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THERMAL AND FISSION NEUTRON-PRODUCED DEFECT CONFIGURATIONS IN PLATINUM

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ABSTRACT

An experimental procedure employing resistivity measurements was used to observe the production of *free* interstitials and vacancies in platinum by atomic recoils produced from thermal neutron capture and fission neutron collision. For thermal neutrons, which produce damage much like fast electrons, free defect production increased nearly a factor of two with increasing irradiation temperature from 30 to 280°K. This is attributed to the increasing thermal dissociation of correlated pairs into free defects. From low-temperature recovery studies it is known that thermal neutrons produce damage which has a large I_D recovery substage indicating an abundant production of correlated pairs. Although the correlated pair population is less in similar recovery studies of the high-energy atomic recoils associated with fission neutron damage, it is still large enough that one would expect to observe the effects of thermal dissociation, or in other terms, the temperature dependence of the I-V recombination volume. In contrast to the thermal neutron case, virtually no temperature dependence of free defect production was found for fission neutron damage produced over the same temperature range. This result suggests that correlated pairs are present in the vacancy-rich central region of the fission neutron displacement cascade, but upon thermal dissociation the interstitial partner is annihilated before reaching a stable trapping site outside the cascade.

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1. Experiment

Experiment [1] and theory [1,2] suggest that with increasing irradiation temperature above Stage I the probability increases that the partners of newly produced close and correlated Frenkel pairs will dissociate into free defects rather than recombine. In contrast, it is well known that when produced at very low temperatures such pairs inevitably recombine upon annealing through Stage I. Dissociation can be studied in the Stage II temperature range, where vacancies are immobile and interstitials are mobile but can be trapped at impurities. Thus the vacancy and interstitial partners of a pair which dissociates into free defects after the pair is produced can be retained and detected by residual resistance measurements. Of course, free defects produced directly by a knock-on event are also retained in the same manner.

2. Experimental

A study of the temperature dependence of pair dissociation, that is the temperature dependence of free defect production, is facilitated by certain experimental conditions and procedures.

a. An appreciable percentage population of the defect types produced by the irradiating particle must be in the form of I_C (close) and I_D (correlated) Frenkel pairs, since their small (I_C) or zero (I_D) binding energy gives the best possible chance for dissociation. Figure 1 shows the isochronal annealing of small concentrations of thermal (~ 0.34 ppm) and fission (~ 0.55 ppm) neutron damage produced in Pt near 4°K. Although greater for thermal neutrons, the damage produced by both types shows an abundance of I_C (20°K subpeak) and I_D (27°K subpeak) Frenkel pairs.

b. To maximize the possibility to observe the temperature dependence of dissociation, it is desirable that Stage II occupy a wide temperature span. For Pt, Stage II spans nearly the decade from 30 to 300°K.

c. Damage production measurements should be made on the smallest possible defect concentrations so as to maximize the retention of dissociated interstitials by impurity trapping and minimize their loss by recombination with nonpartner vacancies. In the present experiments, damage production was measured after irradiation at various temperatures, T_i , using equal doses of irradiation which produced defect concentrations less than ~ 0.25 ppm above 30°K.

d. Since it is believed that more than one type of impurity is present, the active trap concentration in Stage II is temperature dependent. To minimize the influence of a possibly widely varying active trap concentration on the retention of dissociated interstitials, measurements were made after a postirradiation anneal at a parametric temperature, T_A , greater than the variable irradiation temperatures, T_i . In this manner, the retention of free interstitials (and their partner vacancies) derived from pair dissociation during irradiation at several temperatures $T_i < T_A$ can be studied using a constant active trap concentration characteristic of T_A (T_A traps). It is recognized that during irradiation at T_i some free interstitials may be retained at traps active between T_i and T_A . The post-irradiation anneal at T_A , however, serves the purpose of detrapping those interstitials so that only T_A traps participate in their retention.

e. After each two-step procedure of irradiating at T_i and annealing at T_A , it is desirable to restore the specimens to their preirradiation

condition in preparation for repeating the procedure with a new value of T_i . Efforts to accomplish this were made using a third step where the samples were annealed at temperatures greater than T_A (thermal neutron sample: 750°K; fission neutron sample: 436°K). Although these treatments did not produce precise restoration of the postirradiation resistivity, ρ_0 , the sequence of T_i values used in the experiment revealed that the influence of the small residue changes in ρ_0 on the results was not only small but predictable, allowing accurate corrections to be made.

3. Results

Figure 2 shows the results obtained for thermal neutron damage. It can be noted that all values of T_A produced a family of curves which is internally consistent throughout the Stage II temperature range. For $T_A = 418^\circ\text{K}$, however, the growth of damage resistance above $T_i = 30^\circ\text{K}$ is some factors smaller than for other T_A values. This is related to the fact that 418°K is above Stage II. It can also be seen in Fig. 2 that for $T_A = 300^\circ\text{K}$ the retained damage increases nearly a factor of two for irradiation temperatures between 23 - 230°K.

Figure 3 shows similarly obtained results for fission neutron damage which is produced by primary knock-ons having mean energies of 20 keV compared to the thermal neutron recoils of 70 eV. In striking contrast to the thermal neutron results, the damage retained in the fission neutron case shows no increase over the Stage II temperature range. This result suggests that the paired interstitials which dissociate during fission neutron irradiations at T_i are unable to reach traps where they can be retained. It can then be concluded that the dissociated interstitials

recombine with nonpartner vacancies. This can occur if the damage produced by the fission neutrons can be described by the usual picture of a displacement cascade having a vacancy-rich interior at relatively high concentration and outlying interstitials comprising the boundaries. If the close and correlated pairs which dissociate during irradiation are located within the vacancy-rich core, then they can easily recombine with nonpartner vacancies leaving no chance to escape the cascade and find an impurity at which they could be retained by trapping.

It is presently believed that the results of these experiments do not make a distinction between the well-known one- and two-interstitial models. The dissociation of pairs and the subsequent trapping of interstitials is imagined to occur with either the crowdion or dumbbell types. If conversion of the crowdion occurs athermally at the time of trapping, the action would not be seen by this experiment.

List of Figure Captions

- Figure 1 Isochronal recovery rates of damage produced by fluences of 1.5×10^{17} thermal and 3.2×10^{15} fission neutrons/cm².
- Figure 2 Damage resistivity remaining in Pt after irradiation at T_i and anneal at T_A for equal thermal neutron doses of 6.4×10^{16} n/cm².
- Figure 3 Damage resistivity remaining in Pt after irradiation at T_i and anneal at T_A for equal fission neutron doses of 3.2×10^{15} n/cm².

List of References

- [1] R. R. Coltman, Jr., C. E. Klabunde, J. K. Redman, and A. L. Southern,
Phys. Rev. Lett. 26, 131 (1971).
- [2] K. Schroeder and K. Dettmann, Z. Phys. B 22, 343 (1975).

FIG. 1

FIG. 2

FIG. 3

Damage Resistivity Remaining After Irradiation at T_I and Anneal at T_A .