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Magnetoelastic effects on the elastic constants of $HoAl_2$

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Abstract. Measurements of the elastic constants C_{11} and C_{44} of single crystalline $HoAl_2$ are reported from 4.2 K up to 280 K. In the paramagnetic region the results are interpreted in terms of the magnetoelastic coupling.

Introduction

Magnetoelastic coupling in the paramagnetic region of RE-Al_2 (RE = rare earth) intermetallic compounds has been the subject of several recent works. At present, single crystal elastic constants of $CeAl_2$ [1] (only two constants), $PrAl_2$ [2], $NdAl_2$ [2], $GdAl_2$ [3, 4], $TbAl_2$ [5] and $DyAl_2$ [6] (only two combinations) are reported. The analysis of these results in terms of the interaction between the strains and the crystal electric field (CEF) leads to the quantitative evaluation of the magnetoelastic coefficient [1, 2, 7].

The object of this paper is to present the temperature dependence of the elastic constants C_{11} and C_{44} of single crystalline $HoAl_2$. Moreover we give the value of the magnetoelastic parameter of the C_{44} constant.

Experimental results

RE-Al_2 intermetallic compounds crystallize all in the cubic $MgCu_2$ Laves phase [8]. At low temperature, $HoAl_2$ orders ferromagnetically and the Curie point is $T_c = 29$ K [9]. Below this temperature the magnetic moment rotates from the (110) direction to (100) at 20 K [10], this anomaly appears in particular on the magnetic specific heat curves [9].

The CEF that acts on the free Ho^{3+} ion gives rise to the triplet Γ_5 [1] as ground state and the B_l^m crystal field parameters are [11]:

$$B_4^0 = -7.54 \times 10^{-4}\ \mathrm{K}$$

$$B_6^0 = 7.43 \times 10^{-6}\ \mathrm{K}$$

The $HoAl_2$ compounds were prepared from 99.9% pure RE and 99.999% pure aluminium. The single crystal has been grown by the Czochralski method [12]. As $HoAl_2$ corrodes very strongly the tungsten crucible, it was extremely difficult to obtain a good quality (110) orientated crystal. The one we got did not allow us to measure the complete set of elastic constants C_{11}, C_{12} and C_{44} with sufficient accuracy. We shall present here only the C_{11} and C_{44} modes for a (100) orientated crystal.

By spark cutting and polishing we obtained a sample of approximatively 4 mm diameter and 10 mm length with faces parallel within 0.1 μ, the misorientation was smaller than 1°. Room temperature density was 6.047 ± 0.005 gr/cm^3 which compares well with the theoretical density of 6.085 gr/cm^3 [13].

Ultrasonic velocity was determined by the usual ultrasonic technique at a 10 MHz frequency. From 4.2 K to 35 K temperature was measured with a germistor and for higher temperature up to 280 K with a copper konstantan thermocouple. The absolute temperature accuracy was ± 0.5 K in the region of 25–45 K and ± 0.1 otherwise.

We measured the velocity in the (100) direction of propagation, this leads to the C_{11} and C_{44} elastic constants.

Results are shown on Fig. 1. At 20 K a sharp pic appears on both modes which

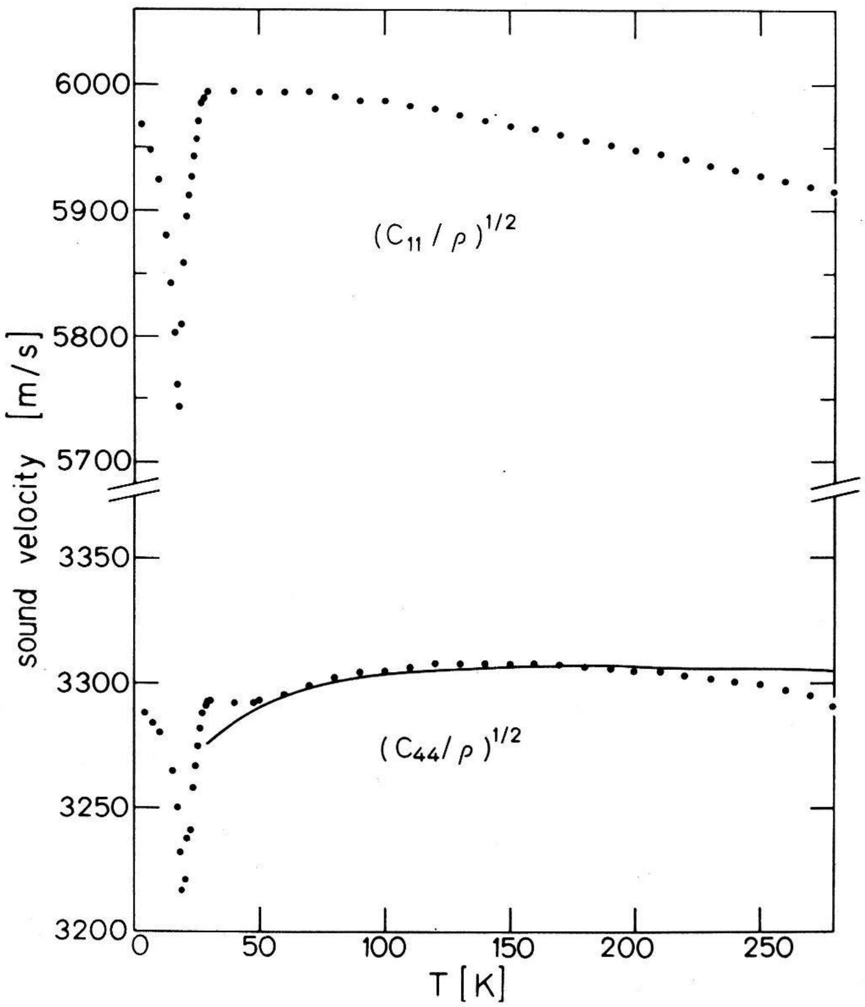

Figure 1
Sound velocity of $HoAl_2$ for the C_{11}- and C_{44}-modes.

corresponds to the rotation of the magnetic moment [10]. In the case of the C_{11}-mode this pic represents a decrease of 3.8% of the sound velocity and 1.5% of the C_{44}-mode. We found $T_c = 29$ K for the Curie temperature in good agreement with literature [9, 10, 11]. Values of the C_{11} and C_{44} elastic constants are given in Table 1.

Table 1
C_{11} and C_{44} elastic constants of $HoAl_2$

T [K]	$C_{11} \times (10^{11}$ N/m$^2)$	$C_{44} \times (10^{11}$ N/m$^2)$
4.2	2.153	0.654
10	2.122	0.650
20	2.075	0.627
25	2.146	0.648
30	2.172	0.656
40	2.172	0.658
50	2.172	0.660
60	2.172	0.660
70	2.172	0.661
80	2.169	0.662
90	2.167	0.662
100	2.167	0.662
110	2.165	0.662
120	2.162	0.662
130	2.159	0.662
140	2.156	0.661
150	2.153	0.661
160	2.151	0.661
170	2.148	0.661
180	2.145	0.661
190	2.142	0.661
200	2.139	0.660
210	2.137	0.660
220	2.134	0.659
230	2.130	0.659
240	2.128	0.658
250	2.124	0.658
260	2.121	0.657
270	2.118	0.656
280	2.115	0.654

Discussion

According to the magnetoelastic theory, the temperature dependence of sound velocity in the paramagnetic region is [14, 2]:

$$V(T) = v_0(1 - \alpha_3 T)^{1/2}(1 - g_3^2\chi_3(T))^{1/2} \tag{1}$$

where v_0 is the background velocity, α_3 is a coefficient issued from all non-crystal electric field effects, g_3 is the magnetoelastic coupling constant and $\chi_3(T)$ the elastic susceptibility [14]. By a least square fit, from equation (1) we calculated the full line on Fig. 1. We have:

$$g_3^2 = 0.20 \times 10^{-3}\ \mathrm{K}$$

$$\alpha = 3 \times 10^{-5}\ \mathrm{K}$$

Furthermore the theory states that g^2 should decrease from one RE-Al_2 to another as:

$$g^2 \sim \alpha \langle r^2 \rangle^2 / a^6 \tag{2}$$

where α is the Stevens factor [15], r^2 the free ion matrix element [16] and a is the lattice parameter. Table II shows how the ratio varies $g_3^2(\text{RE-Al}_2)/g_3^2(\text{CeAl}_2)$ across this series of compounds. The agreement between theory and experiment is only qualitative. In general the experimental ratio is greater than the theoretical one.

Table 2
Values of the $g_3^2(\text{RE-Al}_2)/g_3^2(\text{CeAl}_2)$ ratio

RE-Al_2	Experiment	Theory	Ref.
$PrAl_2$	0.4	0.1	1, 2
$NdAl_2$	0.1	0.01	1, 2
$TbAl_2$	0.003	0.01	7, this work
$HoAl_2$	0.002	0.0005	7, this work

On the other hand, the same comparison with respect to the α_3 parameter indicates a maximum at the beginning of the RE-Al_2 series of compounds [2, 3, 4, 7]. But it is difficult to decide whether this parameter still contains a small magnetoelastic contribution or this variation is the real one.

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