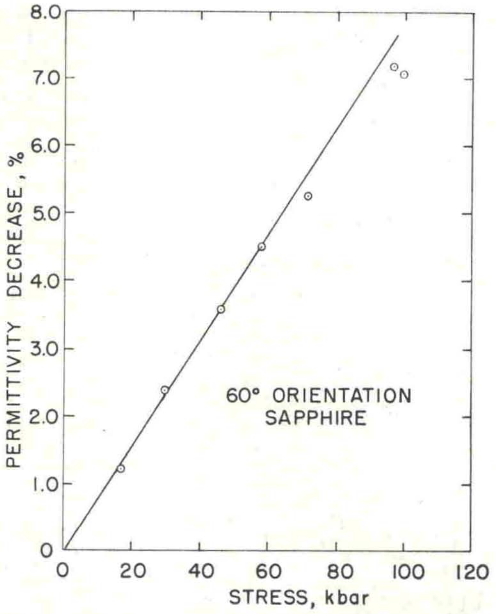

Fig. 7 Permittivity change of sapphire under shock-wave compression as computed from equation (8)

the data necessary to compute the shock velocity. The particle velocity is determined from the measured impact velocity according to equation (6).

To measure the Hugoniot elastic limit, which determines the limit of the elastic wave region, subsidiary experiments were performed with explosive loading [32]. The observed values depend upon the total pressure imparted to the sample and the crystalline orientation and vary from 120 kbar to 200 kbar.

Experiments to measure the permittivity change have been performed on 60 deg orientation sapphire[9] from 20 to 150 kbar with results as shown in Fig. 7. Up to 60 kbar the permittivity is observed to decrease linearly with stress at a rate of 0.078 percent per kilobar. The two higher stress points at 70 and 100 kbar are below the linear extrapolation based on the lower stress data. The current-time waveforms for the higher stresses indicate that conduction is occurring within the sapphire, lowering the current below that predicted from equation (8). Thus, the permittivity change is apparently linear to 100 kbar. At higher stresses we are presently unable to adequately interpret the data in an explicit manner due to the complications of the multiple wave structure resulting from exceeding the Hugoniot elastic limit.

One valuable feature of the shock-wave compression measurement of the permittivity is that the measured current is proportional to the *change* in permittivity. Thus, the shock-wave measurements provide a very sensitive determination of the permittivity change because they do not involve taking the difference between permittivity values obtained at different pressures.

Properties of [111] Germanium

Recently, impact measurements of the resistivity of germanium under shock-wave compression were reported [33, 34]. The technique allowed determination of the resistivity under one-dimensional elastic compression and permitted the identification of the shock-wave pressure induced transition to the white tin structure. Many of the experiments were performed in stress regions for which multiple waves were known to exist due to the cusps in the stress-volume relation at the Hugoniot elastic limit of 44 kbar and at the 120 kbar high pressure phase transition. Accordingly, the experiments were designed to avoid wave interactions which result if the waves are reflected back into the specimen from an impedance discontinuity.

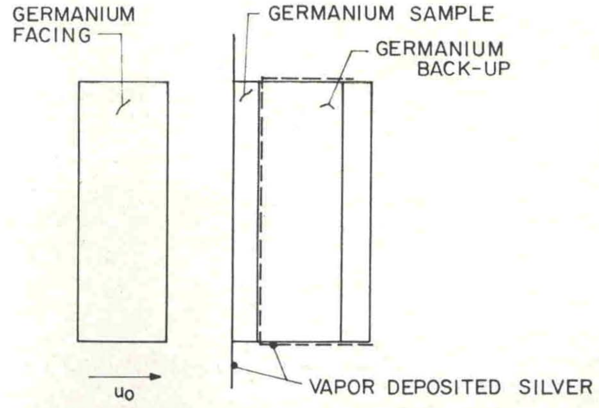

Fig. 8 Experimental arrangement employed to measure the resistance of shock-wave loaded Ge in multiple wave regions

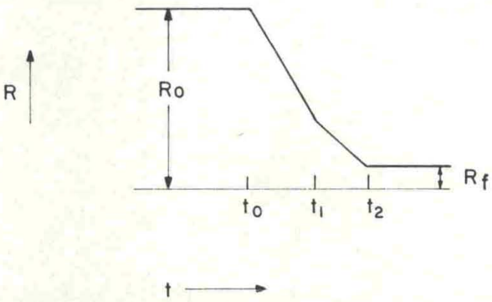

Fig. 9 Expected resistance-time record for a semiconductor exhibiting multiple waves

Again, the shock wave is induced into the sample by the symmetrical impact of [111] orientation germanium disks so that the particle velocity imparted to the specimen is known. With the arrangement as shown in Fig. 8, the resistance between the faces of the specimen disk is then recorded as the shock waves traverse the sample. Backup disks of germanium were carefully mated to the rear of the specimen such that the waves pass through and out of the specimen without reflection.

The propagation of multiple wave fronts divides the specimen into various regions each with a different resistivity and each with a thickness which varies with time depending on the shock velocities. After all the waves have propagated out of the specimen disk, the resistance-time behavior shows a final value, R_f, corresponding to the total stress. The initial unstressed value, R_0, and the final values of resistance are connected by a continuous line consisting of segments of different slope, each segment corresponding to particular wave fronts. This is depicted in Fig. 9 for the case of two wave fronts propagating through the specimen. The resistance-time behavior shows the number of wave fronts (hence the presence of a cusp in the stress-volume relation) and the shock velocity of each wave. However, the division of the total input particle velocity among the various waves is not indicated in the data from a single experiment.

To find the particle velocity associated with each cusp, the impact velocity is varied in small increments around the region of a suspected cusp until a change in the number of waves is observed. This establishes the critical particle velocity of the cusp as accurately as it can be bracketed by the various experiments. In this case, it is particularly important to be able to achieve a preselected velocity. Once the particle velocity associated with the cusp is determined, the stress and velocity for each experiment can be computed. From these measurements

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[9] In an anisotropic crystal, pure longitudinal wave motion is possible only in certain directions called "specific" directions. Although the 60 deg orientation is not theoretically a specific direction for the trigonal system, we have found that under shock-wave compression longitudinal motion is exhibited to a very close approximation. This is not entirely unexpected considering the small variation in elastic constants in the various crystallographic directions.

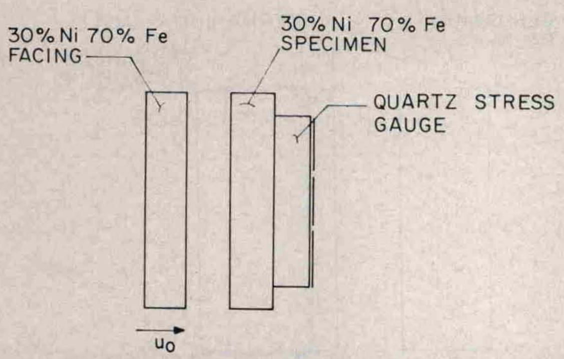

Fig. 10 Experimental arrangement for compressibility measurement on fcc 30 Ni-70 percent Fe

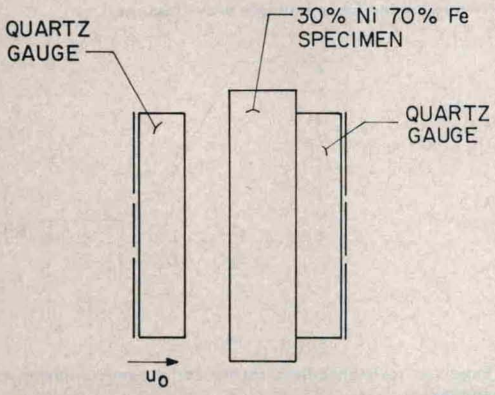

Fig. 11 Experimental arrangement for compressibility measurements employing both impact surface and rear surface measurements of the stress-volume relation

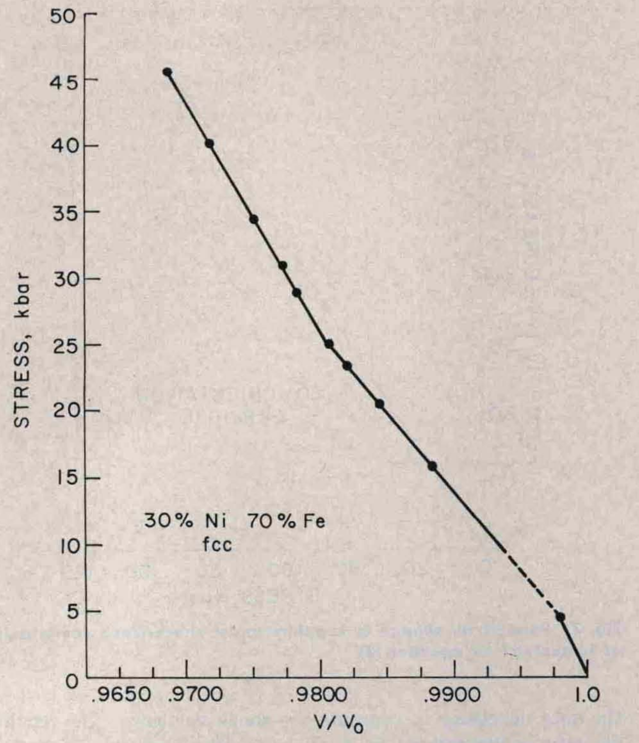

Fig. 12 Stress-volume relation observed for fcc 30 Ni-70 percent Fe

the Hugoniot elastic limit was found to be 44 kbar and the phase transition was found to be at a pressure between 114 and 122 kbar.

Duff and Minshall [35] have demonstrated that the measurement of the shock-wave velocity of a small increment of pressure in the mixed-phase region of a first order transition is sufficient to compute the slope of the pressure-temperature phase line. This unique situation arises because the adiabatic compression resulting from the small pressure increment in the mixed phase region must display a finite compressibility due to the entropy change of the transition. To measure the shock velocity in the mixed phase region, multiple wave reflections and interactions must be avoided and the input stress to the sample must be accurately controlled. This impact experiment is therefore an ideal method for making the measurement. In the mixed phase region of the 120 kbar germanium transition the slope of the phase line was found to be -3.1×10^{-2} kbar deg C^{-1}. This value allows the transition to be identified as the statically observed transition to the white tin structure [34].

With the capability of performing experiments in small pressure increments it is not difficult, although it was not done in this case, to determine the volume change associated with the first order transition. The measurement of the slope of the phase line and the volume change completely specifies the transition since the entropy change of the transition can be calculated from the Clausius-Clapeyron relation.

The results of the resistivity determinations are fully reported elsewhere [34]. They can be summarized by saying that meaningful measurements were obtained only in the elastic region and that the values showed agreement with the theoretical predictions for silicon on the effect of one-dimensional strain on the band structure.

Second Order Transition in 30 Ni-70 Percent Fe

Alloys of about 30 Ni-70 percent Fe in the fcc phase have long been noted for the enormous pressure sensitivity of their magnetic properties. Compressibility determinations for this alloy were recently reported from 4 to 50 kbar which have resulted in an identification of a pressure induced ferromagnetic Curie point transition [36]. Compressibility measurements can be made quite accurately with shock-wave loading techniques and impact experiments have the control necessary to examine the compressibility in enough detail to detect the transition.

Two different experimental arrangements were used for the compressibility measurements. In one case, see Fig. 10, a symmetrical impact is used to produce a known particle velocity in the sample. The stress-time profile which results after the shock wave has propagated some distance from the impact surface is then measured with a high resolution quartz stress gauge.[10] The time for the shock waves to propagate through the measured thickness is obtained from a measurement of the impact time and the arrival time as indicated by the quartz gauge. These rear surface data alone provide sufficient information to precisely determine the stress and volume change for each experiment. In this case, the additional data on the particle velocity imparted to the sample was used principally for a quantitative comparison with the data measured at the quartz gauge interface. This comparison of the independent measurements of the total particle velocity, which is normally not available in other experiments, serves to give greatly enhanced confidence in the result.

The second method employed is much more elaborate but yields considerably more information. This experiment, which is described in more detail elsewhere [12], is similar to that shown above except that the shock wave is produced by the impact of a quartz gauge. This experimental arrangement is shown in Fig. 11. Provisions are made to obtain the signal from the projectile gauge with the result that the stress and particle velocity are obtained at the impact surface as well as the data ordinarily obtained at the rear surface of the specimen disk. Thus, with this experimental arrangement two completely independent sets of measurements are made on each experiment. This unique capability of directly measuring the shock-wave properties with two entirely independent methods on the same experiment is a

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[10] This gauge was developed as a result of the previously mentioned determination of the piezoelectric properties of shock wave loaded quartz [23].