Nano-scale Superelastic behavior of Shape Memory Alloys for potential MEMS applications

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Introduction

Recently, there has been growing interest in the potential use of shape memory alloys (SMA) in micro and nano-scale structures and devices, for example as sensors or actuators in micro electromechanical systems (MEMS). With a growing worldwide market in excess of hundred billion dollars, MEMS constitute a new paradigm of technological development for the present century, and smart materials are converging with miniaturization technologies, enabling a new generation of smart MEMS or SMEMS. Among the different smart materials targeted for use in SMEMS, shape memory alloys have attracted considerable interest [1] because they offer the highest output work density, about 10^7 J/m^3 [2], and exhibit specific desirable thermo-mechanical effects such as superelasticity and shape memory. Most of the research effort is being focused on thin films [3] and with a view to reliable application of these materials, their shape memory and superelastic properties should be carefully characterized at small scales, and one possible approach relies on instrumented nanoindentation techniques. However, the multiaxial nature of deformation around the nanoindenter renders quantitative interpretation of the data very complex, especially for SMAs, which exhibit strongly non-linear behaviour during thermal or stress-induced transformation. This difficulty, together with the interest in developing three-dimensional SMAs devices for MEMS, has moved attention towards the use of compression tests on simple features like micro and nano pillars produced by focused ion beam machining.

Results and discussions

In previous works, completely recoverable superelastic strain and shape memory in micro and nano pillars was first reported for Cu-Al-Ni SMAs [4] showing the competitive advantage of these SMAs over the commercially used of Ti-Ni. In addition several size effects on superelastic behaviour were also demonstrated [5-7] in Cu-Al-Ni SMAs. However, for practical applications the superelastic behavior must be reproducible over hundred or thousand of cycles, in order to be functionally reliable, and the first studies on cycling micropillars by nano compression tests were recently published [8].
In the present work a more complete study on long term cycling has been approached. In Figure 1 a micro pillar of 1.6 mm diameter milled by focused ion beam (FIB) on a [001] oriented single crystal of Cu-Al-Ni SMA is shown. In Figure 2 two consecutive nano compression superelastic cycles performed on the micropillar of Figure 1, by means of a nano-indenter are presented, as an example of the reproducibility of the superelastic behavior at this scale. The reproducibility is quite good, but in order to verify the reliability of such behavior with view to further applications, long-term cycling would be required. So, o perform a more complete study of the long term superelastic cycling, several arrays of micropillars have been milled in a FEI DualBeam Helios 650 FIB and systematically tested by nanocompression in a Hysitron TI 950 instrumented nanoindenter. An excellent superelastic behavior with an extremely good reproducibility at the nano-scale has been observed up to more than 2000 nano compression tests. These arrays of micropillars and the experiments of long term superelastic cycling will be presented and on the light of these results, the potential interest of Cu-Al-Ni SMA for the development of smart MEMS, which are being called SMEMS, will be discussed

Conclusions

Fully recoverable and reproducible superelastic behavior has been obtained during long term cycling tests above thousand cycles. These promising results open the door for designing potential applications doing use of 3D devices of SMA, which could be integrated in MEMS technology.

Acknowledgments

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Figures

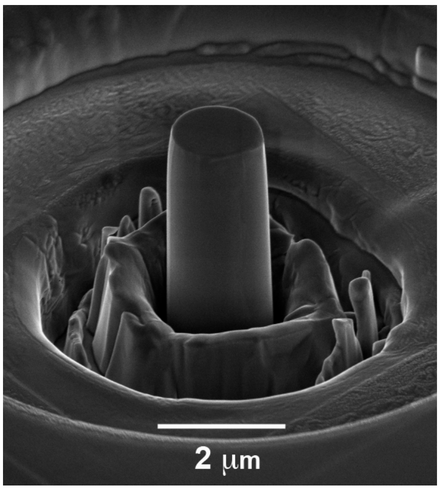

Figure 1: Micropillar of Cu-Al-Ni SMA milled by FIB on a [001] oriented single crystal, for nano-compression tests.

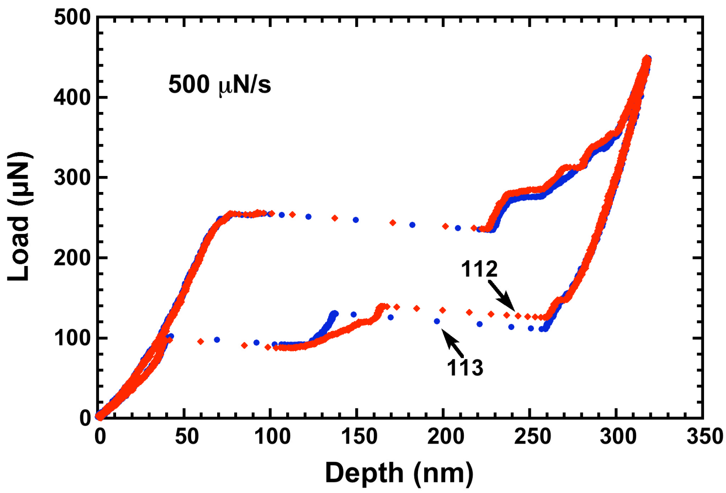

Figure 2: Nano-compression cycling in the Cu-Al-Ni micro pillar of Figure 1, performed in a Hysitron TI-950 instrumented nanoindenter. Reproducible behavior, showing two consecutive cycles numbered as 112 & 113.