APPLICATION OF NUCLEAR PHYSICS METHODS AND NSC KIPT ACCELERATORS FOR INVESTIGATION OF SOLID COMPOSITION

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The results of application of nuclear physics methods and NSC KIPT accelerators in the fields of investigation of metals and alloys, semiconductors, oxidic metals and magnetic materials are outline. The results and potentialities of these methods for determination of concentration and distribution of micro quantities of elements and isotopes, investigation of features and properties of simplest defects are presented. The beams of (1–3) MeV hydrogen and helium ions were used. Element and isotope identification was realized by means of Rutherford backscattering, resonance nuclear reactions and incident ions induced X – ray radiation.

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1. INTRODUCTION

The works of S. Rabin published during 1949–62 are considered by the world scientist society to be first application of accelerators for analysis of substances by means of prompt radiation measurements.

In the Former Soviet Union utilization of the prompt radiation of nuclear reactions for analytical aims was firstly realized by E.V. Inopin, S.P. Tsytko (Ukraine Institute of Physics and Technology, Kharkov) and M.I. Guseva (Institute of Atomic Energy, Moscow) in 1959 [2]. These authors investigated the depth profile and distribution nature of silicon atoms implanted into copper and titanium. The resonances of 28Si(p,γ)29P reaction were used to resolve this problem.

2. METHODS AND THEIR APPLICATION

Rutherford backscattering, nuclear reactions, charged particle induced X- rays, activation analysis are systematically used at KIPT to solve science and technological problems in the field of metals and alloys [3-16], semiconductors [18-31], magnetic materials [32,33], radiation physics [21,23,24,28,33], physics of metal oxide combinations including of high – T superconductors [34,35,36], analytical chemistry, environment objects analysis.

In prompt radiation analysis the presence of an element is detected through the nuclear radiations emitted instantaneously from nuclear reactions produced in the target by the irradiating beam. One of the important advantages of prompt analysis and the backscattering techniques is that they can be used to measure the depth distribution of elements in the surface or near-surface regions of the sample. The dependence of the characteristics of the emitted radiation on depth is due to the energy loss suffered by the incident ions as they penetrate into the sample and also to the energy losses suffered by charged particles emitted from the reaction as they emerge from within the sample.

Since nuclear reaction analysis can provide essentially background-free detection of light elements, depth distributions of trace amounts within the near-surface region can de measured. The primary emphasis in our discussion of prompt radiation analysis is the determination of concentration depth profiles of trace element impurities. In the use of prompt analysis for depth profiles, two different methods are applied, namely, the energy-analysis method and the resonance method. The former is used when the cross section of a nuclear reaction is a smoothly varying function of energy. The latter method is used when a sharp peak (resonance) in the cross section as a function of energy is present, and the depth profile is derived from a measurement of the nuclear reaction yield as a function of the energy of the analyzing beam.

Widespread application of accelerators and nuclear physics methods is conditioned by possibility to determine kind, concentration and distribution of element micro quantities to research migration and diffusion mobility of these elements and their isotopes. Using orientation effects and channeling particles promotes:

– to find location of atoms implanted in to the lattice or (in the case of complicated crystals) to determine sublattice in which implanted ions are placed;

– to determine profile of distribution of implanted atoms and radiation defects created by the implantation;

– to search composition, structure, orientation, production and decay of simplest defects;

– to search mechanism and features of ion motion in well-ordered surroundings etc.

To identify elements and isotopes we used Rutherford backscattering and nuclear scattering of hydrogen and helium ions, the ion induced X-rays as well as prompt radiation of reactions are given in the following table:

Reaction	Ref.	Reaction	Ref.
$^{18}O(p,\gamma)^{19}F$	[3,4]	$^{9}Be(\alpha,n\gamma)^{12}C$	[27,2]
$^{18}O(p,\alpha)^{15}O$	[5,6,9,16]	$^{23}Na(p,\alpha)^{20}Ne$	[19]
$D(^{3}He,p)^{4}H$	[10,11]	$^{16}O(^{3}He^{4}He)^{15}O$	[31]
$^{10}B(\alpha,p)^{13}C$	[7,8]	$^{16}O(\alpha,\alpha)^{16}O$	[33]
$^{11}B(p,\alpha 1)^{8}Be$	[15,25]	$^{7}Li(p,\alpha)^{4}He$	[30]
$^{31}P(p,\alpha)^{28}S$	[18,21]	–	–

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The data of basic investigations in the fields of nuclear spectroscopy and atomic nucleus structure are precondition of these experiments.

3. METALS AND ALLOYS

During 1964-1970 the nuclear physics methods and KIPT accelerators were applied for study of zirconium oxidation and oxygen diffusion in zirconium, niobium and their alloys. To solve the problems it was proposed to use radiation of the resonance reactions (p,γ) [3,4] and (p,α) [5,6,] which occur at the interaction of incident protons with 18O isotope nuclei. The coefficients of oxygen diffusion in zirconium and niobium were determined in the wide range of temperature [7,8]. The mechanism of anion and cation transfer by oxidation process in gas and steam of the water was studied.

For the first time in the Former Soviet Union (1969) the method of composition matter analysis by proton and α-particle induced X-ray radiation was proposed in KIPT. This perspective technique which is widely used in the world at present was successfully developed due to working out and creation of semiconductor Si(Li)-detectors for X-ray spectrometers.

Qualitative new stage in application of accelerators and nuclear physics methods began since discovery of aligned effects. KIPT team was one of the first scientific groups which observed fundamental effect – redistribution of particle flux density in transverse plane of channel [9].

Using channeling protons and helium ions permited to determine location of oxygen and deuterium atoms in niobium [9,10], helium in tungsten [11], boron in tungsten [12], nitrogen in niobium and molybdenum [13,14], carbon in rhenium and nickel [15], oxygen in tantalum [16].

4. SEMICONDUCTORS

Localization of atoms of boron and phosphorus which are widely used elements in microelectronics instrument production technology was determined in silicon by channeling particle method [17,18,21]. Besides depth profiles of interstitial atoms and radiation damage silicon atoms were found [20,22,23]. Thermal stability of defects was fixed. Optimal conditions of base structure forming were determined.

The cycle of investigations of ion implanted 3A5B binary compounds (indium antimonide, indium arsenide, indium phosphide, gallium arsenide) was carried out analysing prompt radiation induced by channeling particles [24]. Data concerning localization of atoms of 1-st and 2-nd periods of the element table in 3A5B were obtained [25]. Modification of implanted atom localization caused by irradiation and annealing was fixed [26]. The regularities of forming and annealing radiation defects in implanted structures were studied. Depth profiles of implanted atoms and radiation defects were determined. The contribution of sublattices in the radiation defect production process was determined. The results of these works served as a foundation for development and optimization of basic structure technology of infrared (IR) detectors. It shown IR–detectors with optimum parameters can be made on the base of beryllium – doped indium antimonide [27,28].

5. METAL OXIDES AND MAGNETIC MATERIALS

Combination of nuclear physics methods and charged particle accelerators turned out the perspective way of investigation of composition and properties of oxidic metal compounds including high–Tc superconductor ones [30]. It was carried out the cycle of works for the sake of optimization of making technology of La2-xSrxCuO4 and Nd2-xCexCuO4 crystals [31]. The crystal structure modification was investigated depending on furnace charge and agglomeration conditions. It was shown oxide sublattice has larger radiation destruction rate in comparison with cation one. The diffusion coefficients of oxygen to YBa2Cu3O7-y were determined [32].

Application nuclear physics methods and accelerators for investigation of properties of ferrite oxide metal compounds, which are used in magneto–optics, computer engineering and quantum electronics is essentially only started now. Tl4+ and Tl3+ ions in the corund crystal lattice are shown to be placed in tetrahedral interstitial space and interstitial space which is shifted along the <0001> direction of the aluminum sublattice [29]. There was found the localization of the boron and nitrogen atoms in the ferrogarnet film lattice. The implanted alloy ion distribution and distribution of radiation defects created by the ions were determined [33].

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