ОПТИЧНІ, ОПТОЕЛЕКТРОННІ І РАДІАЦІЙНІ СЕНСОРИ

OPTICAL AND OPTOELECTRONIC AND RADIATION SENSORS

PACS codes: 34.50Rk, 31.70Hq, 95.55Sh ;
УДК 535.42.,539.184.

LASER PHOTOIONIZATION SENSOR TECHNOLOGY AND NEW POSSIBLE PRINCIPAL SCHEME FOR γ-LASER ON QUICKLY DECAYED NUCLEAR ISOMERS WITH ELECTRIC FIELD AND AUTO-IONIZATION SORTING OF EXCITED ATOMS

S. V. Ambrosov

Odessa National Polytechnic University, P.O.Box 116, Odessa-9, 65009, Ukraine

Abstract

LASER PHOTOIONIZATION SENSOR TECHNOLOGY AND NEW POSSIBLE PRINCIPAL SCHEME FOR γ-LASER ON QUICKLY DECAYED NUCLEAR ISOMERS WITH ELECTRIC FIELD AND AUTO-IONIZATION SORTING OF EXCITED ATOMS

S. V. Ambrosov

Optimal schemes of the laser photo-ionization sensing technology for creation of new possible principal scheme of γ-laser on quickly decayed nuclear isomers with autoionization or electric field ionization sorting excited atoms are developed.

Key words: laser photo-ionization sensor technology, γ-laser on quickly decayed nuclear isomers, optimal schemes

Анотація

ЛАЗЕРНО-ФОТОІОНІЗАЦІЙНА СЕНСОРНА ТЕХНОЛОГІЯ І НОВА МОЖЛИВА ПРИНЦИПІАЛЬНА СХЕМА γ-ЛАЗЕРА НА ЯДЕРНИХ ІЗОМЕРАХ, ЩО ШВИДКО РОЗПАДАЮТЬСЯ, ІЗ СОРТИРОВКОЮ ЗБУДЖЕНИХ АТОМІВ МЕТОДОМ АВТО-ІОНІЗАЦІЇ ТА ЕЛЕКТРИЧНИМ ПОЛЕМ

С. В. Амбросов

Розроблені нові схеми лазерно-фотоіонізаційної сенсорної технології та нова можлива принципіальна схема γ-лазера на ядерних ізомерах, що швидко розпадаються, із сортировкою збуджених атомів методом автоіонізації або іонізації електричним полем.

Ключові слова: лазерно-фотоіонізаційна сенсорна технологія, γ-лазер на ядерних ізомерах, що швидко розпадаються, оптимальні схеми

Аннотация

ЛАЗЕРНО-ФОТОИОНИЗАЦИОННАЯ СЕНСОРНАЯ ТЕХНОЛОГИЯ И НОВАЯ ВОЗМОЖНАЯ ПРИНЦИПИАЛЬНАЯ СХЕМА γ-ЛАЗЕРА НА БЫСТРОРАСПАДАЮЩИХСЯ ЯДЕРНЫХ ИЗОМЕРАХ С СОРТИРОВКОЙ ВОЗБУЖДЕННЫХ АТОМОВ МЕТОДОМ АВТОИОНИЗАЦИИ И ЭЛЕКТРИЧЕСКИМ ПОЛЕМ

С. В. Амбросов

Разработаны новые схемы лазерно-фотоионизационной сенсорной технологии и новая возможная принципиальная схема γ-лазера на быстрораспадающихся ядерных изомерах с сортировкой возбужденных атомов методом автоионизации или ионизации электрическим полем.

Ключевые слова: лазерно-фотоионизационная технология, γ-лазер на быстро распадающихся ядерных изомерах, оптимальные схемы

Carrying out the effective methods for isotopes and nuclear isomers, obtaining especially pure substances or their control and cleaning from admixtures is considered as one of the actual problem of modern nuclear technology and technology of the semiconductor and other materials (c.f.[1-19]). The basis for its successful realization is, at first, carrying out the optimal multi stepped photo-ionization schemes for different elements and, at second, availability of enough effective UV and visible range lasers with high average power. The standard laser photo-ionization scheme may be realized with using processes of the two-step excitation and ionization of atoms by laser pulse. The scheme of selective ionization of atoms, based on the selective resonance excitation of atoms by laser radiation into states near ionization boundary and further photo-ionization of the excited states by additional laser radiation, has been at first proposed and realized by Letokhov et al (c.f. ref.[1]). This scheme represents a great interest for laser separation of isotopes and nuclear isomers. However, a significant disadvantage of the two-step selective ionization of atoms by laser radiation method is a great difference between cross-sections of resonant excitation σ_{exc} and photo-ionization σ_{ion} ($[\sigma_{exc}/\sigma_{ion}]>10^4\div10^8$). It requires the using very intensive laser radiation for the excited atom ionization.

The same difficulty is arisen in task of sorting the excited atoms with excited nuclei in problem of creation of γ-laser on quickly decayed nuclear isomers [1]. Originally in ref.[3] Letokhov has considered a possibility of creating a γ-laser, based on a recoiless transition between lower nuclear levels and shown that a γ-laser of this type in the 20-60 keV region is feasible. A feature of design is operation based on relatively short-lived isomer nuclear states with lifetime of 0,1 to 10 sec. Author has cestimated the minimal number of excited nuclei required for obtaining appreciable amplification and possibility of producing sufficient amounts of excited nuclei by irradiation of the target with a thrmal neutron beam or by resonant γ-radiation. It is important that low-inertia laser selection of a relatively small frction of excited nuclei of a given composition from the target by the two-step method of selective laser photoionization of atoms with excited nuclei by the radiation from two lasers is principally possible [3]. But, it is obvious that here there is a problem of significant disadvantage of the two-step selective ionization of atoms by laser radiation method [1].

The situation is more simplified for autoionization resonance's in the atomic spectra, but detailed data about characteristics of these levels are often absent (c.f.[4,5,12,17]).. Main problems here are connected with difficulties of theoretical studying and calculating the autoionization resonance characteristics. In ref. [15-18] new optimal schemes for the laser photo-ionization sensors of separating heavy isotopes and nuclear isomers were proposed. It has been carried out the modelling a new, optimized scheme for the laser photo-ionization sensor. It is based on the selective laser excitation of the isotope atoms into excited Rydberg states and further autoionization and DC electric field ionization mechanisms. To carry out modelling the optimal scheme of the *U* and *Tm* isotopes (nuclei) sensing, the optimal laser action model and density matrices formalism (c.f.[15-18]) have been used. The similar technologies and the optimal schemes of laser photo ionization method have been developed for control and cleaning the semiconductor substances [17]. Namely, the optimal laser photo-ionization schemes for preparing the films of pure composition on example of creation of the 3-D hetero structural super lattices (layers of $Ga_{1-x}Al_xAs$ with width 10Å and GaAs of 60Å) have been proposed and new models of opti-

mal realization of the first step excitation and further ionization of the Ga^+ ions in Rydberg states by electric field are calibrated.

In this paper we propose the optimal schemes of the laser photo-ionization sensing technology for creation of new possible principal scheme of γ-laser on quickly decayed nuclear isomers with laser autoionization or electric field ionization sorting excited atoms.

Let us remind that in a classic scheme the laser excitation of admixture atoms is realized at several steps: atoms are resonantly excited by laser radiation and then it is realized photo ionization of excited atoms [1]). In this case photo ionization process is characterized by relatively low cross section $\sigma_{ion}=10^{-17}$-10^{-18}cm^2 and one could use the powerful laser radiation on the ionization step. Alternative mechanism is a transition of atoms into Rydberg states and further ionization by electric field. As result, requirements to energetic of the ionized pulse are decreased at several orders. The main feature and innovation of our scheme is connected with using the autoionization and DC electric field ionization mechanisms on the last ionization step of the laser photoionization sensor technology. Such an optimal scheme can be used as basis for realization of sorting definite excited atoms wth necessary excited nuclei of the A^+ kind, which are obtained by optimal method of selective photo-ionization of the A kind atoms in the beam in mixture with other atoms. This topic is key one in this article. In fig. 1 we present the possible advanced scheme γ — laser on quickly decayd nuclear isomers with using laser photoionization sorting excited nuclei M^*_{k+1} with electric field amd autoionization and electric field ionization mechanisms.

In fact our scheme generelizes the known Letokhov scheme [3], but it is significantly more effective and optimal, first of all, from energetics point of view. The suitable objects for modelling laser photoionization separation technology are the isotopes of alkali element Cs, lanthanides and actinides. We have carried out the modelling for isotopes of $_{55}Cs^{133}_{78}$ and $_{70}Yb^{171}_{101}$. As example, we consider a scheme for the laser separation and sensing the *Cs* isotopes. The resonant excitation of the Cs can be realized by means dye lasers with lamp pumping (two transitions wavelengths are: $6^2S_{1/2}\rightarrow 7\,^2P_{3/2}$ 4555A and $6^2S_{1/2}\rightarrow 7\,^2P_{1/2}$ 4593A) [15]. The next step is in the further excitation into the Rydberg S,P,D states with n=8-15 (the optimal value n=12). Final step is the auto-or electric field ionization of the Rydberg excited atoms and output of the created ions. The scheme will be optimal if an atom is excited by laser radiation to state, which has the decay probability due to the auto-or electric field ionization bigger than the radiation decay probability. In figure 1 we present the numeric modelling results of the optimal form of laser pulse in the photoionization scheme with auto-or electric field ionization by solving the corresponding differential equations system [16-18]. The following definitions are used: δ+dashed line is corresponding to optimal form of laser pulse, curves 1 and 2 are corresponding to populations of the ground and excited states of Cs. The δ -pulse provides maximum possible level of excitation (the excitation degree is about ~0,25; in experiment [1] with rectangular pulse this degree was ~ 0,1). It is in great degree similar to analogous scheme with stochastic collisional ionization mechanism [15]. In fig.2 there is also presented the typical behaviour of the ground (curve 1) and excited (curve 2) states population. Let us remember data regarding the excitation and the ionization cross sections for studied system: the excitation cross section at the first step of the scheme is ~10^{-11}cm^2; the ionization cross-section from excited 7^2P_2 state: $\sigma_2=10^{-16}$cm^2, from ground state $\sigma_2=10^{-18}$cm^2 [1]. One can see that the relation of these cross sections is 10^5 and 10^7 correspondingly. This fact provides the obvious non-efficiency of standard photoionization scheme.

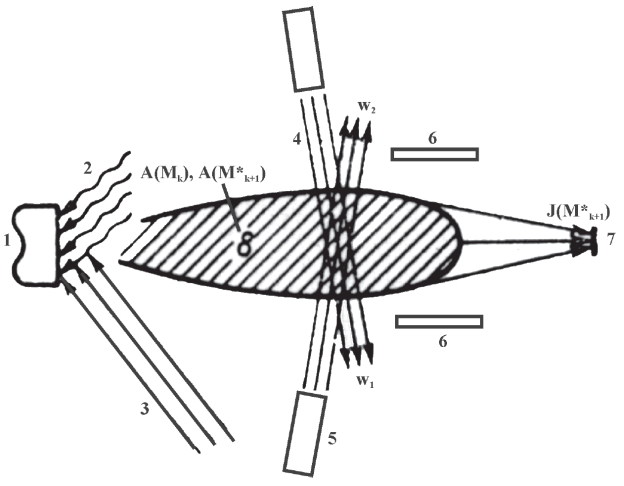

Fig.1. To possible advanced scheme γ — laser on quickly decayd nuclear isomers with using laser photoionization sorting excited nuclei M^*_{k+1} with electric field amd autoionization and electric field ionization mechanisms: 1 — target of atoms M_k; 2- flux of slow neutrons; 3 — laser ray for evaporation of target; 4 — laser ray for the first step excitation of atoms with excited nucleus $A(M^*_{k+1})$; 5 — laser ray for second-step excitation to Rydberg states and autoionization or ionization by external electric field; 6 — collector system; 7 — atoms with excited nucleus $A(M^*_{k+1})$; 8 — flux of evaporated atoms;

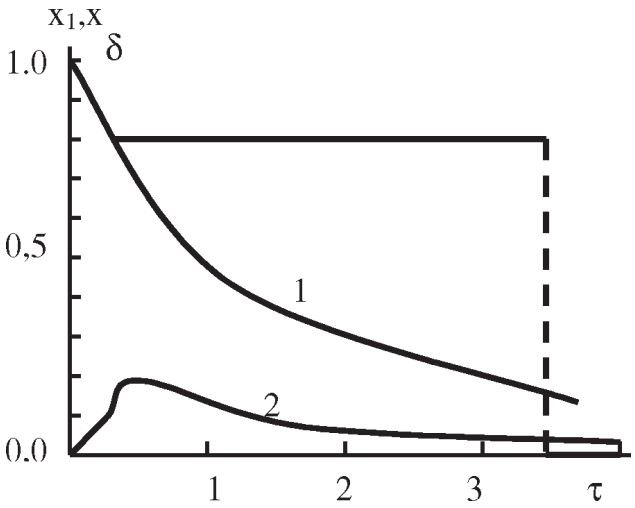

Fig.2. Results of modelling Cs isotopes separation process by the laser photo-ionization method (δ+dashed — laser pulse optimal form; see text)

A use of the autoionization or DC electric field mechanisms at the final step for ionization of the Rydberg excited atoms provides more optimal scheme from energetic point of view. For example, for the $6p^2P_{1/2} - 15^2D_{3/2}$ transition the corresponding cross section ~10^{-15}cm^2 under strength of electric field 12 kV/cm [1]. The autoionization cross section has order ~10^{-13}cm^2. So, from energetic point of view, this type of ionization can be very perspective alternative to classical two-step photoionization scheme (c.f.[1,3]). The similar data are obtained for the Yb isotopes separation. So, the laser photo ionization scheme with ionization by electric field (with optimal set of energetic and radiative parameters: pulse form, duration, energetic for laser and electric field pulses etc.) and autoionization of the Rydberg excited atoms could provide significantly more high yield and effectiveness of the whole process than the other known schemes (c.f.[1]). So, it can be used in creation of new possible principal scheme of γ -laser on quickly decayed nuclear isomers with autoionization or electric field ionization sorting excited atoms.

References:

1. Letokhov V.S. Nonlinear Selective Photoprocesses in atoms and molecules. — M.,1983. — 408c.
2. Goldansky V.I., Letokhov V.S. Effect of laser radiation on nuclear decay processes// Sov. Phys. JETP. — 1974. — Vol.67. — P.513-516.
3. Letokhov V.S., On nucleare transition g-lasers // JETP. — 1973. — Vol.64. — P.1565-1567.
4. Ivanov L.N., Letokhov V.S. Spectroscopy of autoionization resonances in heavy elements atoms// Com.Mod.Phys.D.:At.Mol.Phys. — 1985. — Vol.4. — P.169-184.
5. Glushkov A.V., Ivanov L.N. Radiation Decay of Atomic States: atomic residue and gauge non-invariant contributions // Phys. Lett.A. — 1992. — Vol.170,N1. — P.33-37
6. Glushkov A.V.,Ivanov L.N. DC Strong-Field Stark-Effect: consistent quantum-mechanical approach// J.Phys.B: At. Mol. Opt. Phys. — 1993. — Vol.26,N16. — P.L379-L386.
7. Ryabov E.A. Laser separation of isotopes on the basis of IR multi-photon dissociation of molecules// Usp.Phys.Nauk. — 2004. — Vol.174. — P.684-688.
8. Stoll W. Present Status of industrial Isotope separation by laser technology// Atomic and Molecular Pulsed Lasers. — Tomsk: SO RAN, 2001. — P.71.
9. Buchanov V.V., Kazaryan M., Kalugin M., Prokhorov A.M. Laser separation of Silicon Isotopes by the AVLIS Technology// Atomic and Molecular Pulsed Lasers. — Tomsk: SO RAN,2001. — P.72.
10. Glushkov A.V., Ambrosov S.V., Shpinareva I.M. Non-linear Selective Photoprocesses in Atoms and Molecules and their Optimal Governing. Optimized Isotope Separation Schemes// Atomic and Molecular Pulsed Lasers. — Tomsk: SO RAN, 2001. — P.70.
11. Glushkov A.V., Ambrosov S.V., Korchevsky D.A., Ignatenko A.V., DC Stark Effect in Non-H atoms: Operator Perturbation theory// Intern. Journ. Quant. Chem. — 2004. — Vol.99.,N5-P.685-592.
12. Glushkov A.V., Rusov V.D., Ambrosov S.V., Loboda A.V. Resonance states of compound super-heavy nucleus and EPPP in heavy nucleus collisions // In: New projects and new lines of research in nuclear physics.Eds. G.Fazio, F.Hanappe, Singapore : World Sci. — 2003. — P.126-142.
13. Glushkov A.V., Ambrosov S.V., Loboda A.V., Gurnitskaya E.P., Prepelitsa G.P., Consistent QED approach to calculation of electron-collision excitation cross-sections and strengths: Ne-like ions // Int. Journ.Quant.Chem. — 2005. — Vol.104, N4 . — P. 562-569.
14. Ambrosov S.V., Malinovskaya S.V., Glushkov A.V., Ignatenko V.M., Laser field action on surface and new selective photo-ionization method optimal schemes for preparing the films of pure composition at atomic level// Surface and Interface Anal. — 2005. — Vol.16. — P.953-958.
15. Ambrosov S.V., Laser photo-ionization sensor of the separating isotopes and nuclear reactions products: theory and new scheme// Sensor Electr. Micr.Tech. — 2004. — N2. — P.37-45.

16. Ambrosov S.V. Laser photo-ionization sensor of separating heavy isotopes and nuclear isomers: ionization by DC electric &laser field (U,Tm)// Sensor Electr.Micr.Tech. — 2005. — N1. — P.34-40.
17. Ambrosov S.V., New optimal schemes of the laser photo-ionization technologies for cleaning the semiconductor materials and preparing the films of pure composition at atomic level// Functional Materials. — 2003. — V.10,N2. — P.201-205.
18. Ambrosov S.V. Selective Photo-ionization of atoms: resonant re-charging in vapours of alkali elements and uranium // Photoelectronics. — 2002. — Vol. 11. — P.40-45.
19. Glushkov A.V., Malnovskaya S.V., Ambrosov S.V., New scheme of g -laser on quickly decayed nuclear isomers// Preprint I.Mechnikov Odessa Nat.Univ., Inst. Phys. №A-1, Odessa (2004).