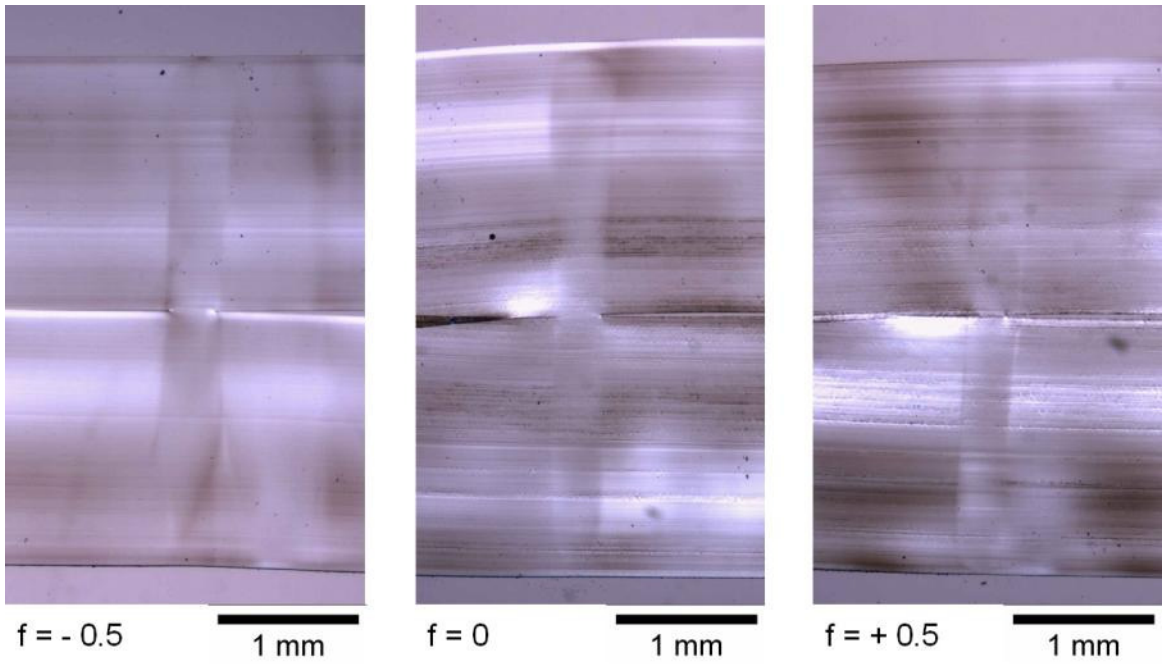
Fiber laser @1.55µm

Laser power: P= 100 W

Feed rate: v= 2 m/min

Optimal setting prevents melting of surface and deliver smallest width of heat affected zone

No further limitation of depth of heat affected zone



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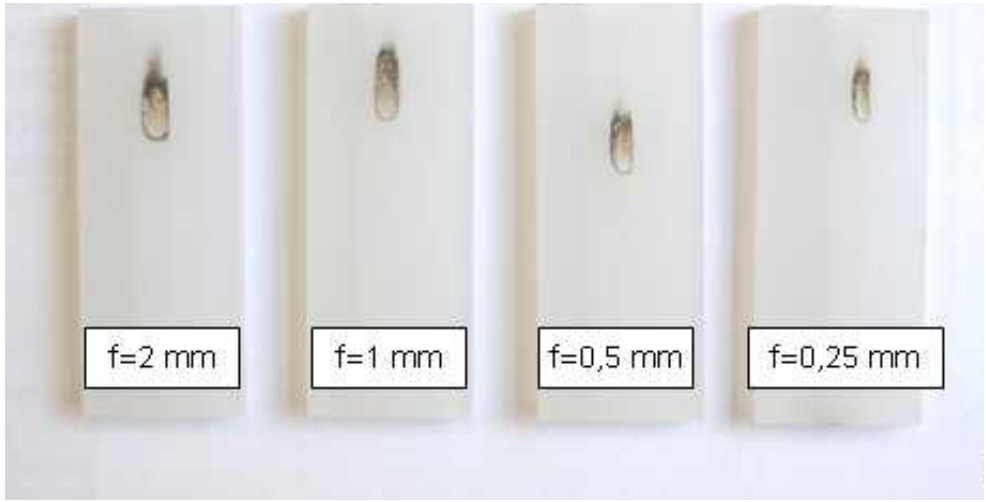
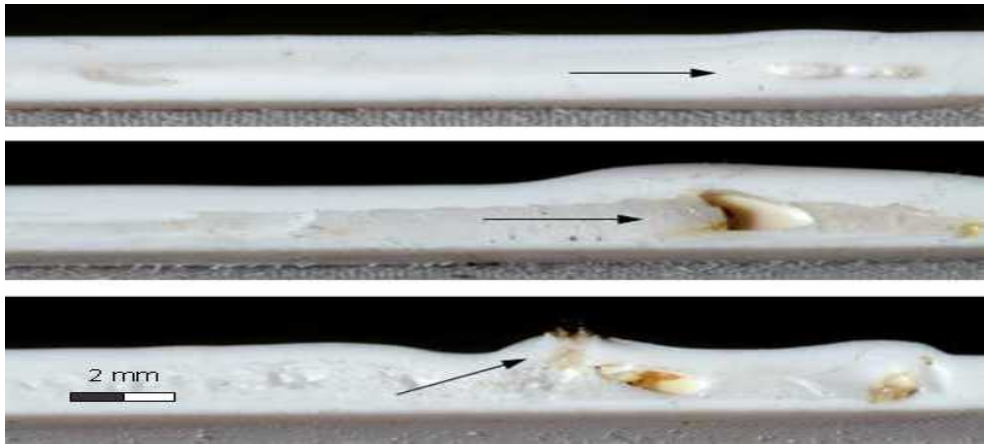
Innovative approaches for the polymer welding

Welding of transparent polymers

Due to the reduced absorption at 1.55 µm and therefore higher laser power needed, the thermal damage of the joining partners can occur





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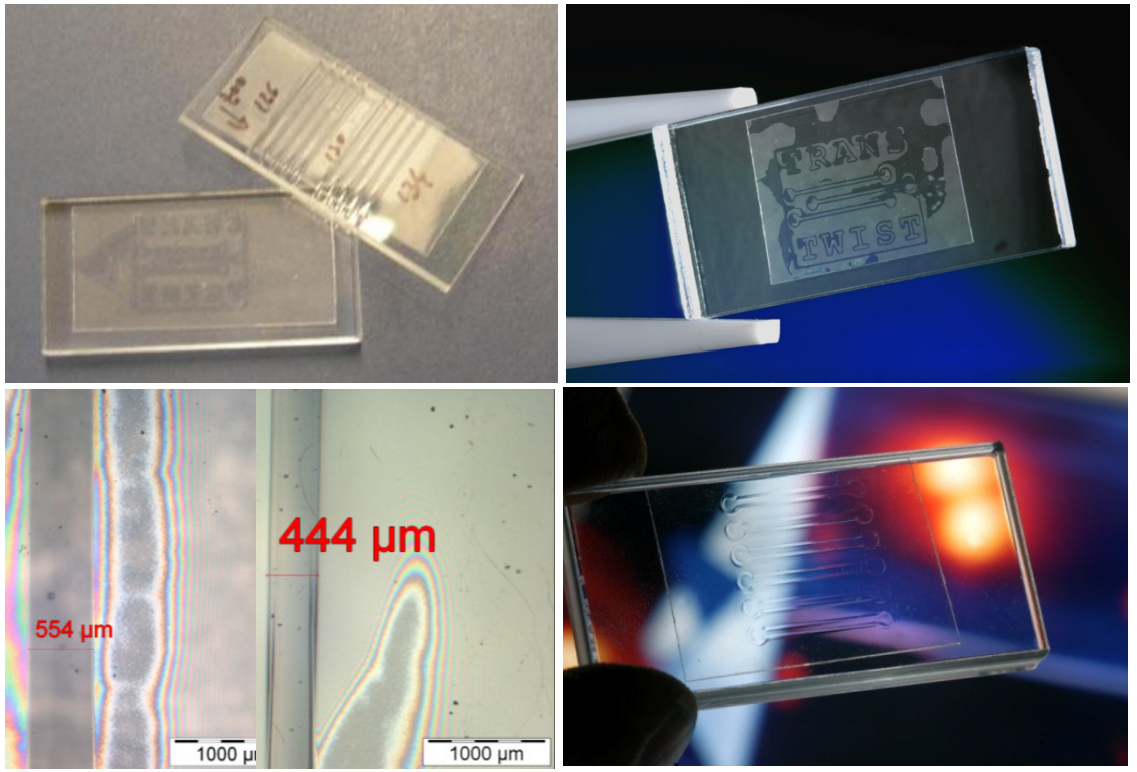
Innovative approaches for the polymer welding

Welding of transparent polymers

- Diode laser @1.7µm
- Fiber laser @1.908µm
- Material - PMMA
- Feed rate up to
  v= 3 m/min



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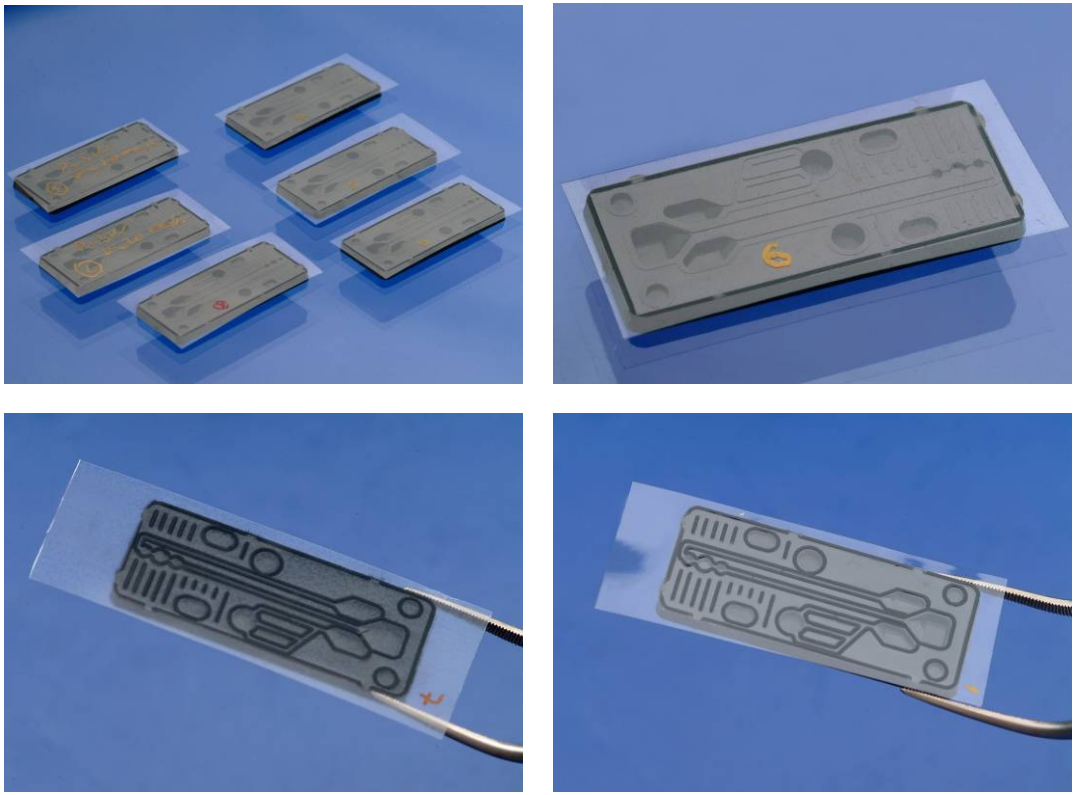
Application examples

Welding of microfluidic devices

Microfluidic device
- PMMA or PP

Cover foil (75 µm)
-PMMA or PP

P= 1,4 – 6,6 W
v= 50 up to 300 mm/s
d_0= 70 µm
D_{weld}=100 up to 500 µm



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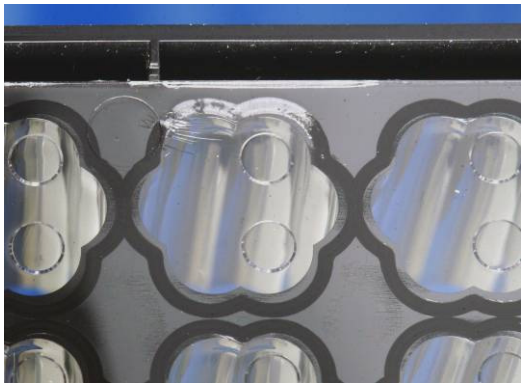
Application examples

Welding of multi-well plates

Multi well plate
- Polystyrene (PS)

Bottom part (1 mm)
- Polystyrene (PS)

P= 2,7 – 3,5 W
v= 16 up to 30 mm/s
d_0= 75 µm
d_{weld}= 700 µm



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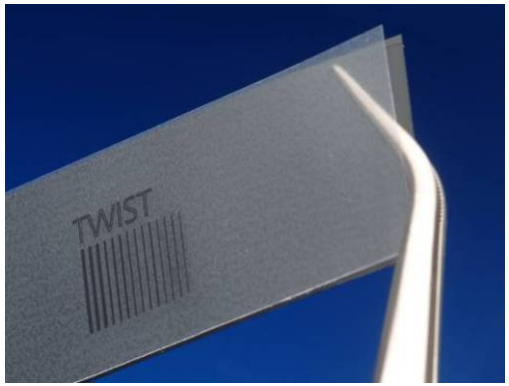
Application examples

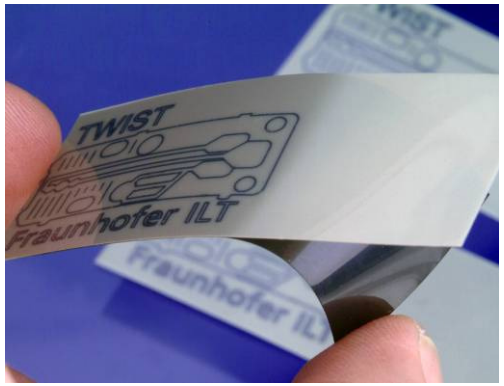
Welding of foils

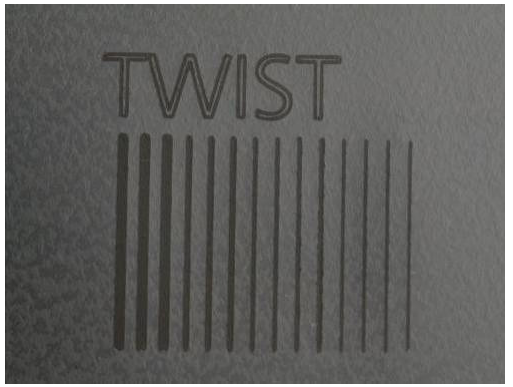
Foils

-Polypropylene (PP) in transparent and black with a foil thickness of 100 µm

P= 1,4 – 5,9 W
v= 50 up to 250 mm/s
d_0= 70 µm
d_{weld}= 150 up to500 µm







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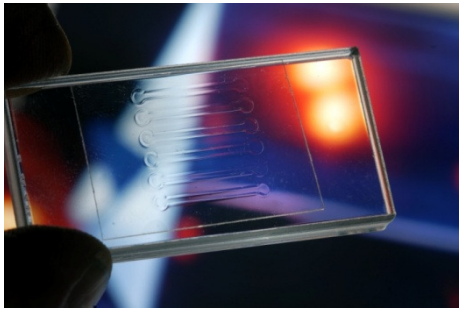
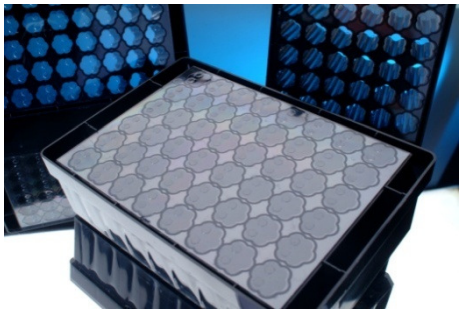
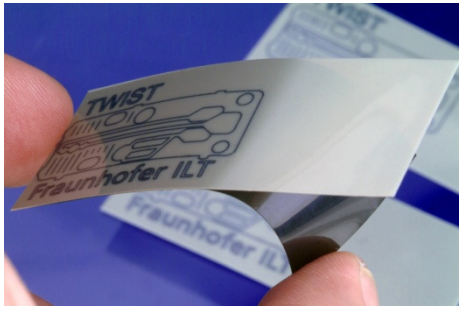
Summary and Outlook







- **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

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Thank you for your attention!

Fraunhofer ILT, Aachen

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