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GA-3367

THERMALLY ACTIVATED DISLOCATION MOTION IN FCC AND REFRACTORY BCC METALS

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JOHN JAY HOPKINS LABORATORY FOR PURE AND APPLIED SCIENCE

P.O. BOX 608, SAN DIEGO 12, CALIFORNIA

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This is a preprint of a paper submitted for publication in Physical Review Letters.

U.S. Atomic Energy Commission
Contract AT(04-3)-167
Project Agreement No. 4

August 12, 1962

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Amplitude-dependent internal friction evidence is presented below which demonstrates the strong differences in dislocation mobility which exist between the two classes of cubic metals--the face-centered cubic, represented by Al and Cu, and the body-centered cubic, represented by Ta, Nb, Mo, and W.

A number of workers[1-5] have constructed several dislocation-relaxation models designed to explain the internal-friction relaxation peak (Bordoni peak[6]) which appears with plastic deformation of fcc metals. In these models, the peak results from the thermally assisted jumping of segments of dislocation lines between energy wells separated by a potential energy barrier which is both periodic and intrinsic to the lattice (the Peierls' potential[7]). These models, which depend on the concept of a Peierls' barrier, will henceforth be referred to as P-models.

Amplitude-dependent internal friction due to dislocation motion is considered[8, 9, 10] to result from the hysteretic unpinning and repinning of dislocation loops from impurity pinning points when the oscillating measuring stress exceeds a certain value--the breakaway stress. By applying any of the aforementioned P-models to this pinned dislocation model, the mobility of the loop lying between pinning points becomes strongly temperature-dependent in the vicinity of the temperature of the peak. Thus, at temperatures above the peak, the loop can move unimpeded by the lattice; and if the oscillating measuring stress is of sufficient magnitude, the loop can pull free of the impurities to be recaptured on the return cycle, producing hysteretic amplitude-dependent internal friction. On the other hand, at temperatures below the peak, the loops are "frozen" behind the lattice potential barriers and therefore are unable to contribute to hysteretic internal friction. As the temperature is lowered through the region of the peak, the amplitude-dependent internal friction should, according to these models, show a relatively sharp drop, the size of which should depend on the dislocation density and the network length associated with a given peak.

Figure 1a shows the combined α and β deformation peaks[11] in plastically deformed high-purity Ta. The specimen was first deformed at 300°K to 50% torsional strain, and then measurements were made at 6 cps at various oscillating shear-strain amplitudes. In Fig. 1b is plotted the amplitude-dependent internal friction, ΔQ^{-1}, obtained by subtracting the amplitude-independent curve represented by the measurements made at an amplitude of 1×10^{-7} from the other curves in Fig. 1a. Note that as the temperature is lowered, ΔQ^{-1} for all amplitudes decreases monotonically, with a particularly sharp drop occurring in the vicinity of the group of β peaks near 160°K; another smaller drop is barely resolvable in the region of the group of α peaks (110°K). (Analogous results have been obtained for Nb, Mo, and W and will be reported elsewhere.) The deformation peaks of the refractory bcc metals thus exhibit the temperature-dependence of the amplitude-dependent internal friction predicted by the P-models.

The data of Paré,[12] in Fig. 2a, show the amplitude-dependence of the Bordoni peaks of Cu. In Fig. 2b is plotted ΔQ^{-1} taken from the data in Fig. 2a. As the temperature is lowered, ΔQ^{-1} is seen to rise in the vicinity of the Bordoni peak, contrary to prediction. This behavior is not confined to Cu alone, since recently published data[13] on the Bordoni peak in 99.996% pure Al show a similar anomaly in the temperature-dependence of ΔQ^{-1}.

If it is assumed that dislocations in Cu and Al behave according to the P-models, the data in Fig. 2b show that at least one of the following conditions must exist: (1) The dislocations are pinned as discussed above, but they represent only a small fraction of the total number of dislocations present; (2) they are pinned, but restrained by elastic internal stresses

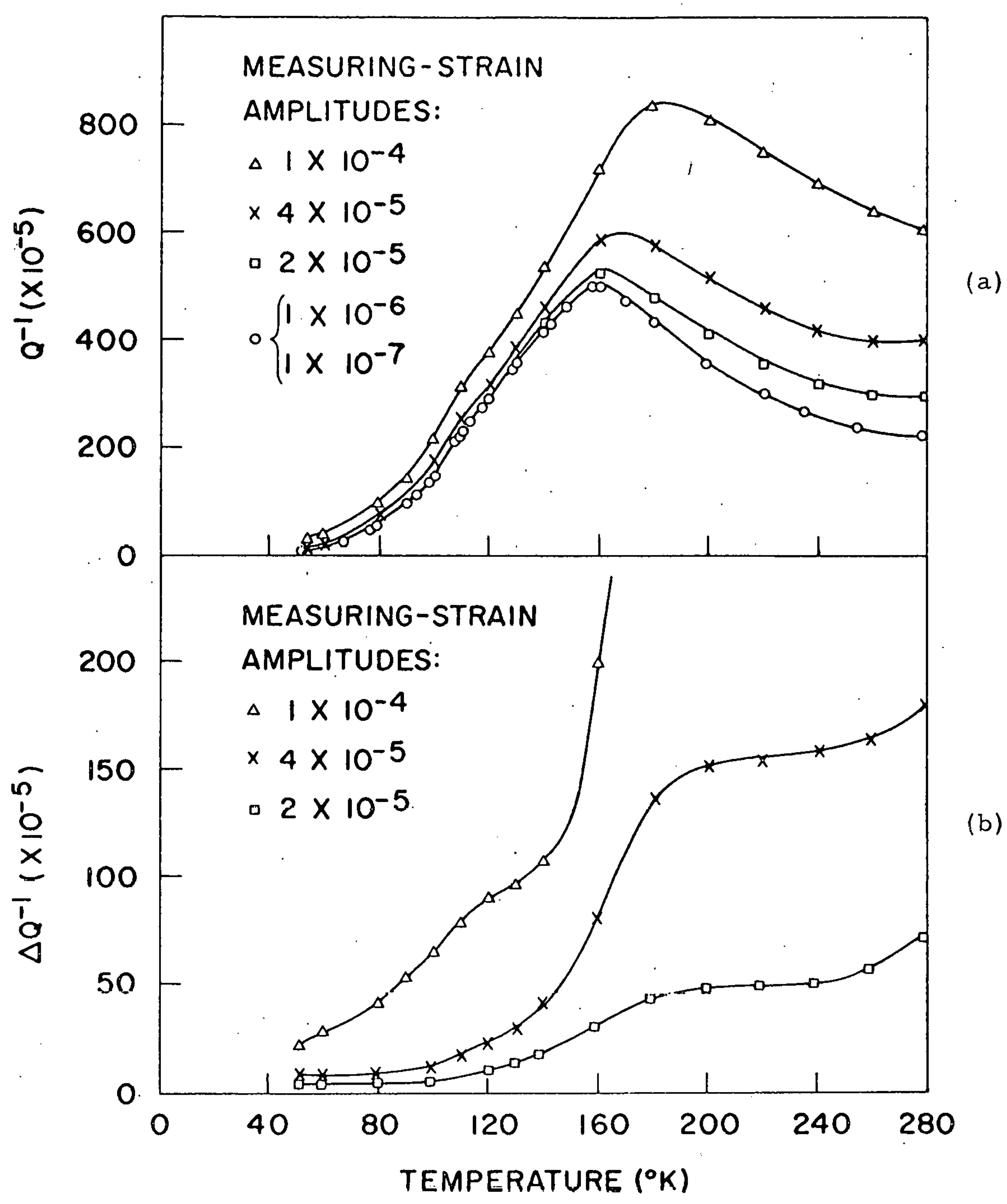

Fig. 1--99.997 at.-% pure Ta deformed to 50% in torsion at 300°K (measurements made at 6 cps at various shear-strain amplitudes): (a) internal friction, Q^{-1}, versus temperature; (b) amplitude-dependent internal friction, ΔQ^{-1}, versus temperature for various amplitudes

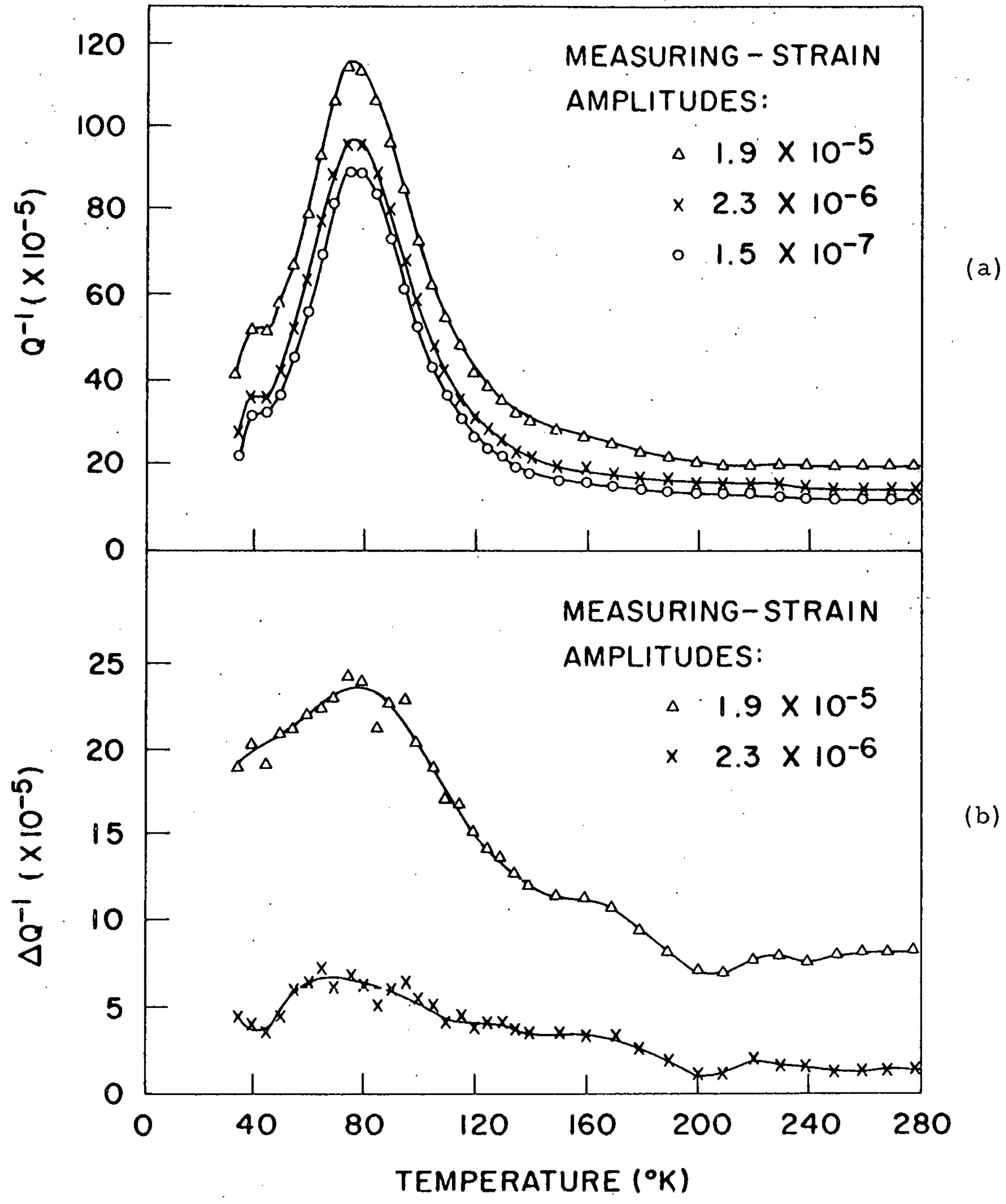

Fig. 2--99.999 at.-% pure Cu deformed to 10% by rolling at 300°K (from data of V. Paré[12]; measurements made at 5500 cps at various strain amplitudes): (a) internal friction, Q^{-1}, versus temperature; (b) amplitude-dependent internal friction, ΔQ^{-1}, versus temperature for various amplitudes

from producing breakaway from their pinning points[14]; (3) they are able to remain unpinned. Since in case (3) it is reasonable to assume that only a small proportion of the dislocations present can remain unpinned, the above observations imply that, if the P-models are applicable to fcc metals, only a small fraction of fcc dislocations must depend on thermal activation to move over non-vanishingly small energy barriers at low stresses. This is to be compared with the case of dislocations in the refractory bcc metals, where the data of Fig. 1b show that essentially all the dislocations in bcc Ta must be thermally activated over potential barriers which range from 0.2 to 0.4 ev.

These results further imply that the modulus defect[10] measured at 4.2°K in the fcc metals should be considerably larger than that associated with the Bordoni peak alone, while the modulus defect measured at 4.2°K in the refractory bcc metals should be quite small compared with that associated with the deformation peaks alone. Both of the conclusions appear to be borne out by modulus-defect observations in these metals.[15][11]

The author wishes to thank Dr. A. S. Nowick of the I. B. M. Research Laboratories and Dr. J. L. White of General Atomic for their critical comments, and Dr. P. H. Miller, Jr., for his encouragement and support throughout this work.

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