Reprinted from JOURNAL OF APPLIED PHYSICS, Vol. 36, No. 12, 3955–3956, December 1965

Shock-Wave Compression of Germanium from 20 to 140 kbar*

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(Received 12 July 1965)

THE object of this note is to report stress–volume results between 20 and 140 kbar for germanium, shock loaded in a state of one-dimensional strain along the [111] crystallographic direction. Resistance–time measurements, made while the shock wave traverses the sample, circumvent difficulties inherent in the usual free surface velocity methods.

Shock loading was accomplished by impacting large diameter-to-thickness ratio disks of germanium upon each other in order to ensure a state of one-dimensional strain in all but the periphery of the disks for the duration of the experiment. One disk, mounted on the face of a projectile, was accelerated to a measured high velocity by means of a compressed gas gun[1] and was impacted in vacuum upon the specimen disk mounted on the end of the gun. Angular misalignment between the impacting surfaces was about 5×10^{-4} rad.[2] Germanium back-up disks were mated to the rear of the specimen. The thicknesses of the impact and back-up disks were chosen so that the stress waves propagated through and out of the specimen disk without reflection until, finally, the specimen was stressed uniformly to the impact value for a brief interval preceding the arrival of unloading waves.

The disks, 38 mm in diameter, were cut from single crystals of high purity n-type germanium of nominal 50-$\Omega\cdot$cm resistivity and were oriented with their faces parallel to a (111) crystal plane. Their dislocation density was approximately 6×10^3/cm^2. Depending on the particular experiment, the thicknesses of the specimen disks were 3.2, 4.0, and 8.0 mm.

The resistance–time history resulting from stress waves propagating through the specimen was obtained by recording the voltage–time history across the thickness of the specimen disk under constant current conditions. The constant current of one ampere was applied to the specimen disk about 500 nsec before impact to prevent resistive heating of the disk. Both faces of the disk were entirely electroless nickel plated to provide Ohmic electrodes. The impact surface electrode of the specimen was also coated with vapor deposited silver and maintained at ground potential. The back-up disk assembly, entirely vapor coated with silver, served as the circuit lead to the other electrode.

For impact stresses in the range of several hundred kilobars, multiple waves are observed which indicate the presence of slope discontinuities, or cusps, in the stress–volume relation.[3] During the time these waves are propagating across the specimen thickness, the specimen is essentially divided into a number of zones separated by the different wave fronts. Thus, the electrical resistance between the electrodes of the specimen is equal to the sum of the resistances of the zones. Assuming time independent wave velocities, stress amplitudes, and resistivities, the initial and final values of the resistance are connected by a continuous line made up of segments of different slope, each segment corresponding to the propagation of a wavefront through the specimen. The initial and final values of the resistance explicitly define the change in resistivity due to the impact stress; the discontinuities in slope show the existence of multiple waves and define transit times for each wave from which the wave velocities can be calculated. The complications resulting from wave reflections and subsequent interactions, which are inherent in free surface velocity techniques, are avoided.

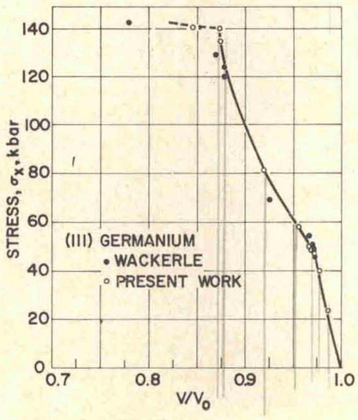

FIG. 1. Stress–volume relation.

In order to determine the stress–volume relation, the particle velocity associated with each wave must be known in addition to the wave velocity. Because of symmetry, the total particle velocity imparted to the specimen disk is one-half the experimentally measured impact velocity. In general the division of the total particle velocity between multiple waves is unknown from a single experiment; however, if in a series of experiments the total particle velocity is systematically varied in the immediate neighborhood of a suspected cusp in the stress–volume relation until a change in the number of waves is observed, the particle velocity associated with each of the multiple waves can be established. The stresses and volumes associated with any multiple wave structure can then be calculated from conservation of mass and momentum relationships.[4,5]

The stress–volume values determined in this manner are shown in Fig. 1 and compared to values obtained by Wackerle[6] from a free surface velocity technique. Two cusps were observed and investigated, the first at 44±4 kbar corresponds to the transition between elastic and plastic behavior, and the second at 140±10 kbar is probably related to the phase transition between the diamond and β-tin crystal structures which was first observed by Minomura and Drickamer[7] at a hydrostatic pressure of 120 kbar. The large uncertainties quoted result from limited data in the neighborhoods of the cusps rather than from lack of precision in the measurements.

The authors are indebted to J. Wackerle for allowing them to use his stress–volume data prior to publication.

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* Work supported by the U. S. Atomic Energy Commission.

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[2] The techniques involved in a gun experiment are discussed by W. J. Halpin. O. E. Jones, and R. A. Graham in ASTM Special Technical Publication No. 336, Symposium on Dynamic Behavior of Materials (ASTM 1963); and in Ref. 1.

[3] R. G. McQueen, S. P. Marsh, and Jerry Wackerle, Bull. Am. Phys. Soc. **7**, 447 (1962).

[4] G. E. Duvall in *Response of Materials to High Velocity Deformation* (Interscience Publishers, Inc., New York, 1961), p. 165.

[5] This assumes that the particle velocity associated with each cusp is independent of impact stress amplitude.

[6] Jerry Wackerle, Los Alamos Scientific Laboratory, Los Alamos, New Mexico (private communication).

[7] S. Minomura and H. G. Drickamer, J. Phys. Chem. Solids **23**, 451 (1962).