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Ferromagnetic Iron-Palladium Shape Memory Alloys

Shape memory (SM) alloys are materials that return to a previous shape after thermal treatment. In effect, they undergo a phase transformation from a high temperature, strong, austenite structure to a low temperature, weaker, martensite structure. In the martensite form the material can be deformed, but on heating beyond its transformation temperature it reverts to its previous shape. On cooling the material retains its austenite form.

The most widely used SM alloy is nickel-titanium (NiTi) which operates in a temperature range of –50 to 100°C. NiTi is used in several small-scale applications, for instance as actuators (utilising the martensite to austenite transformation), where fast response is not needed. Fast response requires rapid heat dissipation, possibly via a thin film structure. If improved response could be achieved, high-performance and high-power density actuators could be fabricated. In practice the actuation response in conventional SM alloy thin films can be improved by two orders of magnitude from the bulk form, to ~ 100 Hz.

Actuation response could be further improved if ferromagnetic SM alloys were used, using a magnetic field to effect the phase transformation. Only a few ferromagnetic SM alloy systems are known, one being iron-palladium (Fe-Pd) with a thermoelastic f.c.c. to f.c.t. martensite transformation near Fe-30 at.% Pd and SM effects in the bulk form; the martensite phase is ferromagnetic. The magnetic-field-induced strain is small, but thermal SM effects in ductile Fe-Pd are of interest. Few reports describe the fabrication of thin Fe-Pd films, and none describe their SM behaviour.

Now, a team of researchers from the Himeji Institute of Technology and Osaka Municipal Technical Research Institute, Japan, and the University of Washington, U.S.A., have fabricated thin film Fe-Pd ferromagnetic SM alloys and investigated their thermally induced SM behaviour (S. Inoue, K. Inoue, K. Koterazawa and K. Mizuuchi, *Mater. Sci. Eng., A*, 2003, 339, (1–2), 29–34).

Fe-Pd films were deposited onto fused quartz and silicon by DC magnetron sputtering. Fine Pd wires placed on the Fe-Pd target were used to control the Pd content to an accuracy of ~ 1 at.% Pd. The resulting as-deposited Fe-28.5 at.% Pd film had a disordered b.c.c. structure which changed to f.c.t. when quenched after an anneal at 900°C for 60 minutes. The f.c.t. phase transformed to a f.c.c. phase on heating from room temperature to 133°C, at transformation temperature ~ 40°C. The reverse f.c.c. to f.c.t. transformation is also thermoelastic.

A diaphragm-shaped 1 μm thick film fabricated on a thin silica substrate flattened on heating but returned to its starting shape on cooling. It has a narrow transformation hysteresis loop of ~ 4°C and the difference between the martensite-finish and austenite-finish temperatures is 10°C. The martensite-start temperature is 43°C. The maximum strain was ~ 0.05% on thermal cycling. SM behaviour occurred for over 50 cycles. This film displayed perfectly reversible ballooning behaviour, which strongly suggests potential applications in actuators, including micropumps.

Calculating Strain in Fe-Pd Polycrystals

Scientists from the University of Washington, U.S.A. (Y. Liang. T. Wada, H. Kato, T. Tagawa, M. Taya and T. Mori, *Mater. Sci. Eng., A*, 2002, 338, (1–2), 89–96) have also developed an averaging method to calculate the uniaxial stress-strain relationship in polycrystalline Fe-Pd. Strain within a grain is caused by changes to the variants of the martensite Fe-Pd structure. Internal stress and elastic energy accumulate. Stress also acts on a grain due to the surrounding grains.