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On the Presence of Depleted Zones in Platinum*

M. J. Attardo
Brookhaven National Laboratory
Upton, New York

and

J. M. Galligan
Columbia University
New York, New York

MASTER

In the bombardment of materials with heavy particles a large amount of energy can be deposited in a very small region by a primary knock-on atom and the local atomic arrangement can be thereby drastically disrupted.⁽¹⁾ Various measurements of physical properties of such irradiated materials indicate the presence of distributions of defects which are removed in a step-like manner by annealing.⁽²⁾ One of the more interesting physical property changes accompanying fast particle irradiation is the attendant change in mechanical properties of irradiated crystals.^(3,4) The defect which is responsible for the mechanical property changes of irradiated crystals is only removed at high temperatures, temperatures corresponding to self diffusion.⁽⁴⁾ This observation, as well as others, has led to the model of a depleted zone⁽⁵⁾ as being responsible for the changes of mechanical properties of irradiated crystals. A depleted zone is envisioned as a region of crystal where a high local concentration of point defects exists - a belt of interstitials surrounding a multiply connected complex of vacancy clusters.⁽⁵⁾ We would like to present here some evidence which lends support to the existence of such defects.

The experimental technique used to directly observe the irradiated material was field ion microscopy, which has been extensively described elsewhere.⁽⁶⁾ The

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irradiated platinum (99.999% pure) was annealed prior to irradiation at 1300°C by resistively heating in vacuo of $<10^{-7}$ torr. This material was examined, prior to irradiation, in a field ion microscope⁽⁷⁾ operated at 4.2°K in order to characterize the material. The annealed wire was then irradiated to an integrated neutron flux of 1×10^{18} nvt ($E > 1.4$ Mev), and this wire examined in the field ion microscope. Repeated examination of such irradiated materials revealed the presence of large disturbances of the lattice which are apparently introduced by isolated damage events. A micrograph of one is shown in Fig. 1.

As stated above a large number of specimens, in the unirradiated condition, were examined to characterize the material. From these examinations it can be stated that no such disturbances of the atomic arrangement are observed in well annealed platinum. Furthermore, the specific effect of impurities⁽⁶⁾ as well as other damage products⁽⁸⁾ have been previously observed, and they are distinctively different from those reported here.

We would like to present two other pieces of evidence that indicate that these disturbances of the regularity of the lattice are strikingly similar to Seeger's depleted zone.⁽⁵⁾ Firstly, by careful field evaporation of one atomic layer at a time, the spatial distribution of a disturbed region could be mapped out, Fig. 2, from which it can be seen that we are dealing with a multiply connected region in the crystal. This is quite similar to the computer simulated damage distribution calculated by Beeler.⁽⁹⁾ Secondly, the examination of a large number of irradiated specimens allowed us to establish a density for such disturbed regions in order to compare the results with the density predicted theoretically. This calculation predicts $\sim 5 \times 10^{16}$ disturbed regions/cm³,⁽¹⁰⁾ while our measured density is approximately 6×10^{15} disturbed regions/cm³.

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Another interesting aspect of these observations is the detailed shape of the depleted zones in the irradiated platinum. The shapes of a few individual disturbed regions were specifically examined, by field evaporation, to determine if the disturbed region had any characteristic anisotropy of shape. Within the limits of the field evaporation technique no such anisotropy of shape was observed. The exterior shape of the zone was generally found to be highly irregular and the volume constituting the zone was found to be multiply connected. This is roughly what one expects from the depleted zone model.

Finally, in Fig. 3, we present a measured size distribution of disturbed regions in the irradiated platinum. As shown there is a smooth decrease in the number of disturbed regions with increasing size of the disturbed region. In the measurements of the size of any individual disturbed region, the maximum size was obtained from field evaporation through the whole disturbed region. The maximum size we have used is the largest diameter across the disturbed region being measured.

From this measurement an additional argument can be made. It is expected that the energy distribution of the neutrons used in this experiment (the Brookhaven Graphite reactor - hole E7) would approximate a $1/E$ distribution of neutron fission spectrum. If we, accordingly, assume that the volume of the cluster is proportional to the energy of the neutrons used we should get a linear plot of the number of disturbed regions versus $1/\text{volume}$. This is shown in Fig. 3b.

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FIGURE CAPTIONS

- Fig. 1 - Micrograph of a disturbed region in Pt irradiated to 10^{18} nvt,
E>1.4 Mev.
- Fig. 2 - The spatial distribution of defects in a disturbed region in irradiated Pt.
- Fig. 3a - Measured size distribution of disturbed regions in Pt.
- Fig. 3b - Plot of number of disturbed regions vs reciprocal of the volume of the region.

SPATIAL DISTRIBUTION OF LATTICE
DEFECTS IN A DISTURBED REGION

○ VACANCY
□ INTERSTITIAL

FIGURE 2

PLOT SHOWING RECIPROCAL RELATION BETWEEN
SIZE OF DISTURBED REGIONS AND THEIR FREQUENCY
OF OCCURRENCE

OBSERVED SIZE DISTRIBUTION OF DISTURBED REGIONS
IN PLATINUM IRRADIATED TO 10^{18} nvt, $E > 1.4$ MeV