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DEEP ION IMPLANTATION: ADVANTAGES AND CURRENT PROBLEMS

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I. INTRODUCTION

The ion implantation method of treating and analysis of solids, mainly in order to achieve some desirable modification of their properties, has a long history [1]. But in the beginning only low energy ion beams, from several keV to several hundred of keV, were using for this purpose. The main reason was that it is rather not so difficult and expensive to construct an equipment producing beams of large enough intensity of such ions. Meanwhile, current needs and arising new problems caused that during about last ten years and even earlier ion beams of much higher energy, up to several MeV/u, are also widely used. With the help of such ions it turned out to solve a variety of important problems having practical and cognitive meaning. So, swift heavy ions (SHI) are, in particular, commonly applied for modelling an influence of neutrons on different materials used in nuclear plants and exposed to radiation because this way the time of accumulation of required doses of damages in these materials is shorter by a factor of 10^3 - 10^6 as compared to the time of exposition to neutron beams. Moreover, the samples irradiated with heavy ions are much less radioactive ones. Another way of wide application of energetic ions is for the production of spatial structures in semiconductors and they have also shown to be a unique tool for the creation of nuclear filters. The aim of the article is a short and concise overview of current problems and selected applications of SHIs.

II. ADVANTAGES OF SWIFT HEAVY IONS APPLICATION

High energy heavy ions used for treating different materials have, besides some similarity, many remarkable advantages over the ions of traditional implantation energy range. The most important of them may be briefly listed as follows:

1. Projected ranges of such ions in irradiated materials exceed ~10 mm and so make possible to avoid an influence of surface effects of flowing down of point defects and, as a consequence, to consider the relevant implanted layers as macroscopic buried metastable structures. So, for example, the projected range of $^{12}C^{2+}$ ions of energy of 8.25 MeV/u in iron and silicon are equal to 70.1 and 185.0 μm respectively, whereas the similar ranges for $^{84}Kr^{7+}$ equal 11.1 and 27.4 μm.
2. New created buried layers have, as a rule, different electric, optical, thermal, chemical etc. properties then substrate materials.
3. As a result of intense enough energy deposition in an implanted layer the process of (re)crystallisation may there occur much easier creating this way required spatial configurations having expected properties (for example, [2]).
4. At high energies of ions their inelastic ionisation losses exceed the elastic ones, i.e. $(dE/dx)_{inel.} > (dE/dx)_{el.}$, which changes the process of accumulation and evolution of defects during implantation, especially in the case of

dielectric and semiconductor materials when the lifetime of local overheating around „tracks" may turn out to be sufficient in order to stimulate processes of diffusion and recristallization.

5. For some problems high energy ions proved to be a unique toll, for example, for modelling a spectrum of cosmic rays which produce damages in electronic devices and living tissues exposed to high energy radiation in different space programmes of investigation [2].

6. Such ions cause considerably less damages of the surface layers of implanted solids than ions of much lower energy do.

7. As the energy losses of heavy ions on excitation of electronic subsystems of a substrate material reach their maximum value at the energy of these ions around ~1 MeV/u a direct observation „in-situ"of such a way increased luminescence make possible to investigate in more detail the process of evolution of defected structure of irradiated materials [3].

III. WHAT CAN BE DONE WITH SWIFT IONS?

Owing to the above listed advantages of swift heavy ions application one can outline briefly the main trends in the relevant investigations:

1. Modification of characteristics (electric, optical, thermal, chemical etc.) of materials themselves (i.e. not only their surfaces).
2. Change of diffusion processes in materials.
3. Purification, passivation, hardening and radiation resistance increasing of materials.
4. Modelling of some (physical, chemical, biologic) properties of materials and complex structures.

IV. SOME EXAMPLES

Below we present a few of examples illustrating a usefulness of various application of swift heavy ions. Of course, they do not exhaust all the diversity of the use of deep ion implantation. For more information in the field we refer the reader to wide current literature and, in particular, to [2] and GSI Scientific Annual Reports.

1. Modification of temperature dependence of manganin resistance [4]

Manganin is commonly used as a convenient pressure gauge within the large range of values above about 100 MPa owing to the linear dependence of its electric resistance on pressure. Nevertheless, the manganin resistance reveals acceptable weak temperature dependence within too narrow temperature interval only what may cause some systematic errors, difficult to be allowed for. So, attempts have been made to widen this interval using ion implantation techniques and some promising results were obtained so far at comparatively rather low doses of Ar and Xe ions, equivalent to the implanted

ion concentration of about 10^{18} cm^{-3} within the layers of thickness of 0.25 and 0.34 μm, respectively [5].

2. Observation of diffusion through latent tracks [6]

In order to increase the diffusion constant D_{Ar} of argon gas through polymer foils the authors of [6] irradiated stack of Makrofol KG foils, each consisting with 5 layers of 30 μm, with uranium ions of 11.4 MeV/u, perpendicularly to the surface. The fluence was between $3 \cdot 10^{10}$ and $5 \cdot 10^{11}$ ions/cm^2. The results of measurement of the diffusion of argon through all foils at 21°C is shown in Fig.1 as a function of ion range R. Quoted are there the relevant calculation of energy loss of such ions vs. R. It is clearly seen from the figure that D_{Ar} rapidly increases with increasing R, at least up to R≅100 μm.

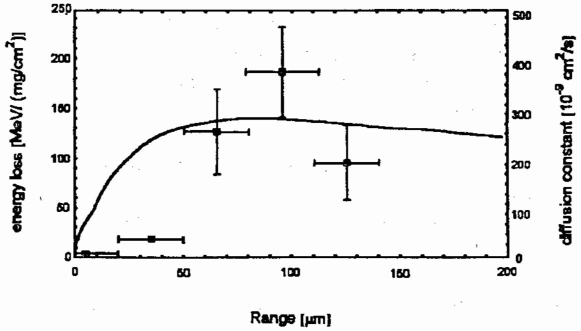

Fig. 1 . The diffusion constants of one stack irradiated with $5 \cdot 10^{11}$ ions/cm² uranium ions. The theoretical energy loss by TRIM [4] is shown by the solid line. [6]

3. Defect evolution in nanostructured materials [7]

In order for searching for enhanced radiation resistance materials the authors of [7] have studied the correlation between defect density and the grain size of nanocrystalline Pb and ZrO_2 with different initial grain sizes from 10 to 300 nm. They irradiated these materials using 4 MeV Kr ions with fluences from $1 \cdot 10^{15}$ to $2 \cdot 10^{16}$ Kr/cm^2 . The results for ZrO_2 are shown in Fig.2. One can see that at about 100 nm of grain size a saturation in the defect density occurs for ZrO_2. Similar investigation for nanocrystalline Pb demonstrated quite a linear dependence between defect density and grain size [7]. The conclusion of the authors of [7] is that both nanocrystalline Pb and ZrO_2 show enhanced radiation resistance and are suitable materials for applications in irradiation environments and space research [7].

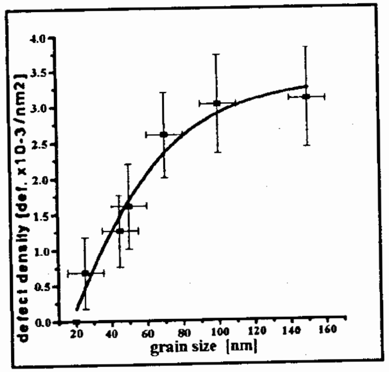

Fig.2. Correlation between measured defect density and grain size for ZrO_2 (after [7]).

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Глубокая ионная имплантация:
преимущества и актуальная проблематика

Кратко обсуждаются преимущества применения быстрых тяжелых ионов (~1 МэВ/а.е.м.) для анализа и обработки твердых тел с целью изменения их свойств. В качестве иллюстрации приведены некоторые типичные примеры.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

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Deep Ion Implantation: Advantages and Current Problems

We summarise briefly the advantages of swift heavy ions (~1 MeV/u) application to analysis and treating of solids in order to modify their properties. As an illustration some examples of this application are also quoted.

The investigation has been performed at the Laboratory of High Energies, JINR.

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