EXCITATION OF ISOMERIC LOW-LYING LEVEL OF NUCLEUS ^{181}Ta BY RELATIVISTIC ELECTRONS

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Influence on efficiency of exciting of the E1-level ^{181}Ta with energy 6.24 keV of neutron-capture reaction and photonuclear processes by means of the processes caused by passage of powerful electron beam through tantalum is studied. Strengthening of reaction yield ^{181}Ta(γ,2n)^{179}Ta and neutron-capture reaction ^{181}Ta(n,γ)^{182}Ta by means of high intensity of high-energy electrons are discovered.

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1. INTRODUCTION

Radiation and absorption by the charged particles in various structures intensively is investigated. This is caused by huge influence of such processes on the most different areas of natural sciences, technics, vital functions of the person. A striking illustration of the influence of the processes of radiation generation is the creation and use of free-electron lasers. Radiation processes can be both spontaneous and forced, which are caused by an intense external field.

The first indications of the role of spontaneous and induced processes were examined sufficiently long ago [1]. However investigation of such processes continued intensively and in present time [see eg. 2,3]. Also a theory of passage of charged particles in matter is developing intensively [4-7]. The radiating processes are observed in large spatial areas in the case of passage of high-energy radiation through substance. Consequently, the environment has a significant effect on electromagnetic phenomena. It is necessary to mention about of wake potential of the charged particles which causes slowly fading fluctuations wake charge density [5], the virtual excitation of atomic electrons by accelerated particles, which produce a dynamic polarization of the target [8], etc. It should be noted the effect of the crystal lattice on the generation of electromagnetic radiation [9].

The above-mentioned processes can lead to excitation of nuclear states with low energy, which in turn can be used to create X-ray lasers.

2. MATERIALS AND METHODS

Tantalum target of 1 mm thickness were irradiated by an electron linear accelerator KUT-20 ("Accelerator" Science and Research Establishment of NSC KIPT). Experimental setup is shown in Fig. 1. The distance between the targets chosen 1 mm. The electron energy was 36 MeV, average current 9.5 μA. Duration electron bunches irradiation has made about 16 ps, the peak intensity - 9.44 A. The diameter of the electron beam on the first target was 4.6 mm.

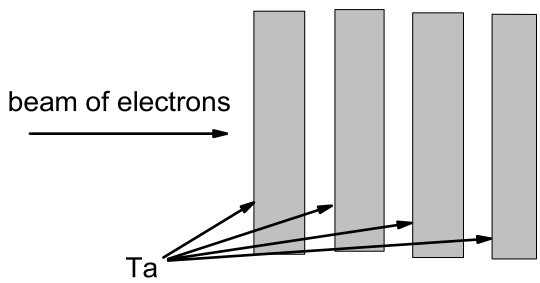

Fig.1. *The scheme of experiment*

The activity of ^{179,182}Ta was measured by means of detector based on high-purity germanium and Ge(Li)-detector with an energy resolution on line ^{137}Cs 661.6 keV 1.25 keV and 3.2 keV on line 1333 keV, respectively.

3. RESULTS AND DISCUSSION

The reaction yield ^{181}Ta(γ,2n)^{179}Ta and ^{181}Ta(n,γ)^{182}Ta for the incoming and outgoing beam of tantalum plates is shown in Fig. 2. The reaction yield ^{181}Ta(γ,2n)^{179}Ta and ^{181}Ta(n,γ)^{182}Ta for the incoming and outgoing beam which calculated by PENELOPE-2008 is shown in Fig. 3,4.

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Feature of these dependences of reaction yield are increase their value at the transition from one to the other plate. Theoretical calculations show as rule opposite results. Probably the increase of yield of reaction ^{181}Ta(γ,2n)^{179}Ta and ^{181}Ta(n,γ)^{182}Ta is caused by excitation of the lower level of the tantalum-181 with an energy of 6.24 keV. Its parameters are listed in Table.

The parameters of the lower level of the nucleus ^{181}Ta

polarity transition	energy, keV	Γ_c, eV
E1	6.24	7.6 10^{-11}
$T_{1/2}$, μs	basic state	excited state
6.05	$7/2^+$	$9/2^-$

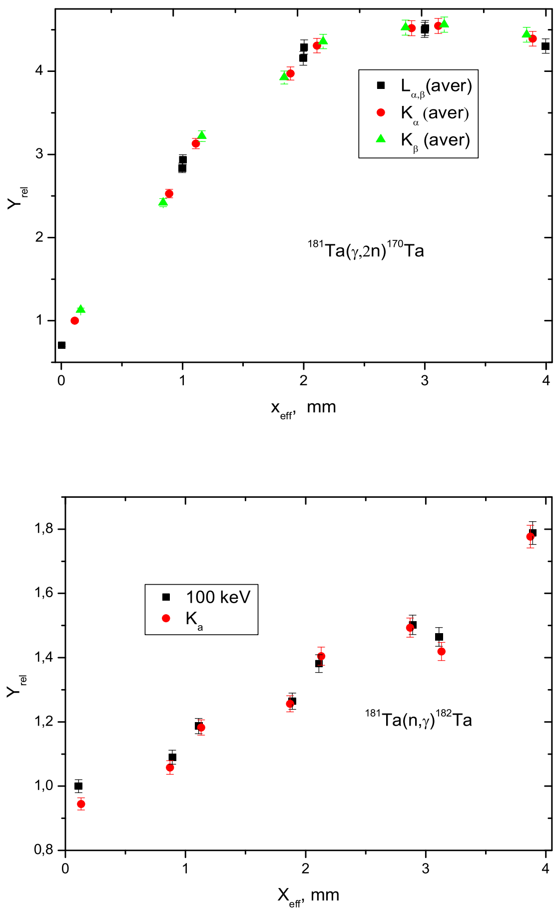

Fig.2. *Relative change of intensity of lines ^{179}Ta from effective depth for Ta samples (above). Relative change of intensity of lines ^{182}Ta from effective depth for Ta samples (below)*

Among processes which can cause high excitation efficiency of state of tantalum 6.24 keV it is possible to note the following.

Scattering of Meller. For small recoil energy of electron ($\Delta << \gamma$-1) it is expressed by the equation [10]:

$$d\sigma = \frac{4\pi e^4}{mv^2}\frac{d\Delta}{\Delta^2}, \qquad (1)$$

where Δ - the energy of the recoil electron, e - electron charge, v, m - the velocity and mass of the incident electron. For the recoil energy of electron 6.32 keV cross section of formation of low-energy electrons can be several kilobarn.

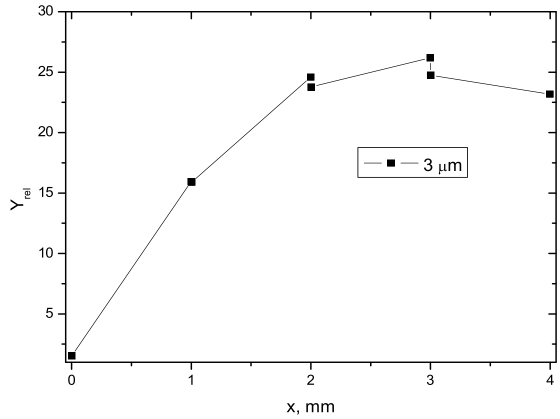

Fig.3. *The calculated yield of reaction ^{181}Ta(γ,2n)^{179}Ta for an entering and leaving bunch from a layer thickness 3 microns*

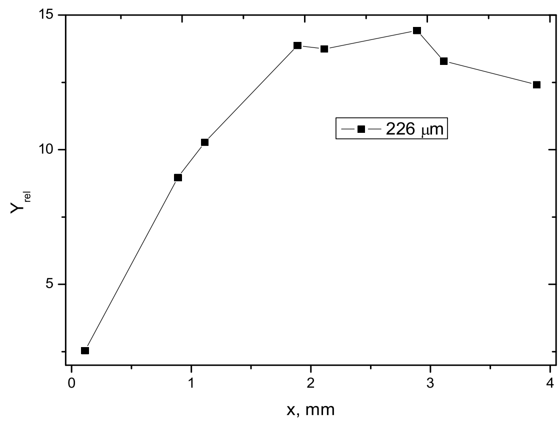

Fig.4. *The calculated yield of reaction ^{181}Ta(γ,2n)^{179}Ta for an entering and leaving bunch from a layer thickness 226 microns*

Emission of soft photons in collisions of ultrarelativistic electrons with the nucleus. In this case the cross section is:

$$d\sigma_{\varpi} = \frac{16}{3}Z^2\alpha r_e^2\frac{d\omega}{\omega}\ln\frac{\epsilon^2}{m\omega}, \qquad (2)$$

where Z - charge of the nucleus, r_e - radius of the electron, α - the fine structure constant, ω - frequency of soft photons, ϵ - the energy of the incident electrons [11]. Cross sections for gamma rays at forward angles (up to 5°) may be tens of barns.

The distance between the electrons in a bunch is about 1.7 microns. Naturally a coherent radiation with wavelengths much larger than 1.7 microns can be. As shown in [2] at the passage of electrons of a bunch there is possibility of modulation of its density and the formation of one or more of the quasi - compact electron bunches. This can result in radiation of wavelength smaller than in the original size of the bunch.

A possible explanation the generation of electromagnetic radiation may be caused by mechanism which is presented in [3]. The presence of periodic inhomogeneity, and wake potential of slowly decaying collective oscillations of the electron density in the electron bunch which passes in textured tantalum may excite radiation with frequencies that correspond to the high numbers of harmonics, ie, maximum of the emission spectrum can correspond frequencies, which are much superior to the natural frequencies of the oscillators [3].

It is known that the resonant interaction of gamma rays or particles with nuclei in the crystal lattice, which lead to excited state (compound nucleus) has a collective character [12,13]. In this case, if the state of the lattice is not changed, the Coulomb excitation and subsequent gamma decay will be of a coherent character. For multipolarity E1 and M1 at grazing collisions of charged particles with the lattice atoms becomes possible manifestations of coherent processes in the Coulomb excitation in a crystal. Gamma rays are emitted from the cones with the axis along the beam direction. To obtain a significant effect of coherent excitation is necessary to use extremely low-lying levels of the isomer type and use beams fast enough particles so that the momentum transfer p - p$'$ (p, p$'$ - the initial and final momentum of the incident particle) is not very different from the wave vector gamma quanta [12-14]. Note that the coherent excitation of the medium of the moving particle, leading to a coherent electron loss was observed by surface scattering of helium ions by crystal tungsten [15]. It is known that rolled tantalum has a high degree of texture in the {100}. This can lead to coherent excitation of 6.24 keV level of tantalum, which is due to the influence of the crystal structure. Note that for the period of oscillation of the electrons channeling particles with transverse energy $E_o = U_o$ (U_o - the maximum value of the transverse energy of the particle) can be much greater than for positrons (semichanneling particles). Therefore, for some of the electrons passing tantalum plate, can be realized undulator radiation with sufficiently low energy (6...10 keV energy range). Accordingly, it can cause stimulated emission level of 6.24 keV tantalum-181 high-gain due to its high population inversion. We know that in the low-frequency spectral-angular density of the radiation intensity is almost independent of frequency [9,16].

It is known that the lifetime of the state 6.24 keV of tantalum-181 in the high-temperature laser plasma is greater than the lifetime of a given level in the neutral atom [17]. The authors of [17] suggest that this may be due to the decrease in the probability of internal electron conversion due to the ionization of the upper atomic shells up to M-shell inclusive. It is possible that the lifetime of the excited state 6.24 keV of the tantalum-181 depended by elastic deformations in the crystal tantalum when a beam of electrons passes [18]. It is known that inhibition of gamma-resonance self-absorption of iron-57 observed at high power ultrasound [19]. Therefore, the generation of ultrasonic waves in plates of tantalum can lead to high levels of occupancy 6.24 keV ^{181}Ta and thus lead to increased nuclear reaction yield ^{181}Ta$(\gamma,2n)^{179}$Ta and ^{181}Ta$(n,\gamma)^{182}$Ta. The main feature of the manifestation of the effect of excitation level of 6.24 keV due to higher yield of reactions ^{181}Ta$(\gamma,2n)^{179}$Ta and ^{181}Ta$(n,\gamma)^{182}$Ta in the transition from one plate to the other. For example, for L-line calculation gives a decrease in the intensity of the reaction yield ^{181}Ta$(\gamma,2n)^{179}$Ta at the transition from one to the other of plate, but the experimental data is shows an increase in the yield of the reaction.

In Fig. 5 shows the calculated yield of ^{181}Ta$(n,\gamma)^{182}$Ta tantalum plates are caused by neutrons which have arisen in a given plate, in the assumption that the neutron yield in each plate is uniform. Influence of each plate on others is described by the equations of a flat source. It was assumed that the yield (n,γ)-reaction is due mainly resonance neutrons. You can see that the ratio of the yield of reaction ^{181}Ta$(n,\gamma)^{182}$Ta/^{181}Ta$(\gamma,2n)^{179}$Ta significantly greater for the first tantalum plate.

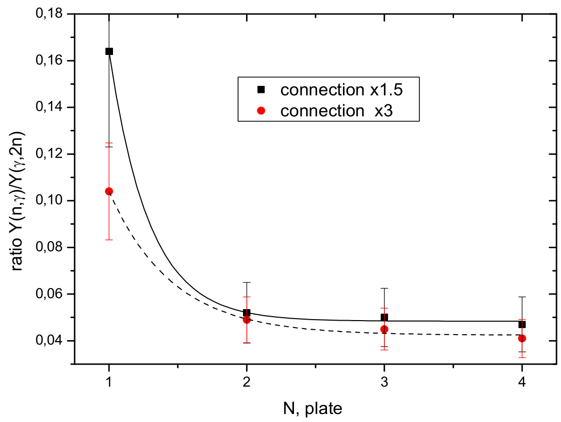

Fig.5. *The calculated ratio of activity ^{182}Ta/^{179}Ta for plates of tantalum*

4. CONCLUSIONS

1. The main feature of the manifestation of the effect of excitation level of 6.24 keV is due to higher yield of reactions ^{181}Ta$(\gamma,2n)^{179}$Ta and ^{181}Ta$(n,\gamma)^{182}$Ta in the transition from one plate to the other. At the same time, the calculation for the L-lines shows reduction in the intensity of the reaction yield ^{181}Ta$(\gamma,2n)^{179}$Ta in the transition from one plate to the other, but for the experimental data observed increase in the yield of the reaction.

2. Found a higher yield of ratio reaction ^{181}Ta$(n,\gamma)^{182}$Ta/^{181}Ta$(\gamma,2n)^{179}$Ta for the first plate of tantalum.

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ВОЗБУЖДЕНИЕ НИЗКО-ЛЕЖАЩЕГО ИЗОМЕРНОГО УРОВНЯ ЯДРА ^{181}Ta РЕЛЯТИВИСТСКИМИ ЭЛЕКТРОНАМИ

Н.П. Дикий, А.Н. Довбня, Ю.В. Ляшко, В.И. Никифоров, В.Л. Уваров, И.Д. Федорец

Рассмотрено влияние процессов, обусловленных прохождением сильноточного пучка электронов через тантал, на скорость заселения E1-уровня ^{181}Ta с энергией 6,24 кэВ, на радиационный захват нейтронов и фотоядерные процессы. Обнаружено усиление фотоядерной реакции ^{181}Ta$(\gamma,2n)^{179}$Ta и реакции радиационного захвата нейтронов ^{181}Ta$(n,\gamma)^{182}$Ta при высокой интенсивности высокоэнергетических электронов.

ЗБУДЖЕННЯ НИЗЬКО-ЛЕЖАЧОГО ІЗОМЕРНОГО РІВНЯ ЯДРА ^{181}Ta РЕЛЯТИВІСТСЬКИМИ ЕЛЕКТРОНАМИ

М.П. Дикий, А.М. Довбня, Ю.В. Ляшко, В.І. Нікіфоров, В.Л. Уваров, І.Д. Федорець

Розглянуто вплив процесів, обумовлених проходженням потужнострумового пучка електронів через тантал, на швидкість заселення E1-рівня ^{181}Ta з енергією 6,24 кеВ, на радіаційне захоплення нейтронів і фотоядерні процеси. Виявлено посилення фотоядерної реакції ^{181}Ta$(\gamma,2n)^{179}$Ta і реакції радіаційного захоплення нейтронів ^{181}Ta$(n,\gamma)^{182}$Ta при високій інтенсивності високоенергетичних електронів.