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Pretransformation twinning in In-Tl alloys

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The mechanical-response coefficients controlling the torsional vibrations of In-Tl alloy bars oriented along the [100] and [110] directions have been measured as a function of temperature at resonance frequencies of about 100 Hz. Both coefficients have been observed to decrease almost linearly at the same rate as the temperature approaches the martensitic-transformation temperature. It is proposed that this unusual low-frequency premartensitic shear behavior represents dynamic and reversible twinning on a very fine scale.

The ferroelastic martensitic transformation in indium-thallium alloys is of interest since it is of nearly second but distinctly first order.[1,2] The present views of the transformation characteristics of the indium-thallium alloys are derived from ultrasonic data,[3-5] neutron,[6,7] electron,[8] and x-ray-scattering information,[9] and electron microscopical observation.[10] Based on the pronounced softening of the elastic constant $(C_{11}\text{-}C_{12})/2$, the corresponding low-frequency behavior of the TA_2 mode, the ⟨110⟩ streaking, and the concomitant x-ray-diffuse scattering, it was proposed that the low-frequency {110}⟨110⟩ modes control the transformation mechanism[11] although this is not in accord with the pronounced ⟨111⟩ streaking.[8]

The volume elastic and structural properties of the parent and product phases can be phenomenologically related to each other through a Landau formalism[12] and precursor states have been modeled by a Landau-Ginzburg approach.[13,14] It has been suggested that these periodic precursor structures may exist in the parent phase and further proposed that the tweed microstructure and the intermediate fct phase in Fe-Pd result from the presence of these precursors.[15-17]

This study was conducted using In-Tl alloy single crystals prepared from 99.99% pure starting materials by vacuum melting and subsequent crystal growth using the Bridgman technique. After growth the crystals were annealed for one week at a temperature 15 K below the melting temperature. The resultant crystals transformed at temperatures within 5 K of the transformation temperatures anticipated from their average composition.[18] The mechanical response coefficients controlling the [100] and [110] torsional vibrations were measured as a function of temperature. The measurements were carried out using a previously described apparatus[19] at resonance frequencies of about 100 Hz.

The measured temperature dependence of the low-frequency torsional response coefficients, which will be called shear constants in the following, of an In- 24 at.% Tl single crystal at temperatures above the transformation temperature are presented in Fig. 1. Formally, the [100] and [110] torsional shear constants correspond to C_{44} and $3(C_{11}\text{-}C_{12})/[4-(C_{11}\text{-}C_{12})/C_{44}]$.[20] The data shown in Fig. 1 need to be compared with previously published ultrasonic data.[5] These ultrasonic data show that $\frac{1}{2}(C_{11}\text{-}C_{12})=10^{-1}$ GPa at about 10 K above the transformation temperature and that $d[\frac{1}{2}(C_{11}\text{-}C_{12})]/dT>0$. They further show that $C_{44}=10$ GPa at the same temperatures and that $d[C_{44}]/dT<0$ except very close to the transformation temperature. The present low-frequency data indicate that $\frac{1}{2}(C_{11}\text{-}C_{12})=10^{-1}$ GPa at about 10 K above the transformation temperature and that $d[\frac{1}{2}(C_{11}\text{-}C_{12})]/dT>0$ in agreement with the ultrasonic data. However, it follows from Fig. 1 that $\frac{1}{2}C_{44}\approx\frac{1}{2}(C_{11}\text{-}$

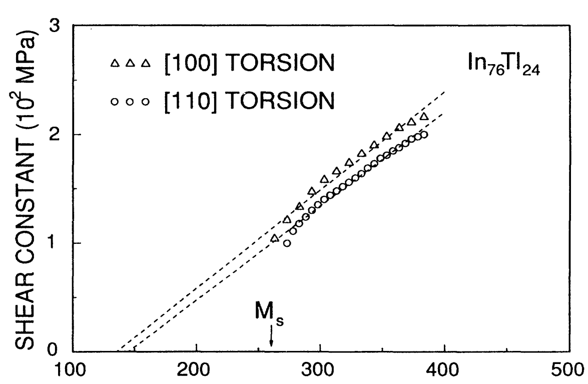

FIG. 1. Temperature dependence of the shear constants controlling the torsional vibrations [100], C_{44}, and [110], $2(C_{11}\text{-}C_{12})/[2+(C_{11}\text{-}C_{12})/C_{44}]$, in In-24 at.% Tl single crystals determined at about 100 Hz.

C_{12}), i.e., both shear constants are very small and of the same order of magnitude. In addition, Fig. 1 shows that both constants soften at the same rate and approach zero at about 110 K below the fcc-fct transformation temperature. Hence, in sharp contrast to the ultrasonic data, the low-frequency data indicate that the shear elastic constants are almost isotropic. Such a behavior can be understood if the elastic constant C_{44} is highly dispersive or if the corresponding mode of deformation at the present low frequencies of measurement is not truly elastic.

An alternative potentially reversible deformation mechanism is twinning. It is known that cubic face centered structures twin on $\{111\}\langle 112\rangle$-type systems.[21] The strong tendency of diffuse streaking along $\langle 111\rangle$ directions observed in an electron-diffraction study[8] and by ourselves[22] might signal the presence of twins of very small dimensions. The shear elastic constant corresponding to $\{111\}\langle 112\rangle$ twinning, C_t, is given by $C_t=[2(C_{11}-C_{12})/2+C_{44}]/3$. It follows that in In-Tl alloys the constant C_t at ultrasonic frequencies[5] would be of the order of 10 GPa whereas the present experimental results indicate that at 100 Hz it drops to the order of 10^{-1} GPa. Hence, it may be concluded that the alloys in question twin much easier at low frequencies. Since there is no evidence of large scale twinning in the fcc phase, it is proposed that at the low frequencies used in this study premartensitic twinning occurs on an extremely fine scale. In contrast, at high frequencies twinning is suppressed as C_{44} is large and increases as the transformation temperature is approached.

The frequency dependence of the premartensitic twinning can now be discussed. Related to the alignment of incipient variants in NiAl by the stress field around a crack,[23] the macroscopic mechanical response of fcc indium-thallium alloys to an external stress can be accomplished by the motion of twin or incipient parent-product boundaries. The motion of these boundaries will be activated at low frequencies where C_{44} becomes small. In contrast, this boundary motion will be frozen and this type of shear deformation will not occur at high frequencies where C_{44} becomes truly elastic.

The proposed low-frequency deformation mechanism suggests that the parent phase in In-Tl softens twofold, elastically, as known,[5] as well as with respect to traditional fcc twinning. The softening with respect to twinning is conceptually very satisfying as the martensitic transformation may be viewed as a process that combines twinning and changes of the unit cell.[24] Therefore, a softening with respect to twinning signals that the parent-product interphase starts to move spontaneously as the martensitic transformation commences, exactly what needs to happen in first-order transformations.

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[1] L. Guttmann, Trans. Metall. Soc. AIME **188**, 1472 (1950).
[2] M. W. Burkart and T. A. Read, Trans. Metall. Soc. AIME **191**, 1516 (1953).
[3] D. B. Novotny and J. F. Smith, Acta Metall. **13**, 881 (1965).
[4] N. G. Pace and G. A. Saunders, Proc. R. Soc. London, Ser. A **326**, 521 (1972).
[5] D. J. Gunton and G. A. Saunders, Solid State Commun. **14**, 865 (1974).
[6] S. W. Wilkins, M. S. Lehmann, T. R. Finlayson, and T. F. Smith, in *Proceedings of the International Conference on Solid-Solid Phase Transformations,* edited by H. I. Aaronson, D. E. Laughlin, R. F. Sekerka, and C. M. Wayman (AIME, Pittsburgh, PA, 1982), p. 1235.
[7] T. R. Finlayson and H. G. Smith, Metall. Trans. A **19**, 193 (1988).
[8] T. R. Finlayson, P. Goodman, A. Olsen, P. Norman, and S. W. Wilkins, Acta Crystallogr. Sec. B **40**, 555 (1984).
[9] Y. Koyama and O. Nittono, Trans. Jpn. Inst. Met. **23**, 285 (1982).
[10] A. Lasalmonie and P. Costa, in *Proceedings of the 3rd International Conference on Martensitic Transformations, ICOMAT-79* (MIT, Cabridge, MA, 1979), p. 538.
[11] Y. Koyama and O. Nittono, J. Jpn. Inst. Met. Sendai **45**, 869 (1981).
[12] O. Nittono and Y. Koyama, Jpn. J. Appl. Phys. **21**, 680 (1982).
[13] G. R. Barsch and J. A. Krumhansl, Phys. Rev. Lett. **53**, 1969 (1984).
[14] G. R. Barsch and J. A. Krumhansl, Metall. Trans. A **19**, 761 (1988).
[15] R. Oshima, M. Sugiyama, and F. E. Fujita, Metall. Trans. A **19**, 803 (1988).
[16] H. Seto, Y. Noda, and Y. Yamada, J. Phys. Soc. Jpn. **59**, 965 (1990); **59**, 978 (1990).
[17] S. Muto, R. Oshima, and F. E. Fujita, Acta Metall. **38**, 685 (1990).
[18] R. W. Meyerhoff and J. F. Smith, Acta Metall. **11**, 529 (1963).
[19] A. Aning, T. Suzuki, and M. Wuttig, J. Appl. Phys. **53**, 6797 (1982).
[20] A. Nowick and B. Berry, *Anelastic Relaxations in Crystalline Solids* (Academic, New York, 1972).
[21] J. W. Christian, *The Theory of Transformations in Meals and Alloys* (Pergamon, Oxford, United Kingdom, 1975).
[22] J. Li and M. Wuttig (unpublished).
[23] L. E. Tanner (private communication).
[24] J. Friedel, *Dislocations* (Pergamon, Oxford, United Kingdom, 1964).