University Of Technology- Iraq
Department of Materials Engineering
General Materials Branch
Fourth class

Smart Materials

Lecture 13 : Shape Memory Ceramics

Class Code on Google Classroom :2shhens

Shape Memory Ceramics

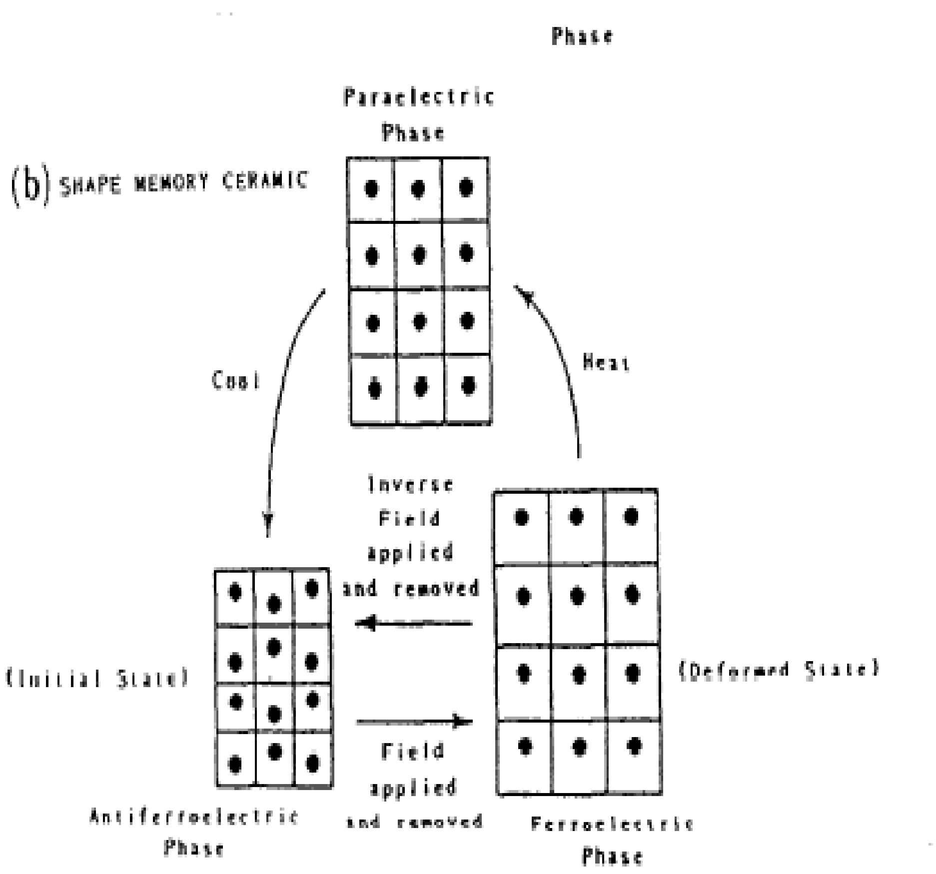
- Shape memory effect is observed not only in special alloys but also in ceramics or in polymers.
- The shape memory effect in alloys originates from a the rmally induced or stress-induced 'martensitic' phase transition.
- After the alloy is deformed largely in the martensitic state, this apparently permanent strain is recovered to its original shape when heated to cause the reverse martensitic transition.
- Then, upon cooling, the shape returns to its original state

Shape Memory Ceramics

- A similar effect is anticipated in ceramics with a certain phase transition, i.e. a 'ferroelastic' phase transition. Reyes-Morel *et al.* demonstrated the shape memory effect as well as superelasticity in a CeO_2,-stabilized tetragonal zirconia (ZrO_2) polycrystal
- The principle of the ceramic shape memory effect is described firstly in comparison with the case of alloys. Phase diagrams, domain reversal mechanisms and fundamental actuator characteristics are then discussed, followed by the practical distinctions between these new ceramics and shape memory alloys. Finally, possible unique applications are proposed including a latching relay and a mechanical clamp

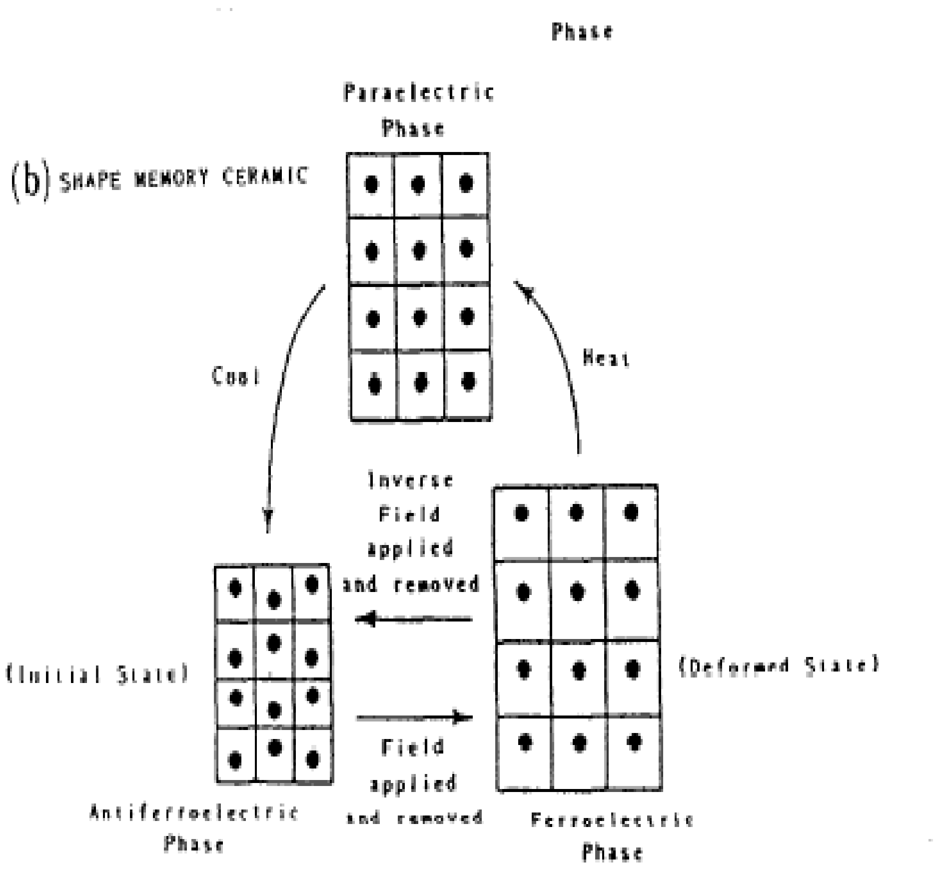
Shape Memory Ceramics

- which shows the uniaxial compressive stress versus strain curve at room temperature, together with the temperature-strain curve showing strain recovery on heating. Under uniaxial compression, the specimen deforms plastically owing to a stress induced tetragonal to monoclinic transition in Ce-doped zirconia.



Shape Memory Ceramics

- Continuous deformation is interruptcd by repeated load drops, providing a nearly constant upper yield stress of 0.7 GPa. Even after unloading, large residual plastic axial strain (- 0.7%) is observed. Subsequent heating produces a gradual recovery of the residual strain due to the reverse phase transition starting at 60•‹C and a burst of strain recovery at 186•‹C. The burst is very sharp, above which approximately 95% of the prior axial strain is recovered.



Shape Memory Ceramics

- Ceramics 'shape memory' has been reported also for certain ferroelectricity related transitions, namely paraelectric-ferroelectric and antiferroelectric ferroelectric transition.
- The former thermally-induced transition revealed a shape-recovery phenomenon similar to zirconia ceramics. On the contrary, the latter is related to an electric field-induced transition, and exhibits large displacement (0.4%) with a 'digital' characteristic or a shape memory function, which is in contrast to the essentially 'analogue' nature of conventional piezoelectric/electrostrictive strains with 0.1% in magnitude.

Comparison of the shape memory characteristics between alloys and antiferroelectric ceramics

Properties	Antiferroelectric	Shape memory alloy
Driving power	Voltage (mW ~ W)	Heat (W ~ kW)
Strain ($\Delta L/L$)	$10^{-3} \sim 10^{-2}$	$10^{-2} \sim 10^{-1}$
Generative force	100 MPa	1000 MPa
Response speed	msec	sec ~ min
Durability	$> 10^6$ cycles	10^4 cycles

Sample preparation and experiments

- Antiferroelectric perovskite ceramics from the PZT system have been inves tigated in which successive phase transitions from a PE, through an AFE, to a FE state appear with decreasing temperature. 1 2 PZT ceramics P b_0 99 Nb_0 0 2 [Zr_0 6Sn_0 4) 1 -y Tiy)]_0 98 O3 (0.05 < y < 0.09) (abbreviated hereafter as PNZST) were prepared from reagent grade oxide raw materials, PbO, Nb_2O_5, ZrO_2,
- SnO_2 and $Ti0_2$ Bulk samples were prepared by hot-press sintering at 1200°C.
- Unimorphs were fabricated with two thin rectangular plates (22 mm x 7 mm x 0.2 mm) bonded together. Multilayer samples (12mm x 4.3mm x 4.3mm) with each layer 140µm in thickness were also fabricated using the tape casting technique: those with platinum electrodes were sintered at a temperature of about 1250°C.

Sample preparation and experiments

- surfaces of the thin ceramic plate (*t* = 0.2 mm) were coated with carbon evaporated electrode. X-ray diffraction patterns were recorded at the electrode surface for several different bias voltages
- The displacement or strain induced by an alternating electric field (0.05 Hz) was detected with a strain gauge (Kyowa Dengyo, KFR-02-C1-1 I), a magneto-resistive potentiometer (Midori Precisians, LP-1U) or a differential transformer-type (Millitron, No. 1202).
- For the dynamic displacement in unimorphs, a noncontact-type eddy current displacement sensor (Kaman, KD-2300) was used. The electric polarization and the permittivity were measured with a Sawyer-Tower circuit and an impedance analyzer (Hewlett-Packard 4192A), respectively.
- to observe the domain structures, a CCD microscope with a magnification of x 1300 was applied to a thinly-sliced sample of large grain (> 50pm) PNZST ceramics with interdigital electrodes on the surface.

Comparison with shape memory alloys

- Outstanding merits of the ceramics over the alloys are:

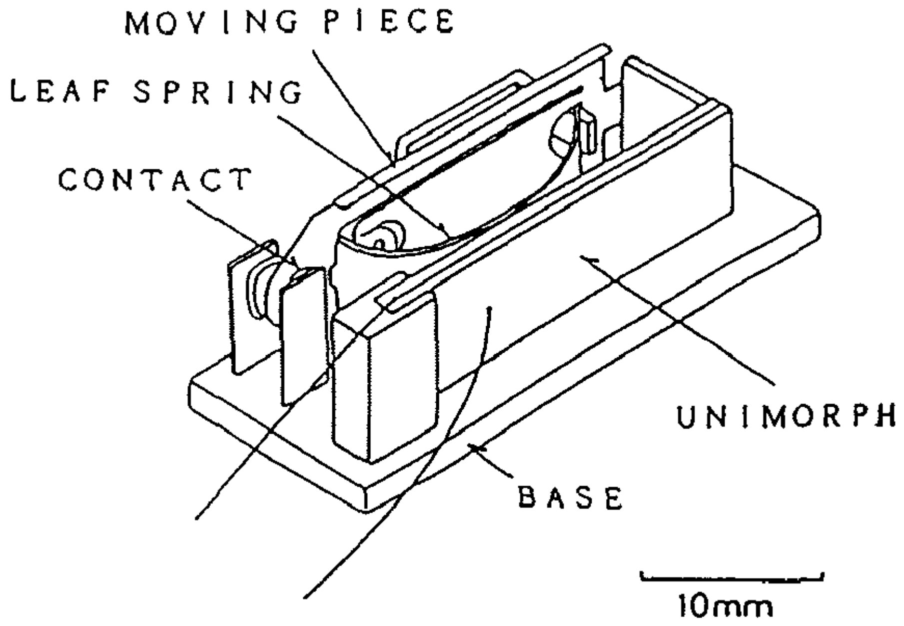
1. Quick response in msec,
2. Good controllability by electric field to memorize and recover the shape without generating heat,
3. Low energy consumption as low as 1/100 of the alloy, and
4. Wide space is not required to obtain the initial shape deformation

Applications of shape memory ceramics

- The shape memory material can be applied to devices such as latching relays and mechanical dampers, where the ceramic is capable of maintaining the excited ON state even when electricity is not applied to it.

Latching relay

- This igure shows the structure of a newly fabricated latching relay, which is composed essentially of a mechanical snap-action switch and a shape memory unimorph driving part." The snap-act on switch is easily driven by a 50pm displacement, having mechanically bistable states. The unimorph is fabricated with two y = 0.063 ceramic plates of 22mm x 7mm area and 0.2mm thickness, bonded together with adhesive



Mechanical clamper

- *A* mechanical clamper suitable for microscope sample holders has been constructed by combining a 20-layer shape memory stacked device (y = 0.0635) and a hinge-lever mechanism as shown in Fig. Application of a 1 ms pulse voltage of 200 V can generate the longitudinal displacement of 4 pm in the 4 mm-thick multilayer device, leading to 30 pm tip movement of the hinge