Class 3: Electron Microscopy - Transmission and Analytical

Novel Shape Memory Alloy Nanowires

Introduction

Shape memory alloys have been widely recognized in the field of metallurgy. Generally, the prerequisites for the shape memory behavior are thermoelastic martensitic transformation, ordered parent and martensitic phases, and the internal twins in the martensite.

During the past decade, people found that nanomaterials exhibited significantly enhanced properties when their sizes were reduced down to the nanometer scale. However, so far less efforts were made on the traditional shape memory alloys. Here, we demonstrate our recent success in novel shape memory alloy nanowires.

Sample Preparation

Step 1: Prepare anodized aluminum oxide (AAO) nanotubes on Al substrate using electrochemical method (Fig. 1);
Step 2: Inside a piston chamber place the experimental material (In–21 at.% Tl) on the top of AAO and heat up until the sample melts, and then mechanically inject the melt into the AAO nanoholes (Fig. 2). After dissolving the AAO template, the nanowires were obtained.

Characterization

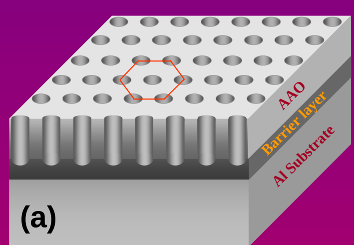
The nanowires were studied using a heating stage in a JEOL 2010 transmission electron microscope (TEM) at 200 kV. Fig. 3 shows the *in-situ* phase transitions of 15 nm nanowires. At room temperature (RT), the nanowires exhibit dense martensite twins with the face-centered tetragonal (fct) structure, while at higher temperature they transform to face-centered cubic (fcc) structure without twins, but when cooled down the twins reappeared, demonstrating the reversible fct-fcc transitions.

Similar reversible transitions are also observed in the 70 nm nanowires (Fig. 4). By crystallographic analysis, the twining plan is found to be (-101), and the growth direction [110].

Conclusions

The In-Tl shape memory alloy nanowires were successfully prepared by the simple mechanical injection method. *In-situ* TEM characterization revealed their reversible fct-fcc phase transitions associated with internal {101} twins, providiing promising characteristic to achieve the shape memory effect on the nanoscale.

Fig. 1 Template preparation



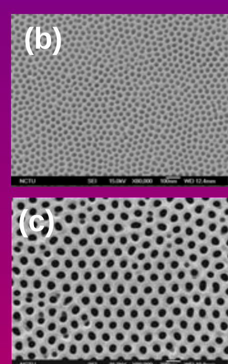
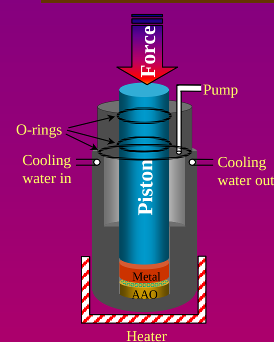


Illustration of the AAO template structure (a), and SEM images AAO with diameter of 15 nm (b) and 70 nm (c).

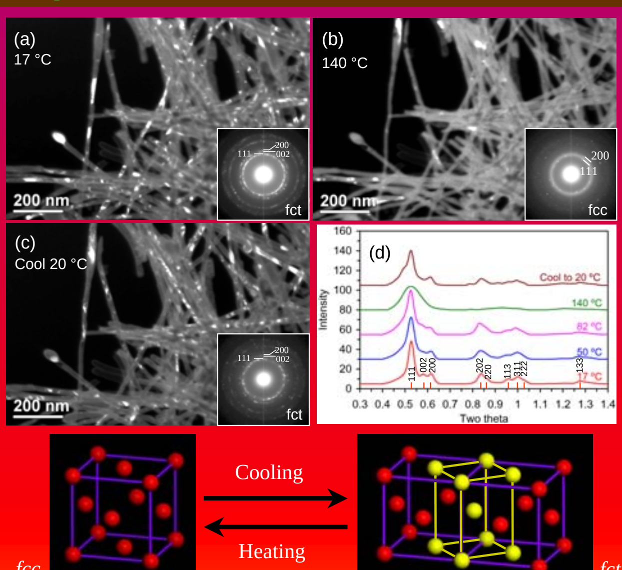
Fig. 2 Mechanical injection



The sample is placed on the top of the AAO template. When it melts after heating, it is injected into the AAO nanopores by a mechanical force.

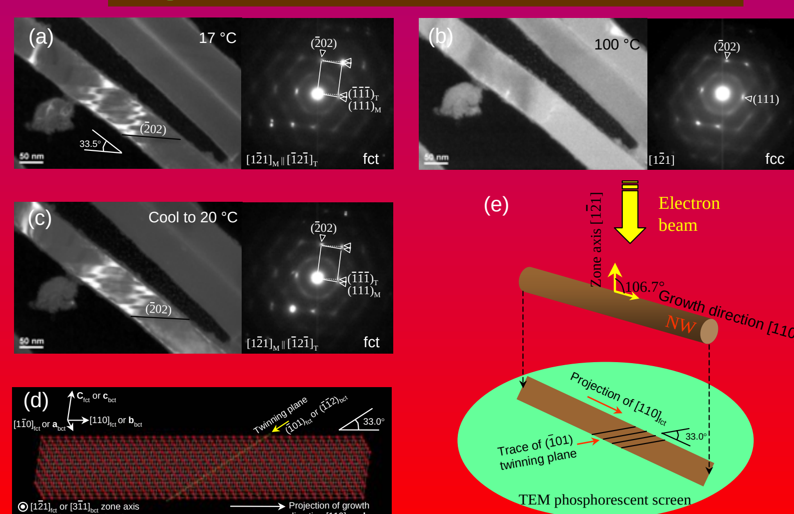
The piston chamber is pumped to avoid the sample oxidation, and cooling water is running around the O-rings to protect them from damage at the high temperature.

Fig. 3 TEM of 15 nm nanowires



In situ heating of small nanowires (15 nm) from RT (a) to 140 °C (b), and then cool down to RT (c). Structure models are shown on the bottom. The electron diffraction intensity profiles at different temperatures are shown in (d). At RT, the electron diffraction pattern is indexed as the fct structure, while at high temperature, it transforms to fcc structure.

Fig. 4 TEM of 70 nm nanowires



In situ heating of single nanowires (70 nm) from RT (a) to 100 °C (b), and then cool down to RT (c). Again reversible transformations are observed. A structural model of the nanowire is shown in (d), viewing along the [1-21] zone axis, where the trace of (-101) twins are at 33.0° angle with the nanowire axis. In fact, as shown in the crystallographic analysis in (e), the nanowire axis direction is [110], which is at 106.7° with the zone axis (or electron beam). After projecting on the TEM screen, the nanowire axis and twin plan are at 33.0° angle, consistent with observed angle of 33.5° in (a).