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ULTRASONIC ATTENUATION AND OCCURRENCE OF THE MARTENSITIC TRANSFORMATION IN THE HIGH $T_c$ A15 COMPOUND $V_3Si$

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Abstract - The $[100]$ shear modulus $C_{44}$ is known to be nearly temperature independent in the case of $V_3Si$, an extensively studied compound for which many authors tried to associate the lattice instability and the high superconducting transition temperature.

We report new sound velocity and attenuation measurements of this $[100]$ shear mode. The temperature change of the sound velocity displays a 6 % relative decrease while a large increase in the attenuation of this mode occurs for $T$ decreasing from 80 K to $T_c = 17$ K.

This new observation gives a strong support for a very recently proposed approach to the occurrence of the structural transformation in $V_3Si$.

1. Introduction

The $V_3Si$ A15 compound is known to undergo a structural transformation from a cubic symmetry to a tetragonal one at $T_m = 21$ K, a few degrees above the superconducting transition temperature ($T_c = 17$ K).

Furthermore this compound exhibits an anomalous elastic behaviour as a strong softening of the acoustic shear mode $C_s = \frac{1}{2} (C_{11} - C_{12})$ [1] occurs on cooling despite the structural transformation is observed or not. Non transforming samples are believed to have a "defect perturbed lattice" [2,3].

The lattice softening of $V_3Si$ has been studied by sound velocity and attenuation measurements by Testardi and Bateman [4], the softening of the transforming samples being stronger than that of the non transforming ones.

As shown by these authors, the attenuation $\alpha_s$ of the shear mode $C_s$ increases as temperature decreases below 100 K, while the attenuation of other acoustic modes increases only near $T_m = 21$ K.

Sound velocity and attenuation measurements have been performed on several $V_3Si$ single crystals (both transforming and non-transforming). Shear waves being generally more sensitive to a symmetry break-down, even local one, than longitudinal waves, we investigated particularly the shear waves along $[100]$ axis ($C_{44}$).

The new results, reported below, allow us to specify the common feature of the two Kinds of $V_3Si$ samples and to propose a new significance for $T_m$. 

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2. Experiment
All V₃Si samples studied have been prepared by the high frequency floating zone method and submitted to specific heat analysis [5]. Two of these samples (S₂ and S₅M) exhibit the specific heat anomaly at Tₘ = 21 K commonly associated with the occurrence of the transformation. The third one denoted S₄M (V₃,2 Si) does not show such an anomaly and, therefore, it is considered as non transforming. It becomes superconducting at 15 K while for the stoechiometric samples S₂ and S₅M the critical temperature is near 17 K. Ultrasonic experiments were performed as a function of the temperature using an Y-cut quartz transducer (10 MHz) bonded to the sample with Nonaq, the pulse-superposition method of Mc Skimin [6] being used to measure the wave velocities.

3. Results
3.a - The velocity Vₛ and the attenuation αₛ of the acoustic shear mode Cₛ along [110] polarized [110] measured on the sample S₄M

The results of velocity measurements obtained in this case are displayed on Figure 1 and compared with previous results obtained by Testardi and Bateman [4] on transforming and non transforming samples denoted respectively "T" and "NT".

As the temperature decreases, it appears clearly that the 3 samples S₄M, "T" and "NT" behave similarly until 80 K is reached.

The attenuation αₛ (Figure 2) measured on S₄M shows approximately the same relative variation with the temperature as that displayed by sample "T" [4]. Unfortunately the corresponding results were not reported for the sample "NT" and thus complete comparison cannot be achieved.
3.b - The velocity $V_T$ and the attenuation $\alpha_T$ of the acoustic shear mode $C_{44}$ along [100] measured on the samples $S_2, S_4 M, S_6 M$

The ultrasonic velocity $V_T$ of this mode show a slight relative decrease of 4-7% between room temperature and 4.2 K in agreement with previous results obtained in [4]. The results of the ultrasonic attenuation $\alpha_T$ measured on the three studied samples and on different parts of them, are displayed on Figure 3.

The following observations can be drawn:
- The increase of $\alpha_T$ between 80 K and 25 K appears to be a common feature for all the samples investigated independent of their state whether transforming or not.
- For $T < 25$ K, the results are depending on the samples and are related to the scanned part of the sample.

Thus the general behaviour of $\alpha_T$ differs markedly from that measured by Testardi which reported a marked increase between $T_m = 21$ K and $T_c$.

4. Discussion

Two important features arise from the results presented above:
- the attenuation $\alpha_T$ behaves same as $\alpha_S$ (see figures 2 and 3).
- the increase of $\alpha_S$ and $\alpha_T$ starts at the same temperature $80 \pm 5$ K.

The increase of $\alpha_T$ cannot be explained by the following classical mechanisms:
- attenuation due to electrons appears not suitable to explain such an increase considering that $\alpha_T$ remains nearly constant in the superconducting state.
- according to the classical treatment [7] the reduction of the velocity $V$ would imply an increase of the attenuation proportionnal to $1/V^3$.

If $1/V_S^3$ scales roughly the attenuation $\alpha_S$, the change of $V_T$ is too small to explain, within this treatment, the large increase of $\alpha_T$. 
Recent thermal conductivity measurements [8] on the two class of $V_3Si$ samples show a common behaviour in the temperature range 1.2 - 5 K of both samples, which was interpreted by the existence of planar defects associated in the case of non transforming samples with the boundary between the tetragonal domain and the cubic matrix.

For transforming samples, anomalies of thermal expansion [9,10,11] extending up to at least 60 K were interpreted as evidence for tetragonality.

The anomalous increase of the attenuation $\alpha_T$ between 80 K and 20 K can be explained by losses resulting from the diffraction of the ultrasonic waves by the tetragonal domains developing below 80 K. This temperature can be associated with the onset of sensitivity of ultrasonic attenuation to tetragonality, implying that the nucleation temperature would be higher than 80 K. The increase of the attenuation on cooling depends also on the level of tetragonality which would be lower in the case of non transforming crystal as shown by sample $S_4M$.

The upper part of the attenuation $\alpha_T$ for temperature lower than 25 K displays quite a different behaviour (Figure 3).

In most cases a hump is observed in cooling and could be interpreted as a reduction of the effective area of the boundary of tetragonal domains scanned by the ultrasonic beam. The decrease of the attenuation must be then a consequence of the collapse of some domains in a single one and would be related to the anomaly observed in specific heat measurements near $T_m = 21$ K. Consequently the meaning of $T_m$ would be quite different from the onset of the lattice transformation.

Figure 3 - The attenuation $\alpha_T$ of the shear mode $C_{44}$ along [100] for the 3 samples $S_2$, $S_{4M}$ and $S_{5M}$.
In another case $\alpha_T$ increases continuously (see S5M) indicating an extent of the tetragonal domains even in the presence of superconductivity. This observation is in agreement with the results of Gibbs et al [11] and Fawcett [12].

The same kind of analysis based on the occurrence of tetragonality at higher temperature may account for different anomalous effects observed previously as the second harmonic conversion in ultrasonic wave propagation reported by Testardi [13]. The discontinuous behaviour of $\frac{\partial C_S}{\partial P} \left( C_S = 1/2 (C_{11}-C_{12}) \right)$ as a function of pressure observed by Larsen and Ruoff [14] near 90 K for a non transforming sample and the existence of a minimum of $\frac{\partial C_S}{\partial P}$ reported by Garcia and Barsch [14] near 80 K for a transforming sample could be explained within the scope of tetragonality.

5. Conclusion

Anomalous attenuation of the ultrasonic shear mode $C_{44}$ along [100] was interpreted as the occurrence of tetragonality at temperatures extending up to and a minimum of 80 K, where it is in agreement with other observations.

The difference between transforming and non transforming samples can be explained by the level of tetragonality occurring in each sample.

Studies are underway to achieve a better understanding of the development of tetragonality according to a recently proposed approach to the occurrence of the structural transformation in $V_3Si$ [16].

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