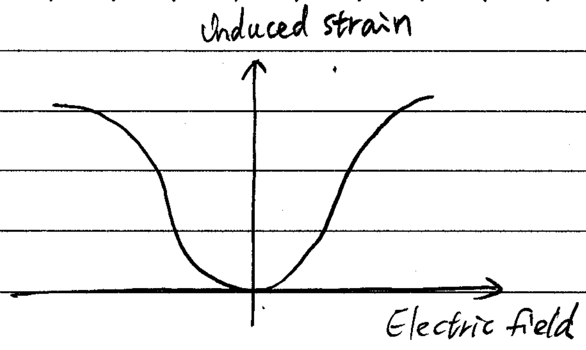
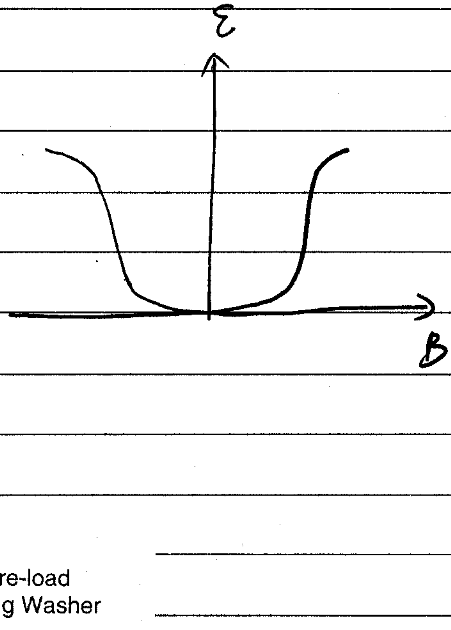
Electrostrictive Materials:

- similar to piezoelectric materials with slightly higher free strain
- nonlinear strain-field relations
- very sensitive to temperature



Magnetostrictive Materials: (e.g. Terfenol-D)

- produce strains when exposed to magnetic field
- highly nonlinear between applied magnetic field and induced strains
- magnetostrictive transducers are large in size
- far from fragile once housed and prestressed



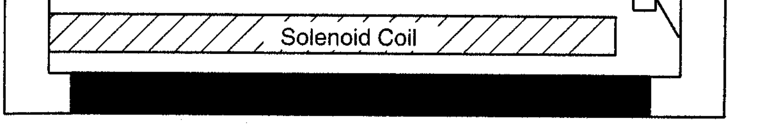


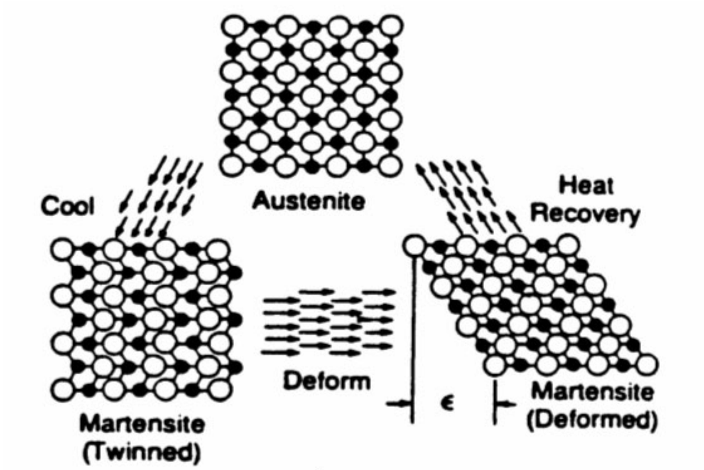
Figure 5.3: Schematic diagram of a Terfenol-D actuator.

Shape Memory Alloys (SMAs)

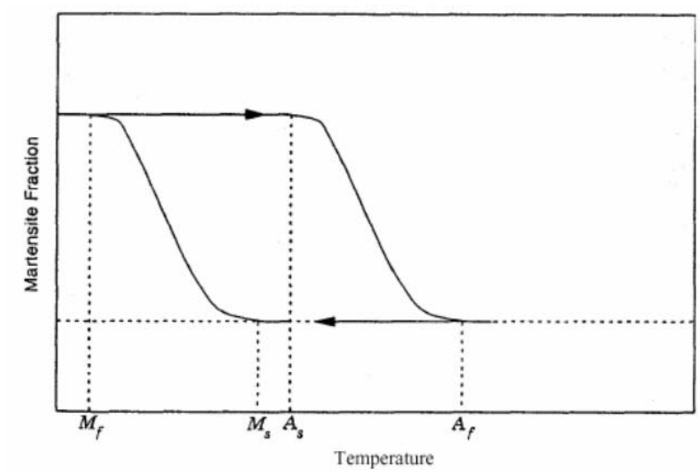
- capable of memorizing its original configuration after heated above the characteristic transition temperature
- can produce large displacements and forces.
- most common SMA is Nitinol
  - Ni : nickel , Ti : titanium
  - nol : Naval Ordinance Laboratory
- heat may be internal (electrical heating)
- slow response time
- nonlinear hysteresis
- modeling is quite difficult

• <u>Pseudoelastic</u> : when an SMA in the austenite phase ($T > A_f$), a plastic strain is achieved under stress loading, the full strain can be recovered upon unloading.

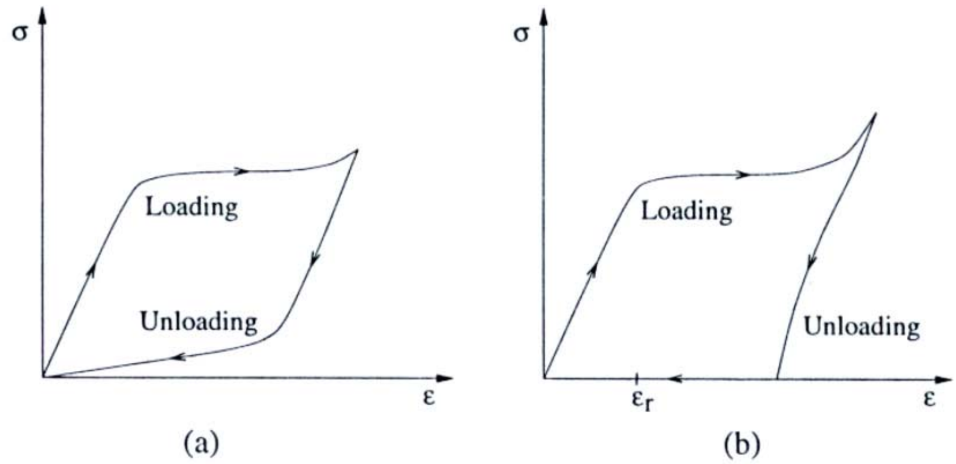
• <u>Shape memory effect</u> : when $T < A_s$ during the stress-induced martensite phase transformation, a large residual strain ε_r remains after unloading. This strain can be recovered by heating SMA to $T > A_f$.



Representation of the changes in the crystal form of SMAs which leads to the shape memory effect



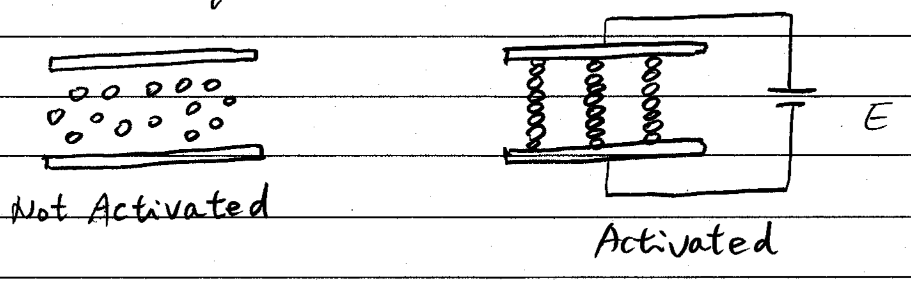
Schematic diagram of transformation of a shape memory alloy



(a) Pseudoelasticity: stress-strain hysteresis loop ($T > A_f$)
(b) Shape memory effect: residual strain ε_r ($T < A_s$)

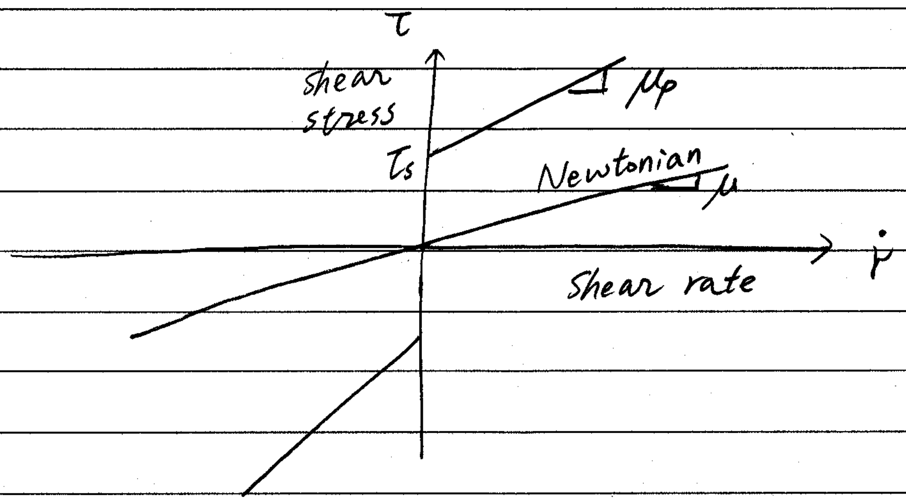
Electro-rheological (ER) Fluids

- ER fluids are colloidal dispersions of solid particulates in nonconducting or insulating oils
- display reversible changes in dynamic yield stress due to an application of an electric field



- A recipe for a couple of ER fluid

1 cup of mineral oil + 1 cup of starch = 2 cups of ER fluid

- 

Newtonian fluid $\tau = \mu \dot{\gamma}$

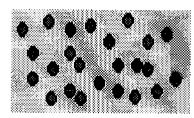
where μ is the absolute viscosity

Bingham plastic $\tau = \tau_s + \mu_p \dot{\gamma}$

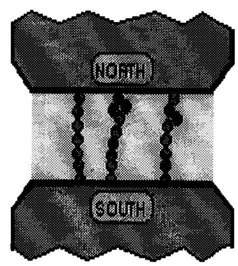
- Disadvantages (ER Fluids):
  - high voltage required
  - lack of long term stability
  - complexity of actuator / control design

Magneto-rheological (MR) Fluids

- suspensions of micro-sized, magnetizable particles in oil
  e.g. soft iron particles in mineral oil
- Newtonian in absence of applied field



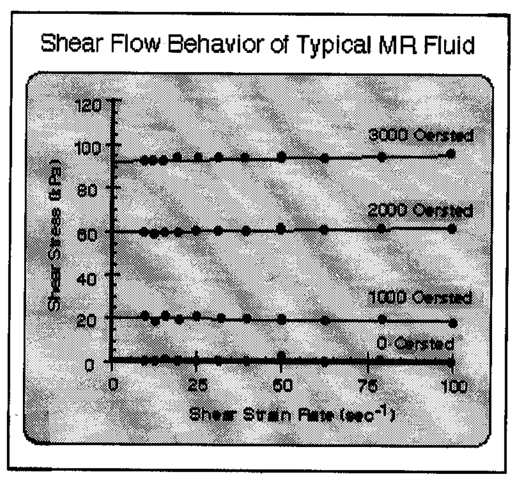
- develop yield strength when field applied
  high yield stress : 50–100 kPa for 150–250 kA/m (≈ 2-3 kOe)
  cf. ER Fluid : 2–5 kPa for 3-5 kV/mm



- Bingham plastic model :

$$\tau = \tau_s(H) + \mu_p \dot{\gamma}$$

- Good stability
- Fast response time
- Broad operating temperature range

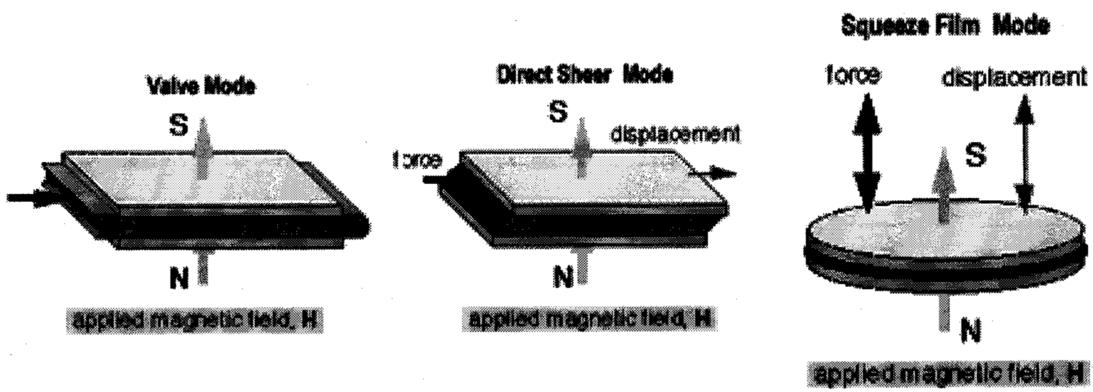


- Three basic modes of operation for MR fluids:

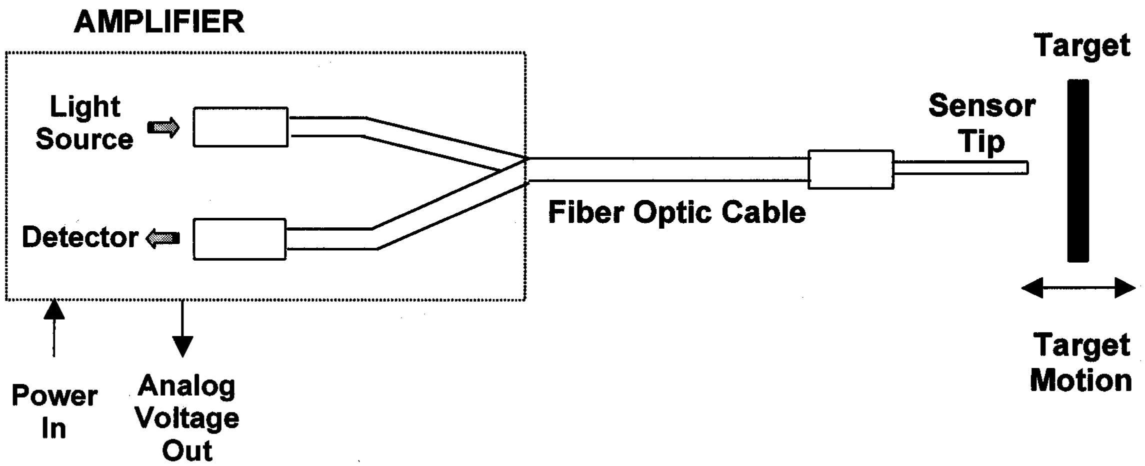
(a) flow mode (valve mode)

(b) shear mode (clutch mode)

(c) squeeze mode (compression mode)



Fiber Optic Sensors



- lightweight
- mechanically flexible, diverse geometry possible
- low maintenance, high reliability
- no actuation abilities