Shape Memory and Superelasticity at Nano-scale

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The thermoelastic martensitic transformation is responsible for the thermo-mechanical properties of Shape Memory Alloys (SMA), which are widely used for practical applications as sensors and actuators and in particular they are good candidates to be incorporated in Micro Electro-Mechanical Systems (MEMS). However, the characterization of the shape memory and superelastic behavior at micro and nano scale requires new experimental methodologies.

First, the study of nucleation of martensite plates has been observed at nano-scale by in-situ transmission electron microscopy (TEM), and in particular the nucleation of martensite on the core of the dislocations was reported [1]. New dynamic experiments showing the stress-induced transformation during superelastic in-situ tests at TEM will be presented.

In addition, in the present work we present a new experimental approach for the mechanical characterization of the superelastic behavior by using an instrumented nano indenter to perform nano-compression tests on micro and nano pillars milled by focused ion beam (FIB). Superelastic behavior has been demonstrated along hundred of cycles with a recovery resolution in the range of the nanometer, and shape memory has been also reported in simple devices as nano pillars of about 400 nm diameter.

Some previous results [2,3] in Cu-Al-Ni micro and nano pillars milled by FIB on single crystals will be overviewed, and new results concerning the evolution of the mechanical behavior during compression cycling at nano scale will be presented. In addition these micro pillars exhibit an anomalous ultra-high damping at nano scale, which could be very useful to damp vibrations in MEMS, improving its reliability. We finally discuss the observed behavior, which evidences the existence of size-effects at nano scale on the superelastic behavior, and in general on the martensitic transformation.

In order to understand the martensitic transformation at small scale, in-situ transmission electron microscopy superelastic tests [4], on similar samples, have also been performed to follow the evolution of the martensites nucleation. These experiments also evidence a size-effect on the selection rules for martensite nucleation, which exhibits a different behavior at nano scale than in bulk materials. Finally, a general discussion on the martensitic transformation behavior at nano scale will be addressed.

References

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Figures

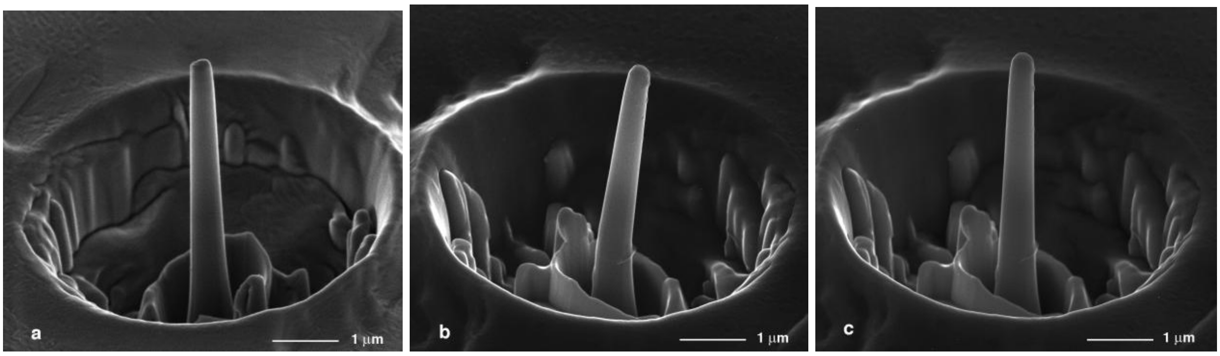

Figure 1: Shape Memory behavior of a nano-pillar. a) Image of a nano–pillar with ~400 nm diameter, from sample SM. b) The same nano-pillar deformed in bending by off-axis compression at the nano indenter. c) Shape recovery of the nano-pillar by in situ heating [2].

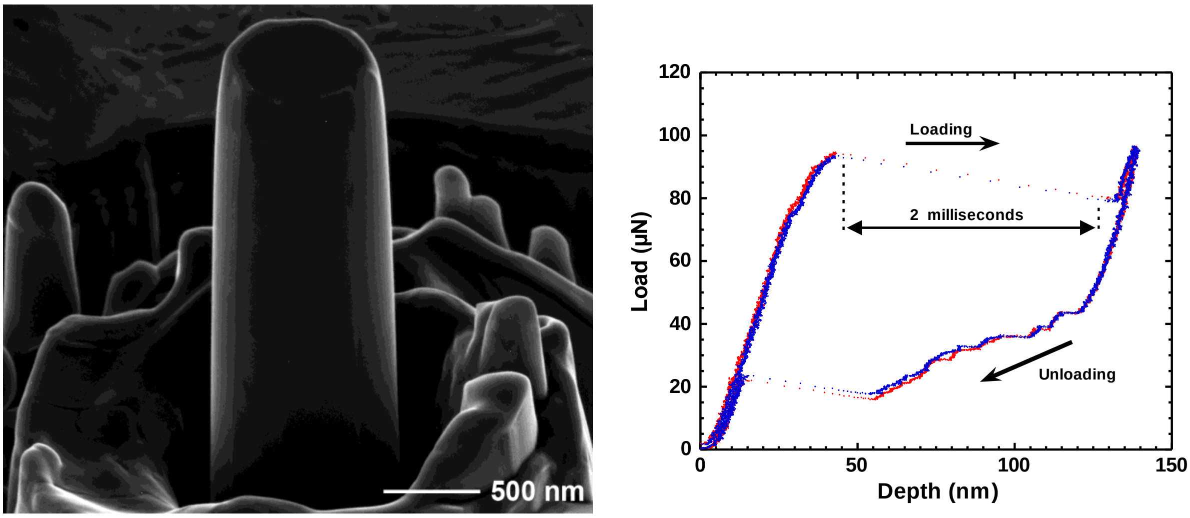

Figure 2: a) Scanning electron microscope image of the sub-micrometer pillar milled by FIB on a Cu-Al-Ni [001] oriented single crystal. It shows a slightly tapered shape with a diameter of about 750 nm at the top, a mean diameter of 900 nm over the bottom part and 3.8 mm height. b) Two consecutive nano-compression tests (in red and blue) obtained after ten prior mechanical cycles on the sub-micrometer pillar [3].