Polymers with Customizable Optical and Rheological Properties based on an Epoxy Acrylate based Host-Guest System

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Collaborative Research Center

- Polymer-based sensor network
- Large-area foils
- No electronic components
- Measurement of
  - Temperature
  - Strain
- Sub-projects
  - Suitable materials
  - Construction of fiber optics
  - Light sources
  - Spectrometers / detectors

polymer foil
[http://www.planos.uni-hannover.de]
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Why polymers?

- Modifiable to application
- Good processability
  - Hot embossing
  - NIL
  - Inkjet-printing
  - ...
- Large-scale systems possible
- Thin layers = economic

polymer foil

[http://www.planos.uni-hannover.de]
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Tailored polymers

- Adjusting viscosity
- Polymerization by UV-light
- Adjusting refractive indices
- Low optical damping
- Continuous operating temperature
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Tailoring viscosity

- Comonomer content
- Different shaping / molding processes
  - Inkjet printing
    \( \approx 10 \text{ mPa}\cdot\text{s (@ 70 °C)} \)
  - Offset printing
    \( \approx 200 \text{ mPa}\cdot\text{s (@ RT)} \)
  - Spin coating
    \( \approx 100 \text{ mPa}\cdot\text{s – 1000 mPa}\cdot\text{s (@ RT)} \)

Dimatix DMP 2831 [www.electronic-data.com]

Heidelberg Speedmaster SM 52 [www.heidelberg.com]
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Adjustment of refractive indices

- Comonomer / dopant
- Waveguides
  - Core
  - Cladding
- Coupling structures

Computed 3D model of printed waveguide (Wolfer et al, Procedia Technology, 2013)
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Materials

- **Main monomer**
  - Epoxy Methacrylate 97-053 (RAHN)

- **Comonomer**
  - Benzyl methacrylate

- **Dopant**
  - Phenanthrene

- **UV initiator**
  - Phosphine oxide

- **Thermal initiator**
  - Lauroyl peroxide
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Radical polymerization

\[
\text{Init}\quad +\quad \text{H}_2\text{C} \quad \text{COR} \quad \rightarrow \quad \text{IniH}_2\text{C} \quad \text{COR} \quad \text{H}_2\text{C} \quad \text{COR} \quad \rightarrow \quad \text{h}^{n}
\]
Mixture preparation

- Materials are mixed
  - up to 30,000 rpm
  - ambient conditions
- Ultrasonic bath

- Viscosity measurement
  - Cone and plate rheometer

IKA T10 basic
[http://static.coleparmer.com]

Bohlin Rheometer CVO 50
[http://mb.uni-paderborn.de/]
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**Sample preparation**

- For refractive index
  - Casting mold (silicon)
  - Glass plates
  - Fluorine ethylene propylene (FEP) foil

- Oxygen inhibition
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mold assembly
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- Oxygen inhibition

- Polymerization
  - Wavelength 405 nm

Hönle UV-Spot 100
[www.hoenle.de]
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Sample preparation

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- Oxygen inhibition

- Polymerization
  - Wavelength 405 nm
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Sample characterization

- Refractive indices
  - Abbe-refractometer
  - Multi-wavelength

- Optical damping
  - UV-Vis spectroscopy

- Differential scanning calorimetry (DSC)
  - Glass transition temperature

ATAGO DR-M2/1550
[www.atagorus.ru]

Varian Cary 50 UV-Vis
[www.speciation.net]
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Viscosity of Epoxy Methacrylate 97-053 + BMA

- Temperature dependency
- Newtonian behavior

![Graph showing temperature dependency and Newtonian behavior of Epoxy Methacrylate 97-053 + BMA.](image)
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Viscosity of Epoxy Methacrylate 97-053 + BMA

- Dependence on BMA
- Dependence on phenanthrene

![Graph showing viscosity dependence on BMA and phenanthrene](image-url)
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Refractive index

- Polymerized samples
- Phenanthrene increases refractive index
  - 0 wt%: 1.568 – 1.570
  - 5 wt%: 1.575 – 1.577
  - 10 wt%: 1.585 – 1.586
- BMA has low influence
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Data combined

- Viscosity
  - Refractive index
- Refractive index
  - Viscosity
- Easy lookup

Epoxy Methacrylate 97-053 + BMA
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Abbe number

- Polymerized samples
- Phenanthrene decreases Abbe number
- BMA has low influence
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Optical damping of Epoxy Methacrylate (EM) + BMA

- Independent on BMA
- Dependent on phenanthrene
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Printed “waveguide”

- Ink-jet
  - width appr. 180 μm
  - height appr. 40 μm

Image of inkjet-printed waveguide taken by confocal microscopy

[Wolfer et al., Procedia Technology, 2014]
Spincoated waveguide

- width appr. 10 μm
- height appr. 5 μm
- monomode

Output facet of a fabricated single-mode inverted rib waveguide

[Gleissner et al., Eurosensors Conference, 2015]
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Self writing waveguide

- Laser writing through monomer
- Between two fibers
- Low loss connection

Schematic of the different process steps of the self-written waveguide formation

[ Günther et al., Optics Letters, 2015]
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Summary

- Viscosity adjustable in a wide range
  - $1.5 \text{ Pa}\cdot\text{s} > \eta > 8 \text{ mPa}\cdot\text{s} (@ 20 \, ^\circ\text{C})$
  - Suitable for different shaping methods
  - Range can be extended
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- Refractive index tunable
  - $1.570 < n < 1.585 (@ 20 \degree\text{C}, 589 \text{ nm})$
  - Independent of viscosity
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  - Independent of viscosity

- Dispersion
  - Abbe numbers: 29 to 38

- Optical damping
  - As low as 0.15 dB/mm @600 nm
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