Ion Implantation Science and Technology

Edited by

J. F. Ziegler

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Preface

Ion implantation is the major technology used to introduce impurities into solids in a uniform and reliable way. Its primary application is in the semiconductor industry where it is usually the technique of choice for the electrical doping of semiconductors.

This book is a tutorial presentation of the science, techniques, and machines of ion implantation. Its purpose is both to introduce this complex field in a simple way, and to act as a reference work which can lead to the thousands of scientific papers of the field. For this purpose there is an extensive index, and each chapter lists excellent review papers on specialized subjects.

The first section of this book concerns the science of ion implantation. It covers the historical development of the field, and the basic theory of energetic ion penetration of solids. The major concentration of this section is to explain the nature of the creation of damage in crystalline silicon during ion implantation, and the methods which can be used to recover the original crystallinity. Especially helpful are the TEM photographs scattered throughout this section which show the many phases of the morphology of ion implantation damage. Methods are described which allow the quantitative evaluation of the success of the implantation and the recovery of the semiconductor.

The last half of this book describes the ion accelerators (implanters) used in ion implantation, with a detailed presentation of the major components which require maintenance. A large part of this section concerns the methods of quantitatively evaluating the performance of ion implanters. A chapter is devoted to the extensive safety hazards of implanters and methods to maintain safe operation.

J. F. ZIEGLER

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THE HISTORICAL DEVELOPMENT OF ION IMPLANTATION

Lienhard Wegmann

Balzers AG, Balzers
Principality of Liechtenstein

I. DEFINITION AND TYPES OF ION IMPLANTERS

Ion implantation is a very broad topic and very common in nature. We want to restrict our historical survey to the physical aspect and to artificially induced implantation of ions. It seems that this was first done by Rutherford (06) in 1906, when he bombarded aluminium foil with α - particles, in our language doubly charged positive helium ions. The first ion implanters were therefore simple glass tubes containing the radioactive radon, as described by Rutherford and Roydes in 1909 (Fig. 1). They produced a shower of α - particles. (Rutherford however was not interested in how the structure of the aluminium foil changed, but rather how the α- particles were scattered).

As another type of ion implanter we have to consider any <u>gas discharge equipment</u> which causes a bombardment of a target by accelerated ions (Fig. 2).

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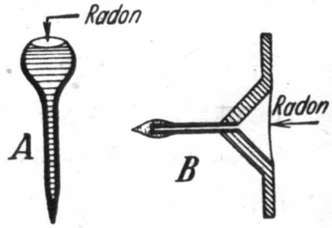

Fig. 1. Rutherfords "Ion Implanter", 1909, an α- particle emitting Radon source. H. Geiger (33).

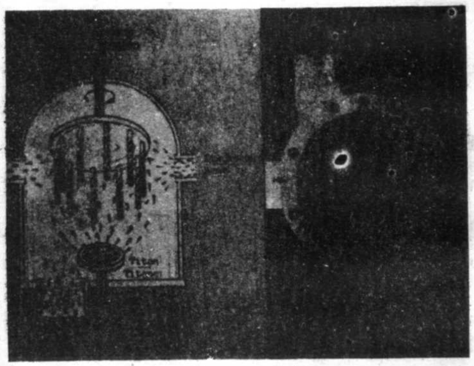

Fig. 2. Ion plating. Machine tools are coated in a gas discharge with a hard titanium nitride layer. At the left the principle, at the right the installation (Balzers).

By convention this technique is not called ion implantation, but ion plating or physical vapour deposition. This is because the deposition effect exceeds the implantation effect due to the low energy of the ions and the high doses, and the size of the target is

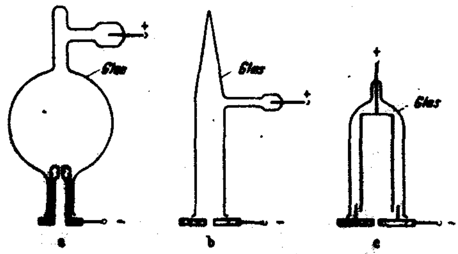

Fig. 3. Early types of canal ray tubes, D. Kamke (56).

changed, which is not the case in ion implantation. Ion plating produces very hard metallic or ceramic surface layers for machine tools, dental instruments or watch cases and the market for it is growing very rapidly.

Another type of ion implanters is the ion source producing a focused ion beam. This beam has a certain energy due to the necessity of an extraction voltage. The ion source was invented in the early thirties in the form of the canal ray tube (Fig. 3). One of the first users was again Rutherford. The ion source implanter today is used for producing solar cells, where an analysis of the beam is not necessary and all the ions produced by the source are implanted together. An installation made by Siffert at the Centre de Recherches Nucleaires at Strasbourg (Fig. 4) produces solar cells by implanting all the ions delivered by a source fed with BF_3 gas, i.e. B^+, F^+, BF^+, BF_2^+ and impurities. This installation works with silicon strips and carries out sputter cleaning, ion implanta-

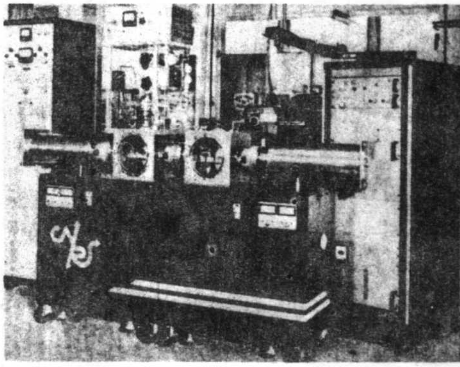

Fig. 4 Production prototype for solar cells with ion implantation at the Centre de Recherches Necleaires, Strasbourg, France 1979 (P. Siffert).

tion, annealing and drive-in as well as contacting, all in one flow.

Gas discharges and ion sources normally work at energies up to 5 keV, which gives the very low penetration depth or "projected range" of up to only 100 Angströms. For producing deeper penetration another type of ion implanter uses an ion source followed by an accelerator. Typical acceleration voltages are 40 to 400 keV and allow projected ranges up to 1 micrometer. Today this kind of ion implanter is used for ion implantation in metals. In many cases separation of the different ions is not necessary for producing hard, wear resistant or corrosion resistant surfaces. The design of such metallurgical implanters is quite simple. The sophisticated part of this kind of machines lies in the handling of the complicated shaped target, which

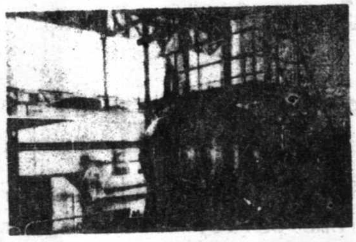

Fig. 5. Prototype of an ion implanter for metals at Harwell, 1978 (G. Dearnaley).

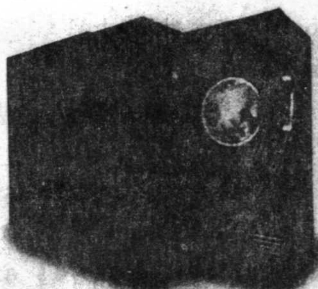

Fig. 6. Zymet's modern metallurgical implanter (A. Wittkower).

must be turned in all directions under the ion beam. An example of one of the first metallurgical implanters is the installation constructed by Dearnaley at Harwell (Fig. 5). Fig. 6 shows a modern ion implanter for surface treatment.

II. ION IMPLANTERS FOR SEMICONDUCTORS

All these types of implanters generally are not suited for implanting semiconductor devices. The flat shape of the wafers is indeed advantageous. But because of the extreme purity of the basic material (as for example silicon single cristals) and its sensitivity to dopants and the penetration depth, we need an implanter which is able to produce

- one ion species at
- one energy and
- one precise dose over the whole wafer and from wafer to wafer.

This needs an ion beam with separation of the different ion species, with acceleration, with a scanning system, which distributes the beam homogeneously over the whole wafer and, precise measurement of the implanted dose is also needed.

We will now restrict our historical review to the type of ion implanter suited for producing semiconductor devices and we will start with the beginning of this technology. Ion bombardment of semiconductors had been reported since 1948, but no operative device was produced.

The first successful ion implantation in semiconductors doubtlessly took place in 1954, when (after similar works of W.G. Cussins in 1953 at Cambridge, UK) Shockley (54) took out his patent for "forming semiconductive devices by ionic bombardment " (Fig. 7). Amazingly, the main innovation claimed in this

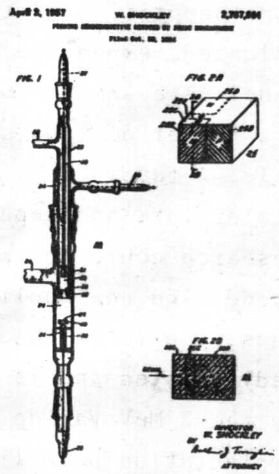

Fig. 7. First page of the basic patent of Shockley (54).

patent is not the ion bombardment, which was known, but the newly introduced step of annealing after implantation. It remains a typical attribute of ion implantation that its success depends largely on factors which have nothing to do with the actual ion implantation equipment.

Yet within the same patent, Shockley also defines the necessary equipment for the ion implantation step. His own apparatus was very simple and could neither separate nor scan (nevertheless Shockley was able to produce a junction!). But in a very fundamental manner he mentioned nearly all the possible techniques: mass separation, electrical and mechanical scanning systems, the writing beam implanter and the mask projection implanter.