ENERGY RELEASED ON ANNEALING QUENCHED-IN DEFECTS IN GOLD

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To date, experimental studies on quenched-in defects in close-packed metals have relied mostly on resistometric techniques.[1] However, inherent difficulties in the corresponding theoretical interpretation of these resistivity results make such a study an indirect one. More recent measurements— such as specimen length changes,[2] in addition to resistivity changes, during annealing of these defects— have helped to supplement the results. A fundamental quantity to measure is the energy released during the annealing. In the formation of the imperfection, energy is stored in the lattice. It is released in form of heat upon annihilation of the defect. Such basic information would further contribute to the understanding of the defects and their annealing behavior. The purpose of this note is to present some preliminary experimental results on the energy released when the quenched-in defects in gold anneal isothermally.

The calorimeter has been described earlier.[3] The gold specimens (99.999%) consisting of rectangular slabs 0.5in.×0.4in.×0.020in., were heated in a furnace and quenched in an ice-water mixture. The quenching rates varied from 0.8×10^4 to 1.1×10^{4} °C/sec. Unlike the resistometric procedure, the first measurements were possible, in these preliminary results, only after about 20 minutes (t_i) from time of quench ($t=0$). (The calorimeter is now being modified to improve this.) The annealing process was followed for about 7-8 hours (t_f) thereafter. The energy released during this interval is tabulated in Table I.

The rate of energy release at t_i indicates that an appreciable fraction, $\Delta E(t_0 \to t_i)$, has been evolved prior to t_i and not detected; also at t_f, the power indicates a smaller fraction, $\Delta E(t_i \to t_\infty)$, released for the period $t > t_f$. In the early period of the measurements, starting at t_i, it is found that the power can be described, to better than 5%, by a simple second order kinetic expression. Koehler, Seitz, and Bauerle[4] suggest that at quenching temperatures reported here the kinetics are complex, probably involving multiple vacancies. We are not at this time able to elucidate this point but only use the second order expression as a means of extrapolating the experimental data from t_i to t_0. The values of the energy increments, $\Delta E(t_0 \to t_i)$, thus evaluated are listed in Table I. The Table also lists the estimated values of $\Delta E(t_f \to t_\infty)$ as well as the probable "total" energy based on an average value of these

Table I. Energy released on annealing quenched-in defects in gold.

Sample	Run No.	T_Q(°C) (Quenching temp)	T_a(°C) (Annealing temp)	t_f (min)	$\Delta E(t_i \to t_f)$ (cal/g atom) (Exptl) ($t_i = 20$ min)	$\Delta E(t_0 \to t_i)$ $\left(\frac{\text{cal}}{\text{g atom}}\right)$	$\Delta E(t_f \to t_\infty)$ $\left(\frac{\text{cal}}{\text{g atom}}\right)$ (calc)	ΔE_{total} $\left(\frac{\text{cal}}{\text{g atom}}\right)$	$\frac{\Delta\rho}{\Delta E/E_f}$ $\left(\frac{\text{cm } \mu\text{ohm}}{\text{atom\%}}\right)$	$\frac{\Delta E_{\text{total}}}{\Delta\rho}$ (cal/gram μohm-cm)
1	1	855 ± 15	44.0	120	0.67	0.63	. . .	. . . .	. . .	. . .
1	2	835 ± 15	38.5	480	0.42	0.13	0.3^a $0.1_4{}^b$ $0.1_0{}^c$	0.7 ± 0.3	4.5	0.3
1	3	860 ± 15	51.8	500	1.14	0.36	0.3^a $0.2_5{}^b$ $0.1_0{}^c$	1.7 ± 0.3	2.3	0.4_9
2	1	885 ± 15	47.0	410	1.01	0.68	$0.5_4{}^a$ $0.2_3{}^b$ $0.1_1{}^c$	2.0 ± 0.3	2.4	0.4_7

[a] Estimated assuming $\Delta E(t_f \to t_\infty)$ proportional to fractional quenched-in resistivity remaining at t_f (reference 2).
[b] Estimated from extrapolating power data for $t > t_f$.
[c] Integrating second-order expression $\Big]_{t_f}^{t_\infty}$

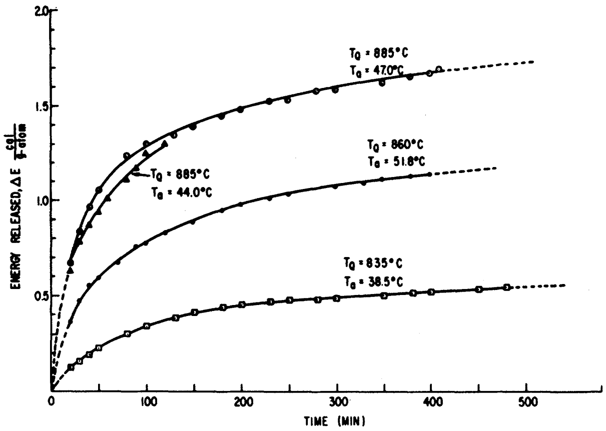

FIG 1. Energy released as a function of time during isothermal annealing of quenched-in defects in gold from different quenching temperatures, T_Q, and annealing temperatures, T_a.

numbers. (See also Fig. 1.)

It is interesting to combine these calorimetric results with the resistivity data of Bauerle and Koehler[2] and to determine the resistivity increase per one atomic percent of vacancies, $\Delta\rho/c$, based on experimentally derived quantities. That is, $\Delta\rho/c = \Delta\rho/(\Delta E/E_f)$ where $\Delta\rho$ is the quenched-in resistivity, ΔE the energy evolved, and E_f the energy of formation of the defect. These values must all be determined for a given specimen having the same thermal history and quenched at comparable quenching rates. We have not, in this preliminary work, made any attempt to determine E_f independently. Bauerle and Koehler[2] report that, for gold specimens, comparable to those used in this work, $\Delta\rho = A \exp(-E_f/kT_Q)$. They found that the formation energy, $E_f = 0.98$ ev, does not vary with quenching rates, whereas the constant A does. Extrapolating their decrease in A, we obtain a value of $A = 4.0 \times 10^{-4}$ ohm-cm appropriate to our quenching rate $\sim 1 \times 10^{4\circ}$ C/sec. The values of the ratio $\Delta\rho/c$ obtained in this way are tabulated in Table I. The best value of $\Delta\rho/c \simeq 2.4 \times 10^{-6}$ ohm-cm/atom %, since the value obtained for the lowest quenching temperature has a large experimental uncertainty. Koehler, Seitz, and Bauerle,[4] based on resistometric and fractional length changes[2] and estimates of the volume increase per vacancy ($\Delta V/V$), report for $\Delta V/V = 1$ the value $\Delta\rho/c = 3.2 \times 10^{-6}$ ohm-cm/atom % or for $\Delta V/V = 0.4$,[5] $\Delta\rho/c = 1.3 \times 10^{-6}$ ohm-cm/atom %. Our value of $\Delta\rho/c$ implies $\Delta V/V \sim 0.7$. Recent theoretical work of Tewordt[6] reports values which average about 0.5 for $\Delta V/V$.

Table I also lists the values of $\Delta E/\Delta\rho$, the ratio of the energy released to the resistivity change upon annealing the defects. These values are to be compared with the ratio $\Delta E/\Delta\rho = 1.7$ cal/gram microhm cm obtained by Overhauser[7] for copper irradiated by deuterons and a value $\Delta E/\Delta\rho = 3.0$ cal/gram microhm cm determined from results of Blewitt et.al.[8] on annealing copper irradiated by neutrons.

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MICROWAVE AND LOW-FREQUENCY OSCILLATION DUE TO RESONANCE INSTABILITIES IN FERRITES

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Microwave and low-frequency oscillations have been observed in single crystal yttrium iron garnet (YIG) disks, with Fig. 1 showing a typical oscillation spectrum. These sideband oscillations were observed with the YIG disk placed in a microwave resonant cavity, with microwave power above a certain critical value incident on the cavity, and with a dc magnetic field applied normal to the disk and of such magnitude as to cause ferromagnetic resonance at the microwave frequency. These oscillations can also be observed as a modulation of microwave output of the cavity.

The particular sideband spectrum shown in