Micro Actuators

- Electrostatic actuator
  - comb drive actuator
- Magnetic actuator
- Thermal actuator
- Piezoelectric actuator
- Shape memory alloy actuator
- Pneumatic actuator
Introduction of Shape Memory Alloy

(I) Background:

- In the early 1950s, Shape Memory Effect (SME) was first observed in AuCd and later in InTi, and in 1963 it was also found in NiTi.

(II) The basic properties of SMA:

- Shape Memory Alloy (SMA) is called a kind of smart material or intelligent materials. SMA can recover its original shape by heating or cooling over a certain temperature, i.e., memorize its original shape, after it has been deformed.

- SMA materials can sustain and recover large strains of the order of 10% without inducing irreversible plastic deformation which is impossible to most of the material.

- **One-way SMA:** the material can remember and recover to its original austenite shape in higher temperature.

- **Two-way SMA:** the material can remember and recover to its higher temperature austenite shape and lower temperature martensite shape.
### Table 1.3 Materials with Shape Memory Effect [C. Liang 1990]

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Composition</th>
<th>Transformation Temperature (As) Range, deg.C</th>
<th>Transformation Hysteresis, deg.C</th>
</tr>
</thead>
<tbody>
<tr>
<td>AgCd</td>
<td>44–49 at.% Cd</td>
<td>-190–50</td>
<td>~15</td>
</tr>
<tr>
<td>AuCd</td>
<td>46.5–50 at.% Cd</td>
<td>30–100</td>
<td>~15</td>
</tr>
<tr>
<td>CuAlNi</td>
<td>14–14.5 wt.% Al, 3–4.5 wt.% Ni</td>
<td>-140–100</td>
<td>~35</td>
</tr>
<tr>
<td>CuSn</td>
<td>~15 at.% Sn</td>
<td>-120–30</td>
<td></td>
</tr>
<tr>
<td>CuZn</td>
<td>38.5–41.5 wt% Zn</td>
<td>-180–10</td>
<td>~10</td>
</tr>
<tr>
<td>InTl</td>
<td>18–23 at% Tl</td>
<td>60–100</td>
<td>~4</td>
</tr>
<tr>
<td>NiAl</td>
<td>36–38 at% Al</td>
<td>-180–100</td>
<td>~10</td>
</tr>
<tr>
<td>TiNi X (X=Pd, Pt)</td>
<td>50 at% Ni+X</td>
<td>-200–700</td>
<td>~100</td>
</tr>
<tr>
<td>TiNiCu</td>
<td>~15 at% Cu</td>
<td>-150–100</td>
<td>~50</td>
</tr>
<tr>
<td>TiNiNb</td>
<td>~15 at% N.b.</td>
<td>-200–50</td>
<td>~125</td>
</tr>
<tr>
<td>TiNiAu</td>
<td>50 at% Ni+Au</td>
<td>20–610</td>
<td></td>
</tr>
<tr>
<td>TiPd X (X=Cr, Fe)</td>
<td>50 at% Pd+X</td>
<td>0–600</td>
<td>~50</td>
</tr>
<tr>
<td>MnCu</td>
<td>5–35 at% Cu</td>
<td>-250–180</td>
<td>~25</td>
</tr>
<tr>
<td>FeMnSi</td>
<td>32 wt% Mn, 6 wt% Si</td>
<td>-200–150</td>
<td>~100</td>
</tr>
<tr>
<td>FePt</td>
<td>~25 at% Pt</td>
<td>~130</td>
<td>~4</td>
</tr>
<tr>
<td>FePd</td>
<td>~30 at% Pd</td>
<td>~50</td>
<td></td>
</tr>
<tr>
<td>FeNi X (X=C, Co, Cr)</td>
<td>few wt% X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
(IV) Work density:

Table 1.5 Comparison of maximum word density for various types of microactuators [R.H.Wolf 1995]

<table>
<thead>
<tr>
<th>Type of Actuator</th>
<th>Shape Memory Alloy (NiTi)</th>
<th>DC magnetic</th>
<th>Bimetallic</th>
<th>Electrostatic</th>
<th>Piezoelectric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. work density (*10^6 J/m^3)</td>
<td>10.4</td>
<td>0.9</td>
<td>0.5</td>
<td>0.4</td>
<td>0.1</td>
</tr>
</tbody>
</table>

As shown in Table 1.5, the energy density of NiTi is typically two orders of magnitude higher than those of other commonly used microactuation schemes. The high energy density is necessary for an actuator to generate high reaction force against the external pressure or force action.

(V) TiNi v.s. CuZnAl Alloys:

Table 1.4 Comparison of TiNi and CuZnAl Alloys [H.Funakubo 1987].

<table>
<thead>
<tr>
<th>Item</th>
<th>TiNi Alloy</th>
<th>CuZnAl Alloy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery Strain</td>
<td>max 8%</td>
<td>Max 4%</td>
</tr>
<tr>
<td>Recovery Stress</td>
<td>max 400 Mpa</td>
<td>Max 200 Mpa</td>
</tr>
<tr>
<td>Repetition Life</td>
<td>10^3 (=0.02)</td>
<td>10^2 (=0.02)</td>
</tr>
<tr>
<td></td>
<td>10^7 (=0.005)</td>
<td>10^5 (=0.005)</td>
</tr>
<tr>
<td>Corrosion Resistance</td>
<td>good</td>
<td>Problematic, especially stress</td>
</tr>
<tr>
<td></td>
<td></td>
<td>corrosion cracking</td>
</tr>
<tr>
<td>Workability</td>
<td>poor</td>
<td>Fair</td>
</tr>
<tr>
<td>Shape Memory Processing</td>
<td>comparatively easy</td>
<td>fairly difficult</td>
</tr>
</tbody>
</table>

- TiNi alloy is superior to the alloy CuZnAl.
- Most of SMA materials used in micro devices are TiNi (Nitinol).
Martensite transformation [Austenite(A) to Martensite(M)]

The martensite transformation is a lattice transformation which involves shearing deformation and is resulted from cooperative atomic movement.

\[ \xi = 0 \] indicates that the material is in the pure austenite state; conversely \( \xi = 1 \) that the material is in the pure martensite state.

- Four important transformation temperature:
  
  - \( M_s \): martensite start point
  - \( M_f \): martensite finish point
  - \( A_s \): austenite start point
  - \( A_f \): austenite finish point

Martensite fraction \( \xi \):

\[ \xi = \frac{V^M}{V^{A+M}} \]

Where \( V^M \) is the volume of the martensite,

\( V^{A+M} \) is the total volume including martensite and austenite.
• Upon cooling from pure austenite state ($\xi = 0$), the martensite transformation begins at $M_s$ and finishes at $M_f$.

• On heating from pure martensite state ($\xi = 1$), the reverse transformation begins at $A_s$ and completes at $A_f$. 
(VII) Diagram of Stress-Strain of SMAs

- **T>A_f**: Loading (martensite transformation) and unloading (reverse transformation) curves form a complete loop.

- **A_s<T<A_f**: Loading (martensite transformation) and unloading (reverse transformation) curves do not form a complete loop. On unloading, when the applied stress is reduced to zero, the reverse transformation doesn’t complete, i.e. 0<ξ<1. The material is now a mixture of the martensite and the austenite in the stress-free state.

- **T<A_s**: The reverse transformation doesn’t occur during unloading process. The material is only composed of the pure martensite and no austenite exists.
Applications of SMA in Industry

(i) SMA pipe coupling

(ii) The SMA fastener, (a) Original Shape, (b) Straighten Ends, (c) Insert, (d) Heating and Fasting

Fig. 1.24 The schematic diagram of the construction of SMA micro-manipulate
THIN FILM SHAPE MEMORY MICROVALVES WITH ADJUSTABLE OPERATION TEMPERATURE

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Figure 3: Operation principle of the microvalve
Driving Principle of SMA Micropump

(a) Cooling

(b) Heating
A TITANIUM-NICKEL SHAPE-MEMORY ALLOY ACTUATED MICROPUMP

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SMA MICROGRIPPER WITH INTEGRATED ANTAGONISM

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Figure 1: Operation principle of the SMA microgripper
Si MICROMECHANICAL FIBER-OPTIC SWITCH
WITH SHAPE MEMORY ALLOY MICROACTUATOR

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Fig.1 Structure of fiber-optic switch
LINEAR MICROACTUATORS BASED ON THE SHAPE MEMORY EFFECT

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Figure 1: Scheme of the linear actuators

Figure 2: Stress-optimised microdevice of NiTiCu