THE NATURE OF THE DEFECTS IN IRRADIATED A-15 COMPOUNDS*

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ABSTRACT

From transmission electron microscopy and heat capacity measurements radiation induced damage in A-15 compounds was found to be inhomogeneous, consisting of small disordered regions in an ordered matrix. Some consequences of this result are discussed.

INTRODUCTION

One of the controversial topics in the study of A-15 compounds of the type A_3B is the nature of the defects introduced in them by high energy nuclear irradiations and how they degrade the superconducting and normal state properties [1,2]. Two kinds of defects have been proposed in the past - (a) antisite defects and (b) 'an unknown universal defect' containing large static displacement resulting in bond bending. Both of these defects were assumed to be homogeneously distributed on the atomic scale. However evidence is now available indicating that the radiation damage in these compounds is in fact inhomogeneous [3-6].

A systematic electron microscopy TEM study of neutron irradiated Nb_3Sn has now been completed [3] to ascertain the nature of this inhomogeneity. TEM identified the inhomogeneities to be disordered regions (size $\sim 35\text{\AA}$) in a much less disordered matrix. In neutron irradiated Nb_3Sn they are of size $\sim 20-60\text{\AA}$. These regions are interpreted from detailed contrast calculations [7] to be regions where local values of S , the long range order parameter, is much less than the surrounding matrix. The disordered regions still retain the A-15 structure and therefore probably contain a high density of antisite defects. They

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are also associated with localized areas of strain. Therefore both the antisite defects and the large static displacements are present in the disordered regions. The seemingly opposite points of view about the nature of the defects are thus reconciled.

Recently Pande has proposed a theory [3] for the degradation of the superconducting transition temperature (T_c) based on his electron microscopic observations in these compounds. According to this theory the T_c of an irradiated A-15 compound is given by

$$\ln(T_c/T_{co}) = (Q+Q_1) \frac{1-F_v}{F_v}^{-1} + A \ln \frac{\theta_D}{\theta_S} + \ln\left(\frac{T_{cs}}{T_{co}}\right) \quad (1)$$

where Q , Q_1 and A are material parameters, F_v is the volume fraction of the disordered regions, θ is the Debye temperature. S refers to the matrix, D to the disordered regions and o to the unirradiated material. This relation was obtained on the basis of proximity effect [3] between the disordered regions and the ordered matrix. In this model [3] the main contribution to T_c degradation was considered to be due to the first term on the right hand side in Equation (1) which depends on the volume fraction of the disordered regions. The basis of this model, namely, the irradiation damage is inhomogeneous is further supported by our heat capacity measurements [8,9] on a neutron irradiated single crystal V_3Si discussed below.

Width of the Superconducting Transition Temperature

An important result of our heat capacity measurement was that ΔT_c the width of the superconducting transition temperature T_c consistently increased with fluence. This is consistent with our assumption that the neutron damage is inhomogeneous on the scale of coherence length. In fact one can predict accurately the variation of the width with fluence from Equation (1) [10] as well as the T_c at which $\Delta T_c/T_c$ will be maximum in agreement with observations in neutron irradiated Nb_3Sn [6]

and α -irradiated V_3Si [11]. Thus the inhomogeneous nature of the radiation damage is well established.

Electronic Heat Capacity

For V_3Si the experimental heat capacity C for $T \geq 20^\circ$ could be well represented by the expression [12] $C = C_\infty + \beta T^3$ where C_∞ is the saturated (constant electronic term and βT^3 is the lattice term. Thus the electronic heat capacity $C_{el} (= C - \beta T^3)$ vs T would be a constant for $T \geq 20K$. Such a result is in fact obtained for our unirradiated V_3Si (Fig. 1). Interestingly the same qualitative behavior is observed for our V_3Si specimen for all irradiations, although C_∞ decreases. This leads us to believe that the original unirradiated state is retained even in the damaged specimens, but the amount of the material with those original characteristics decreases with fluence.

Resistivity

Finally we wish to comment briefly on the resistivity ρ of such irradiated materials, especially on the role played by disordered regions. A semiquantitative relation between T_c and ρ_0 the residual resistivity can be obtained as follows: From (1) noting that $F_V \approx 1-S$ and for many A-15 compounds $Q \approx Q_1$ [4], we obtain the well known relation [13,14]

$$T_c/T_{co} \approx e^{-\alpha(1-S)}, \text{ where } \alpha \equiv -\log\left(\frac{T_{cd}}{T_{co}}\right) \quad (2)$$

Now using an empirical relation between ρ_0 and S due to Muto [15] which is well obeyed in A-15 compounds one obtains a relation between T_c and ρ_0 theoretically i.e.

$$\Delta\rho_0 \approx 2x\Delta\rho_0 \max\left[1-\frac{x}{2}\right] \text{ where } x = \frac{\log(T_c/T_{co})}{\log(T_{cd}/T_{co})} \quad (3)$$

where $\Delta\rho_0$ is the change in ρ_0 on irradiation. This relation is found to be well obeyed experimentally. The nature of the damage becomes

even more significant when the thermal variation of ρ is considered. Mendelssohn and co-workers [17] consider a model of a composite system of disordered regions in an ordered matrix to explain the temperature variation of resistivity ρ in irradiated plutonium. If the temperature variation of the resistivity of the disordered regions is taken constant that of the composite system can only come from the ordered matrix. However as the damage increases the volume fraction of the ordered regions get smaller and correspondingly the thermal variation of ρ gets smaller. This would lead to an apparent failure of Mathiessen's rule. By analogy [18] such a failure should also occur in A-15 compounds. In fact the resistivity of irradiated plutonium bears a striking resemblance to irradiated A-15 compounds.

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ic ordering. However this does not change the conclusions.

FIGURE CAPTION

Fig. 1. Electronic heat capacity $C_{el}(=C-\beta T^3)$ vs T . The numbers represent T_c 's of the specimen.