LA-UR-05-5514

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Intended for: LOW-TEMPERATURE CONFERENCE, August 2005, GAINSEVILLE

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Form 836 (7/06)

Ultrasonic Probe of the AuZn Fermi Surface

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Abstract. We, for the first time, apply the ultrasonic pulse-echo technique to explore the Fermi surface of the martensite phase of the single crystalline AuZn shape memory alloy. The ultrasonic measurements were performed in the magnetic fields of up to 45 T in the temperature range of 0.07 < T < 300 K. In the martensite phase (T < 64 K), the oscillations of the speed of the longitudinal sound wave propagating in the (110) direction indicated a strong acoustic de Haas - van Alphen effect. In addition to the earlier described oscillations with frequencies of 1140 and 4720 Tesla, we observed a new frequency of 120 Tesla, which was predicted theoretically. Corresponding effective masses were in favorable agreement with those expected from band structure calculations.

Keywords: Martensitic Phase Transition, Shape Memory Alloy, Acoustic de Haas – van Alphen Effect, Fermi Surface.
PACS: 71.18.+y; 72.55.+s; 43.35.Cg; 43.35.Gk.

The role of the electron gas in formation of the metallic bonds and thermodynamical stability of metals is commonly recognized. An interaction of itinerant states at the Fermi surface with Brillouin zone boundaries leads to an electronically-driven energy lowering mechanism of the crystal [1]. Even though the Fermi surface already touches the Brilloiun zone and necks extend beyond it in pure copper [2] and data on the effects of alloying on the Fermi surface are scarce, this model is also used to explain phase stability in alloys, including shape memory alloys. Low phonon background associated with the low transformation temperature (T = 64 K) combined with low effective electron masses makes the AuZn shape memory alloy an attractive model for exploration of the electronic properties of metals [3].

In this work, we report the results of our investigations of the acoustic de Haas - van Alphen (dHvA) effect in AuZn single crystal. We used the pulse-echo technique to explore the properties of the longitudinal sound wave propagated along the (110) direction of the crystal. The measurements were done in the temperature range of 0.07-300 K in a quasi-static magnetic field of up to 45 T. The relative change of the speed of sound was detected with precision of up to 10^{-7}. The sample has been mounted on a single-axis goniometer that allowed us to control the angle of the magnetic field with respect to the crystallographic directions with precision of not worse than 1 degree.

In our crystal, in close agreement with Ref. [4], the speed of the longitudinal (110) sound linearly rises from 3740 at the room temperature to 3870±20 m/sec at 85 K. The austenite to martensite phase transition is marked by sharp decrease of the sound speed and increase of its attenuation coefficient. It occurs at the temperature of 64 K without any noticeable precursor features. This value coincides with the lowest ever observed transition temperature for simple shape memory alloys [3], confirming the high compositional and stoichiometric quality of the sample.

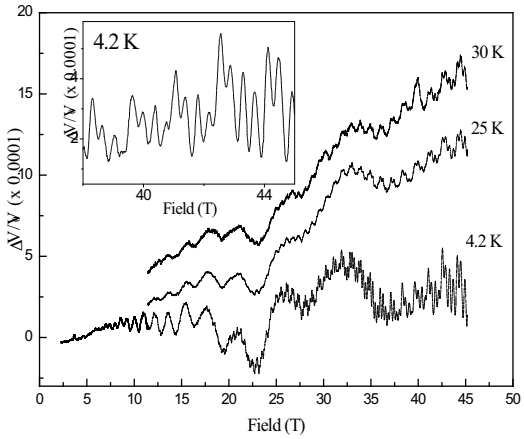

FIGURE 1. Oscillations of the speed of sound measured at several temperatures. The inset shows the high field part of these oscillations. The 60.3 MHz longitudinal sound wave and the field are both directed along (110) crystallographic direction.

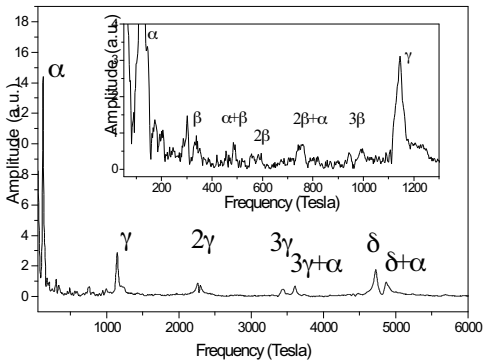

FIGURE 2. Fourier image of the 4.2 K oscillations (Fig.1). The inset shows magnified view of the low-frequency part of the spectrum. Some peaks are split by 46 Tesla, however this frequency was not detected explicitly.

Quantum oscillations of the sound speed have been observed in the broad temperature range below the transition: 70 mK – 50 K. Their amplitudes strongly depend on the orientation of the sample with respect to the magnetic field and are the highest when the field is oriented along the (110) direction (Fig.1). In the Fourier image of these oscillations (Fig.2), besides the earlier investigated frequencies [5]: 303 (labeled _), 1141 (labeled _) and 4770 T (labeled _), there is a strong peak at 120 T (labeled _). The presence of a corresponding extremal electron orbit was predicted theoretically [6], however it was not observed in the previous experiments.

Figure 3 (a) presents sample plots to determine the effective mass for the _ oscillation. Fitting the data with the Lifshitz-Kosevich expression simplified to $A=aT/sinh(aT)$ [7], gives the effective mass for the _ electron orbit as $m^*_{_}\sim aB/14.7=0.12\pm0.01\ (m_e)$. A similar analysis for _ and _ oscillations gives $m^*_{_}=0.21\pm0.01\ (m_e)$ and $m^*_{_}=0.32\pm0.01\ (m_e)$, in agreement with previous experimental results and theoretical predictions [5].

The Dingle plot for the _ oscillation is presented in Fig. 3(b). The Dingle temperature $T_{D_}$ one can estimate to be equal to 19 ± 1 K. Similarly, we find $T_{D_}=16\pm3$, $T_{D_}=16\pm1$ K.

To summarize, the analysis of the acoustic dHvA effect in the AuZn martensite phase not only confirmed the results of the earlier studies, but also allowed us to estimate parameters of the Fermi surface cross-section that has not been observed by other methods. Finally, it is especially noteworthy to observe quantized effects in the speed of sound in any martensite phase, because it was the large acoustic dampening that lead to the discovery of the shape memory effect in NiTi alloys.

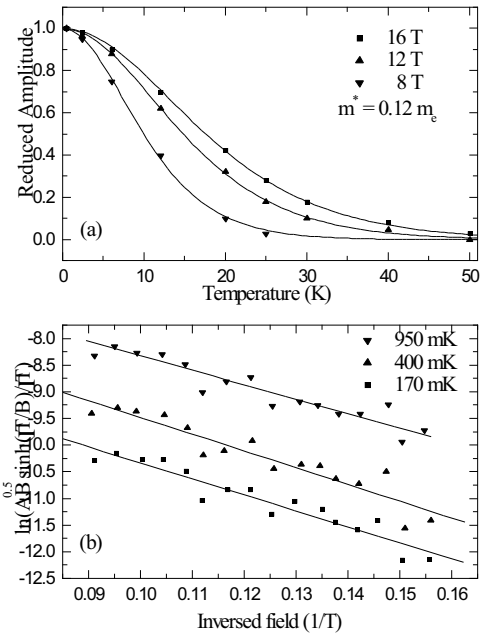

FIGURE 3. (a) Amplitude of the _ oscillation as a function of temperature. Solid lines represent fit of the experimental data with Lifshitz-Kosevich expression.
(b) Dingle plot for the same Fermi surface cross-section. Because of non-monotonic field dependence of the oscillation amplitude at high fields, only low-field data are used.

NHMFL is supported by NSF Cooperative Agreement No. DMR-0084173, State of Florida and DOE. The ultrasonic research at the NHMFL is supported by the In-House Research Program.

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