Ion Beam Excitation of TXRF Yield

V.K. Egorov[1*], E.V. Egorov[1], M.S. Afanas'ev[2]

[1] *IMT RAS, Chernogolovka, Moscow district, Russia*

[2] *IRE RAS, Fryazino, Moscow district, Russia*

The work presents short discussion of TXRF and PIXE methods peculiarities. Taking into account of these peculiarities we realized the experimental scheme for TXRF measurements at ion beam excitation of characteristical fluorescence. The scheme is built on base of the planar X-ray waveguide-resonator with specific design. Features of the new experimental method and parameters of ion beam analytical complex Sokol-3 used for the method realization are discussed.

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I. INTRODUCTION

X-ray fluorescence analysis of materials in conditions of the total external reflection of the exciting radiation flux on the studied surface (TXRF) has today conventional status as the more effective method for quantitative element diagnostics of material objects on base of X-ray fluorescence [1]. Main feature of the method is the fact of its implementation in the total external reflection conditions. These conditions provide excitation of a thin surface layer with thickness 3-5 nm, and X-ray fluorescence yield characterizes atoms filling this layer. In the result, TXRF spectrometry is characterized by very low magnitude of the background deposit and absence of the matrix effects [2]. In comparison with XRF conventional analytical data TXRF application allows to decrease of pollutions detection limits and to simplify the experimental results treatment. At the same time, TXRF analysis as well as conventional X-ray fluorescence spectrometry at the fluorescence yield excitation by X-ray, gamma radiation and electron beams has some difficulties at the light elements diagnostics in materials. It is illustrated by Fig. 1, which presents Kα and Lα characteristical fluorescence excitation cross-sections for different elements in conditions of MoKα radiation flux application. Comparison of YKα and AlKα cross-sections shows that efficiency of the yttrium fluorescence excitation is higher as aluminum one on four orders. X-ray fluorescence difficulties of light elements diagnostics in materials can be compensate by use of the fluorescence analysis in conditions of ion beam excitation (by PIXE method) [3]. The fluorescence excitation mechanism in PIXE spectrometry differs from ones featured to other excitation methods. PIXE bears some similarity to electron excitation of the fluorescence yield but it characterized by small value of the bremsstrahlung photon intensity. In the result, PIXE measurements distinguish by low levels of the background. But the principle factor of

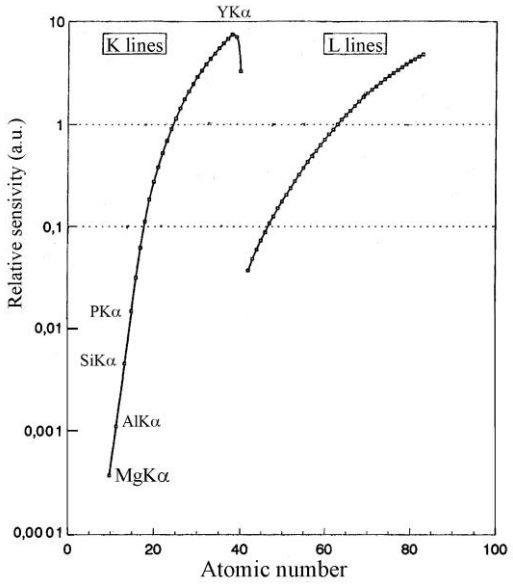

Figure 1: Cross-sections of Kα and Kβ different elements lines excitation in conditions of MoKα radiation flux as the exciting agent [1].

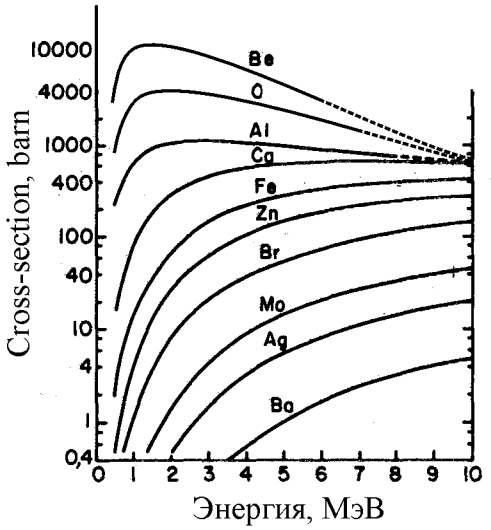

Figure 2: Cross-sections energy dependences of Kα different elements lines excitation at application of H^+ ion beam as the exciting agent [4].

*Electronic address: egorov@iptm.ru

the PIXE spectrometry is high cross-section of X-ray fluorescence excitation for light elements. It is illustrated by Fig. 2 [4]. For example, the cross-section of X-ray fluorescence excitation for AlKα and YKα lines in conditions of proton (E_0=1 MeV) beam application is higher for aluminum fluorescence yield in comparison with YKα one on three orders. So, PIXE is the most preferable method for light element diagnostics in materials.

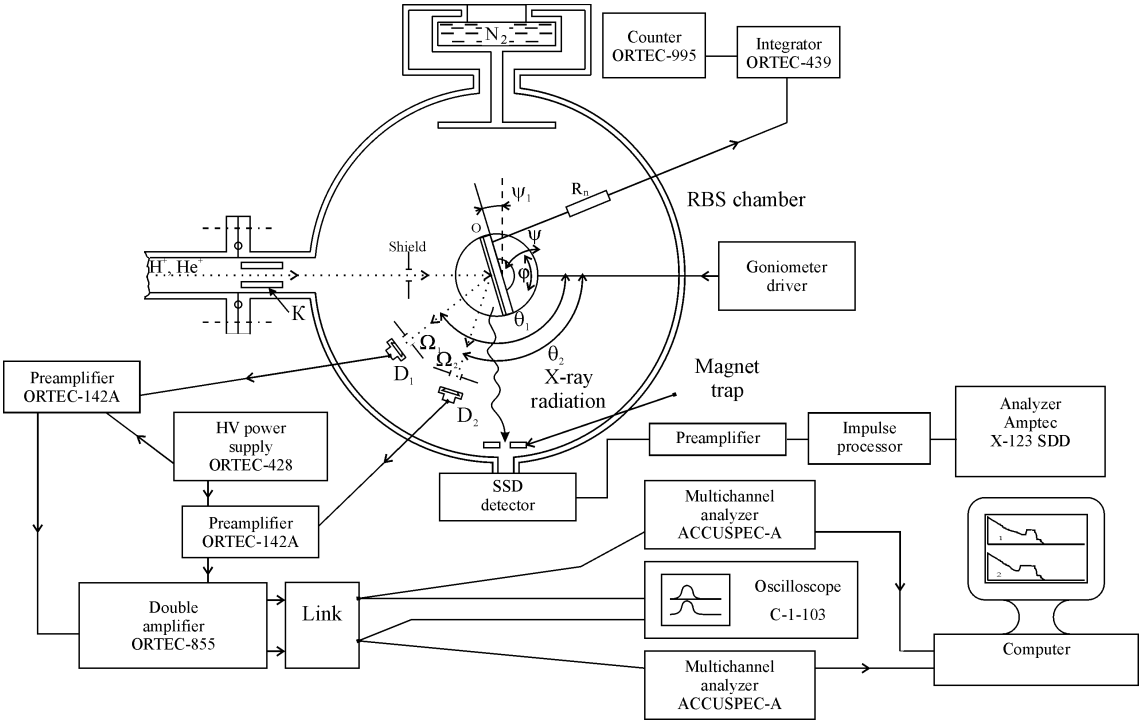

Figure 3: Experimental chamber of Sokol-3 ion beam analytical complex and systems for the product registration of ion beam interaction with studied target.

II. ION BEAM EXPERIMENTAL FACILITY

Experimental investigations were executed by use of measuring resources of Sokol-3 ion beam analytical complex [5]. Central object of these resources is the vacuum chamber for Rutherford backscattering and X-ray fluorescence diagnostics at ion beam excitation. Figure 3 shows detection equipment disposition in the chamber and set of external apparatus used for effects registration of ion beam interaction with target. The chamber equipped by digital goniometer with target holder and double detectors systems for registration of scattering ions and nuclear reaction products (D_1 and D_2 on different angles around of initial ion beam propagation direction). The chamber provides with special vacuum flange (Fig. 4) equipped by X-ray detector holder. The flange strengthening in the chamber defines angle between direction of the ion beam propagation and the detector axis. For exception of scattering ions hit into X-ray detector its holder equipped by collimator with strong Nd-Fe magnets.

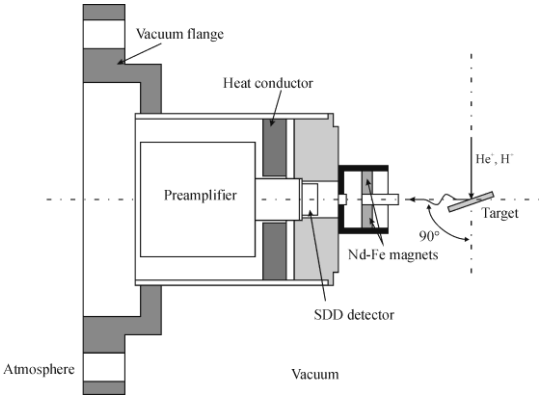

Figure 4: Vacuum flange of Sokol-3 experimental chamber with holder for SDD of Amptek X-123 spectrometer. Holder contains

Hearts of the Sokol-3 ion beam analytical complex is ESU-2 van de Graaff accelerator working in the energy range 0.05-2.0 MeV with energy stability 0.05%. It allows to generate He^+ and H^+ ion beams in the current range 0.001-50 μA. Diameter of ion beam spot on the target can be varied from 0.1 to 2 mm. Vacuum in the experimental chamber is near $1 \cdot 10^{-6}$ torr ($8 \cdot 10^{-3}$ Pa).

III. IMPLEMENTATION SCHEME OF TXRF AT ION BEAM EXCITATION (TXRF-PE)

Analysis of material element composition by PIXE method is the effective diagnostical procedure but it has specific feature. Ion beam excites a characteristical fluorescence in surface material layer with thickness corresponding to ion track

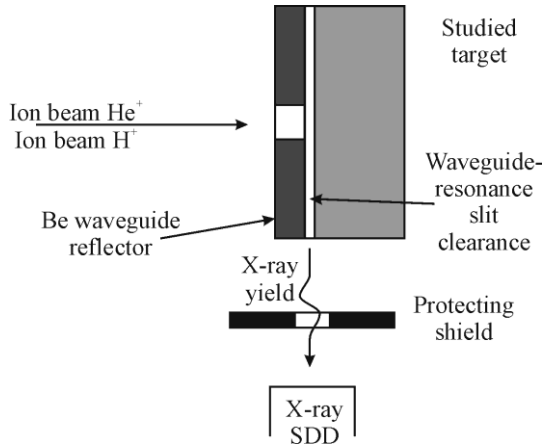

Figure 5: Scheme of TXRF-PE method realization in conditions of application of planar waveguide-resonator with specific design.

length in the material. But the characteristical fluorescence yield intensity registered by X-ray detector will be defined by own mass absorption coefficient. In the result, every X-ray line will correlate to element concentration (without taking into account matrix effects) in the material surface layer with thickness defined by its energy. This effect hampers the quantitative element concentration analysis executing by PIXE method. Neutralization of the matrix effect is very difficult problem. At the same time, the dependence of thickness fluorescence yield can be suppression by application of specific registration scheme including the planar X-ray waveguide-resonator (PXWR) [6]. Figure 5 presents this scheme. High energy ion beam falls on the target through a hole in the Be plate (polished reflection). Distance between target and Be plate surfaces is defined by thickness of Ti strips deposited on Be plate surface t=1500 nm. Be and target surfaces create the waveguide-resonance slit clearance. Ion beam excites X-ray fluorescence yield in wide angular range. At the same time, the waveguide-resonance slit clearance can allow to propagate the fluorescence radiation, which hits into the clearance under angles of total external reflection. Flux of this radiation will correspond to thin surface layer with thickness 3-5 nanometers as similar as in conditions of standard TXRF method. But owing to ion beam excitation of the characteristical fluorescence the XRF spectrum registered by detector will be contain high intensity lines of light elements. So, it is possible to say that we suggest new effective procedure for effective light element diagnostics in the thin surface target layer.

IV. EXPERIMENTAL RESULTS

For the experimental study the multielemental target was chosen. Its composition was defined by method of Rutherford backscattering of H^+ ion beam. Figure 6 presents RBS spectrum of the target. It contained set of light elements ($Na_2Zr_{1.3}Si_{1.9}Al_{0.1}P_1O_{12}C_2$).

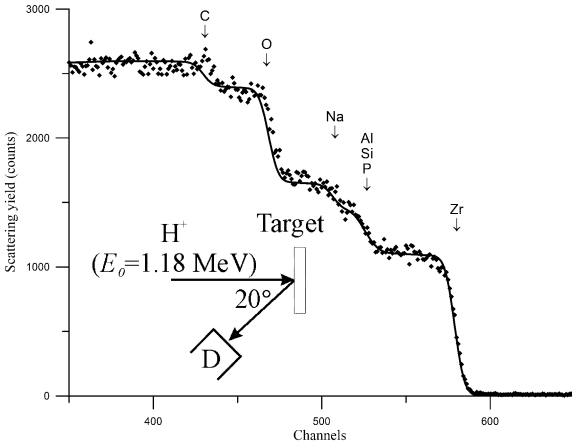

Figure 6: Theoretical and experimental spectra RBS H^+ ions (E_0=1.18 MeV) for $Na_3Zr_{1.3}Si_{1.9}Al_{0.1}P_1O_{12}C_2$ target collected for scattering angle 160°. Arrows show energy corresponding to scattering on the surface. Energy step 1.9 keV/channel.

At the same time, the accurate spectrum approximation is not possible without information about relationship among Al, Si and P atomic concentration in the target structure. Similar information can be obtained by application of TXRF-PE. Spectrum of X-ray fluorescence yield in conditions of ion beam excitation and planar waveguide-resonator application is presented on Figure 7. The spectrum demonstrates NaKα, AlKα and SiKα beautiful lines, PKα and ZrLα intensive doublet and OKα small line. X-ray detector is equipped by Be window with thickness 8 μm. The window does not allow to see carbon line. Quality data about AlKα, SiKα and PKα peaks intensity obtaining on base of the spectrum allows to get the quantity element composition of the target from the RBS spectrum. TXRF-PE spectrum describes element composition of thin surface layer of the target with thickness near 5 nm. But it carries influence of matrix effects and lines intensities can not use directly for quantitative evaluation of the material element concentration [7].

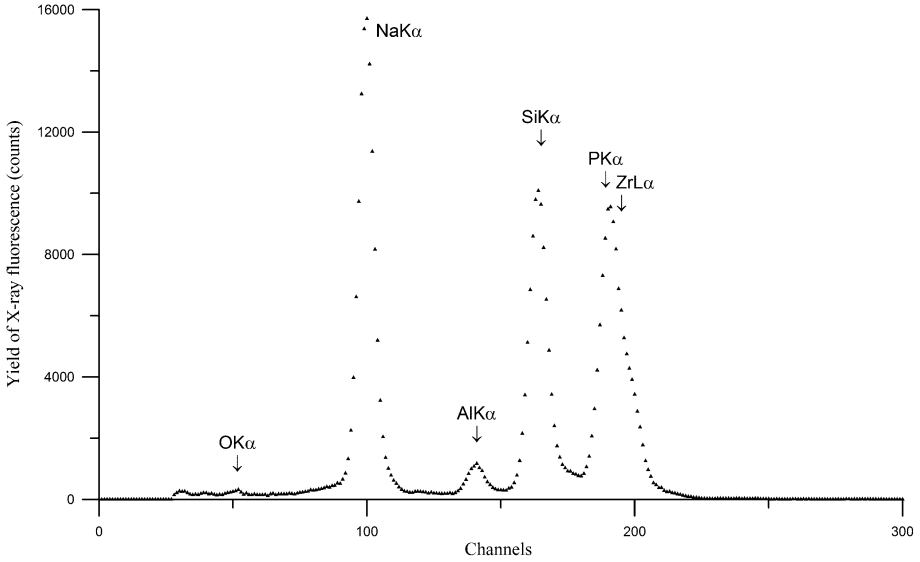

Figure 7: TXRF-PE spectrum of $Na_3Zr_{1.3}Si_{1.9}Al_{0.1}P_1O_{12}C_2$ collected at H^+ (E_0=1.18 MeV) ion beam excitation in conditions of PXWR with slit clearance 0.15 μm application. Energy step 10.2 eV..

V. CONCLUSION

The work presents short description of TXRF-PE experimental method for material element diagnostics with PXWR use and first experimental data obtained by its application. PXWR including into X-ray optical scheme of TXRF-PE spectrometer does not remove matrix effects but increases fluorescence yield featured to thin surface layer of studied material.

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