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RECOVERY BY ANNEALING OF T_c IN DISORDERED Nb_3Pt

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Recovery by Annealing of T_c in Disordered Nb_3Pt.*
D. DEW-HUGHES, R. CATON,+ R. JONES, and D. O. WELCH, Brookhaven National Lab.—Nb_3Pt has been disordered by rapid 'splat' quenching, which results in the superconducting critical temperature falling from 11K to below 7K. The kinetics of reordering, as evidence by the recovery of T_c, were followed by isothermal and isochronal anneals. The results were analyzed according to Welch's model of reordering in A15 compounds[1] and were found to follow 2nd order kinetics, as had been assumed in an earlier study of recovery in several neutron-irradiated A15 compounds.[2] The activation energy for the reordering process is 3.5±0.2eV. These results will be compared to those on the recovery of samples of Nb_3Pt irradiated to a dose of 7.5×10^{18}nvt fast (E>1MeV) neutrons with a T_c=6.15K. The implications of this work for the nature of radiation damage in A15 compounds will be discussed.

[1]D. O. Welch, to be published.
[2]D. Dew-Hughes, S. Moehlecke, D. O. Welch, J. Nuc. Materials 72, 225 (1978).
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In an earlier study the kinetics of the recovery of T_c in a number of neutron irradiated superconducting A15 compounds were analyzed in terms of a model formulated by D. O. Welch.[1] It was assumed that the reduction in T_c consequent upon neutron irradiation was due to anti-site disorder alone, and to be directly proportional to it. (Whether the disorder is random or heterogeneously distributed is not particularly relevant, as inhomogeneities spaced at distances below the coherence length apart will be averaged out.) Recovery of T_c is presumed to be a consequence of the re-establishment of crystallographic order.

The reordering kinetics for a compound A_3B with the A15 structure are given by:

$$\frac{dy}{dt} = -f_v \frac{12\nu_A e^{-U_A/kT} \nu_B e^{-U_B/kT}}{\nu_B e^{-U_B/kT} + 3/4 y \nu_A e^{-U_A/kT}} y^2 \qquad (1)$$

where $y \equiv (1-T_c/T_{co})$ is assumed to be proportional to (1-S), S being the usual Bragg-Williams order parameter. f_v is the fraction of vacant lattice sites, $\nu_A(\nu_B)$ in the attempt frequency and $U_A(U_B)$ is the activation energy for the jump of an A(B) atom on a B(A)

site into an adjacent vacancy on an A(B) site.

If the rate of jumping of an A atom into a vacant A site is very much greater than the rate of jumping of a B atom into a vacant B site, i.e. $\nu_A e^{-U_A/kT} >> \nu_B e^{-U_B/kT}$ then (1) becomes:

$$\frac{dy}{dt} \cong -16 f_v \nu_B e^{-U_B/kT} y \qquad (2)$$

a first order process.

If the reverse is true, i.e. $\nu_B e^{-U_B/kT} >> \nu_A e^{-U_A/kT}$, or if y is small, then (1) becomes:

$$\frac{dy}{dt} \cong -12 f_v \nu_A e^{-U_A/kT} y^2 \qquad (3)$$

a second order process.

Analysis of reordering data on Nb_3Sn and Nb_3Ge irradiated to various doses, and in Nb_3Al of varying composition has produced the following conclusions:

(i) The kinetics appear to be marginally better described by a 2nd order rather than a 1st order process. This is in line with solid state diffusion results in Nb_3Sn and V_3Ga which suggest that B atoms are more mobile than A atoms in these materials.

(ii) The recovery takes place in three stages with three activation energies. At low temperature the activation energy is very small, a few tenths of an eV. At intermediate temperatures the activation energy is ~1 eV, and at high temperatures it is ~2 eV.

This can be explained by a variation in i_v, the formation of vacancies. In addition to disorder, neutron irradiation produces an excess of vacancies. During initial stages of recovery, many of these anneal out to sinks, or condense into clusters and dislocation loops. Thus the activation energy for the first stage of recovery is $(U_A - U_{vm})$ where U_{vm} is the activation energy for vacancy migration. As $U_A \cong U_{vm}$, the observed activation energy is small, and may even be negative.

At some point f_v is in equilibrium with the sinks, and if this value of f_v is greater than the equilibrium value for thermal vacancies, f_v will remain constant and the measured activation energy $= U_A$. At higher temperatures f_v will increase due to the production of thermal vacancies and the measured activation energy will be $(U_A + U_{v_f})$ where U_{v_f} is the vacancy formation energy.

While the above gives a reasonable explanation of the observations, confirmatory experiments are highly desirable. Rapid 'splat' quenching of A15 compounds should induce anti-site disorder without giving rise to the same excess of vacancies and other defects which result from neutron irradiation. Studies on the recovery of such material should yield an activation energy which corresponds to that of the third stage in the previous study, i.e. $(U_A + U_{v_f})$.

Loss of the volatile constituent mars attempts to 'splat' quench Nb_3Sn and V_3Ga. With the simple 'rat-trap' apparatus available, a cooling rate sufficiently high to maintain thermal disorder in Nb_3Al or V_3Si was not achievable. Bulk 'splat' quenched Nb_3Ge reverts to the equilibrium, nonstoichiometric composition upon annealing. It was, however, found possible to 'splat' quench Nb_3Pt and reduce T_c from ~11 K to below 7 K. Most of this reduction in T_c is restored by an appropriate anneal.

Recovery of T_c during isothermal anneals at 750°C and 900°C, and isochronal anneals was studied. Second order kinetics were followed with less ambiguity than for irradiated material, confirming the less complicated nature of the rapidly quenched defect state. The activation energy for recovery was determined by four different methods, and found to be 3.5±0.2 eV. These results are being directly compared with those from an as yet incomplete study of the recovery of Nb_3Pt irradiated to a dose of 7.5×10^{18} nvt fast (E>1 MeV) neutrons. Recovery is more rapid than in the 'splat' quenched material, and preliminary results suggest that the activation energy is about 2 eV. U_{v_f} in this material is therefore ~1.5 eV.

These results are important in that they tend to confirm the assumptions made in the earlier study of irradiated materials.[1] In particular they support the idea that it is

primarily the anti-site disorder which is responsible for the degradation of T_c in irradiated A15 compounds.

References

1. D. Dew-Hughes, S. Moehlecke and D. O. Welch, J. Nuc. Materials 72, 225 1978).