ELASTICITY AND ANELASTICITY OF CHROMIUM

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In a recent paper Overhauser[1] has discussed the antiferromagnetism of chromium as a spin density wave (SDW) state. Above the spin-flip temperature and below the Néel temperature (referred to below as the intermediate temperature range) there are eight allowed transversely polarized linear SDW's which, it is supposed, can become energetically inequivalent as a result of the application of stress. Overhauser points out that transitions between SDW states may be anelastic giving rise to magnetomechanical damping of the kind already observed by de Morton[2] in polycrystalline chromium wire oscillating in torsion at a frequency of about 1 cps. Neutron diffraction analysis[3] shows that below the spin-flip temperature the SDW's are longitudinally polarized, only one magnetic state exists, and consequently the mechanism responsible for magnetomechanical damping is no longer operative. de Morton[4] has observed the predicted decreases in damping of torsional oscillations at temperatures below the spin-flip temperature.

It also follows that in the intermediate temperature range the elastic strain resulting from the application of a stress will have a component of magnetic origin. For example, SDW states which are elongated along the direction of stress will be energetically favored when tensile stress is applied. Hence, at temperatures for which the strain depends on the distribution of SDW states, the values of elastic moduli will be anomalously low. Below the spin-flip temperature and above the Néel temperature the strain cannot be relaxed by SDW transitions, and the observed values of elastic moduli should not be anomalous. The existence of this trench anomaly is apparent from the measurements of de Morton[4] on the temperature variation of rigidity modulus at a frequency of 1 cps.

Measurements have been made here on the temperature variations of Young's modulus and logarithmic decrement of longitudinal oscillation of chromium specimens[5] of rectangular section $0.3\ \text{cm} \times 0.2\ \text{cm}$. The specimens were attached to suitable single quartz crystals and the composite system excited into resonant longitudinal oscillation by a self-oscillatory system. The current flowing through the quartz crystal at resonance was continuously recorded as a function of temperature, and the values of logarithmic decrement were determined from these records. The results shown in Fig. 1 were obtained at a frequency of about 35 kc/sec using a specimen of chromium cut from the hot rolled strip and not subject to any subsequent heat treatment. The temperature variation of Young's modulus is similar to that obtained by Fine, Greiner, and Ellis[6] on a specimen of sintered electrolytic chromium which had a fundamental resonant mode for longitudinal oscillations at a frequency of about 70 kc/sec.

The absolute values of Fig. 1 at a given temperature are approximately 1 % greater than those obtained at the same temperature by Fine et al.; both sets of results show anomalies at temperatures of about 120°K and 310°K. The temperature variation of logarithmic decrement shown in Fig. 1 differs from the single peak obtained at 310°K by Fine et al. It is obvious that these results do not exhibit the predicted anomalous variations of Young's modulus or logarithmic decrement. The two possible explana-

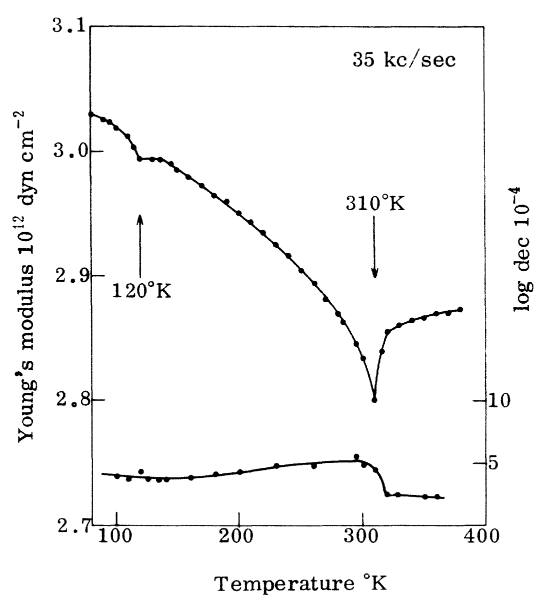

FIG. 1. Temperature variations of Youngs's modulus (upper curve) and logarithmic decrement of longitudinal oscillation (lower curve) for a specimen of unannealed chromium.

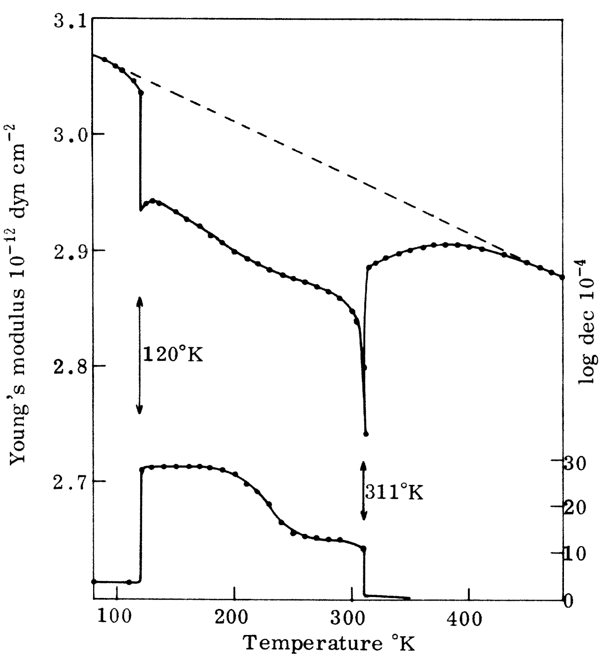

FIG. 2. Temperature variations of Young's modulus (upper curve) and logarithmic decrement of longitudinal oscillation (lower curve) for specimens of chromium annealed, after cutting, for one hour at 1200°C.

tions for the disparity between de Morton's results obtained at 1 cps and those of Fig. 1 are (a) the relaxation time for SDW transitions may be longer than 30 μsec, or (b) the results of Fig. 1 may be typical of chromium in which internal strains prevent the complete development of the SDW state or at least inhibit SDW transitions. The second alternative is the correct one as may be seen from the results of Fig. 2. These were obtained with a specimen of chromium from the same strip as before but heated in vacuo, after cutting, for one hour at 1200°C and furnace cooled. The results now strikingly exhibit the predicted forms of temperature variation both of modulus and logarithmic decrement. Measurements were made for both rising and falling temperatures, and no temperature hysteresis in Young's modulus of greater than one part in 3000 was detected.

In Fig. 2 it is possible to interpolate a smooth line between the high- and low-temperature values of Young's modulus. The observed and interpolated values agree above about 200°C which is the temperature at which Bacon[3] observed the disappearance of residual antiferromagnetic order in single-crystal and polycrystalline samples of chromium. This agreement, if not fortuitous, suggests that the residual antiferromagnetic order is also dependent on applied stress, but that the transitions involved are not anelastic.

It is to be expected that the application of a magnetic field will result in a redistribution of the SDW's which may be detected in a very sensitive way through measurements of Young's modulus. For unannealed specimens no changes greater than one part in 10^5 were detected when a field of 15 kOe was applied. On the other hand, in the intermediate temperature range the values of Young's modulus of annealed specimens were increased by 0.1 % in a field of 15 kOe. Measurements at different frequencies of longitudinal oscillation of annealed specimens show that in the intermediate temperature range the depth of the trench anomaly decreases significantly as the frequency increases. This enables a very rough estimate of 10^{-5} sec to be made as the relaxation time of SDW transitions.

These investigations will be reported in more detail elsewhere.

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[1]A. W. Overhauser, Phys. Rev. 128, 1437 (1962).

[2]M. E. de Mortòn, Phil. Mag. 6, 825 (1961).

[3]The neutron diffraction evidence has been discussed by G. E. Bacon, Acta Cryst. 14, 823 (1961).

[4]M. E. de Morton, Phys. Rev. Letters 10, 208 (1963).

[5]The high-purity chromium was generously made available by the Aeronautical Research Laboratories, Melbourne, Australia. An argon-arc-melted ingot was extruded into a $\frac{1}{2}$-in. diameter rod, which was then formed into a strip by rolling at 900°C. Analysis shows that the material contains 0.0008 wt% nitrogen and 0.03 wt% oxygen with any other impurities below the level of spectrographic detection.

[6]M. E. Fine, E. S. Greiner, and W. C. Ellis, J. Metals 189, 56 (1951).