C00-1053-15
MASTER

Northwestern University

Evanston, Illinois

October 9, 1970

FINAL REPORT

June 15, 1958 to August 31, 1970

U.S. Atomic Energy Commission

Division of Research

Metallurgy and Materials Program

Contract AT (11-1) - 1053, formerly AT (11-1) - 89 Project 15

RADIATION EFFECTS OF ION BOMBARDMENT

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SUMMARY

Positive ion bombardment is an extremely useful technique for studying radiation effects due to displaced atoms. With simple equipment it is possible to duplicate the flux of knocked on atoms produced by fast neutrons in a reactor. The energies of the knocked on atoms can be easily controlled and furthermore the damage rate can be made a million times larger than the damage rate in a reactor if desired. Although the positive ion bombardment effects are confined to a thin surface layer, a variety of techniques are available to measure changes in physical properties.

The first experiments on this project verified the expected relationship between positive ion bombardment and fast neutron bombardment using the optical reflectivity of bombarded surfaces to detect the radiation effects. Similar techniques were then used to obtain ion ranges and to study the effects of positive ion bombardment on diffusion.

With the development of techniques for preparing thin crystals (10A to 10,000 A° thick), it became possible to directly measure the transmission of ions in the energy region of interest (5 to 50 kev). This led to a number of papers on the channeling of different ions in different materials and the determination of critical angles and energy losses for channeled ions at low energies. This phase of the work was greatly facilitated by the acquisition of an electron microscope which made it possible to directly determine the perfection of the required thin foils.

Individual imperfection clusters created by the ion impacts are easily seen with the electron microscope. By using special viewing techniques it has been possible to verify the expected one to one relationship between ion impacts and imperfection clusters and to show that the ion energy required to produce a visible imperfection cluster is lower than previously reported.

During this contract, numerous visits were made to the AEC laboratories at Argonne, Brookhaven and Oak Ridge. The research has been reported at a number of colloquia at numerous laboratories and universities and at talks at conferences. It is worth noting that when this contract was initiated, there were no other current investigations of the relationship between ion bombardment and radiation effects. Now there are numerous investigations in this area under way at many universities and atomic energy laboratories throughout the world. If this contract has partially stimulated the current interest in ion bombardment effects, it has accomplished more than the specific objectives of the individual research projects.

TECHNICAL COMMENTS AND REPRINTS

The research on this project can be grouped into the seven areas listed below as headings in the list of publications resulting from this contract. For each of the areas some technical comments have been prepared to give the relationships between the various papers and to present some unpublished observations. A complete set of reprints or Xerox copies of reprints is included. The pages in this report are numbered consecutively but to avoid confusion, the report page numbers are not put on the reprint pages.

ION BOMBARDMENT OF QUARTZ

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Radiation Effects of Bombardment of Quartz and Vitreous Silica by 7.5 to 50 kev Positive Ions. R.L. Hines and R. Arndt, Phys. Rev. 119, 623 (1960)

The Importance of Thermal Spikes Produced in Quartz and Vitreous Silica. R.L. Hines and R. Arndt, Bull. Am. Phys. Soc. II-4, 158 (1959).

Sputtering of Vitreous Silica by 20 to 60 kev Xe^+ Ions. R.L. Hines and R. Wallor. J. Appl. Phys. 32, 202 (1961).

ION BOMBARDMENT EFFECTS ON DIFFUSION

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Radiation Inhibited Diffusion in Brass. R. Arndt and R.L. Hines, Bull. Am. Phys. Soc. II-5, 147 (1960).

Radiation Enhancement of Bulk Diffusion in 10% $\bar{\text{Zn}}$ - 90% Cu by 30 kev Ne^+ Ion Bombardment. R.A. Arndt and R.L. Hines, J. Appl. Phys. 32, 1913 (1961).

Radiation Effects on Diffusion of Zinc in Brass. R.A. Arndt, Ph. D. Thesis, Northwestern University (1961).

ION RANGES

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Ranges of 7.5 to 52 kev H_2^+ , D_2^+ , He^+ and Ne^+ Ions in Quartz. R.L. Hines, Phys. Rev. 120, 1626 (1960).

Ranges of 5 to 27 kev Deuterons in Aluminum, Copper and Gold. R.L. Hines, Phy. Rev. 132, 701 (1963).

ION BOMBARDMENT OF DIAMOND

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Radiation Damage of Diamond by 20 kev Carbon Ions. R.L. Hines, Phys. Rev. 138., A1747 (1965).

ION BOMBARDMENT EFFECTS ON RESISTIVITY

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ION TRAJECTORIES IN CRYSTALS

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Channeling of 13 kev D^+ Ions in Gold Crystals. C.J. Andreen, R.L. Hines, W. Morris and D. Weber, Phys. Lett. 19, 116 (1965).

Channeling of D^+ and He^+ Ions in Gold Crystals. C.J. Andreen and R.L. Hines, Phys. Rev. 151, 341 (1966).

A Simple Transparency Model for the Channeling of Low Energy Light Ions in Crystals. C.J. Andreen, Arkiv Fysik 35, 563 (1968).

Blocking of D^+ Ions in Single Crystal Gold Films. C.J. Andreen, Arkiv Fysik 35, 595 (1968).

Direct Observation of Channeling in bcc Iron Films. C.J. Andreen, E.F. Wassermann and R.L. Hines, Phys. Rev. Lett. 16, 782 (1966).

Experiments on the Transmission of Low Energy Light Ions through Thin Films of Different Structures. C.J. Andreen, Arkiv Fysik 35, 583 (1968).

Critical Angles for Channeling of H^+ , D^+ and He^+ Ions in Single Crystal Gold Films in the Energy Interval 1-17 kev. C.J. Andreen and R.L. Hines, Phys. Lett. 24A, 118 (1967).

Critical Angles for Channeling of Low Energy Ions in Gold Crystals. R.L. Hines and C.J. Andreen, Bull. Am. Phys. Soc. II-12, 391 (1967).

Critical Angles for Channeling of 1 to 25 kev H^+ , D^+ and He^+ Ions in Gold Crystals. C.J. Andreen and R.L. Hines, Phys. Rev. 159, 285 (1967).

On the Motion of Low Energy Light Ions in Thin Single Crystal Films. C.J. Andreen, Doktorsavhandlingar, Chalmers Tekniska Hogskola, Sweden (1967).

Energy Losses of Channeled D^+ Ions in Gold Crystal Foils from 16 kev to 30 kev.

R. Eldros and R.L. Hines, Bull. Am. Phys. Soc. II-13, 402 (1968).

Relative Energy Losses of Channeled D^+ Ions in Gold. R.L. Hines, Phys. Let. submitted.

ION IMPACT CLUSTERS IN GOLD

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Irradiation Cascade Threshold Energy in Gold. D.E. Weber and R.L. Hines, Proceedings Twenty-eighth Annual Meeting Electron Microscope Society of America, Claitor's Publishing Division, Baton Rouge (1970) to appear.

Electron Microscope Study of Heavy Ion Irradiation Damage of Thin Gold Film.

D.E. Weber, Ph. D. Thesis, Northwestern University (1970).

ION BOMBARDMENT OF QUARTZ

The major objective during the early stages of this research was to establish the value of ion bombardment for studying radiation damage. Preliminary experiments on the bombardment of glass established the presence of observable changes, but the results were difficult to interpret because of the complex chemical and molecular nature of glass. Quartz was an obvious choice for a simpler material and also its behavior under radiation damage from fast neutrons had been studied. The radiation damage in quartz did proceed as expected and is described in the paper "Radiation Effects of Bombardment of Quartz and Vitreous Silica by 7.5 kev to 50 kev Positive Ions."

At the time of these experiments there was considerable speculation that the changes in quartz might be due to high local temperatures produced by the individual knocked-on atoms. With the techniques used in these experiments it was possible to determine the volume affected by the individual knocked-on atoms and consequently estimate the maximum temperature increase in a thermal spike. These results were presented in the paper described by the abstract "The Importance of Thermal Spikes Produced in Quartz and Vitreous Silica".

One question which arose during these experiments concerned the sputtering rates of quartz under ion bombardment. No information was available so a brief investigation was carried out to obtain approximate sputtering ratios. The method employed utilized the volume measurement of a sputtered crater by means of interference fringes. The results are reported in the paper "Sputtering of Vitreous Silica by 20 to 60 kev Xe^+ Ions." It is interesting to note that the sputtered quartz surface retains its optical polish in contrast to a metal surface which quickly loses its polish. Consequently a controlled ion beam can be used to correct a high quality lens while the lens is being tested. The principal investigator was contacted by an engineer from the Perkin

Elmer company concerning the ion polishing of quartz and glass and it is believed that a complete ion polishing system has since been developed.