INTELLIGENT MATERIAL
ABLE TO ADJUST ITSELF ACCORDINGLY
TO ENSURE THE HIGHEST LEVEL OF COMFORT & AFFINITY WITH HUMAN BODY

SMP Technologies Inc.
Introduction

Shape Memory Polymer (SMP)

“DiAPLEX” is the newly developed intelligent material which changes its features according to temperature. (Mitsubishi Heavy Industries Patented.)

1. A large reversible change in elastic modulus across the glass transition temperature (Tg) is unique to SMP.

2. A wide range of new applications for the SMP materials are expanding in such fields as space exploration, medical, clothing, food packaging, health care, toys, and more.
SMP based on Polyurethane

diisocyanate
OCN−R−NCO

polyol
HO−R′−OH

chain extender
HO−R″−OH

Polyurethane

SMP designed by chemical components, molecular weight, mixing ratio.
What’s SMP

- Tg at room temperature
- Narrow transition state
- Drastic change of properties at transition state
Elastic Modulus Property

- The elastic modulus changes largely at the temperature below (hard state) and above (soft state) the glass transition temperature ($T_g$).

- $T_g$ setting of the material can be designed at the desired temperature between -40°C ~ 90°C (-40°F ~ 194°F).
**Property of DiAPLEX (2)**

**Shape recovery and rigidation**

- At a temperature higher than the Tg, Shape memory polymer (SMP) can easily change form by applying low stress.

To remove the external force at the low temperature (<Tg) the formed shape is retained.

- To heat SMP with no external force from a low temperature to a temperature higher than Tg. It eliminates the strain, resulting in recovery of its original shape.

- SMP allows the maximum strain can be applied up to 400%.
Property of DiAPLEX (3)

- **Energy dissipation property**
  - Energy dissipation factor defined by $\tan\delta$ change with the temperature and becomes very large compared to ordinary elastic material. (These material’s $\tan\delta$ are in the range of $0.2 \sim 0.4$)

  The $\tan\delta$ of the DiAPLEX in the transition region is very similar to that of human skin, providing a natural smooth feel when SMP is used in region touched by hand.

Dissipation factor ($\tan\delta$) of human body

<table>
<thead>
<tr>
<th></th>
<th>Lower arm</th>
<th>forehead</th>
<th>Palm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.43</td>
<td>0.51</td>
<td>0.41</td>
</tr>
</tbody>
</table>

高橋元次 高分子 33 巻 1984
Property of DiAPLEX (4)

Diaplex membrane

- Gas permeability property depending on temperature.
  - DiAPLEX membrane has large change in moisture permeability depending on temperature change.
  - Above Tg, high moisture permeability, below Tg small moisture permeability is realized.

<table>
<thead>
<tr>
<th>Path Size</th>
<th>Type Of membrane</th>
<th>Variety of particle size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 μm</td>
<td>Porous</td>
<td>Staphylococcus (0.8 μm)</td>
</tr>
<tr>
<td>0.5 μm</td>
<td></td>
<td>Typhoid bacillus/cholera bacillus (0.6 μm)</td>
</tr>
<tr>
<td>0.2 μm</td>
<td></td>
<td>Smallpox virus (0.21 μm)</td>
</tr>
<tr>
<td>0.1 μm</td>
<td></td>
<td>Influenza virus (0.08 μm)</td>
</tr>
<tr>
<td>0.05 μm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.02 μm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.01 μm</td>
<td>(100 Å)</td>
<td></td>
</tr>
<tr>
<td>50 Å</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 Å</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 Å</td>
<td>Non</td>
<td></td>
</tr>
<tr>
<td>5 Å</td>
<td>Porous</td>
<td></td>
</tr>
<tr>
<td>2 Å</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dia of passage in membrane and molecular dia

Size of path and transmitting substance

Property of DiAPLEX (4)

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Other properties of DiAPLEX

- **DiAPLEX can be applied to your body.**
  - DiAPLEX has been authorized by Japanese Ministry of Health and Welfare as follows;
  - Regulation standard on Food and Food additives
  - Food Hygiene law
  - The pharmaceutical affairs law No.145 in 1960, Article14, section 1.

- **Molding Ability of DiAPLEX.**

- **Forming techniques include;**
  - Injection ,extrusion, and other ordinary forming techniques.
  - Material types available are Pellets, solution, foam, micro-beads ,fiber.
# SMP Materials

<table>
<thead>
<tr>
<th>Index</th>
<th>Material</th>
<th>Molding</th>
<th>Packing unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>MM</td>
<td>Pellet</td>
<td>Injection • Extrusion</td>
<td>20Kg Bag</td>
</tr>
<tr>
<td>MP</td>
<td>Resin &amp; Hardener</td>
<td>Potting</td>
<td>1Kg Can × 2</td>
</tr>
<tr>
<td>MS</td>
<td>Solution</td>
<td>Coating</td>
<td>4Kg Can</td>
</tr>
</tbody>
</table>
## Properties and Applications of SMP

<table>
<thead>
<tr>
<th>PROPERTIES</th>
<th>APPLICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus</td>
<td>Developed &amp; Applied</td>
</tr>
<tr>
<td></td>
<td>Under Developing &amp; Ideal Phase</td>
</tr>
<tr>
<td></td>
<td>• Autochoke for Engine</td>
</tr>
<tr>
<td></td>
<td>• Intravenous Cannula</td>
</tr>
<tr>
<td>Shape Memory Property</td>
<td>• Spoon, scissors, tooth brush and kitchen knife for Handicapped</td>
</tr>
<tr>
<td></td>
<td>• Wig net</td>
</tr>
<tr>
<td></td>
<td>• Dole Hair</td>
</tr>
<tr>
<td></td>
<td>• Water-proofing film tape bandage</td>
</tr>
<tr>
<td></td>
<td>• Printing for leather</td>
</tr>
<tr>
<td></td>
<td>• Transforming photo to canvas</td>
</tr>
<tr>
<td></td>
<td>• Surgical cast</td>
</tr>
<tr>
<td></td>
<td>• Lining of Inner Pipe</td>
</tr>
<tr>
<td></td>
<td>• Artificial Nail</td>
</tr>
<tr>
<td></td>
<td>• Toys</td>
</tr>
<tr>
<td></td>
<td>• Development structures for outer space</td>
</tr>
<tr>
<td></td>
<td>• Readily decomposable Fasteners</td>
</tr>
<tr>
<td></td>
<td>• Memory Material for CD</td>
</tr>
<tr>
<td></td>
<td>• Artificial Muscle</td>
</tr>
<tr>
<td></td>
<td>• Ski insole</td>
</tr>
<tr>
<td></td>
<td>• Shape Memory for natural fiber</td>
</tr>
<tr>
<td></td>
<td>• Shrink Film</td>
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<tr>
<td></td>
<td>• IC Tag</td>
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</tbody>
</table>

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<tr>
<th>PROPERTIES</th>
<th>APPLICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Developed &amp; Applied</td>
</tr>
</tbody>
</table>
| Damping Property | • Lingerie generally (Bra cup)  
| | • Glasses parts (Nose pad, ear pad)  
| | • Damping Material  
| | • Intravenous Cannula  
| | • Inner Support of Mask  
| | • Cosmetics Foundation  
| | • Insole  
| Gas Permeability | • Sports outfit  
| | • Water-proofing film tape bandage  
| | • Humidity Controlled Film  
| | • Diaper Cover  
| | • Water Proof Shoe  
| | • Sanitary Shorts  
| | • Wrapping Film  
| | • Amphibious clothes  
| | • Night cover for showcase  
| | • Lens  
| | • Artificial Blood Vessel  
| | • Artificial Skin  
| | • Gas Separator  

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# Properties and Applications of SMP

<table>
<thead>
<tr>
<th>PROPERTIES</th>
<th>APPLICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume Expansion</td>
<td>• Thermo sensor</td>
</tr>
<tr>
<td></td>
<td>• Inflatable material</td>
</tr>
<tr>
<td></td>
<td>• Panel for Display</td>
</tr>
<tr>
<td>Recovery Force</td>
<td>• Binding Element</td>
</tr>
<tr>
<td></td>
<td>• Clamping pin</td>
</tr>
<tr>
<td></td>
<td>• Self-deployable structures</td>
</tr>
<tr>
<td>Refractive Index</td>
<td>• Lens</td>
</tr>
<tr>
<td></td>
<td>• Thermo sensor</td>
</tr>
<tr>
<td></td>
<td>• Optical Fiber</td>
</tr>
<tr>
<td>Dialectic Constant</td>
<td>• Thermo sensor</td>
</tr>
</tbody>
</table>

![Graph of Volume Expansion and Refractive Index with Tg (Glass Transition Temperature) temperature]
Example of sophisticated applications (1) Fastener-1

Easy disassemble using SMP by heating

Example of sophisticated applications (1)
Example of sophisticated applications (1) Fastener-2
Example of sophisticated applications (1) Fastener-3

Figure 7. Successful active disassembly of the mock assembly of the Sony CD player.

Figure 8. Successful active disassembly of the mock assembly of the Philips digital FM radio.

Figure 9. SMP-SMP Motorola Pager after successful AISM.

Figure 10. SMP-SMP Nokia 6110 after successful AISM.
Example of sophisticated applications (2)

Intravenous syringe cannula

When injection is performed, it keeps its rigid state. Once under the Skin, it becomes flexible, resulting in greater comfort.

From Nipro
Example of sophisticated applications (3)

- **Barrier-free Utensil** from properties (1), (2)
- The physically challenged can perform basic necessities more easily.
- Examples: eating, brushing teeth, scissors and razor using with the unique shaping characteristics of SMP.

Spoon sold by Aoyoshi Co., Ltd

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Example of sophisticated applications (4)

- **Ankle supporter** from properties (1), (2)
- A guard part utilizing FR-SMP (Fiberglass Reinforced Shape Memory Polymer) is available for transformation by heating.
- It can be changed into a shape fitting an ankle easily.

From Nippon Sigmax Co., Ltd.
Inflatable Material for Aero-space Applications

In foam structure, full/stowed volume ratio of 30 ~ 40 has been realized.
Example of sophisticated applications (5)
Example of sophisticated applications (5)
Example of sophisticated applications (6)

Doll hair

1. Denier of the filament of 50d, 70d and more are available
2. Any color is available

3. The doll hair is now on the market from takara toy

• The doll hair is now on the market from takara toy
Example of sophisticated applications (7)

- **Bra-Cup**

  utilizing SMP-Foam which has large dynamic tan δ and J-curve (stress-strain curve)

  Their behavior are very similar to human body.
Example of sophisticated applications (8)

Nose guard for eye Glass

utilizing injection molded SMP

This nose guard has the same mechanical properties to nose
Micro-Brownian motion allows the nonporous polymer membrane to transfer molecules of water vapor.

- At low temperature the polymer molecular chains stop the transfer of water vapor.
- As temperature increases, the formation of free space allows the transfer of water vapor.

Example of sophisticated applications (9)
Example of sophisticated applications (9)

- This intelligent material memorizes conditions of comfort and responds to changes in environmental and ambient temperature.
Example of sophisticated applications (9)

Excellent waterproof, breathable, and anti-condensation are achieved.
Example of sophisticated applications (9)

FORSCHUNGSINSTITUT HOHENSTEIN TEST REPORT

Comparative wear trials with DiAPLEX garments

☐ Test Samples (garments)

☐ Diaplex2-layer 、70d × 70d Taffeta total weight = 1

☐ 0.18Kg

☐ (Tg = 0°C) water vapor resistance Ret 5.39 m².Pa/W

☐ others 2-layer 、70d × 70d Taffeta total weight = 1.28Kg

☐ water vapor resistance Ret 5.67 m².Pa/W

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Example of sophisticated applications (9)

Test results (performed with 4 test persons)

- Diaplex keeps subject warmer than the others.
- Microclimate humidity
  Diaplex keeps subject drier than the others.
- Superior comfort level is achieved.
Example of sophisticated applications (10)

- New vegetable container with SMP film

When temperature rises, perspiration rises, evaporation necessary.

SMP film performs to maintain the optimal condition in the container.

• National refrigerator “Tanto”
Example of sophisticated applications

- Energy efficient and clean low dew condensation helps supermarket freezer unit stay cool and operate at maximum efficiency.
  - Freshness retention
    - Because of its waterproof and vapor permeable properties, Diaplex can maintain proper humidity, helping to prevent clamminess or dryness within the showcase.
  - Energy conservation and anti condensation

<table>
<thead>
<tr>
<th>Electric energy</th>
<th>51.4Kwh</th>
<th>37.1Kwh</th>
<th>26.4Kwh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condensation</td>
<td>Observed</td>
<td>Observed</td>
<td>Not observed</td>
</tr>
</tbody>
</table>

Floor may become wet due to condensation.

- Deodorizing, Antibacterial
  - Diaplex has been specially treated for removing odors such as ammonia, hydrogen sulfide and also possesses antibacterial properties.
  - Covered by Diaplex screen at night.
Example of sophisticated applications (12)
DiAPLEX membrane for textile application

DiAPLEX is intelligent material able to adjust itself accordingly to ensure the highest level of comfort in garments.

Superior waterproof, breathable, and anti-condensation characteristics.