JENOPTIK Laser, Optik, Systeme GmbH

- Was established on July 1, 1995 as 100% subsidiary of the JENOPTIK AG.
About JENOPTIK
History of JENOPTIK

Carl Zeiss sets up workshop for precision mechanics in Jena

Ernst Abbe established the Carl-Zeiss-Foundation in Jena

Ernst Abbe, professor at the university of Jena, joins the company, designing microscopes

Zeiss Jena is converted into a state-owned enterprise doing business in the name of VEB Carl Zeiss Jena

The state-owned Kombinat VEB Carl Zeiss JENA is converted into JENOPTIK Carl Zeiss JENA GmbH

JENOPTIK GmbH

JENOPTIK AG

Jenoptik Carl Zeiss JENA GmbH

splits up into:

Carl Zeiss Jena GmbH

JENOPTIK GmbH

1846

1866

1889

1948

1990

1991

1995

1860

1964

1973
JENOPTIK PC Micro Engineering

JENOPTIK Laser, Optik, Systeme GmbH

Export Ratio: 80%

Pioneer and Market leader: Developing Imprinting Technology since 1992
76 Jenoptik HEX_Systems // 43% market share
Portfolio - PC Mikrotechnik

JENOPTIK Laser, Optik, Systeme GmbH

Portfolio

Hot Embossing Solutions
- HEX01
- HEX02
- HEX03
- HEX04
- UV-Modul

Applications & Service
- Manufacturing, Planning & Process Assistance
- micro/nano components:
  - optical: e.g. lenses, gratings, holograms
  - fluidic: e.g. channels, life science, PCR’s
- continuous development of technology & equipment
- partner University Freiburg

Lithography Solutions
- X-Ray Scanner
  - DEX02
  - DEX03
  - DEX04
- Monochromator
  - MGU1
  - MGU2
- complete Beamline partner Bestec GmbH

partner Bestec GmbH
Hot Embossing Solutions
Hot Embossing Process Schematics
HE – Temperature Pattern Chart

- Temperature top in °C
- Temperature bottom in °C
- Force in N
HE - Process Schematic at Jo-MT

**Chemical sealing**
- glue, solvents
- Thermal

**Most critical step**

**De-Embossing**
- O₂-Purging

**Active De-Embossing**

**Vacuum**

**Condition**

**Process**

**Master**
- Rₐ down to 100nm
- Bending down to 20µm

**Precise Engineering**
- > 100µm

**Si-Machining**
- Wet Etch
- Dry Etch

**Tool Design**

**Substrate & Tool Heating**
- > Tₐ

**Press Tool on the Substrate**
- 20kN-200kN

**Cooling**
- AEROSOL

**Next Step**
- Bonding
- Dicing

**High Resolution Tech.**
- LIGA / UV-LIGA

**Chemical sealing**
- glue, solvents
- Thermal
# Polymers used for Micro Molding

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full name</th>
<th>Temp. Stability in °C</th>
<th>Properties</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>COC</td>
<td>Cycle-olefine/copolymer</td>
<td>140</td>
<td>High transparency</td>
<td>Amorphous</td>
</tr>
<tr>
<td>PMMA</td>
<td>Polymethylmethacrylate</td>
<td>80</td>
<td>High transparency</td>
<td>Amorphous</td>
</tr>
<tr>
<td>PC</td>
<td>Polycarbonate</td>
<td>130</td>
<td>High transparency</td>
<td>Amorphous</td>
</tr>
<tr>
<td>PS</td>
<td>Polystyrene</td>
<td>80</td>
<td>Transparent</td>
<td>Amorphous</td>
</tr>
<tr>
<td>POM</td>
<td>Polyoxymethylene</td>
<td>90</td>
<td>Low Friction</td>
<td>Semi Crystalline</td>
</tr>
<tr>
<td>PFA</td>
<td>Polyfluoralkoxy Copolymer</td>
<td>260</td>
<td>High Chemical resistive</td>
<td>Semi Crystalline</td>
</tr>
<tr>
<td>PVC</td>
<td>Polyvinylchloride</td>
<td>60</td>
<td>Cheap</td>
<td>Amorphous</td>
</tr>
<tr>
<td>PP</td>
<td>Polypropylene</td>
<td>110</td>
<td>Mechanical Properties</td>
<td>Semi Crystalline</td>
</tr>
<tr>
<td>PET</td>
<td>Polyethylene Terephthalate</td>
<td>110</td>
<td>Transparent, Low friction</td>
<td>Amorphous/Semi Crystalline</td>
</tr>
<tr>
<td>PEEK</td>
<td>Polyetheretherketone</td>
<td>250</td>
<td>High Temp. Resistivity</td>
<td>Semi Crystalline</td>
</tr>
<tr>
<td>PA</td>
<td>Polyamide</td>
<td>80-120</td>
<td>Good mech. Properties</td>
<td>Semi Crystalline</td>
</tr>
<tr>
<td>PSU</td>
<td>Polysulfone</td>
<td>150</td>
<td>Chemical and Temp. Resistivity</td>
<td>Amorphous</td>
</tr>
<tr>
<td>PVDF</td>
<td>Polyvinylidenefluoride</td>
<td>150</td>
<td>Chemically inert, piezo-electric</td>
<td>Semi Crystalline</td>
</tr>
</tbody>
</table>
Hot Embossing Process Schematics – Hot Embossing

Hot Embossing
Micro and Nano structuring of polymers for medium and high volume production applications
Hot Embossing Process Schematics – Force
Hot Embossing Process Schematics – De-Embossing
## Polymer Micro and Nano-patterning

### Patterning technology comparison:

<table>
<thead>
<tr>
<th>Technology</th>
<th>Feature Size</th>
<th>Cycle Time</th>
<th>Substrate</th>
<th>Tool/Mold</th>
<th>Aspect Ratio</th>
<th>Applications</th>
<th>Advantages</th>
<th>Dis-advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot Embossing</td>
<td>[30nm; 500µm]</td>
<td>5 Minutes</td>
<td>6 inch</td>
<td>Si, Glass, Ni, Metal</td>
<td>1- &gt;80</td>
<td>Microfluidics, Microoptics Nanostructures</td>
<td>+Unlimited Feature size +Deep Embossing Unit +High Aspect Ratio +Double Side Embossing +multi layer + multi material</td>
<td>+rel. Long Cycle Time</td>
</tr>
<tr>
<td>Nano Imprint Lithography</td>
<td>[20nm; 100nm]</td>
<td>5 Min</td>
<td>100mmx100mm</td>
<td>Si</td>
<td>1-2</td>
<td>Micro and Opto-electronic Devices</td>
<td>+Resist embossing +nanometer structure + single layer</td>
<td>+Microstructures + embossing small areas +rel. Long cycle time +seperation of mold and substrate</td>
</tr>
<tr>
<td>UV- Embossing</td>
<td>[20nm; 100nm]</td>
<td>10 Min</td>
<td>40mmx40mm</td>
<td>UV- Transparent</td>
<td>1-2</td>
<td>Micro and Opto-electronic Devices</td>
<td>+Resist embossing +nanometer structure + single layer</td>
<td>+Microstructures + embossing small areas +rel. Long cycle time +seperation of mold and substrate</td>
</tr>
<tr>
<td>Injection Molding</td>
<td>[100µm]</td>
<td>&gt;1 Min.</td>
<td>Cartridges</td>
<td>Metal</td>
<td>&gt;10</td>
<td>Microfluidics Microoptics</td>
<td>+short cycle time +3-D structures</td>
<td>+mechanical strain +limits feature size + less filling fectore</td>
</tr>
</tbody>
</table>
Hot Embossing Products Line-up

JENOPTIK Laser, Optik, Systeme GmbH
Hot Embossing Solution – HEX01

HEX 01

• Cost effective entry system with tabletop layout
• Pressing force of up to 20kN (50kN Option)
• Embossing temperature up to 320°C (500°C Option)
• Mold non-orthogonality compensation
Hot Embossing Solution – HEX02

JENOPTIK Laser, Optik, Systeme GmbH

HEX 02

- Medium range system
- Pressing force up to 200kN (250kN Option)
- Embossing temperature up to 320°C
  (500°C Option)
- Mold non-orthogonality compensation
- Suggestive user interface with macro
  script language
Hot Embossing Solution – HEX03

HEX 03

• High-end embossing solution
• Pressing force up to 200kN (250kN Option)
• Embossing temperature up to 320°C (500°C Option)
• Temperature stability +/- 1°C
• Maximum substrate diameter 180mm
• Cleanroom compatible
• Active De-embossing™
• Optical alignment with +/- 2μm overlay accuracy
Hot Embossing Solution – HEX03

HEX 03 Chamber (Top)

HEX 03 Chamber (Bottom)
Hot Embossing Solution – HEX04

HEX 04

- Max Substrate Size: 300mm in diam.
- Thickness of Sandwich: up to 20mm
- Max Press Force: up to 400kN (600kN opt.)
- Embossing Temperature: up to 500°C
- Cycle Time: typically 3 min
- Temperature Stability: +/- 2°C
- Optical Alignment: +/- 2µm overlay accuracy
- Cleanroom Compatible
- Active De-embossing™
- Handling Unit
- UV Unit
Key Feature - Active De-Embossing Unit™

With Active De-Embossing Unit™

Without Active De-Embossing Unit™
Double Side Embossing with Alignment

JENOPTIK Laser, Optik, Systeme GmbH
SensLab Tool - Double Side Embossing

JENOPTIK Laser, Optik, Systeme GmbH

PMMA sample, 30 μm line, 200 μm depth

PC sample, 60 μm line

PC: optical microscope diameter

714 μm

95 μm

200 μm
Glass Embossing (1)

With 500°C embossing temperature you can emboss polymers at a higher temperature and low melting glass, for example the following glass materials:

<table>
<thead>
<tr>
<th>Glass Material</th>
<th>Thermal Expansion Coeff. $a^{10^{-6}}$</th>
<th>TC</th>
<th>Yielding Point</th>
<th>Softening Point</th>
<th>Molding Temp.</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0550</td>
<td></td>
<td>325</td>
<td>415</td>
<td></td>
<td>390.420</td>
<td>Corning</td>
</tr>
<tr>
<td>K-PG375</td>
<td>169</td>
<td>343</td>
<td>363</td>
<td></td>
<td>385.360</td>
<td>Sumitco</td>
</tr>
<tr>
<td>P-SK50</td>
<td>112</td>
<td>381</td>
<td>403</td>
<td></td>
<td>435.460</td>
<td>Sumitco</td>
</tr>
<tr>
<td>P-SK60</td>
<td>116</td>
<td>382</td>
<td>404</td>
<td></td>
<td>435.460</td>
<td>Sumitco</td>
</tr>
<tr>
<td>SFWS-01</td>
<td>100</td>
<td>393</td>
<td>413</td>
<td></td>
<td>440.460</td>
<td>Ohara</td>
</tr>
<tr>
<td>SF-57</td>
<td>92</td>
<td>402</td>
<td>519</td>
<td></td>
<td>480.500</td>
<td>Schott</td>
</tr>
<tr>
<td>P-SK11</td>
<td>93</td>
<td>410</td>
<td>437</td>
<td></td>
<td>413.490</td>
<td>Sumitco</td>
</tr>
<tr>
<td>Catk</td>
<td>161</td>
<td>428</td>
<td>464</td>
<td></td>
<td>485.495</td>
<td>Sumitco</td>
</tr>
<tr>
<td>RF-5</td>
<td>84</td>
<td>429</td>
<td>499</td>
<td></td>
<td>500.0</td>
<td>Sumitco</td>
</tr>
<tr>
<td>SF-8</td>
<td>92</td>
<td>430</td>
<td>459</td>
<td></td>
<td>530.0</td>
<td>Sumitco</td>
</tr>
<tr>
<td>FPL53</td>
<td>163</td>
<td>436</td>
<td>456</td>
<td></td>
<td>480.500</td>
<td>Ohara</td>
</tr>
</tbody>
</table>
Glass Embossing (2)

Parameters:
Pressure: 0.22E9 Pa
T = 590°C
t = 60 sec.
Micro and Nano Optic Applications

Feature size < 100nm
  + Optical Filter - Gratings
  + Binary optics
  + Lenses for CD/DVD

+ Aligned Double-Side Embossing
+ Nano-precise Surface Forming
+ Excellent Uniformity

Glass Master
  + E-Beam written
  + Aspect Ratio: 1-50
  + Feature Size: 30nm - 50μm
  + price: up to 10k€

70 nm line space, AR 1

Glass Master
UV-Unit Technology Development

JENOPTIK Laser, Optik, Systeme GmbH

UV-Source
Wavelength
Embossing Temperature
Exposure area

Uniformity (150mm)
Force

High Brightness LED Array
365nm
Ambient up to 100°C
150mm diameter (HEX_01)
Up to 300mm (HEX_04)
< 5%
< 10N up to 10kN
Master Manufacture
Master Manufacturing

**Silicon-Master**
- DRIE manufacturing
- Aspect Ratio 1-2
- Feature Size 100nm - 250μm
- Ra < 100nm
- prize: 0.8k€ - 2k€

**Ni-Master**
- x-Ray LIGA, UV-LIGA, Electroplating
- Aspect Ratio: 1-500
- Feature Size: 100nm - 500μm
- Ra < 10nm
- prize: >15k€

**Glass Master**
- E-Beam writing
- Aspect Ratio: 1-50
- Feature Size: 30nm - 50μm
- Ra < 10%
- price: up to 1k€

**Metal-Master**
- Milling
- Aspect Ratio: 1-50
- Feature Size: 20μm - 1000μm
- Ra > 100nm

**Criteria:**
- Application
- Polymer selection
- Fluidic property
- Edge precision
- Stepness of channel walls
Master – Silicon Master
Hot Embossing with Si-Master small feature
Microfluidics – Capillary Electrophoresis Chips

Detail of Silicon Embossing Tool

Resulting Microchannel

Masters fabricated with silicon dry etching
Hot Embossing with Si-Master small feature(2) – high aspect ratios

Embossed microchannel array

**Embossing tool: Silicon**

H. Becker, K. Lowack, A. Manz
Imperial College, London, IMM Mainz

**Replicated channels in PMMA**

- Height: 5 μm
- Width: 0.8 μm
Hot Embossing with Si-Master small feature(3)

Fluidic Channels
PMMA

23µm

83µm
Hot Embossing with Si-Master small feature

AR: 1.5
Application: Coordinates Mash for Cell-Structures
Master – Nickel Master

Nickel Master: manufactured by Electroplating and LIGA
Hot Embossing with Ni Master(1)

LIGA-Tool
- Material: PMMA
- Height: 150 mm
- AR: 5
Hot Embossing with Ni Master(2)

LIGA-Tool

- Material: PMMA
- Height: 150 mm
- AR: 5
Hot Embossing with Ni Master(3)

LIGA - Tool:
AR: > 20
smallest structure: 7µm
height: 150µm

Capacitive Accelerator-Sensor
Hot Embossing with Ni Master(4)

Capacitive Accelerator-Sensor

LIGA - Tool:
AR:19
• smallest structure: 8µm
• height: ca. 150µm
Hot Embossing with Ni Master(5)

Tool Manufacturing: Electroplating
Ni in Si-Wafer
Hot Embossing Applications
Application Diagrams

- Challenge for Mooré's Law
- Miniaturizations
- Programmable device
- Multiple tests
- Smaller amounts of material and more efficient result
- 100nm~1um: 40Gbits/in²
- Sub-100nm: 100Gbits/in²

- Automotive Sensor
- Embedded Electronics
- Optical Communications
- Wave-guides
- Optical filter
- Computer Network Solution
- Laser pickup readout system
- DVD, DVR: Blue-Ray Lens
- Optical Lens
- Prism Sheet

Material Characters
Solutions for commercial applications

JENOPTIK Laser, Optik, Systeme GmbH

**Microoptic**
- JENOPTIK PC MT
- L.O.S fiber
- Cannon

**Microfluidic**
- Fuji
- Bosch
- Blusi

**Micromechanic**
- JENOPTIK PC MT
- LSU
- LTU
Hot Embossing Applications

Micro-fluidic & Bio-MEMS Applications
Micro-optic Applications
Micro-mechanical Applications
Application based on Polymer MEMS

1. BioMEMS - Bio Sensor
   + Disposal Devices
   + Volume Reduction
   + Faster Reaction

2. Micro-Optic
   + Cost of Ownership Reduction
   + High Integration Factor
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full name</th>
<th>Temp. Stability in °C</th>
<th>Properties</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>COC</td>
<td>Cycle-olefine/copolymer</td>
<td>140</td>
<td>High transparency</td>
<td>Amorphous</td>
</tr>
<tr>
<td>PMMA</td>
<td>Polymethylmetacrylate</td>
<td>80</td>
<td>High transparency</td>
<td>Amorphous</td>
</tr>
<tr>
<td>PC</td>
<td>Polycarbonate</td>
<td>130</td>
<td>High transparency</td>
<td>Amorphous</td>
</tr>
<tr>
<td>PS</td>
<td>Polystyrene</td>
<td>80</td>
<td>Transparent</td>
<td>Amorphous</td>
</tr>
<tr>
<td>POM</td>
<td>Polyoxymethylene</td>
<td>90</td>
<td>Low Friction</td>
<td>Semi Crystalline</td>
</tr>
<tr>
<td>PFA</td>
<td>Polyfluoralkoxy Copolymer</td>
<td>260</td>
<td>High Chemical resistive</td>
<td>Semi Crystalline</td>
</tr>
<tr>
<td>PVC</td>
<td>Polyvinylchloride</td>
<td>60</td>
<td>Cheap</td>
<td>Amorphous</td>
</tr>
<tr>
<td>PP</td>
<td>Polypropylene</td>
<td>110</td>
<td>Mechanical Properties</td>
<td>Semi Crystalline</td>
</tr>
<tr>
<td>PET</td>
<td>Polyethylene Terephtalate</td>
<td>110</td>
<td>Transparent, Low friction</td>
<td>Amorphous/Semi Crystalline</td>
</tr>
<tr>
<td>PEEK</td>
<td>Polyetheretherketone</td>
<td>250</td>
<td>High Temp. Resistivity</td>
<td>Semi Crystalline</td>
</tr>
<tr>
<td>PA</td>
<td>Polyamide</td>
<td>80-120</td>
<td>Good mech. Properties</td>
<td>Semi Crystalline</td>
</tr>
<tr>
<td>PSU</td>
<td>Polysulfone</td>
<td>150</td>
<td>Chemical and Temp. Resistivity</td>
<td>Amorphous</td>
</tr>
<tr>
<td>PVDF</td>
<td>Polyvinylidenefluoride</td>
<td>150</td>
<td>Chemically inert, piezo-electric</td>
<td>Semi Crystalline</td>
</tr>
</tbody>
</table>
In 2007 75% of all μfluidic applications are done in Polymer
Application(1) - μFluidic (SensLab)

Lactate Scout
- Alcohol
- Drug’s
- Oestrogen
Application(2) - μFluidic : PCR Reactors Batch/Continous Flows

Batch PCR Reactor
Larry Kricka, Univ. Pennsylvania
Claudia Gärtner, AMT Jena

Continous Flow PCR System
Andreas Manz, IC London
Application(3) - µFluidic : IZM Waveguide

Master: milled brass

- Channel width: 250µm
- Channel depth: 250µm
- Waveguide width: 250µm
- Waveguide thickness: 250µm

Transmission

- filled fluidic channel
- unfilled fluidic channel

Waveguide width: 250µm
Waveguide thickness: 250µm

Hot Embossed PMMA
Application(4) - BioMEMS : Analytic Chip

JENOPTIK Laser, Optik, Systeme GmbH

Feature Size
[30 nm ~ 500 µm]

Structure for:
• separation
• mixing
• filtering
• passive Valves
• chambers
  • Inlet
  • Analytic-read out
Application(5) – Nano Embossing

Nano Structure realized with a commercial HEX03 Hot Embossing System

PMMA
- 120nm pitch
- 60nm lines
- 120nm depth
- aspect ratio 1:2
Multilevel Master polymer embossed micro-fluidic channels with integrated optical fibres

Optical fibre (50 μm core)
Application(7) - μFluidic : Microfluidic Mixer

Master structure
Masters fabricated with silicon dry etching

Embossed part in PMMA
Application(8) - µFluidic: Cover lid bonding

Cross-section of a single micro channel

Device filled with liquid
Hot Embossing Applications

Micro-fluidic & Bio-MEMS Applications
Micro-optic Applications
Micro-mechanic Applications
Application Micro-Optical Components(1)

Solutions for Manufacturing of Micro-Optical Components

- Aligned Double-Side Embossing
- Nano-precise Surface Forming
- Pneumatic Soft Deembossing
- Excellent Uniformity
Application Micro-Optical Components(2)

Mold (Bottom) for 52 Lenses
Application Micro-Optical Components(3)
Application Micro-Optical Components(4)

JENOPTIK Laser, Optik, Systeme GmbH
Appication - Microspectrometer

Lichtauskopplung mit 45°-Kante

Glasfaser

Lichteinkopplung $\lambda_i - \lambda_x$

selffocussing reflexion grating $(d=0.2 \mu m; g=2 \mu m)$

photodiode array
Material: RT 133
• Structure depth: 45 µm
• Lattice constant: 30 µm
• Filling factor: > 98 %
1. **Goal (was):**
   - New applications of **optical data storage** (next generations after CD, DVD)
   - Optics and/or the assembly around the pure optic components
   - **Blue ray disc**, 405 nm
   - Lens: NA 0.85, shape accuracy: Lambda/4, roughness 10……. 20 nm
   - Cost effectiveness of production: better the with a 16 fold injection molding technology

2. **Market/Customer**
   - In principle……
   - 2002: Matsushita, Mitsubishi, Pioneer, Philips, Sony, Thomson, LG Electronics, Hitachi, Sharp and Samsung
   - define a 25 Gbytes standard, the numerical aperture (NA) of the lens is 0.85
   - Toshiba und NEC develop a DVD follower
   - And so on....
   - Thomson was a partner in the project

3. **Results**
   - 25 and 52 fold embossing assembly
   - Ca. 1 dozen mold insert techniques were tested
   - Yield 85 %
   - Shape accuracy: <lambda/4 (goal was lambda/4)
   - Transmission: dielectric 99%, mot eye: 97 %
   - rms (roughness) 30 nm (goal was 20 nm)
   - Cycle time ca. 10 min
Technology Advisory Board Members

Mission:
Establishing equipment concepts for state-of-the-art Hot Embossing and Nano Imprinting Technology requirements!

Technology: Full size substrate thermal and UV-Imprinting

Applications: µ-Fluidics, µ-Optics, portable HDD


Materials: PMMA, COC, PC, Glass, etc.
Strategic Partner’s

JENOPTIK Laser, Optik, Systeme GmbH
Leading Research Centers for MEMS, Micro Optical and Bio-Nano Developments

Matsushita Central Research, Osaka, Japan
Mitsubishi Advanced Technology R&D Centre, Osaka, Japan
Hong Kong Productivity Council, Hong Kong SAR
SSL, National University Singapore, Singapore
MEMS Exchange / CNRI, Washington, USA
Foundation Tekniker, Bilbao, Spain
Forschungszentrum CAESAR, Bonn, Germany
K.E.T.I, Seoul, South Korea
Forschungszentrum Karlsruhe, Germany
University Turin, Italy
University of California Irvine, USA
Stanford Microfluidic Labs, USA
Berkeley Nanotechnology Labs, USA
Paul Scherer Institut (PSI), CH
IMTEK Freiburg, Germany
UCLA, USA
Pusan National University, Korea
ITRI, Japan
ETRI, Korea
JENOPTIK Mikrotechnik GmbH - WorldWide Installations

Dedicated Micro- & Nano-Hot Embossing Solutions

51 Systems Installed
(sometimes multiple)
New!! JENOPTIK LAB MEMBERSHIP

- Free annual training at Jenoptik Lab
- Free reference and test embossing accomplished by well-experienced Jenoptik application engineer
- Courtesy exhibitor pass for all fairs and conferences in which Jenoptik is participating (for 2005 remains μ-TAS, COMS, etc.)
- Continuous updates about equipment news, process development, etc.
- Use of Jenoptik Mikrotechnik network of users and institutes (get in contact with other customers all over the world)
- Free life time technical phone support and application consulting by Jenoptik chief service engineer
Thank you very much for your attention!

Enrico Piechotka  
Director Marketing & Sales  
PC Mikrotechnik  
Phone: +49-3641-65 3042  
Telefax: +49-3641-65 3562  
Mobile: +49-173-6921451  
enrico.piechotka@jenoptik.com  
www.jo-mt.com

김 정 한  
부장  
기술영업부  
㈜코썸사이언스  
Phone: +82-32-623-6320  
Telefax: +82-32-623-6325  
Mobile: +82-10-5490-5460  
jhkim@kortherm.co.kr  
www.kortherm.co.kr