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XRF WITH A PRIMARY X-RAYS FROM THE TARGET WITH MONOISOTOPICAL SURFACE LAYER

V. Levenets, O. Omelnik, A. Shchur
National Science Center "Kharkov Institute of Physic and Technology", Kharkov, Ukraine
E-mail: levenets@kipt.kharkov.ua

The development is presented of X-Rays fluorescence analysis using as primary source proton induced X-Rays emission. It is offered to make primary target as double-layer using as the backing natural intermixture of isotopes, and as the upper layer – an isotope with the highest threshold of (p,n)-reaction for given element. Such target allows to reach lower detection limits by decreasing of background γ-emission from (p,n)-reactions. The making of target from copper, nickel, zirconium, and molybdenum are discussed. The presented approach has been used for elemental analysis of the samples of zirconium compounds and alloys, soils, plants and sediments.

INTRODUCTION

Nuclear-physical methods of analysis of substances elemental content using charged particles beams from electrostatic accelerators are applied to the solution of the number of analytical problems from metallurgy up to medicine and ecology. The methods using charged particles, elastic scattering under back angles (RBS), charged particles and γ-emission from nuclear reactions (NRA), charged particles induced characteristic X-Rays emission (PIXE) are most spread. This methods use for initiation of analytical radiation immediately beams of particles, but indirect mechanism of excitation are mostly available for solution of some problems. In particular, PIXE induced XRF, using a suitable target-converter as primary fluorescence source may be applied to analyze the samples without sufficient heat and radiation damages [1, 2]. A similar indirect mechanism of excitation X-Rays emission was used in the presented work. The method based on the excitation of a secondary X-Rays fluorescence by a characteristic X-Rays from a target-converter for analysis of ZrF_4, HfF_4, and $ZrCl_4$ is presented and the possibility to reduce a contribution to background component of the continuum bremsstrahlung radiation and gamma emission from nuclear reactions are also considered.

METHOD

The scheme of analysis using PIXE induced XRF is shown on Fig. 1. The set-up includes charged particles accelerator – 1, a primary target – 2, the analyzed sample – 3 and X-Rays detector – 4.

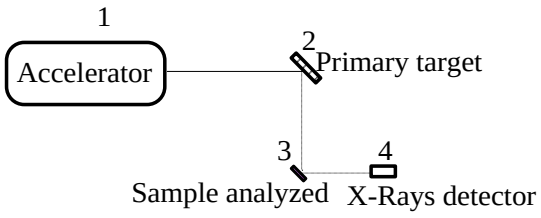

Fig. 1. The set-up for PIXE induced XRF analysis

As the material for a target-converter the element is selected on such a way that characteristic X-Rays have energy, sufficient to excite fluorescence radiation of elements of interest in the sample. The experimental set-up of the technique works as follows. A primary X-Rays emission is generated under irradiation of a target-converter by the charged particle beam, for example protons. This primary emission is used to induce in the analyzed sample secondary fluorescence X-Rays, which are the registered by the detector.

Together with characteristic X-Ray radiation the bremsstrahlung radiation and γ-radiation from nuclear reactions are induced due to interaction of protons with a target-converter matter. The (p,n)-reactions inducing neutrons give basic contribution in this background. The relation between intensity of characteristic and background emission, finally, defines limit of detection. At increasing of protons energy the intensity of characteristic X-Rays of target-converter increases proportionally to 3…4 power of energy and bremsstrahlung radiation intensity increases too. Intensity of a background radiation due to the contribution of γ-radiation from nuclear reactions at proton energies below a threshold for nuclear reactions (p,n)-type is negligible small, and at energies above a threshold this quantity increases sharply and gives basic contribution to the background.

As a result of nuclear reactions γ-quanta with energies from some tens keV up to several MeV, and also particles are emitted. This primary radiation as result of its scattering in the converter, the sample and details of accelerator produces continuous background of electromagnetic radiation, including that with energy in the range of a characteristic X-Rays emission of K- and L-series of analyzed elements in the sample. The threshold energies for nuclear reactions are different for various isotopes of the same element. Therefore the converter is made from isotope with highest thresholds. To preferential cost of target it can be made as a double-layer. Thus thickness of the monoisotopical layer must be chosen such that it is sufficient for decreasing of energy of charged particles up to quantity below a threshold of nuclear reaction (p,n)-type for a material of the second layer. The second layer may be made from the chemical element chosen for a primary target with natural isotopic content. The scheme of a double-layer primary target is given on Fig. 2, where 5 denotes the first monoisotopical layer of primary target and 6 – the backing made from substance with a natural isotopic composition.

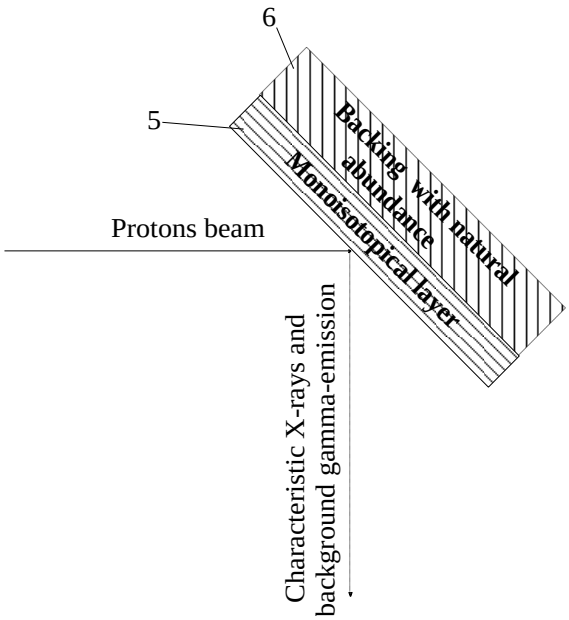

Fig. 2. Scheme of a primary target

EXPERIMENT

Let's view a case with proton energies 2, 3, and 4 MeV and a target-converter, made from copper, with natural isotopic composition containing 69.1% of isotope ^{63}Cu and 30.9% of isotope ^{65}Cu. Thresholds of (p,n)-type reactions for isotopes ^{63}Cu and ^{65}Cu are equal to 4.1 and 2.1 MeV accordingly. Clearly, at energy of protons 2 MeV it is possible to use copper in a natural isotopic composition, but for 3 and 4 MeV it is letter to use isotope ^{63}Cu. Whereas ranges of protons with energies of 2.1, 3 and 4 MeV in copper are equal 19.75, 34.23 and 53.96 μm (SRIM 2006), thickness of a target-converter from isotope ^{63}Cu should be not less than 16 μm for protons with energy 3 MeV and 35 μm for protons with energy 4 MeV. If available accelerator can provide higher energies of protons, and magnitude of energy of primary X-Rays is not so critical, what is valid for the majority of practical problems, it is possible to use a target-converter made of isotopes of nickel, ^{58}Ni and ^{60}Ni, with nickel abundances of 67.9 and 26.2%, and with thresholds for (p,n)-reactions 9.3 and 6.9 MeV.

Let energy of primary X-Rays in the range of 15...18 keV is required for the analysis. This energy diapason corresponds to X-Rays K-serie elements Zr and Mo, and it is preferable to make the target-converter from the isotopes ^{90}Zr, ^{92}Mo or ^{94}Mo. The choice of an isotope for the upper layer of the converter is similar featured above. Thickness of the upper layer is chosen such that energy of protons on an exit from it was less than the threshold energy of (p,n)-reaction for isotopes in the inferior layer, and thus interaction of protons with a material of the inferior layer, is similar to interaction with a material of the upper layer, i. e. there is low probably for nuclear reactions. The required thicknesses of the upper monoisotopical layer may be up to some tens microns on the average and they change for discussed above elements of target-converter in dependence on choice of element and energy of protons. Thickness of the inferior layer which is made from a material of a natural isotopic composition, must be chosen such that to provide sufficient hardness of target-converter.

The set of converters enumerated above, allows to carry out determination of elements in a range up to $Z = 39$ on K-series, and elements with $Z > 50$ on L-series. The offered approach has been used by authors for determination of elements from Ca to Mo, hafnium, tungsten and lead in samples of zirconium and hafnium compounds and alloys, soils, plants and sediments. The use of converters with the offered structure, has allowed to reach lower limits of detection of elements, to raise expressivity of the analysis, to preference analysis cost.

CONCLUSION

The application of a target-converter allows to reduce the component of background caused by (p, n)-nuclear reactions when using charged particles with energy above the nuclear reaction thresholds. This approach allows to use higher energy of beam particles, and accordingly to increase the intensity of a primary X-Ray fluorescence, to reduce detection limits of elements in analyzed sample and to improve the analysis be lowering of spectrum measurement time at the same sensitivity.

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РЕНТГЕНОФЛУОРЕСЦЕНТНЫЙ АНАЛИЗ С ВОЗБУЖДЕНИЕМ ПЕРВИЧНОГО РЕНТГЕНОВСКОГО ИЗЛУЧЕНИЯ ЗАРЯЖЕННЫМИ ЧАСТИЦАМИ В МИШЕНИ С МОНОИЗОТОПНЫМ ПОВЕРХНОСТНЫМ СЛОЕМ

В. Левенец, А. Омельник, А. Щур

Представлена модификация рентгенофлуоресцентного анализа, использующего как источник флуоресценции рентгеновское излучение, возбуждаемое протонами. Предложено использовать первичную мишень с моноизотопным поверхностным слоем и подложкой из того же вещества с естественным изотопным составом. Для изготовления верхнего слоя используется изотоп с наибольшим порогом реакции (p,n)-типа. Такая мишень позволяет снизить пределы обнаружения при элементном анализе за счет уменьшения фонового γ-излучения из реакций (p,n)-типа. Обсуждена возможность изготовления первичных мишеней из никеля, меди, циркония и молибдена. Представленный подход использован для элементного анализа образцов из соединений и сплавов циркония, почв, растений и донных отложений.

РЕНТГЕНОФЛУОРЕСЦЕНТНИЙ АНАЛІЗ ЗІ ЗБУДЖЕННЯМ ПЕРВИННОГО РЕНТГЕНІВСЬКОГО ВИПРОМІНЮВАННЯ ЗАРЯДЖЕНИМИ ЧАСТИНКАМИ В МІШЕНІ З МОНОІЗОТОПНИМ ПОВЕРХНЕВИМ ШАРОМ

В. Левенець, О. Омельник, А. Щур

Представлена модифікація рентгенофлуоресцентного аналізу з використанням в якості джерела флуоресценції рентгенівське випромінювання, що збуджуване протонами. Запропоновано використовувати первинну мішень з моноізотопним поверхневим шаром і підкладкою з тієї ж речовини з природним вмістом ізотопів. Для виготовлення поверхневого шару використовується ізотоп з найбільшим порогом реакції (p,n)-типу. Така мішень дає змогу знизити границі визначення при елементному аналізі за рахунок зменшення фонового γ-випромінювання з реакцій (p,n)-типу. Обговорено можливість виготовлення первинних мішеней з нікелю, міді, цирконію та молібдену. Запропонований підхід використано для елементного аналізу зразків із сполук та сплавів цирконію, ґрунтів, рослин, донних відкладень.