A NEW TYPE OF SUPERELASTIC AND SHAPE MEMORY MATERIALS: THCR$_2$SI$_2$-STRUCTURED NOVEL INTERMETALLC COMPOUNDS AT SMALL LENGTHS SCALES

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Crystalline, superelastic materials typically exhibit large recoverable strains due to the ability of the material to undergo a reversible phase transition between martensite and austenite phases. Applicable to various alloys, ceramics and intermetallic compounds, this reversible transition serves as a general mechanism for superelasticity and shape memory effect. Recently, we noticed that $ThCr_2Si_2$-structured intermetallic compounds exhibit a reversible phase transition between a tetragonal (or orthorhombic) phase to a collapsed tetragonal phase under compression along c-axis of the unit cell by making and breaking Si-Si type bonds. This process has nothing to do with martensitic transformation. This unique reversible phase transformation process motivated us to investigate their potential as a superelastic and shape memory material.

In this study, we studied $CaFe_2As_2$, which is one of $ThCr_2Si_2$-structured intermetallic compounds and has been extensively studied in the field of solid-state physics due to its remarkable pressure sensitive electronic, magnetic and superconducting properties. Millimeter-sized single crystals were grown by Sn-flux solution growth technique, and micropillar compression was performed along c-axis to characterize their mechanical behavior. We confirmed $CaFe_2As_2$ exhibits over 3 GPa strength and over 13% recoverable strain, both of which lead to the ultrahigh elastic energy storage and release 10~1000 times higher than that of conventional high strength materials. Furthermore, we found the exceptional repeatability of cyclic deformation and superior fatigue resistance, compared to shape memory ceramics, which is known as the current state-of-the-art shape memory material. Furthermore, our in-situ cryogenic neutron scattering experiment under pressure showed that $CaFe_2As_2$ exhibits linear shape memory effect below 100 K by restoring the original orthorhombic phase from the collapsed-tetragonal phase. This ultra-low temperature shape memory effect could be used to develop a cryogenic linear actuation and sensor technology for deep space exploration. Note that our observation is only one manifestation among over 400 $ThCr_2Si_2$-type intermetallic compounds, all of which would undergo the same phase transformation process. Thus, we believe that our results will represent a paradigm shift in the area of superelastic and shape memory materials with a new phase transformation mechanism, enable an innovative design of cryogenic linear actuators, sensors, and switching devices in extremely cold environments, and more broadly, suggest a mechanistic path to a whole new class of shape memory materials

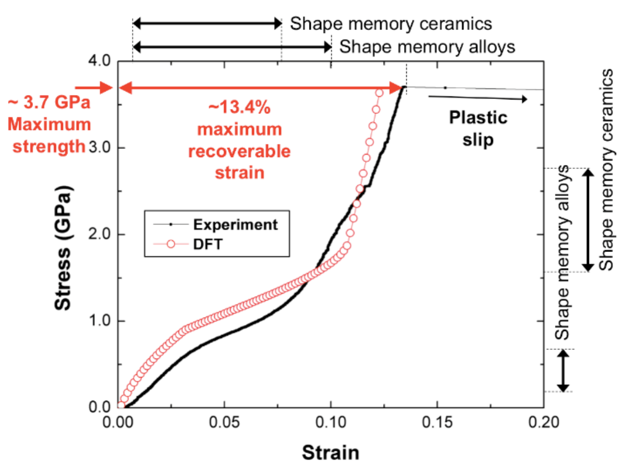

Figure 1 – Stress-strain curve of [0 0 1] $CaFe_2As_2$ single crystal