$\mu\Omega$ cm implies $\beta = -0.17\rho_\theta = -0.20$ which is close to the -0.16 value from Kos's work. Actually silver resistivity is better described using $h = 1.14$.

Now $\beta(V)$ can be found from

$$\beta = (1-h)\rho_\theta = (1-h)(\alpha\theta + \beta)$$

which gives

$$\beta(V) = [(1-h)/h]\,\alpha(V)\theta(V).$$

Finally, resistivity on the hydrostat is given by

$$\frac{\rho}{\rho_0} = \frac{\rho(V,T)}{\rho(V_0,T)} = \frac{\alpha(V)}{\alpha(V_0)}\left(1+\frac{1-h}{h}\,\frac{\theta(V)}{T}\right)\left(1+\frac{1-h}{h}\,\frac{\theta(V_0)}{T}\right)^{-1}. \quad (5)$$

Equation (5) implies that at 120 kbar for silver the empirical correction to ρ/ρ_0 as given by Eq. (1) is -2.3%.

Resistivity change due to shock temperature rise was determined from

$$\frac{\Delta\rho_T}{\rho_0} \equiv \frac{\rho(V,T)-\rho(V,T_0)}{\rho(V_0,T_0)} = \frac{\alpha(V)}{\alpha(V_0)}\left(\frac{T}{T_0}-1\right)\left(1+\frac{\beta(V_0)}{\alpha(V_0)T_0}\right)^{-1}. \quad (6)$$

(T_0 is 298 °K and V and T are volume and temperature in the shocked state.)

The isothermal shock resistivity one wishes to compare to hydrostatic resistivity [Eq. (5)] is

$$\frac{\rho(V,T_0)}{\rho(V_0,T_0)} = \frac{\rho(V,T)-\Delta\rho_T}{\rho(V_0,T_0)}. \quad (7)$$

The experiment provided $\rho(V,T)/\rho(V_0,T_0')$ data where T_0' is ambient temperature; this varied from 295.6 to 298.4 °K° The relation needed to normalize the data is

$$\frac{\rho(V,T)}{\rho(V_0,T_0)} = \frac{\rho(V,T)}{\rho(V_0,T_0')}\,\frac{\rho(V_0,T_0')}{\rho(V_0,T_0)},$$

where

$$\frac{\rho(V_0,T_0')}{\rho(V_0,T_0)} = 1+a(T_0'-T_0), \quad a = 0.00408/°\text{K}.$$

B. Equation of state

A P-V-T equation of state for silver is needed to calculate shock temperatures and temperature coefficients $\alpha(V)$ in the compressed state; both are necessary to correct resistivity-shock pressure data to isothermal conditions. Temperature coefficients are used also in the model calculation of the resistivity of silver under hydrostatic pressure [Eq. (5)].

The equation of state chosen was an analytic fit by Zharkov and Kalinen[20] to static and dynamic P-V data. This equation of state yields a quadratic equation for temperature in the shocked state. The integration in Eq. (4) was performed using a Dugdale-MacDonald formula for the Gruneisen parameter adjusted to agree with the thermodynamic value at 1 atm; results for $\theta(V)$ were fitted to a polynomial

$$\theta/\theta_0 = 4.0465X^2 - 10.5232X + 7.4770,$$

where $X = V/V_0$. This determines numerical results for the resistivity of silver in Eqs. (4)—(6).

The above equation of state determines temperatures reached by a single shock transition from the ambient state, treating the material as a fluid. The actual temperature rise in the experiments will deviate from the simple calculation for the following reasons: (i) The final state in the experiment is not reached by a single shock but by a series of shocks because of the sandwich configuration. (ii) Heat flow from the adjacent epoxy provides additional thermal energy to the foil. (iii) Since the material has strength, there will be heat generated by the irreversible work of plastic deformation. (iv) Porosity, if present, will cause an additional temperature rise due to the extra work of compression done by the shock. These temperature deviations, if significant, will affect results for shock isothermal resistivity and defect resistivity. Reason (i) is treated below and reasons (ii)—(iv) are considered in Appendix B.

C. Reverberation temperature calculation

The sandwich configuration (anvil-foil-anvil) causes the final (P,V,T) state in the foil to be reached by a series of shock reverberations. The amount of deviation from the state reached by a single shock depends on the mechanical shock-impedance mismatch between foil and anvil. (There may also be some small reverberation effects due to the thin epoxy bonding layer.) Continuity conditions for shocks at interfaces between different materials require continuity of longitudinal stress and particle velocity normal to the interface.[11] So pressure and particle velocity in the silver are determined by the shock state in sapphire. However, the final temperature in silver has significant dependence on the shock reverberation path as opposed to a single shock path to the final state. See Appendix A for details of the calculation. For silver in sapphire, reverberation causes a smaller temperature rise than a single shock; this smaller rise by reverberation will affect the correction of shock data to isothermal resistivity by making isothermal resistivity, and hence defect resistivity, higher than if one used single-shock temperatures.

Calculations of the silver-sapphire interaction show that three wave transits are necessary to bring the silver to within 0.1% of the final shock pressure for a 100-kbar shock. In two transits it is within 0.3% and in one transit within 9%. At 100 kbar the temperature change due to reverberation shocks is 4% lower than that due to a single shock. For comparison, temperature change at 100 kbar on the isentrope centered at the initial state is about 20% lower than the single-shock temperature change.

Using the resistivity theory results, resistivity changes due to temperature rise are also calculated. Computations show that at 100 kbar the thermal resistivity change is 4% less than for a single shock. The graph of shock isothermal resistivity vs pressure is not strongly affected by the correction, but the amount of resistivity change attributed to defects generated by the

TABLE I. Results of impact experiments.

Shot No.	Foil type	Foil thickness (μm)	Foil resistance ratio $R_{4.2\,°K}/R_{296\,°K}\times10^3$	Impactor speed and type [a] (mm/μsec)	Pressure (kbar)	Voltage ratio (E/E_0 at 0.5 μsec)	Initial rise time (nsec)
72-065[b]	MRC-A [c]	16.5	3.57	0.637 Al	74.5	1.051	45
72-068[b]	MRC-A	15.6	4.17	0.853 Al	102.1	1.170	65
72-069	MRC-A	17.3	4.14	0.857 Al	103.5	1.073	35
73-009	MRC-A	14.7	4.31	0.390 S	87.1	1.049	37
73-010	MRC-A	14.3	4.38	0.392 S	87.5	1.058[d]	27
73-011	MRC-A	17.0	3.95	0.659 FQ	60.0	1.022	53
73-013	MRC-A	18.0	3.76	0.286 FQ	27.0	1.000	25
73-027	MRC-A	15.9	4.31	0.517 S	115.7	1.120	19
73-028	W3N-A	25.0	2.40	0.531 FQ	48.6	1.035	34
73-029	MRC-UA	16.1	6.85	0.562 FQ	51.8	1.032	36
73-034	MRC-UA	16.0	7.14	0.416 S	92.9	1.087	37
73-036	W3N-A	24.5	2.29	0.395 S	88.2	1.122	84
73-040	W3N-A	24.9	2.39	0.686 FQ	62.4	1.037	32
73-044	W3N-A	24.2	2.38	0.401 S	89.6	1.111	67
73-047	W3N-A	17.6	2.53	0.423 S	94.5	1.149 ± .013	• • •
73-050	W3N-A	24.0	2.25	0.524 S	117.3	1.185	34
73-051	MRC-A	16.9	4.46	0.525 S	117.5	• • •	35
73-056	MRC-A	16.6	4.18	0.89 FQ	83	• • •	• • •
73-059	MRC-A	17.2	4.48	0.530 S	118.6	1.139	34

[a] Al, FQ, and S stand for aluminum, fused quartz, and sapphire impactors, respectively.
[b] Anvils were of Lucalox.
[c] A ≡annealed, UA ≡unannealed.
[d] This value read after 0.14 μsec.

shock is about 20% higher on the MRC curve and 4.5% higher on the W3N curve after the multiple-shock calculation for the data points.

IV. RESULTS OF EXPERIMENTS AND DISCUSSION

Impact experiments were performed on 19 silver foils. Care was taken to prepare the foils in a uniform and well-characterized manner, and the experiment was designed to ensure a state of uniaxial shock compression in the silver. Data output of the impact experiments was in the form of voltage-time profiles which, when analyzed, provided resistivities of silver under shock compression. After correcting for resistivity change due to shock temperature rise, the data were compared to resistivity expected under hydrostatic pressure; from this comparison, shock-generated vacancy concentrations were estimated (Fig. 5).

In some cases postshot recovery and examination of foil pieces by optical and electron microscopy was possible. Effects of annealing on resistivity of one of the recovered foil pieces was studied also.

This section details the above results and discusses analysis of errors and possible spurious effects.

A. Summary of impact experiment results

Data were obtained on resistance changes in silver under shock compression in the pressure range from 27 to 119 kbar. Average initial temperature was 296.4 ± 0.7 °K. Resistance changes differed for silver of two different purities; higher-purity material had larger resistance changes. Annealing also appeared to affect resistance changes; unannealed foils showed slightly higher resistance changes for a given shock pressure than did annealed foils of the same purity.

Shock results, after subtracting resistivity changes due to shock temperature rise from the raw shock data (Sec. III A), are significantly higher than hydrostatic results. The difference is attributed to generation of a high concentration of vacant lattice sites by plastic deformation associated with uniaxial shock compression (see Table II). Both vacancy concentrations generated in all cases and variation of these concentrations with silver purity are difficult to understand. The higher defect resistivity observed in purer silver is opposite to results of quasistatic tensile deformation.[21]

Table I summarizes shot data. Experiments are presented in the order in which they were done. Foil type, state of anneal, foil thickness, and resistance ratio are given. Resistance ratio is the ratio of foil resistance at liquid-helium temperature to that at room temperature, and gives a relative measure of impurity and imperfection content of the foils. Resistance ratios are also affected by scattering of electrons at foil surfaces at 4.2 °K. To correct them approximately to bulk ratios using the Fuchs-Sondheimer theory[22] and a specular coefficient of 0.2,[23] multiply MRC-A ratios by 0.77, MRC-UA ratios by 0.84, and W3N-A ratios by 0.75. The average bulk resistance ratios are 0.0032 for MRC-A, 0.0059 for MRC-UA and 0.0018 for W3N-A (A and UA stand for annealed and unannealed, respectively). Measured impactor speed and type and pressure deduced from the impactor and anvil Hugoniot curves[11] are presented in columns 5 and 6, while column 7 gives the ratio of the voltage drop across the silver foil 0.5 μsec after shock arrival to the preshock voltage drop. The last column is the rise time (10—90%) of the voltage jump on shock arrival at the foil.

The first two experiments, 72-065 and 72-068, were performed using ceramic Al_2O_3 anvils; shot 72-069 used sapphire anvils. Although shots 72-068 and 72-069 were shocked to the same pressure and used silver foils