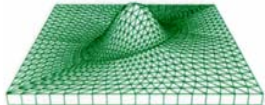


# Comportement et applications des Alliages à mémoire de forme

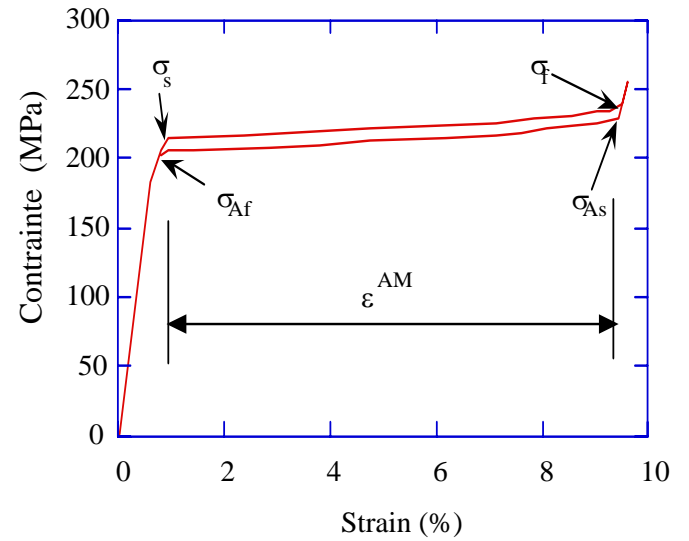
**Etienne Patoor**

Laboratoire de Physique et de Mécanique des Matériaux  
UMR CNRS 7554

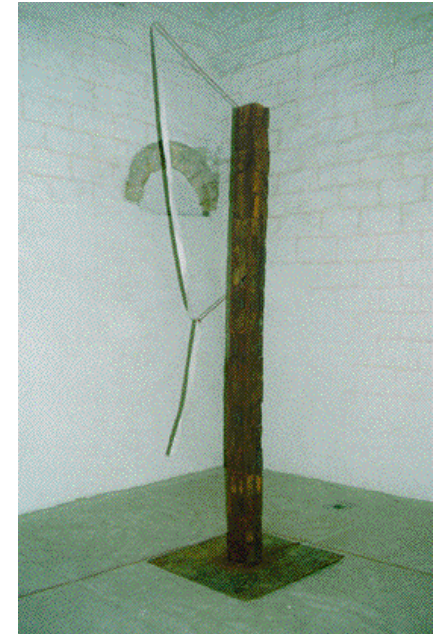
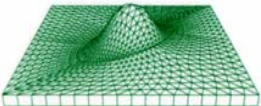
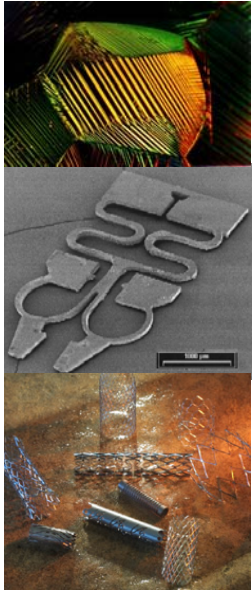


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UMR 7554

Séminaire Matériaux IN2P3 – 17/10/2006



1. Introduction
2. Différents comportements
3. Exemples d'applications

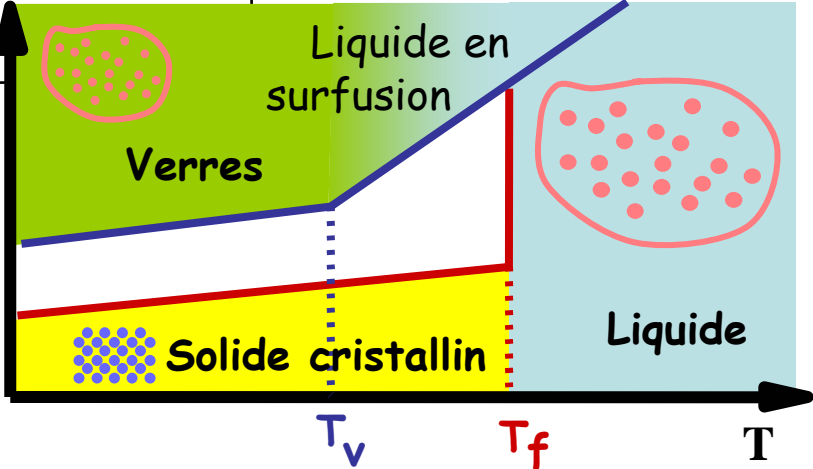


# Classification des transformations de phase

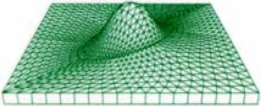
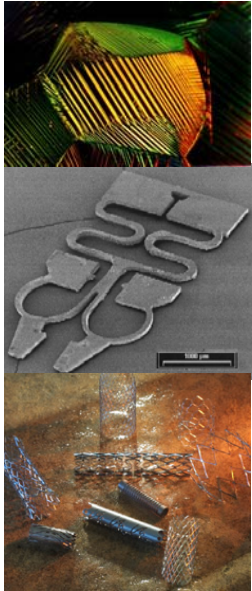
## Transformations du premier et du second ordre

Premier ordre	Second ordre
Ebullition Condensation Solidification	Transition vitreuse

- Propriétés discontinues
- Coexistence des 2 phases
- Interface



## Transformations avec et sans diffusion

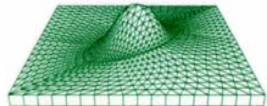
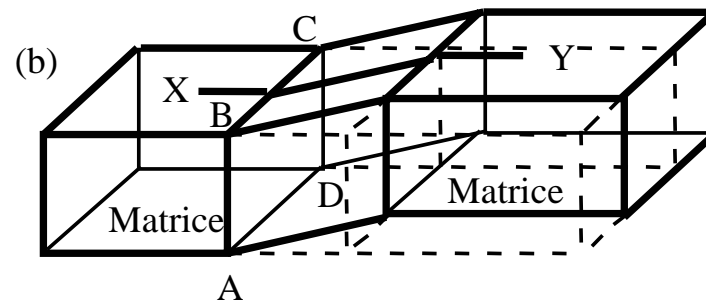
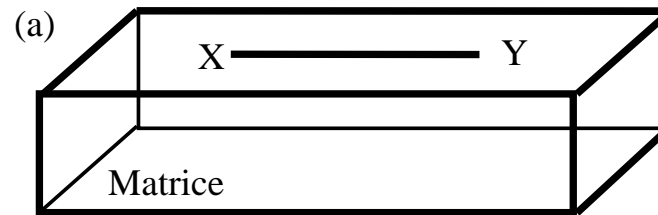
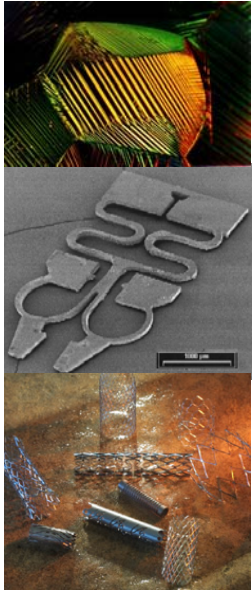


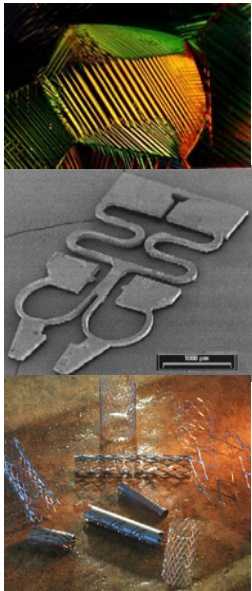
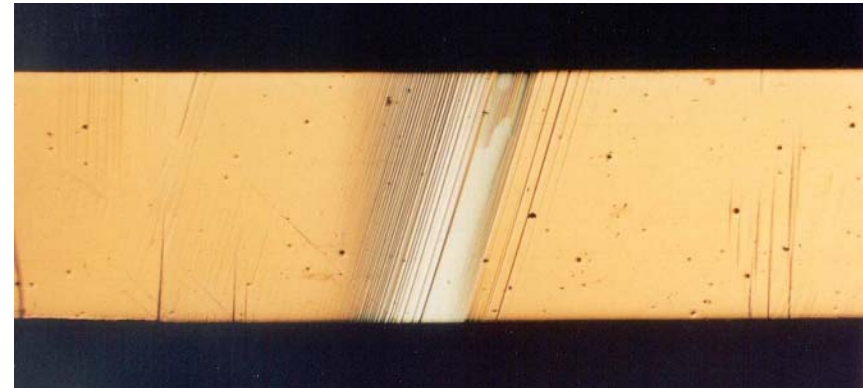
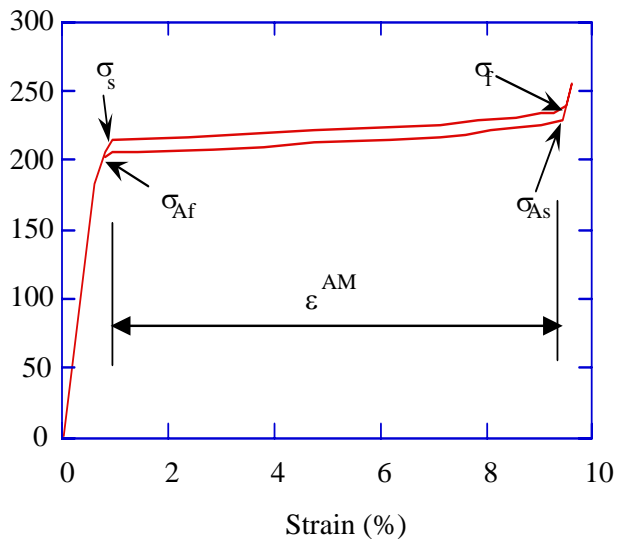
# Définition de la transformation martensitique

□ Transformation du premier ordre

□ Sans diffusion

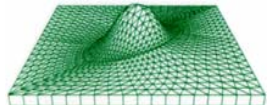
□ A caractère fortement déviatorique





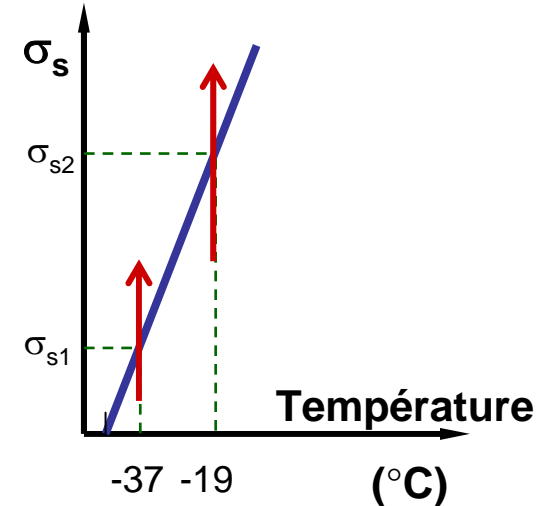
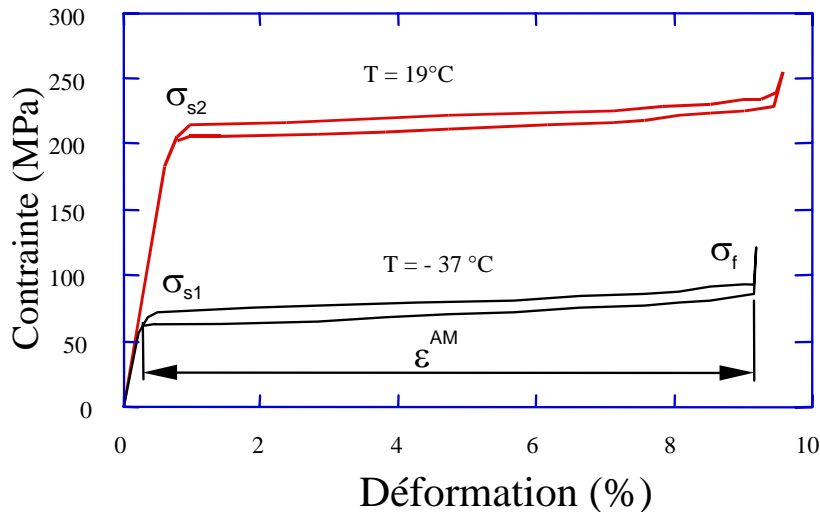
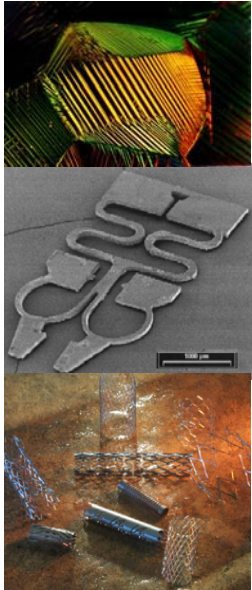
## II. Comportement des AMF

1. Superélasticité
2. Effet mémoire
3. Mémoire double sens
4. Autres propriétés

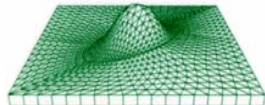


# II.1. Superélasticité

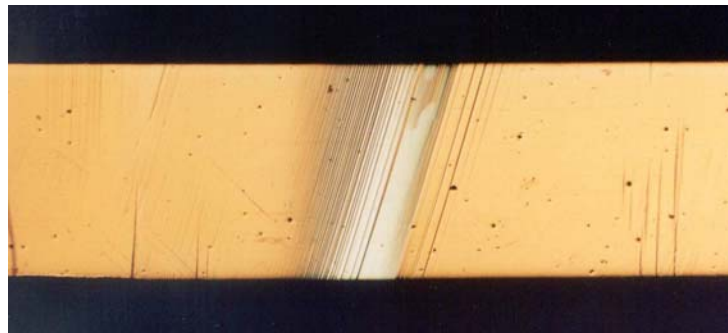
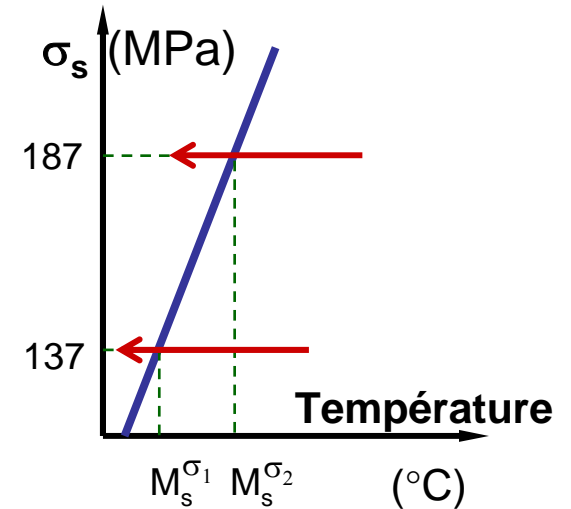
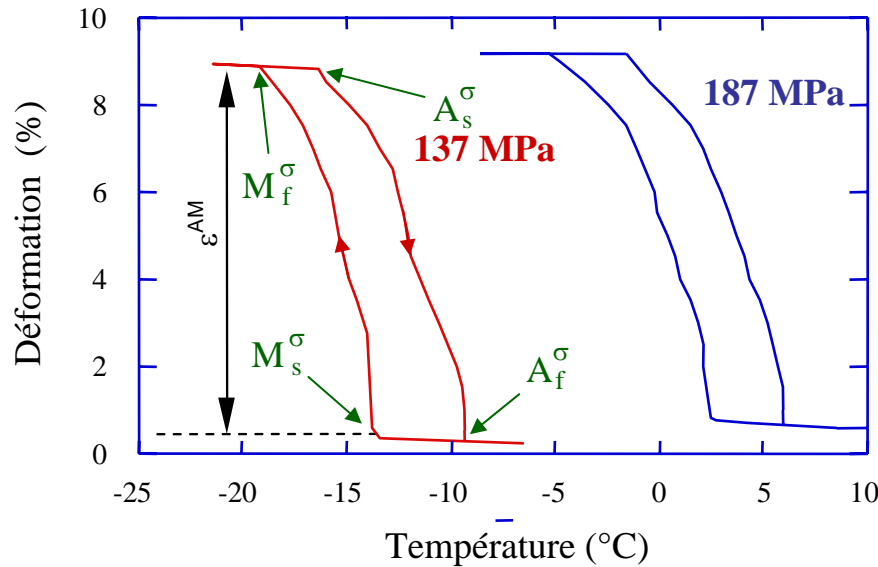
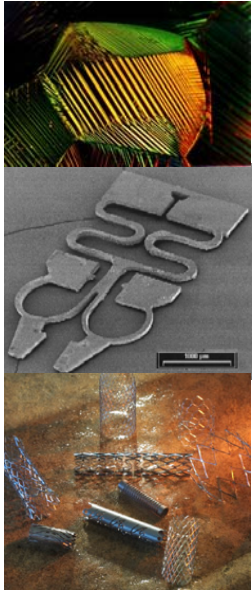
Observée pour la première fois sur un alliage Cu-Zn en 1952



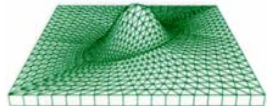
Formation de la variante  
 la mieux orientée  
 par rapport à la contrainte  
 appliquée



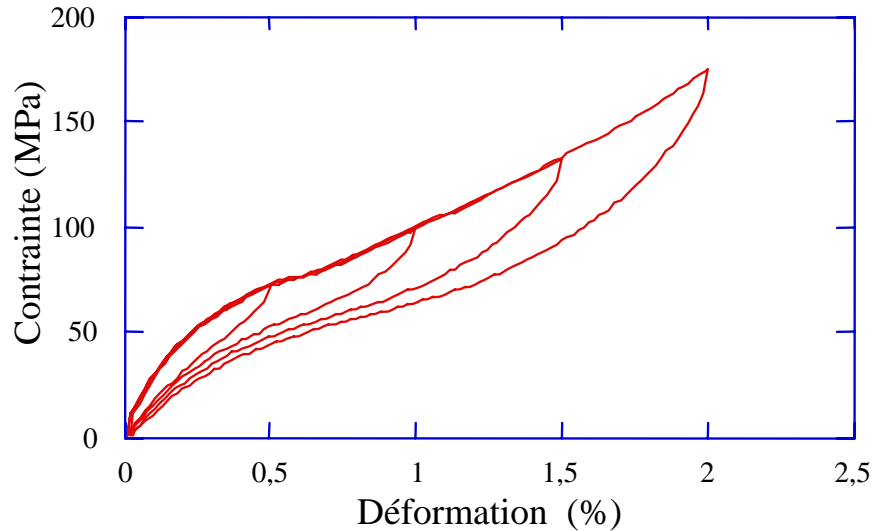
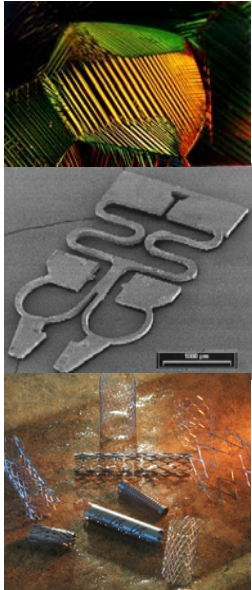
# Comportement Superthermique



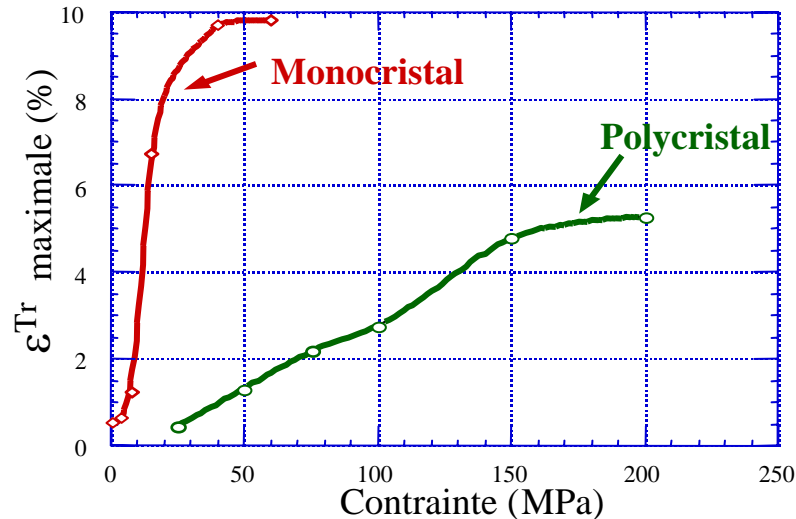
Formation de la variante  
la mieux orientée  
par rapport à la contrainte  
appliquée



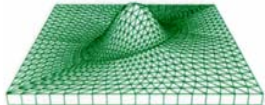
# Influence de la microstructure



Comportement superélastique à température ambiante d'un alliage polycristallin Cu-Zn-Al-Ni ( $M_s = -18^\circ\text{C}$ )

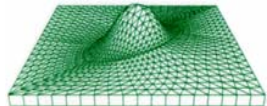
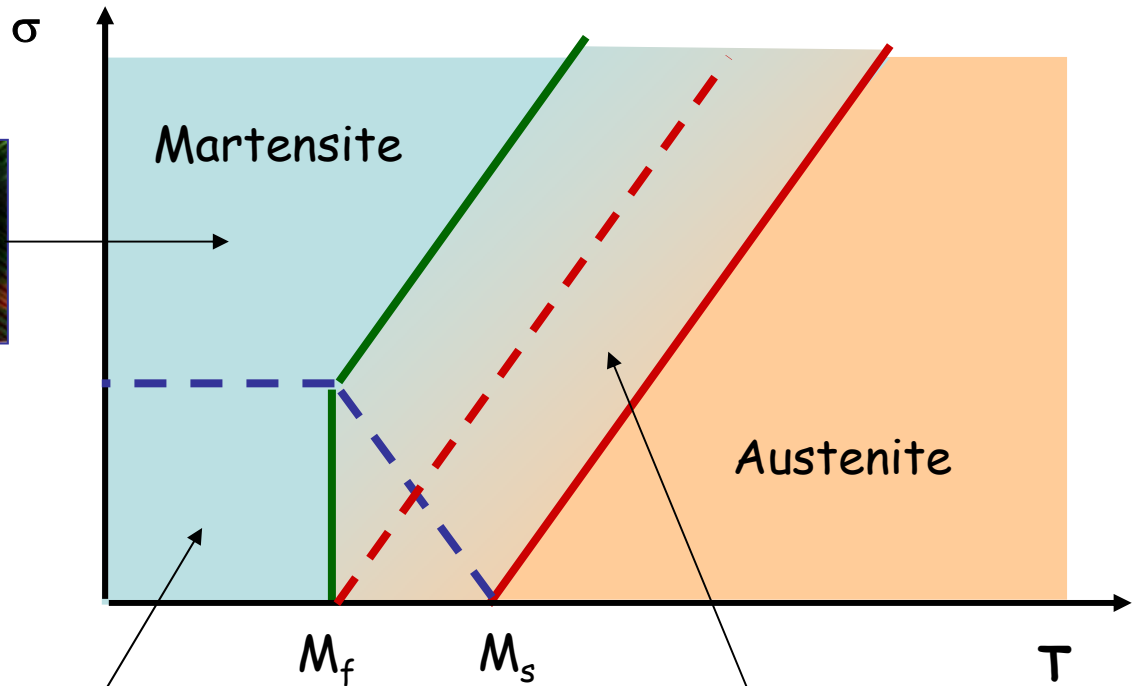
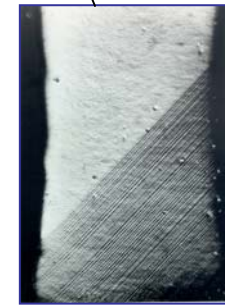
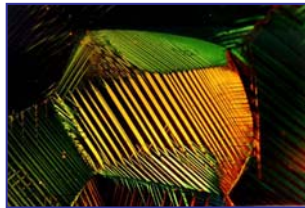
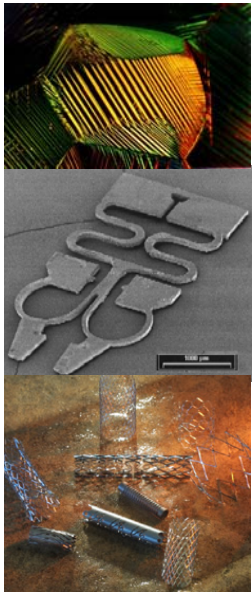


Evolution de la déformation maximale de transformation en fonction de la contrainte appliquée au refroidissement pour un monocristal et un polycristal de CuAlBe de même composition



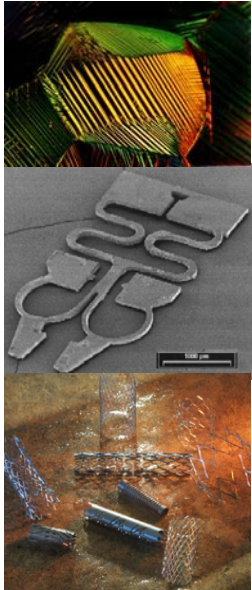


# Influence de la microstructure

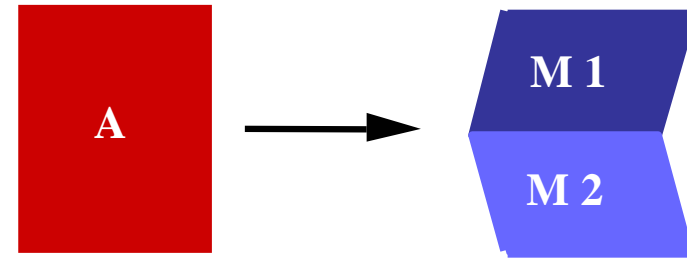


# II.2. Effet mémoire

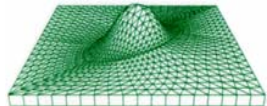
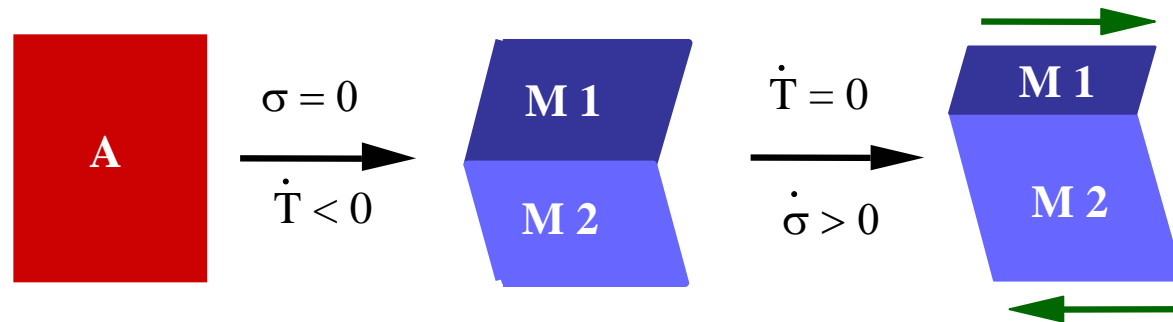
## Refroidissement sans contrainte



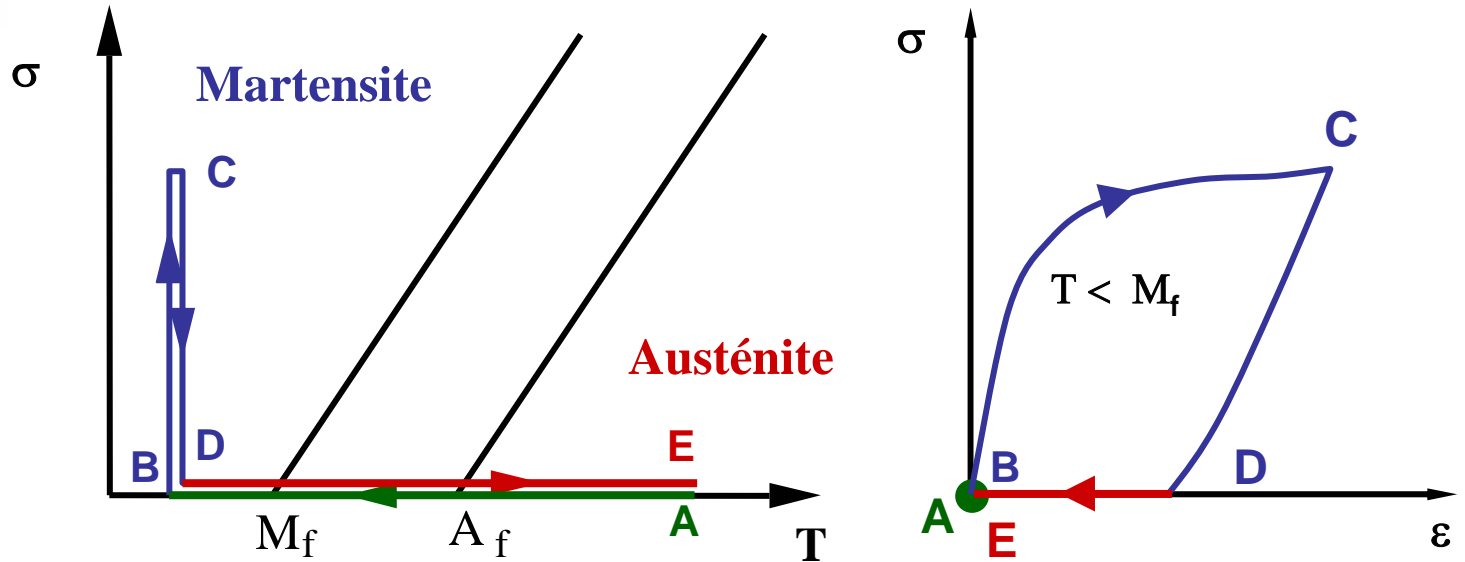
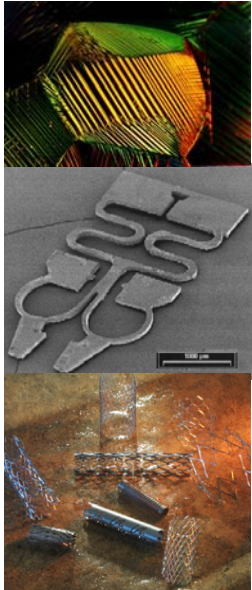
➔ Formation d'une microstructure autoaccommodante



## Mobilité des interfaces martensite/martensite

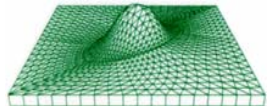


# Mémoire de forme simple sens

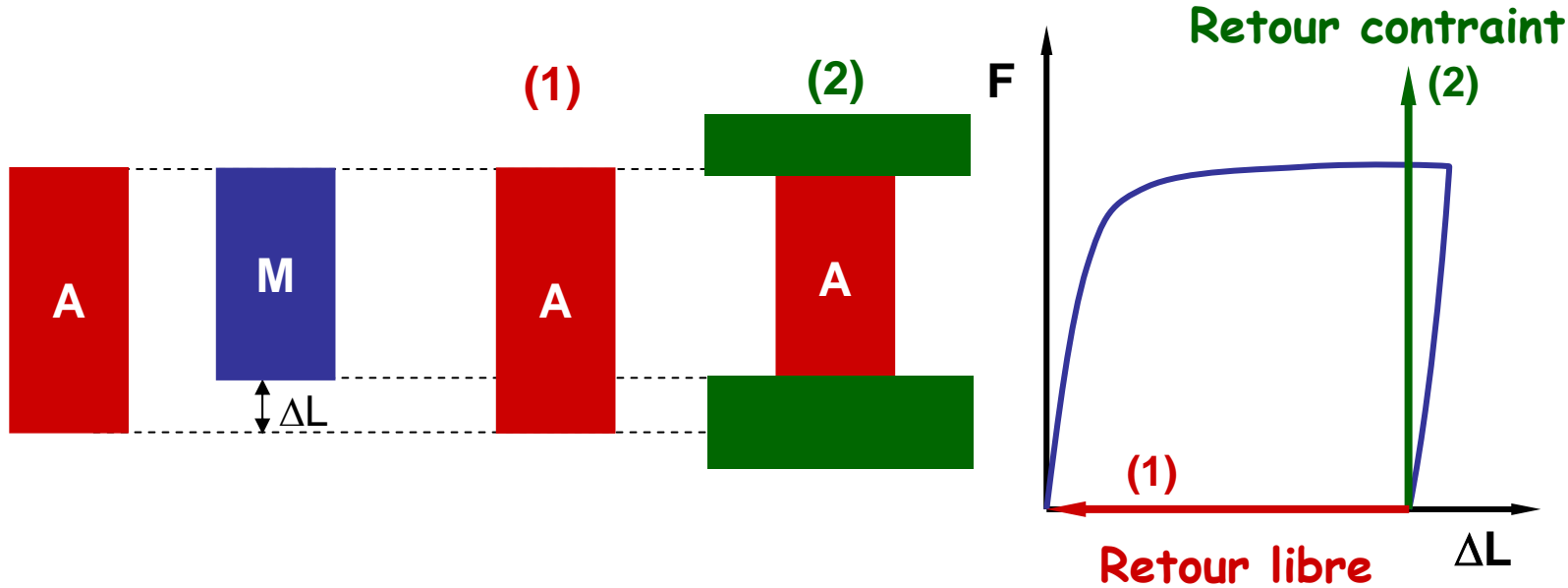
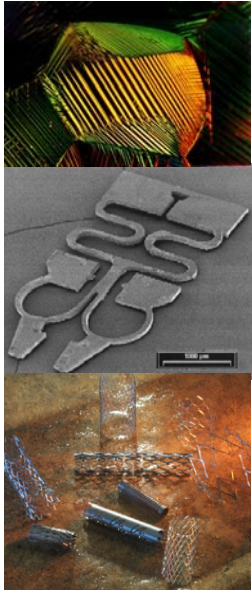


- Refroidissement A-B sans contrainte  
**Martensite autoaccommodée**
- Déformation B-C en phase basse température  
**Réorientation des variantes de martensite**
- Chauffage D-E sous contrainte nulle  
**Retour en austénite et reprise de forme**

La recouvrance de forme se réalise uniquement au chauffage

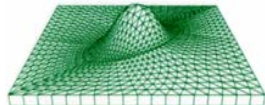
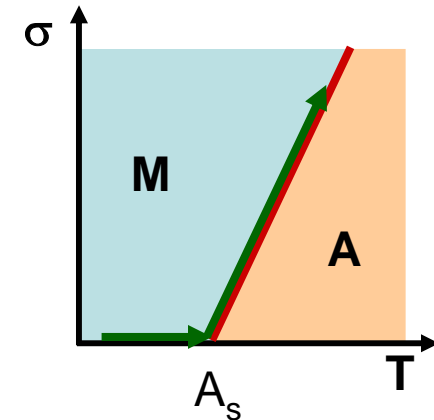


# Application : Retour contraint

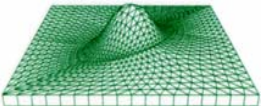
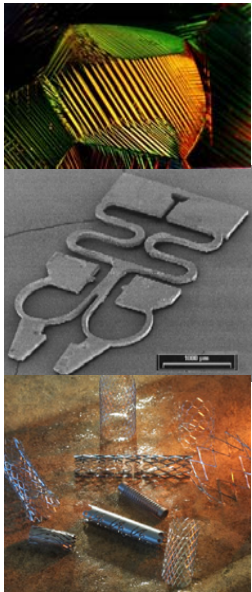
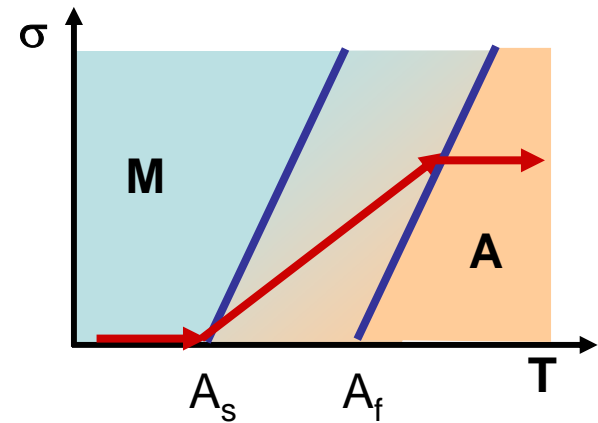
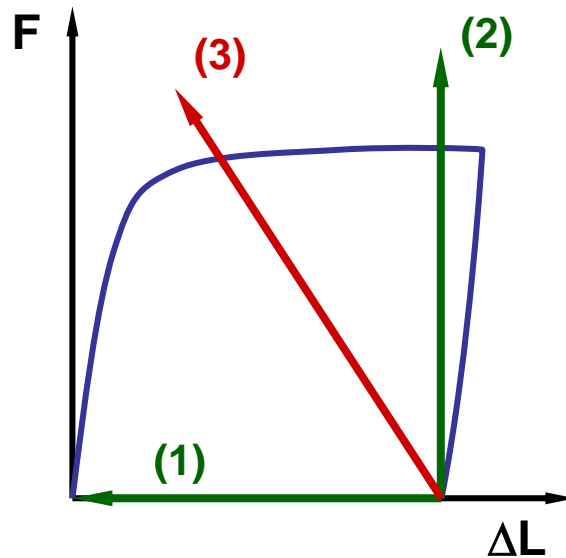
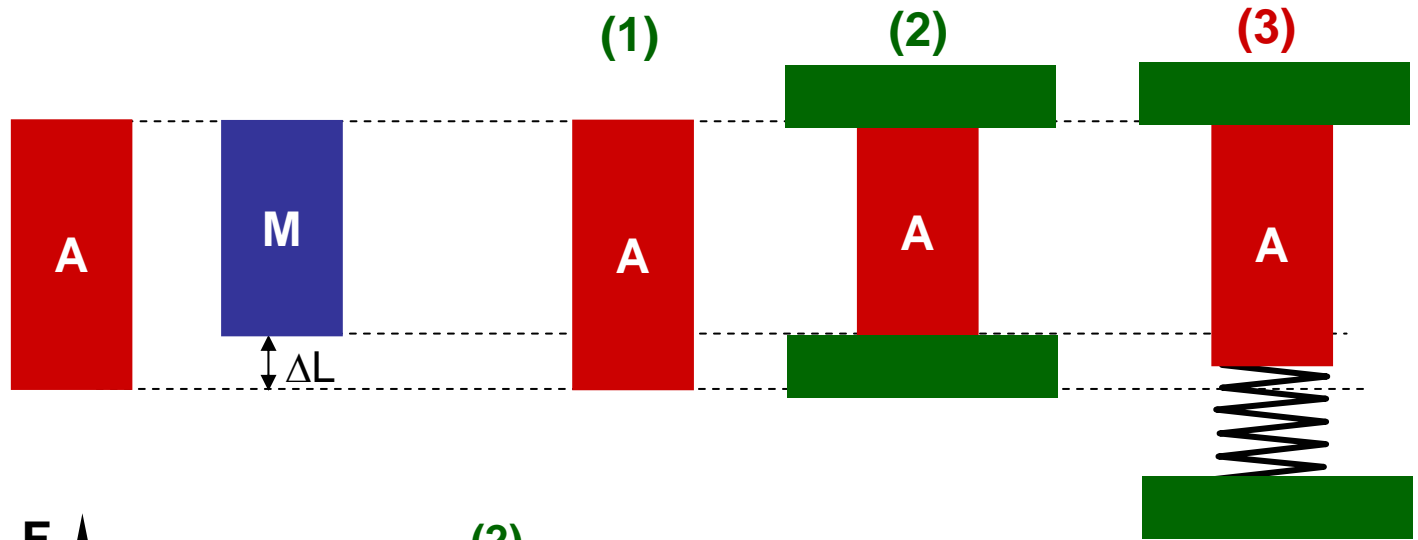


	$M_s$ (°C)	$T_{\text{déf}}$ (°C)	$\varepsilon$ (%)	$\sigma$ (MPa)
NiTi	- 200	- 200	8,0	500 – 900
CuAlNi	+ 70	+ 25	2,0	300 – 400
CuZnAlMn	- 40	- 90	3,5	550 - 650

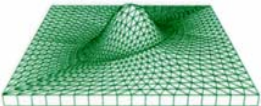
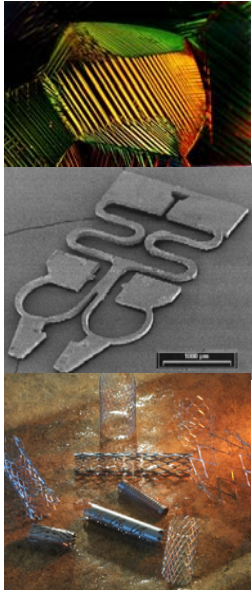
Engineering aspects of SMA (1990) p. 121



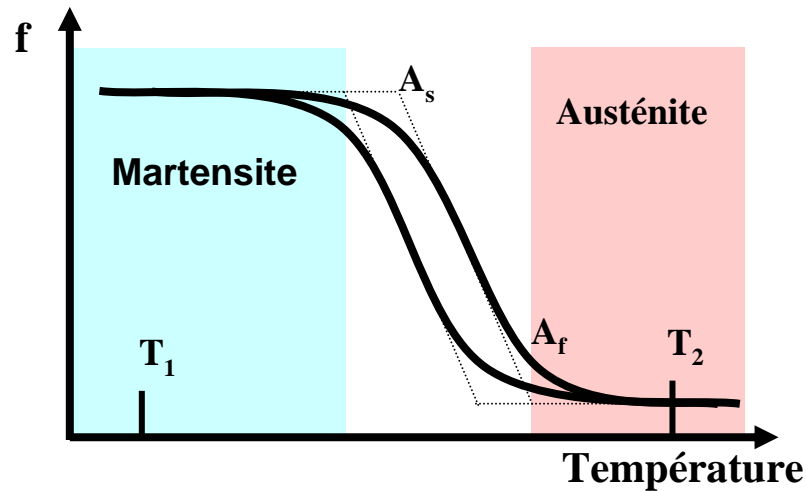
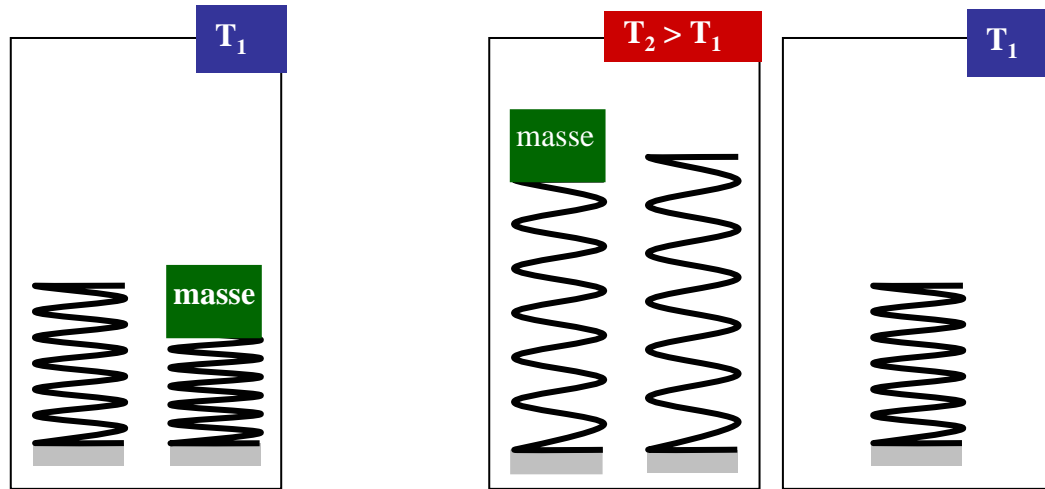
# Application : Production de travail



# II.3. Mémoire double sens

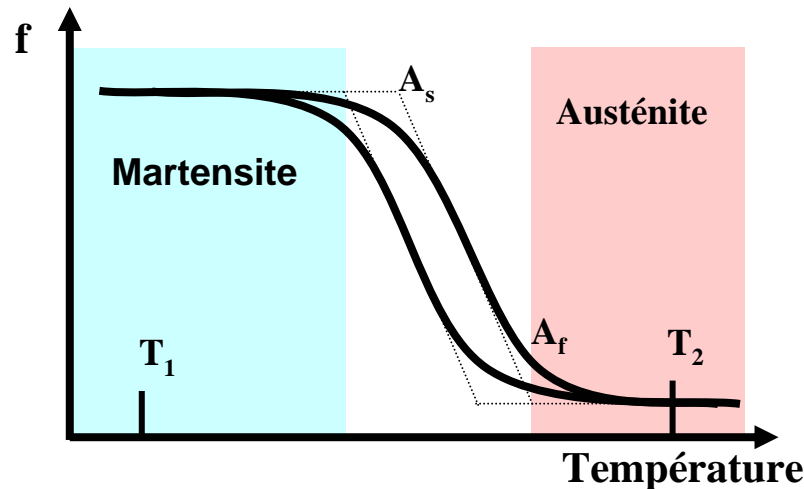
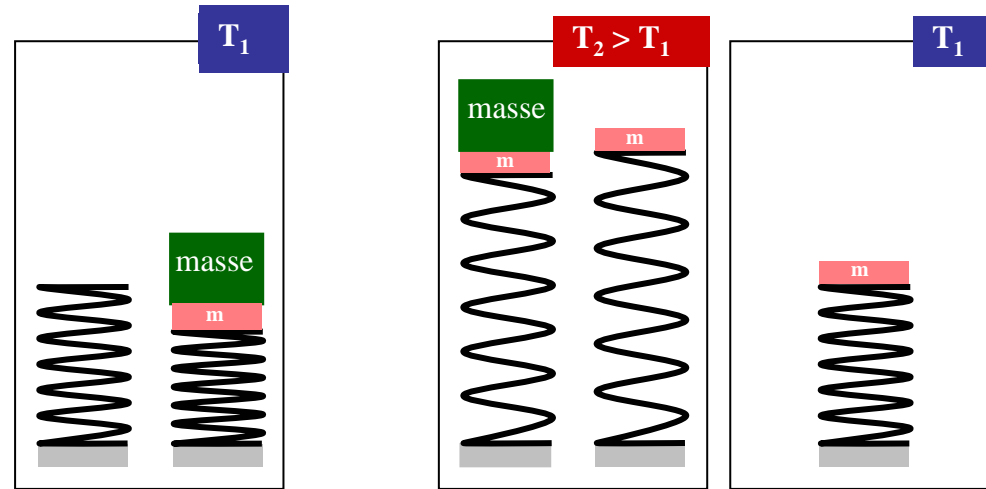
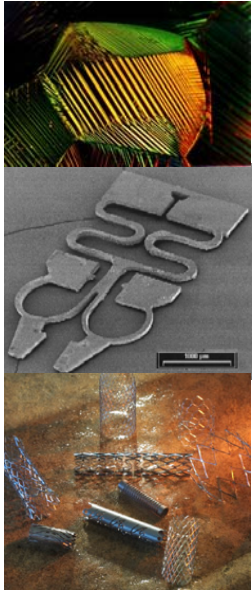


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UMR 7554

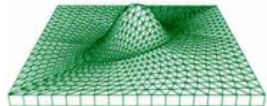


Effet obtenu par éducation

# Mémoire double sens assistée



Education remplacée par une force de rappel



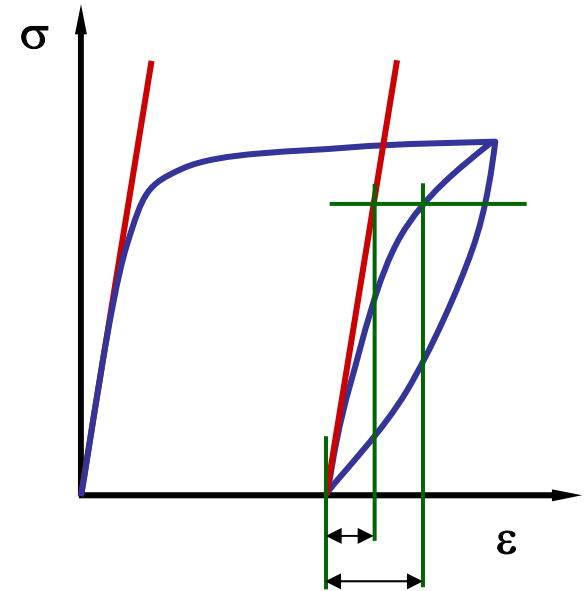
# II.4. Autres effets

## Effet caoutchoutique

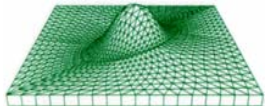
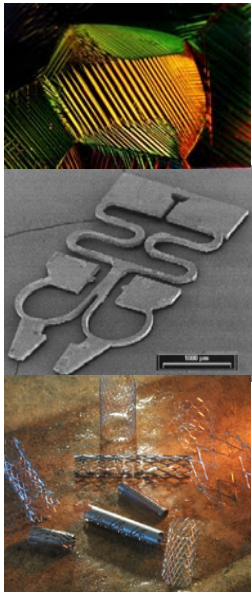
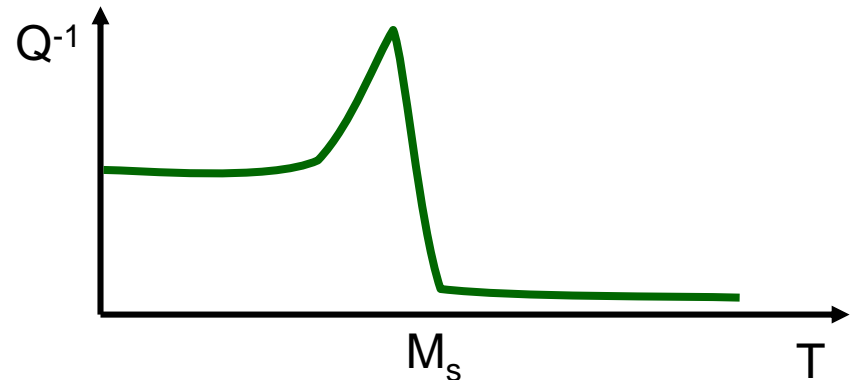
Effet observé pour la première fois en 1932 sur un alliage Au-Cd

$$T < M_f$$

Déplacement réversible des interfaces martensite/martensite



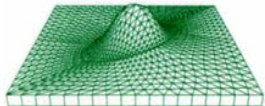
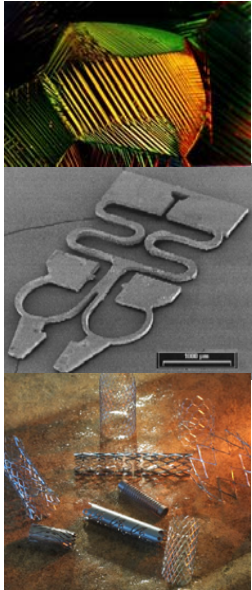
## Amortissement





# III. Applications des AMF

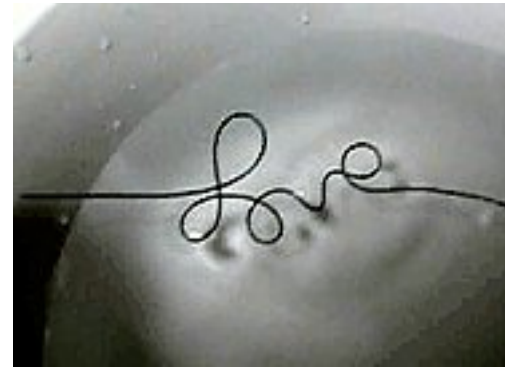
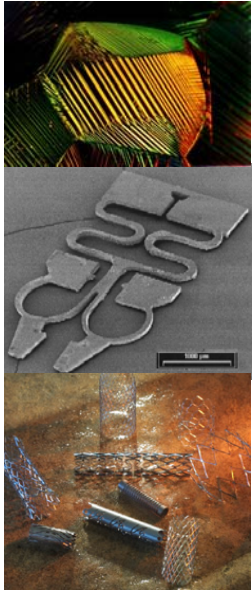
1. Mémoire simple sens
2. Retour contraint
3. Capteurs-actionneurs
4. Superélasticité
5. Applications biomédicales
6. Microsystèmes
7. Mémoire de forme, formes en mémoire



# III.1. One way memory

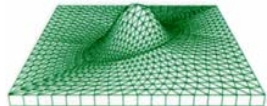
Peu d'application  
industrielle

Gadget, Jouets



TiNi Alloy Company

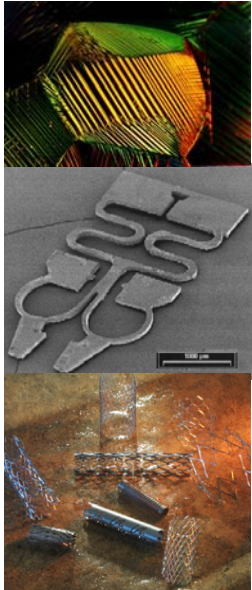
*Two dozen or less: \$3.50/each*



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Séminaire Matériaux IN2P3 – 17/10/2006

# III.2. Retour contraint



Raychem

Première application industrielle (1969)

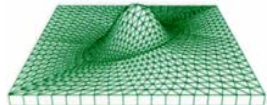
Manchon de connection  
U.S. Navy F- 14 Tomcat



Frangibolt®

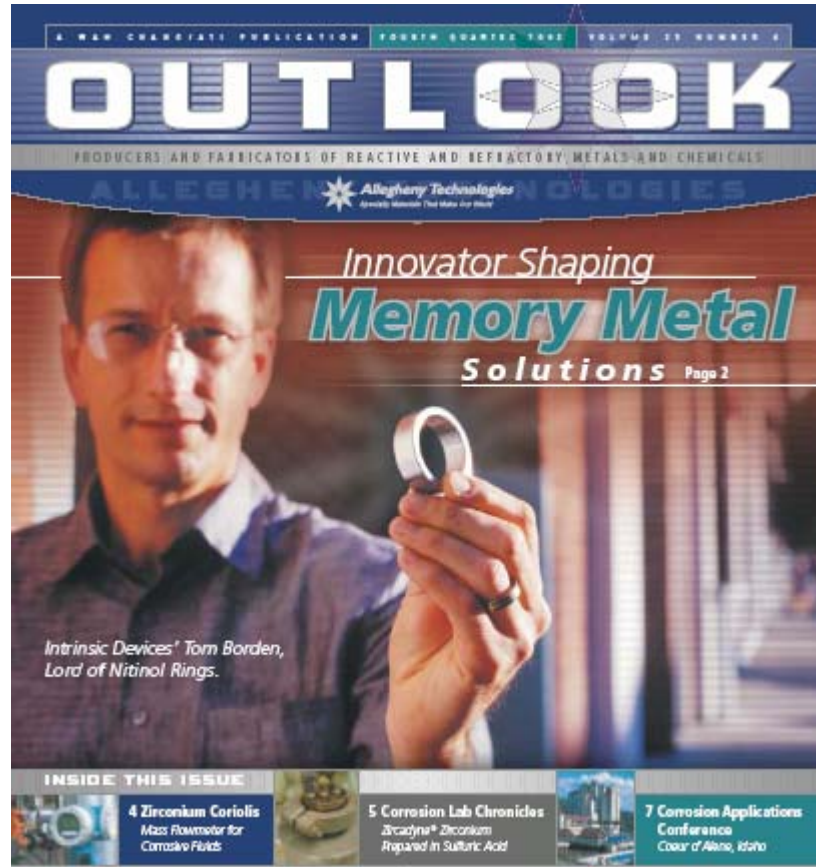
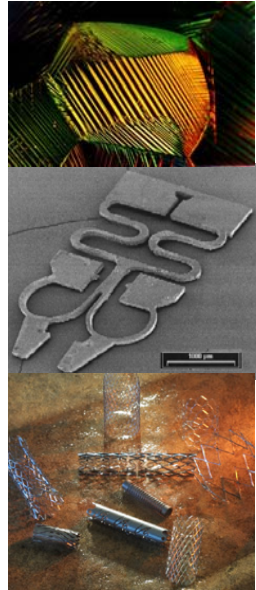
Génère jusqu'à 25 kN d'effort.

TiNi Aerospace, Inc



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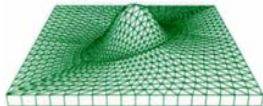
# Couplage



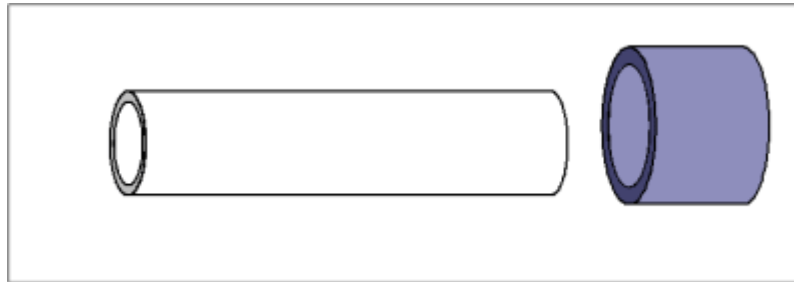
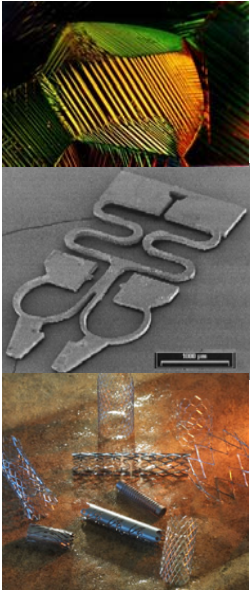
**Manchon Cryofit®**

**Intrinsic Devices, Inc**

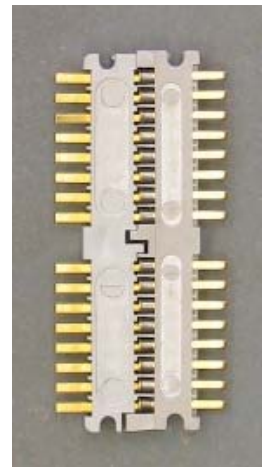
**Séminaire Matériaux IN2P3 – 17/10/2006**



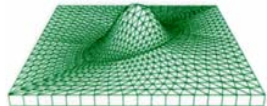
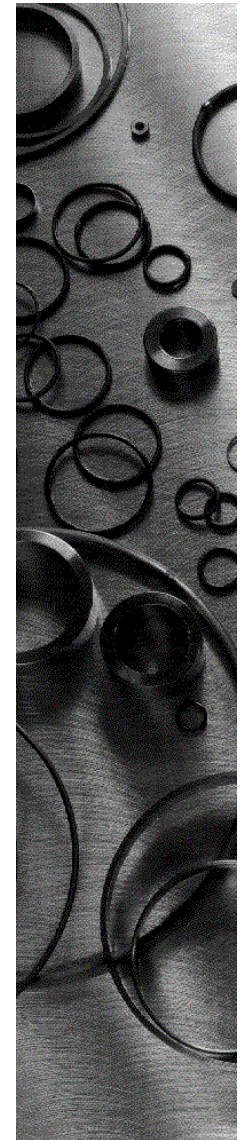
L.P.M.M.  
UMR 7554



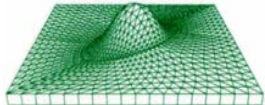
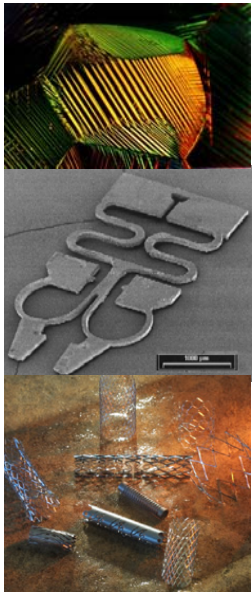
**Tinel-Lock®**



**Cryocon® connector**



# UniLok® Applications

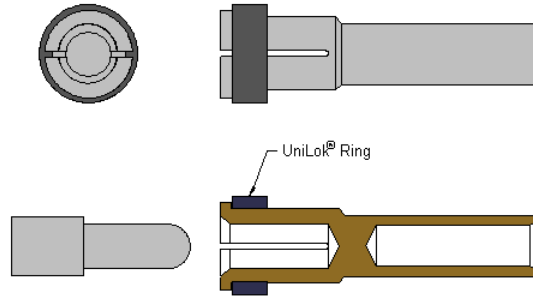


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UMR 7554

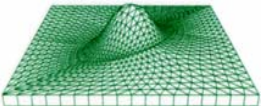
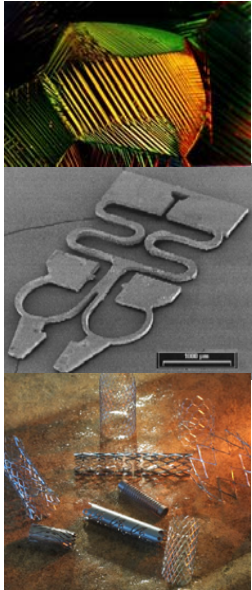
Intrinsic Devices Inc, 2003

**Séminaire Matériaux IN2P3 – 17/10/2006**

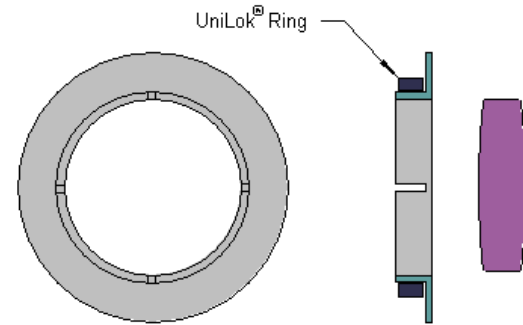
## Zero insertion force connector



Use for munitions, missiles, high amperage buss connections and bulkhead feedthroughs



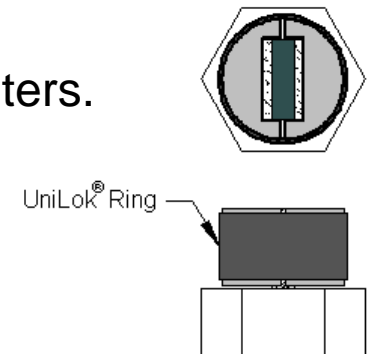
## Lens and Window Mounts

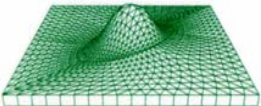
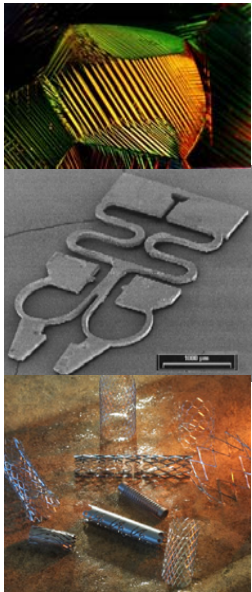


To mount delicate lenses in holders

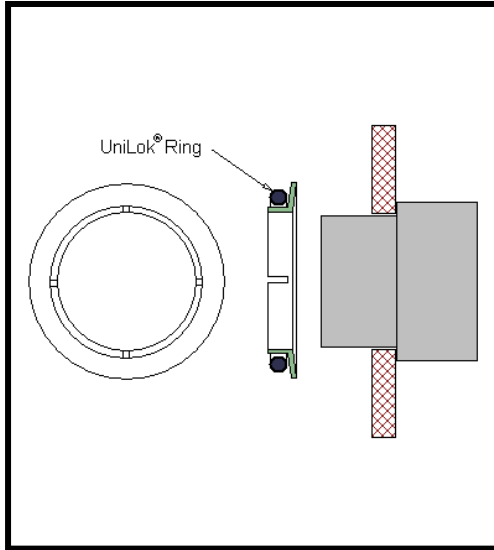
## Accelerometer Assembly

Clamp mass elements and piezoelectric material against the center post of shear type accelerometers. Provide easy assembly, consistent performance, and insensitivity to temperature extremes.

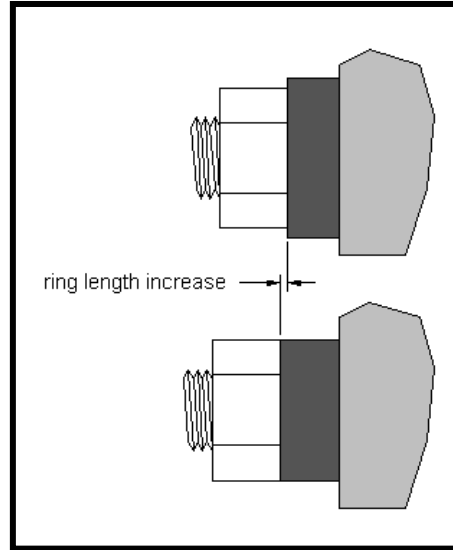




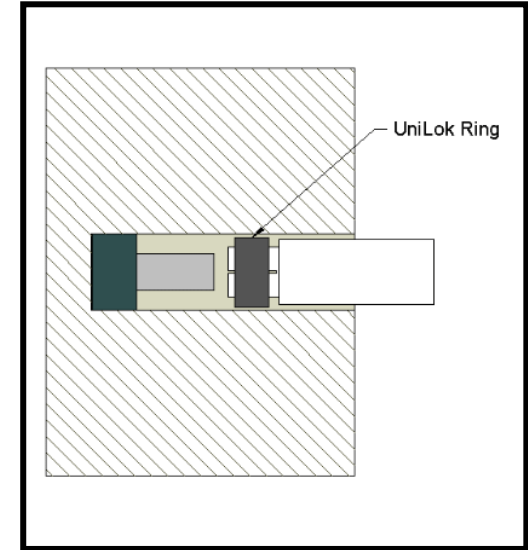
## Axial Preload



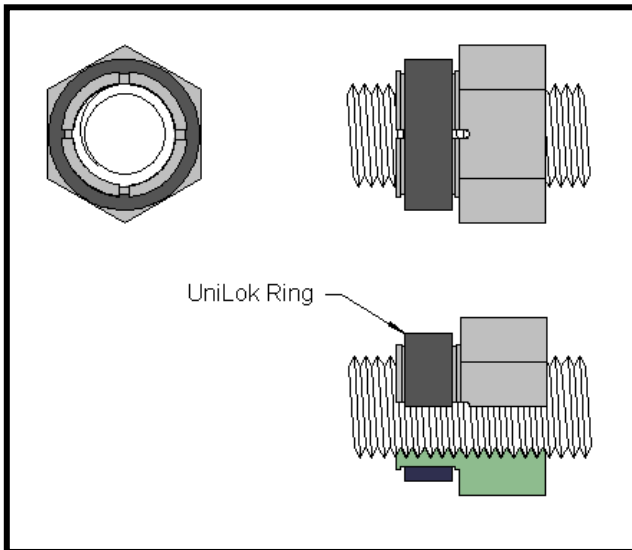
## Preload of Threaded Fasteners



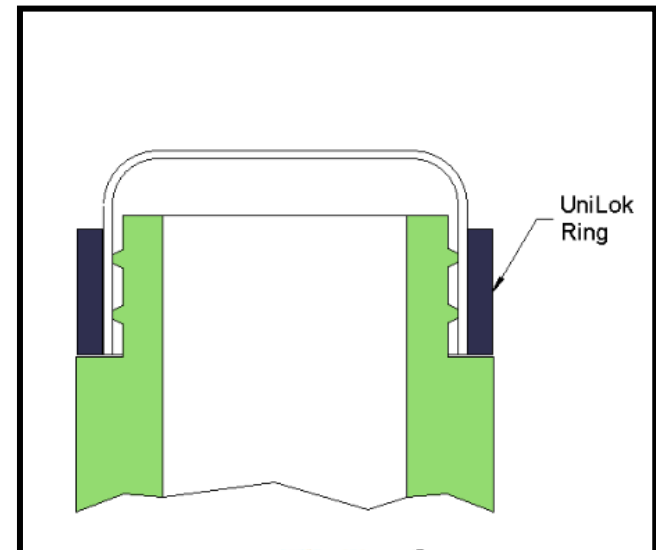
## Blind Assembly



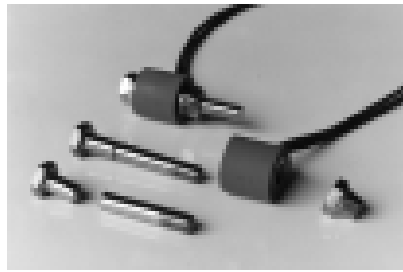
## Locking Nuts



## Hermetic Seal

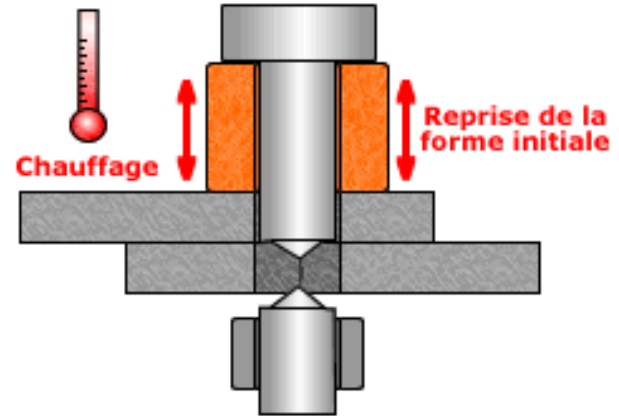
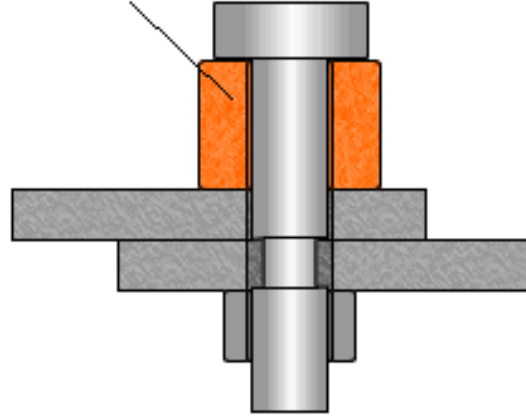




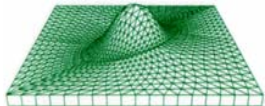
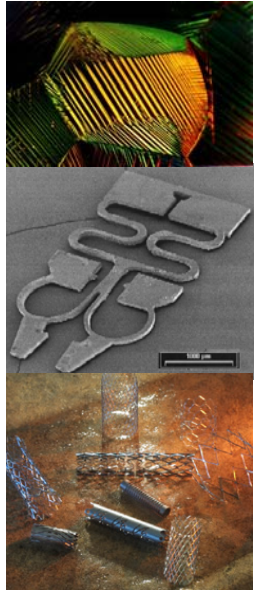


# Frangibolt®

Entretoise en AMF Comprimée



Rupture du boulon sous contrainte

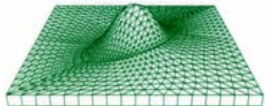
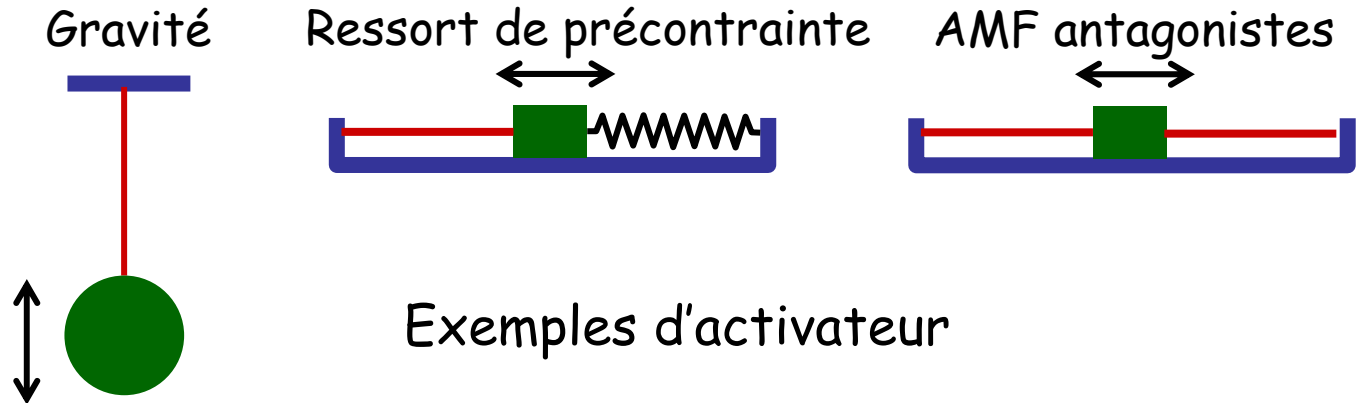
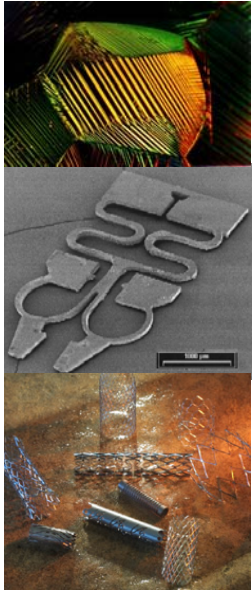


TiNi Aerospace, Inc, 2001

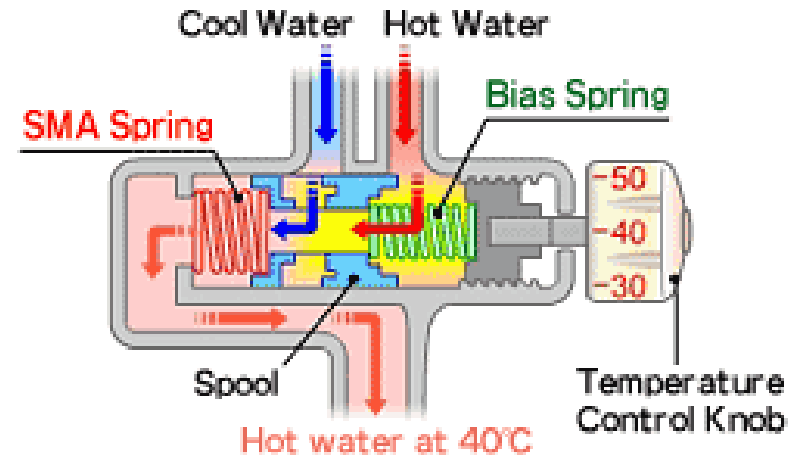
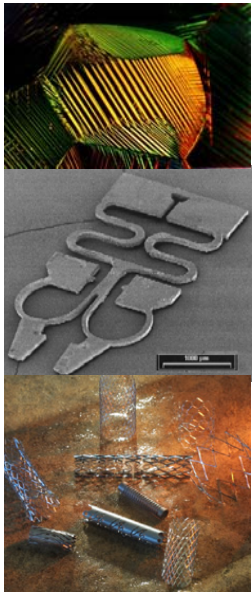
# III.3. Activateurs

3 types d'activateur en AMF

- Activateur thermique
- Activateur électrique
- Activateur différentiel



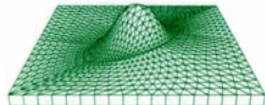
# Domotique



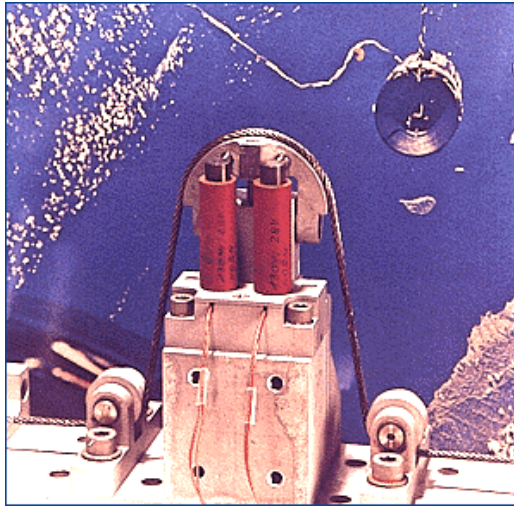
## Valve thermostatée

Pour éviter l'arrivée d'eau brûlante au début de l'écoulement les débits d'eau chaude et d'eau froide sont contrôlés par l'action d'un ressort en alliage à mémoire de forme .

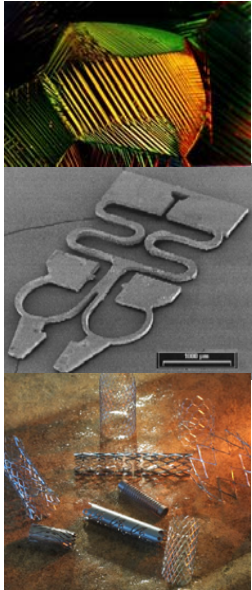
Furukawa Techno Material Co., 2000



# Application aérospatiales



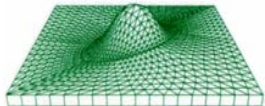
Télescope HUBBLE, 1990



Ce dispositif permet d'assurer le verrouillage des panneaux solaires pendant la phase de lancement et de leur déverrouillage une fois le télescope en orbite.  
Un chauffage à  $115^{\circ}\text{C}$  de l'élément en NiTi permet ce déverrouillage.

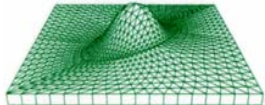
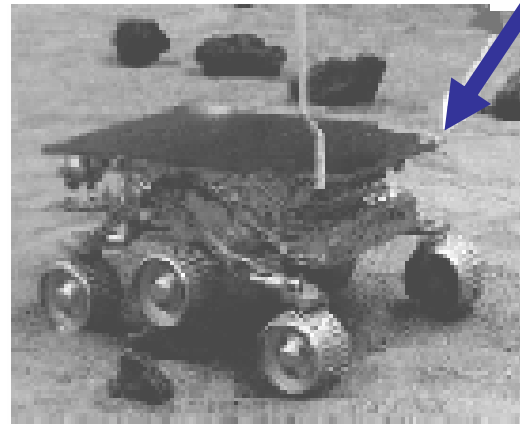
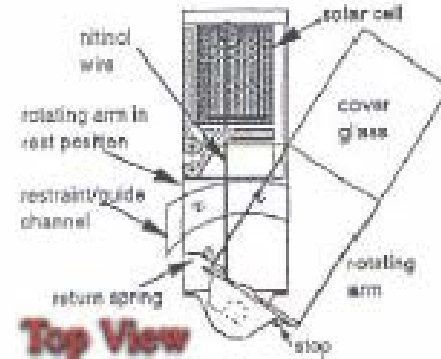
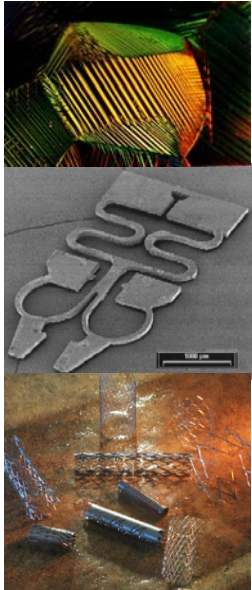
@mt Advanced Materials and Technologies, Belgium

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# Mars Pathfinder

« *Material adhesion Experiments* »



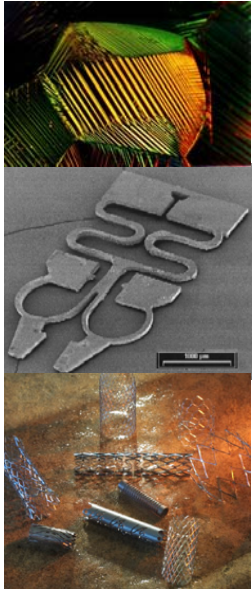
L.P.M.M.  
UMR 7554

Dynalloy

# III.4. Superélasticité

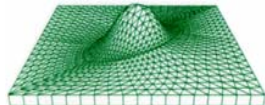


Monture superélastique  
AMF CuAlBe Monocristallin



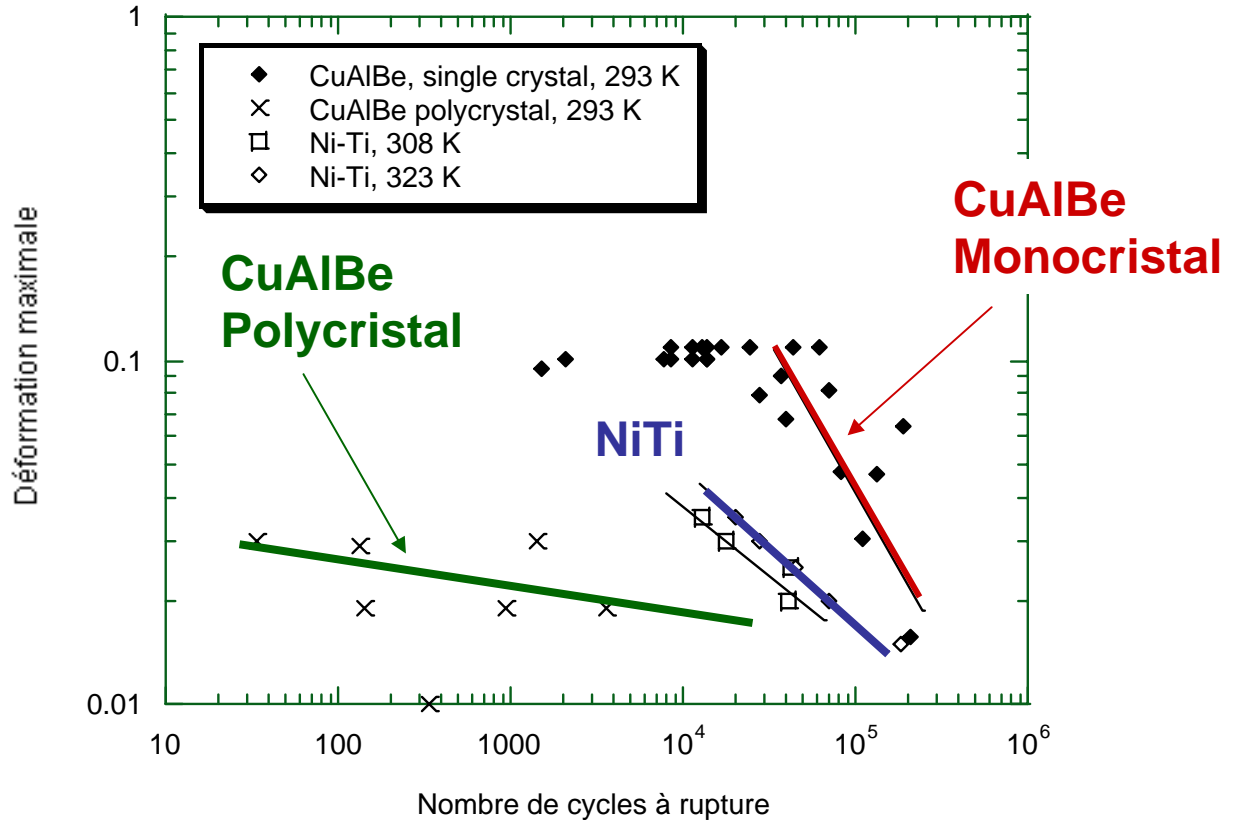
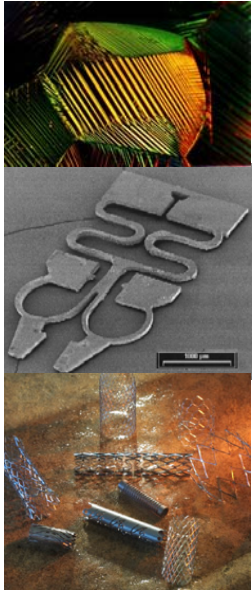
Aspex Technologies, Brevet LPMM

Séminaire Matériaux IN2P3 – 17/10/2006



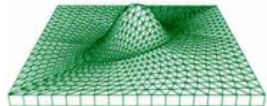
L.P.M.M.  
UMR 7554

# AMF Monocristallins

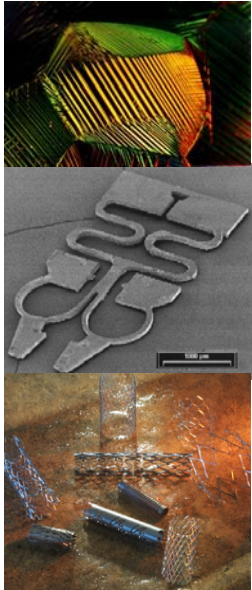


*Courbes de Manson-Coffin pour des AMF poly et monocristallins*

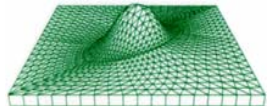
Nathalie Siredey, LPMM



# Applications dans l'habillement



Furukawa Techno Material Co.  
2000

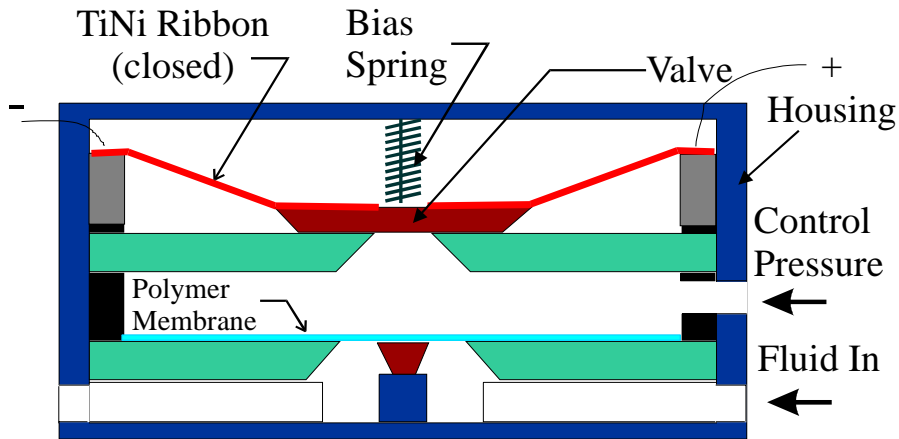
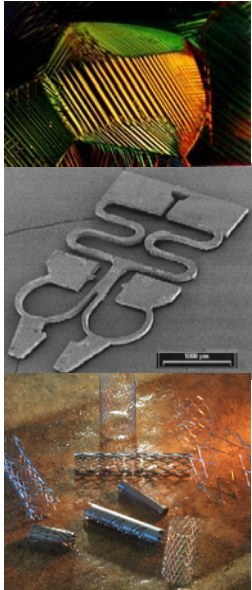


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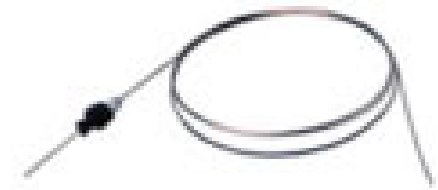
**Séminaire Matériaux IN2P3 – 17/10/2006**



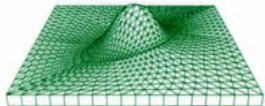
# III.5. Applications biomédicales



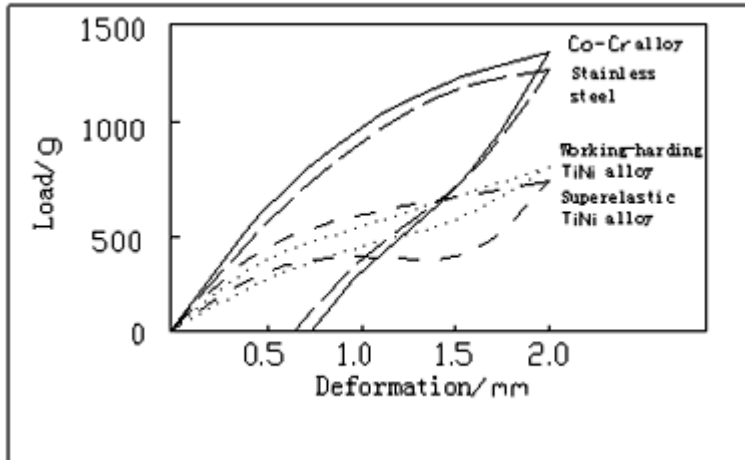
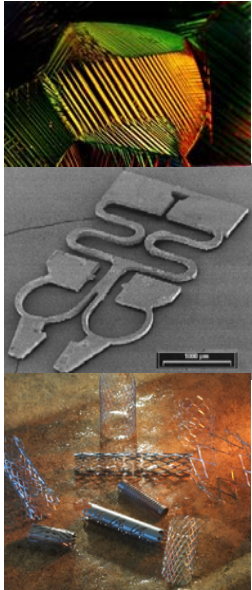
SMA actuated microvalve  
 manufactured by *TiNi Alloy Company*



Fil guide



# Fil orthodontique



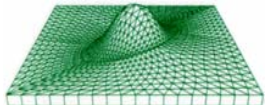
Furukawa

Test de flexion à 90 degrés pour plusieurs matériaux

Alliages	Déformation permanente	Déviaton standard
TiNi suprélastique	0	0
NiTi écroui	1.34	0.20
Alliage Co-Cr A	25.4	0.66
Alliage Co-Cr B	38.8	1.88
Acier inoxydable A	10.3	0.50
Acier inoxydable B	34.0	0.55

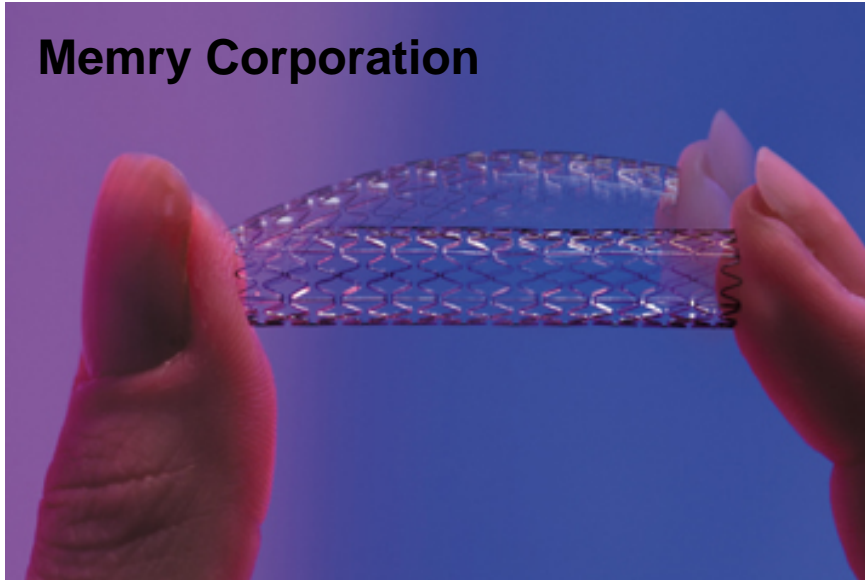
Grikin Advanced Materials Co., Ltd

Séminaire Matériaux IN2P3 – 17/10/2006

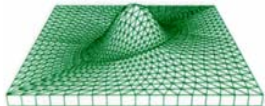
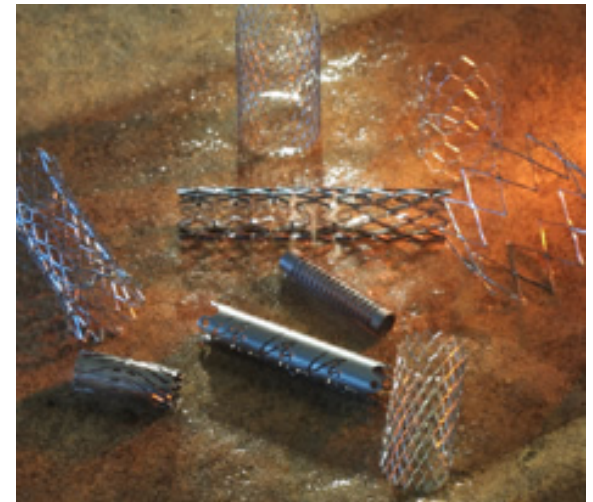
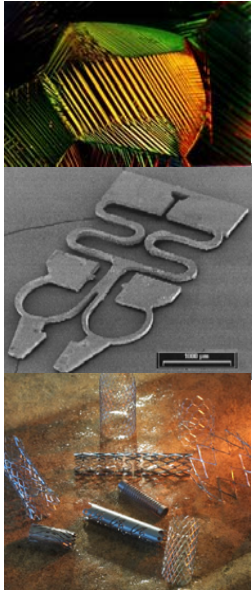


# Stent

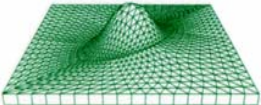
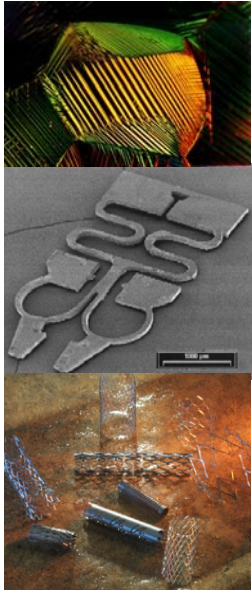
Memry Corporation



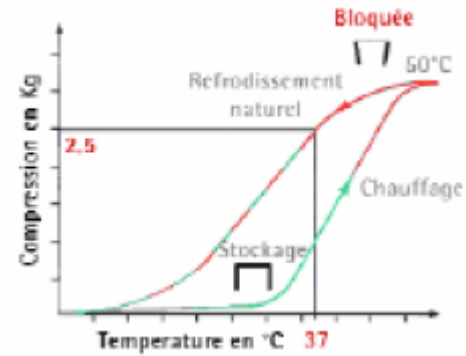
TUBULAR LASER CUT STENTS



# Agraphes d'ostéosynthèse à mémoire de forme

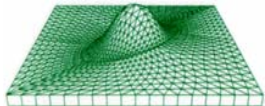
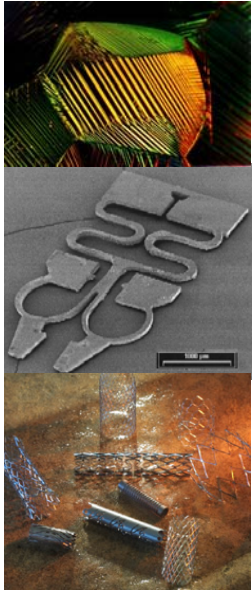


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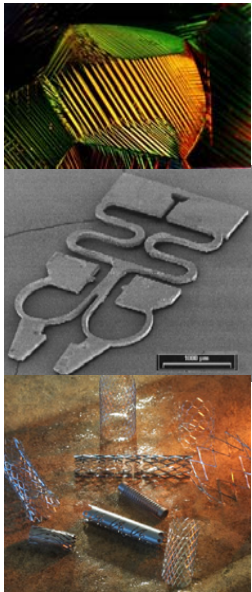


# Implant intra médullaire à mémoire de forme pour arthrodèse interphalangienne



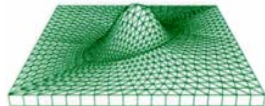
# EASY Clip®

La superélasticité maîtrisée



« Hallux Valgus Memometal kit »

Force de compression inter-fragmentaire constante  
4,5 kg.

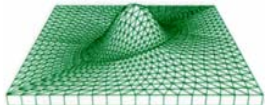
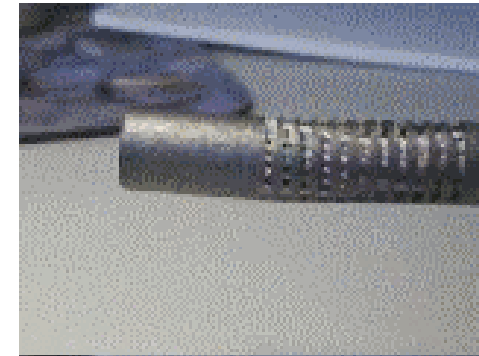
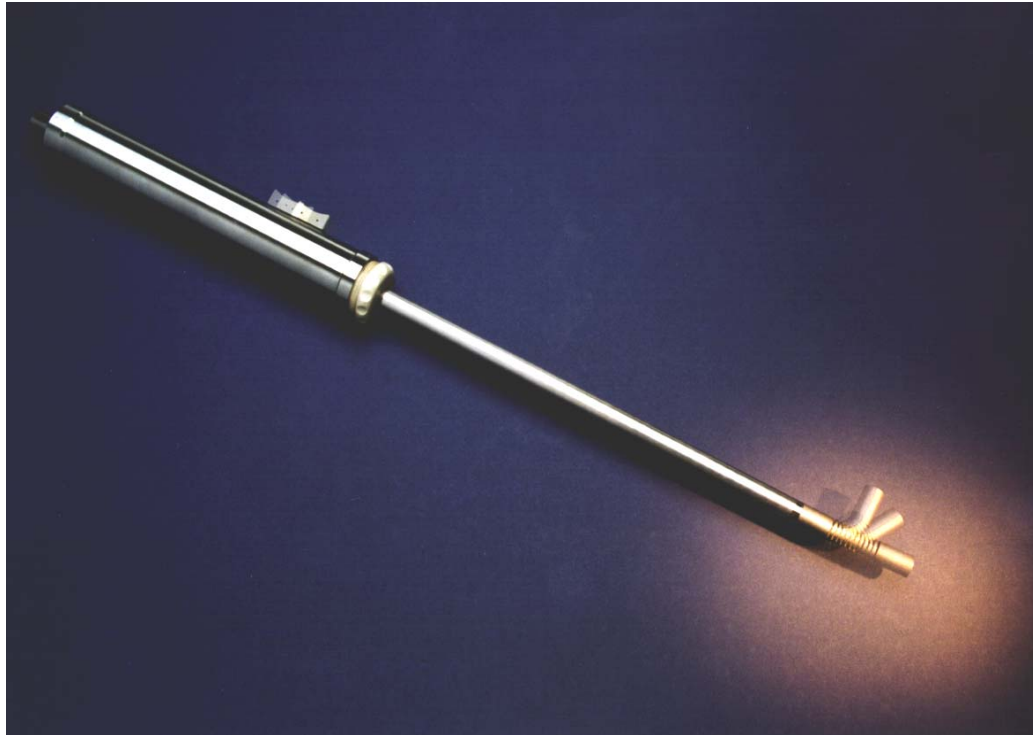
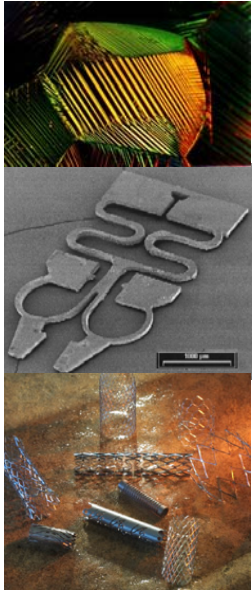


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UMR 7554

Séminaire Matériaux IN2P3 – 17/10/2006



# Support mobile pour caméra endoscopique

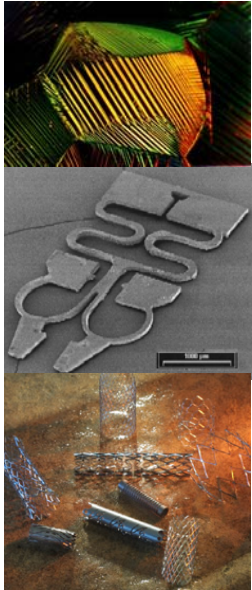


L.P.M.M.  
UMR 7554

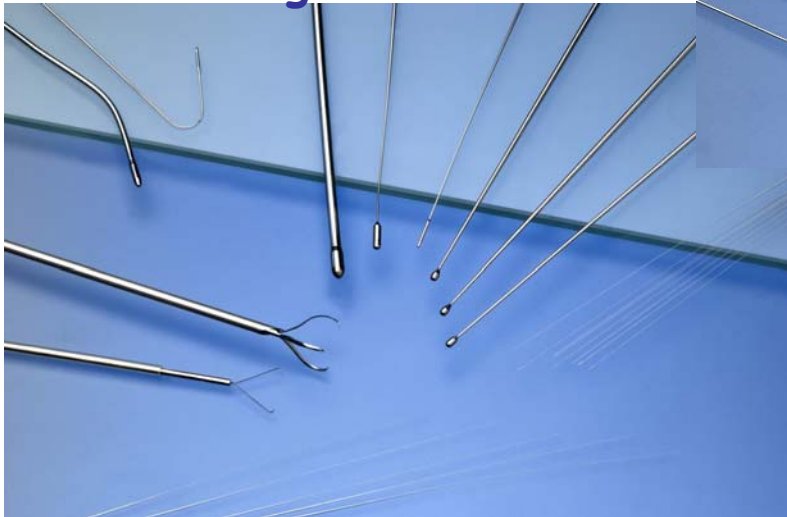
Dr. Harald Fischer, Forschungszentrum Karlsruhe, PDG ENDOSMART GmbH

**Séminaire Matériaux IN2P3 – 17/10/2006**

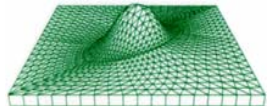
# Instrumentation chirurgicale



## Neurochirurgie



## Chirurgie vasculaire



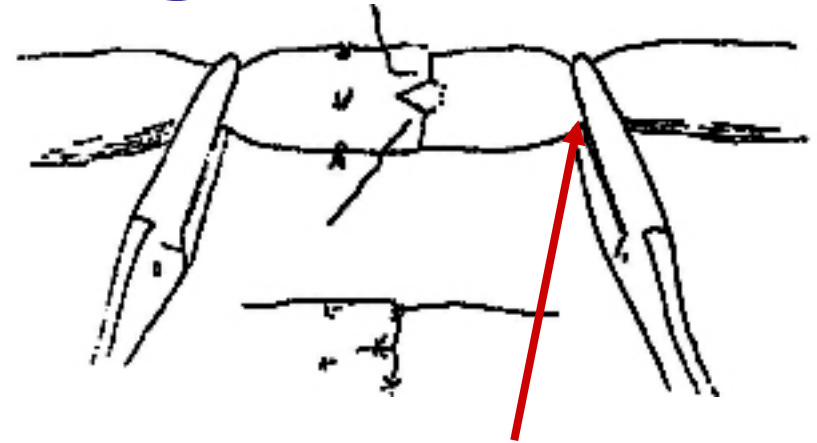
L.P.M.M.  
UMR 7554

Dr. Harald Fischer, Forschungszentrum Karlsruhe, PDG ENDOSMART GmbH

**Séminaire Matériaux IN2P3 – 17/10/2006**



# Forceps intelligents



Traumatisme possible  
si la pression est trop forte



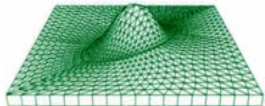
La première greffe de rein au Japon  
a échoué suite à un traumatisme  
Lié à l'emploi des forceps

**AMF superélastique**

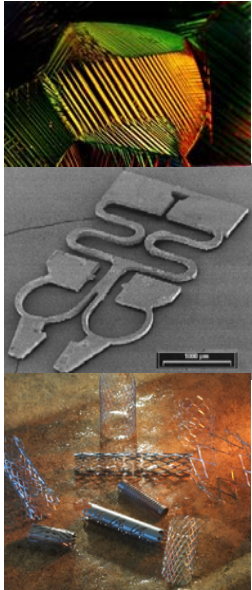


*Tohoku University Biomedical Engineering Research Organization*

**Séminaire Matériaux IN2P3 – 17/10/2006**



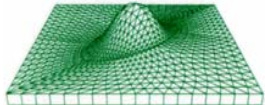
# Medical devices for laparoscopic surgery



Articulating scissors,  
dissectors, retractors



Specimen retrieval bag



L.P.M.M.  
UMR 7554

Memry Corporation

Séminaire Matériaux IN2P3 – 17/10/2006

# Microrobotic for genetic

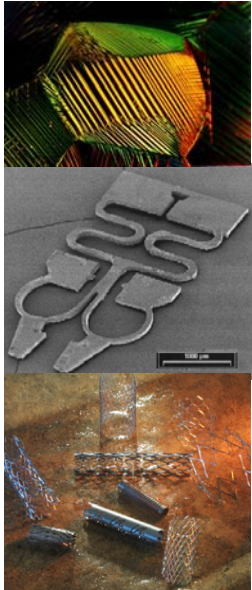
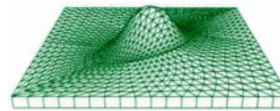


Photo IGBMC-LGIPM

**Objective : DNA hybridization density greater to 3600 samples/cm<sup>2</sup>.**

- Large scale integration
- Drop size ~ 100µm
- High productivity

➔ SMA Activator



L.P.M.M.

*Metz University*

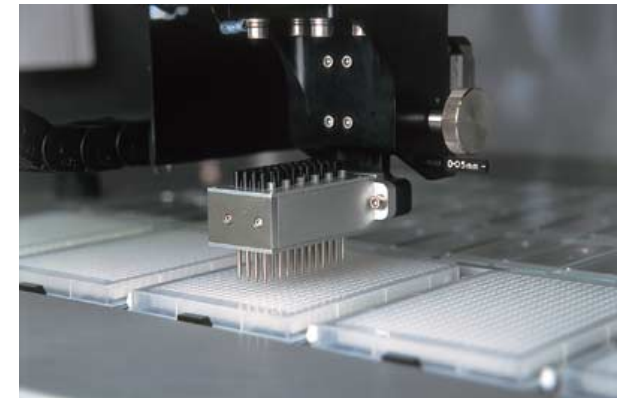
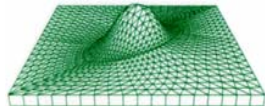


Photo Genetic Microsystems



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UMR 7554

# III.6. Microsystèmes

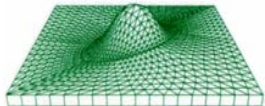
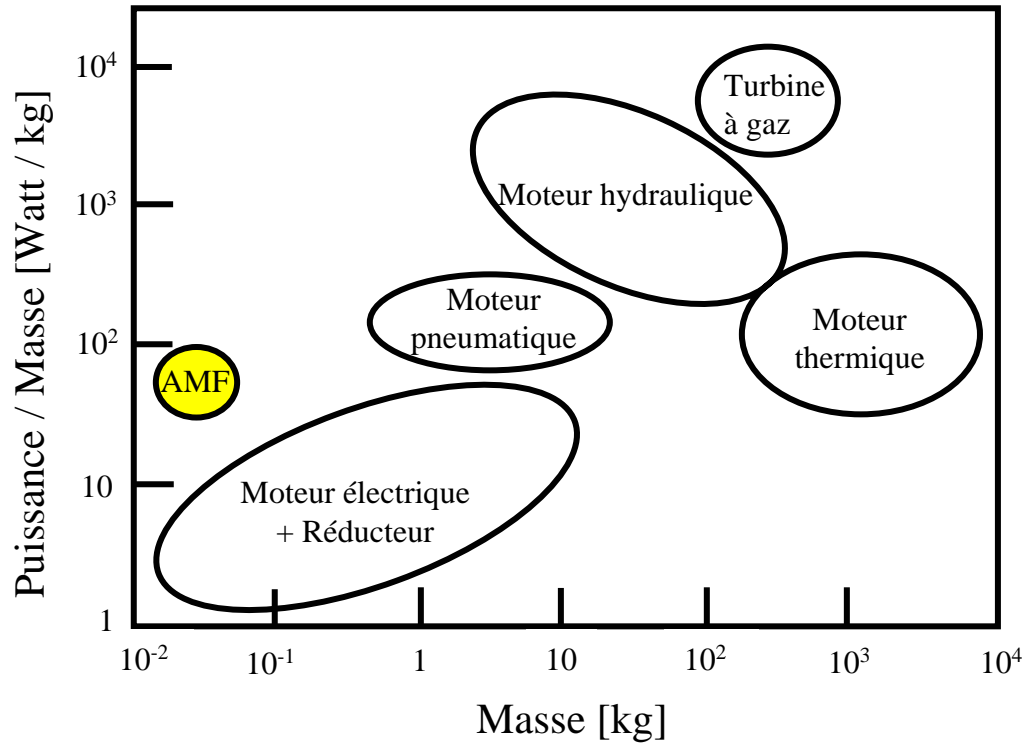
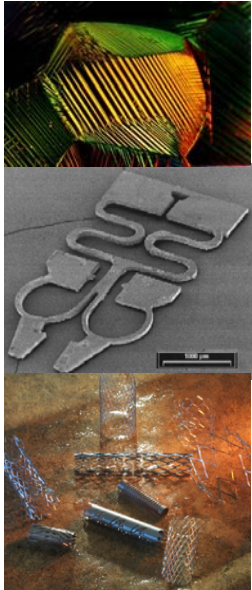
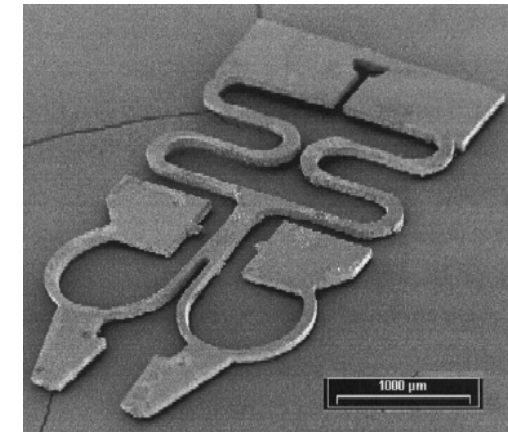
Micropince

EPFL Lausanne



Micropince

IZT Karlsruhe



# Shape memory alloys for micromembranes actuation

P. Surbled\*, B. Le Pioufle, E.H. Yang, H. Fujita

LIMMS/CNRS-IIS, Institute of Industrial Science, University of Tokyo  
 7-22-1 Roppongi, Minato-ku, Tokyo 106-8558, Japan

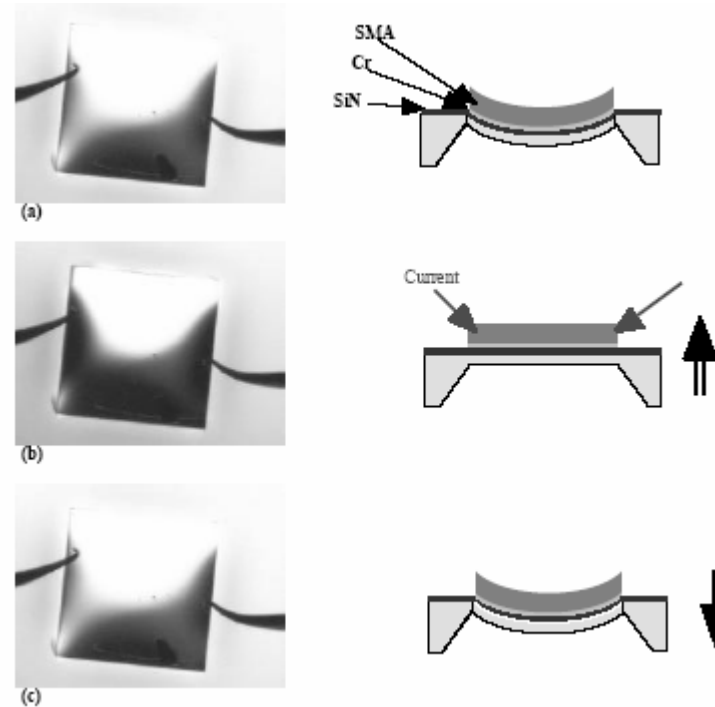
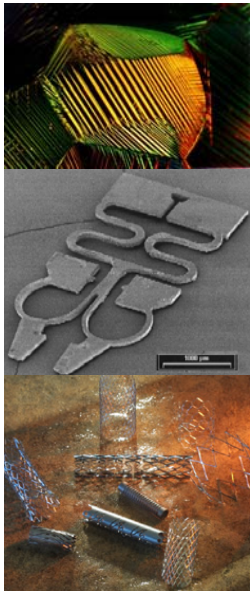


Fig. 7. Actuation of a 1 mm square SMA membrane: (a) initial shape, (b) during heating ( $i=500\text{mA}$ ), (c) recovery to the initial shape after current shut-off

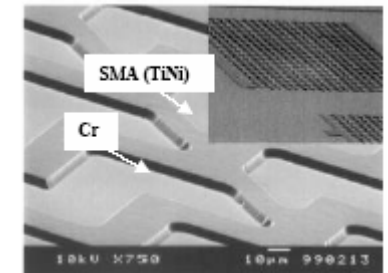
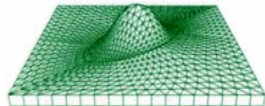
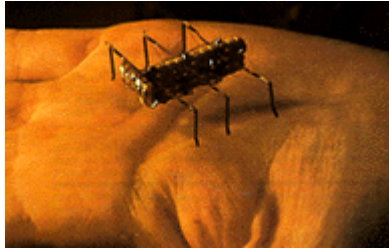


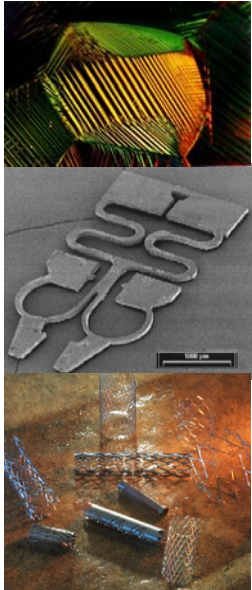
Fig. 4. Frontside of the active membrane ( $2 \times 2\text{mm}^2$ ) before releasing



# Micro robotics applications and nanotechnology

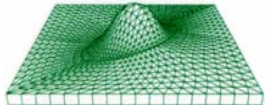


**MondoTronics**



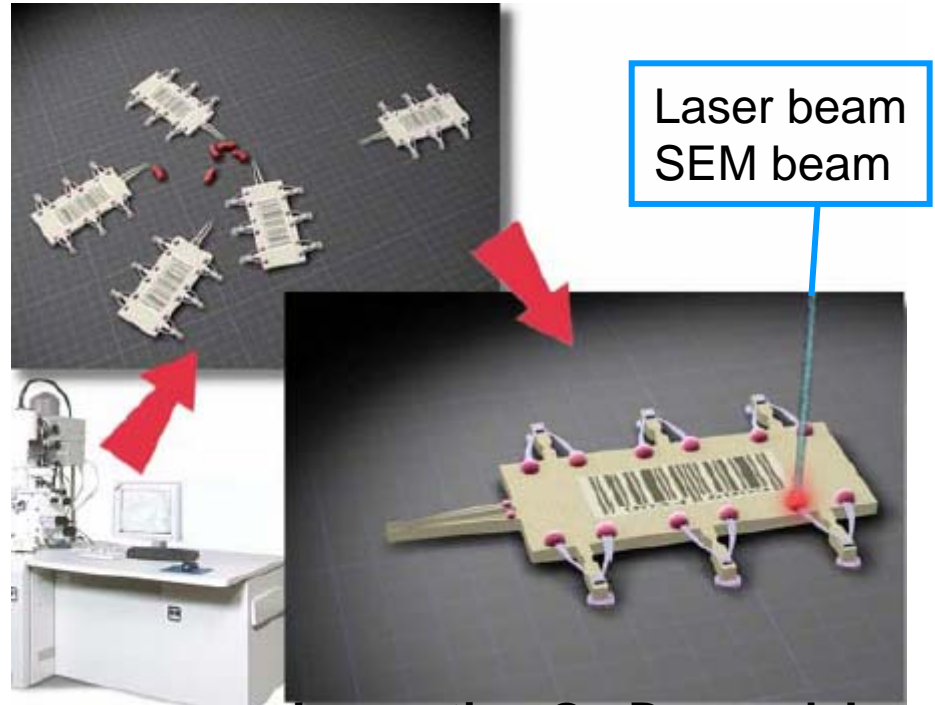
Construction or control of medical devices.

Manipulation of protein and genetic components



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UMR 7554

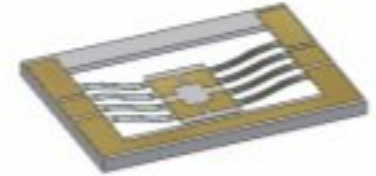
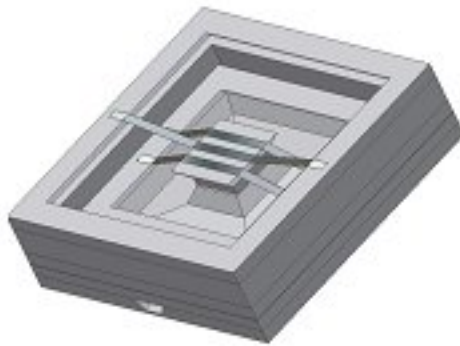
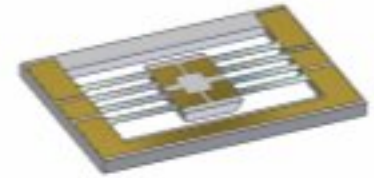
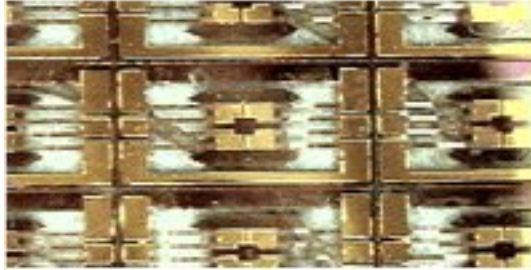
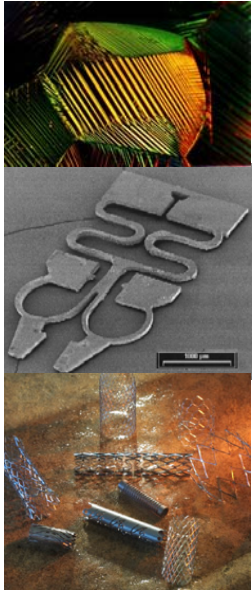
## Wireless SMA actuators



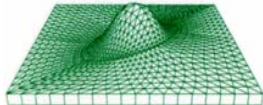
Laser beam  
SEM beam

**Innovation On Demand, Inc**

# TiNi Thin Film Actuators



Built on a 5.1 x 8.1 mm silicon chip.  
 Eight ribbons of thin film 4  $\mu\text{m}$  thick, 250  $\mu\text{m}$  wide and 2.15 mm long.  
 Can lift 30-40 grams for a distance of 100 to 400  $\mu\text{m}$ .  
 60-80 mA ( $\sim$ 2.4volts) are necessary to operate.



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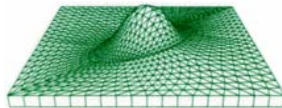
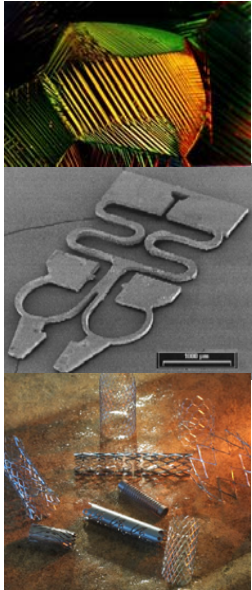
TiNi Alloy Company

Séminaire Matériaux IN2P3 – 17/10/2006

# Micropositionneur différentiel AMF



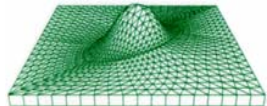
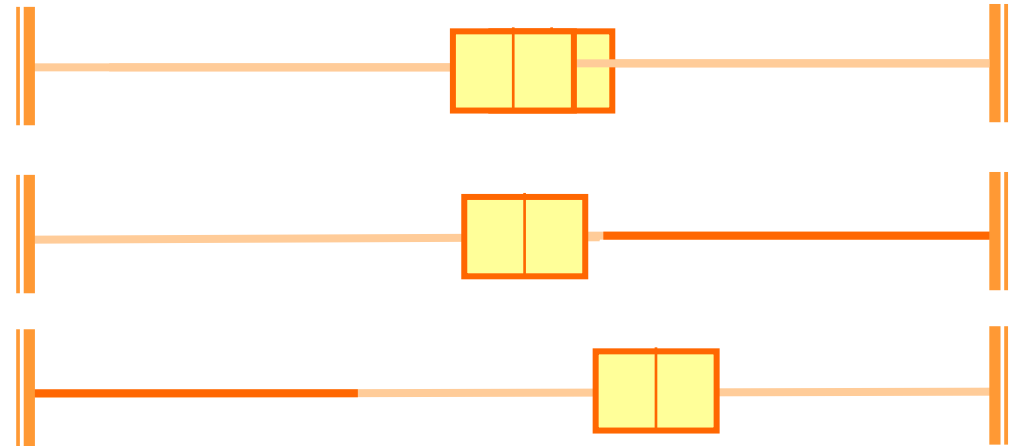
- Précontrainte
- Chauffage partie droite
- Chauffage partie gauche



L.P.M.M.



*A. Hautcoeur*



L.P.M.M.  
UMR 7554



# Micropositionneur différentiel AMF

## FUNCTIONNEMENT DU MICRO POSITIONNEUR AMF

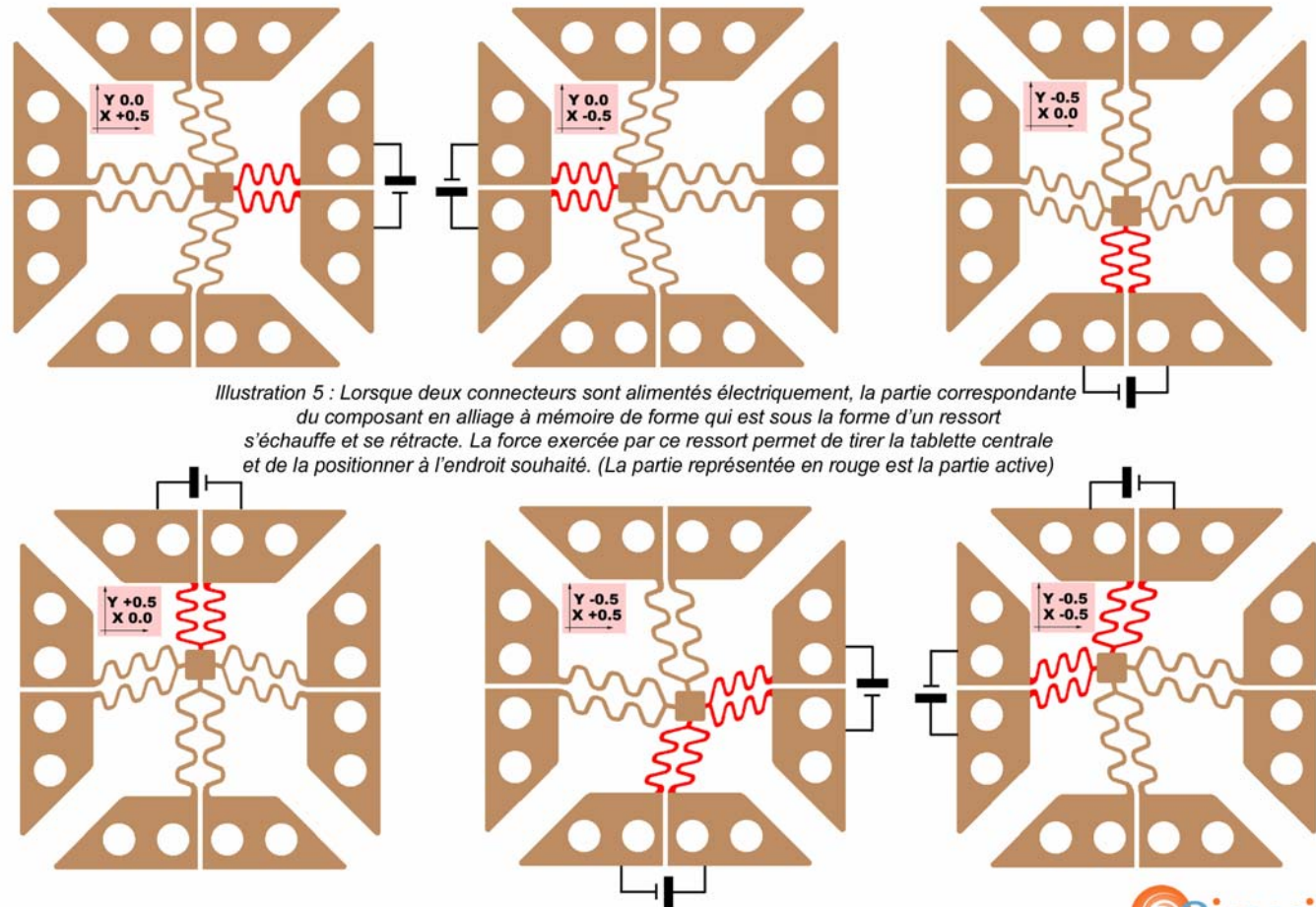
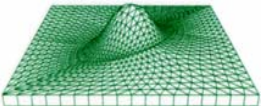
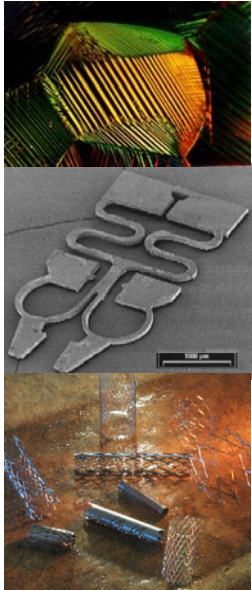
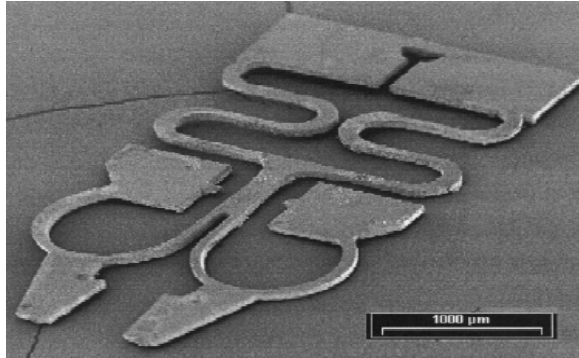


Illustration 5 : Lorsque deux connecteurs sont alimentés électriquement, la partie correspondante du composant en alliage à mémoire de forme qui est sous la forme d'un ressort s'échauffe et se rétracte. La force exercée par ce ressort permet de tirer la tablette centrale et de la positionner à l'endroit souhaité. (La partie représentée en rouge est la partie active)

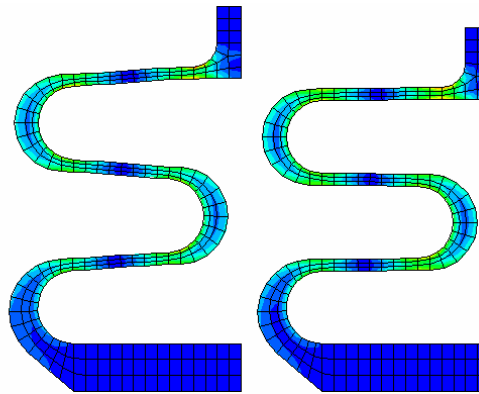
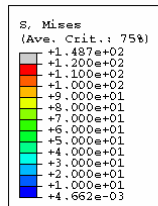
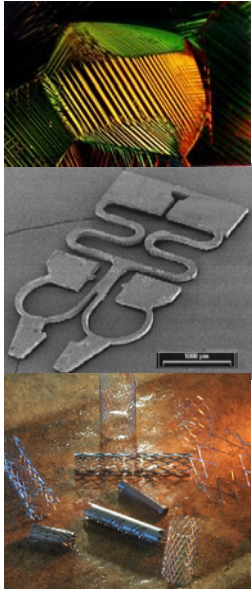


# Simulation par éléments finis

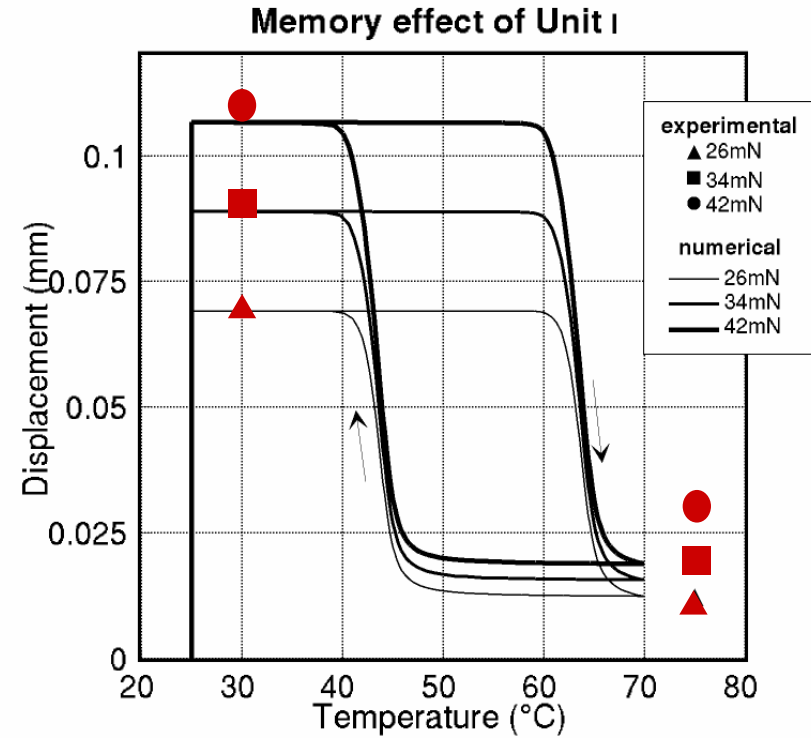
ABAQUS, UMAT



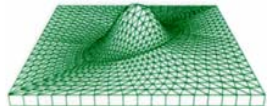
Micropinçe (Kohl et al. 2002)



2

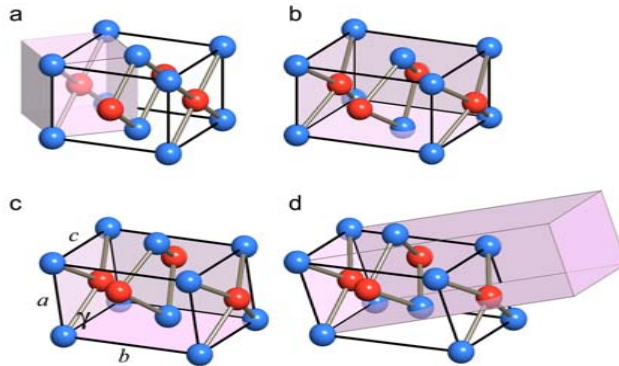


Thèse Bertrand Peultier  
LPMM – ENSAM -2005

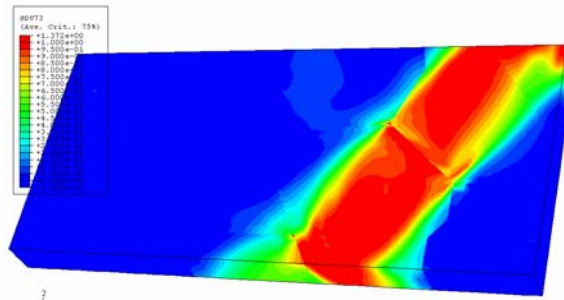
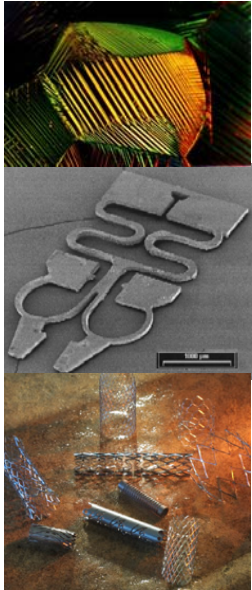
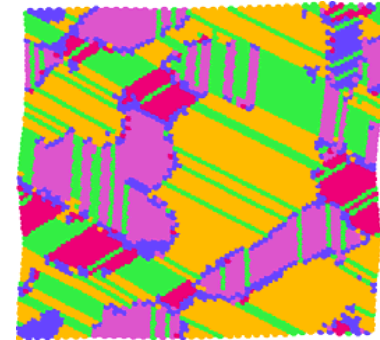


# Simulation : du nano au macro

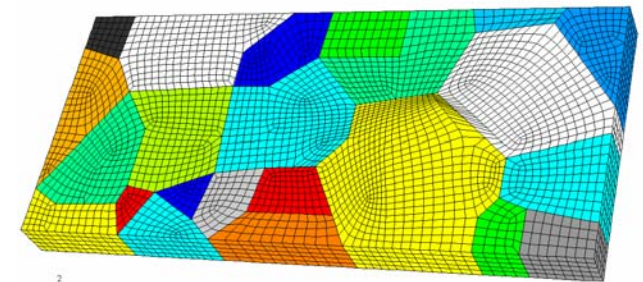
Structures cristallines



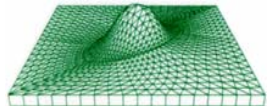
Microstructure en domaine



Simulation numérique

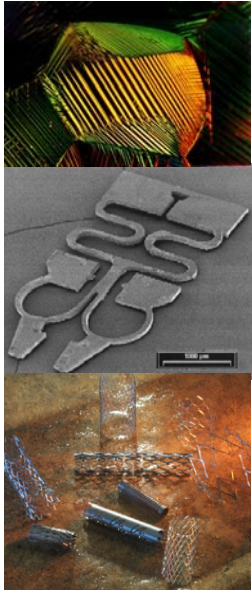


Structure polycristalline



# III.7. Mémoire de forme

## Forme en mémoire



"Onibaba".



Etienne Krähenbühl (gauche) et Rolf Gotthardt (droite).



"Single way to Bethlehem"

