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LASER PHOTOIONIZATION TECHNOLOGY AND NEW EQUIPMENT PRINCIPAL SCHEME FOR PREPARING THE FILMS OF SUPER PURE COMPOSITION AT ATOMIC LEVEL

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Abstract

LASER PHOTOIONIZATION TECHNOLOGY AND NEW EQUIPMENT PRINCIPAL SCHEME FOR PREPARING THE FILMS OF SUPER PURE COMPOSITION AT ATOMIC LEVEL

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New optimal schemes for laser photo-ionization technology for control and cleaning the semiconductor substances and preparing the films of pure composition on atomic level are developed and new corresponding equipment principal scheme is presented.

Key words: laser photo-ionization technology, preparing films, cleaning semiconductors, optimal schemes

Анотація

ЛАЗЕРНО-ФОТОІОНІЗАЦІЙНА ТЕХНОЛОГІЯ І НОВА ПРИНЦИПІАЛЬНА СХЕМА УСТАНОВКИ ДЛЯ ВИГОТОВЛЕННЯ ПЛІВОК ОСОБЛИВО ЧИСТОГО СКЛАДУ НА АТОМНОМУ РІВНІ

С. В. Амбросов

Розроблені нові схеми лазерно-фотоіонізаційної технології контролю та очищення напівпровідникових речовин і виготовлення плівок особливо чистого складу на атомному рівні. Представлено нову принципіальну схему відповідних установок.

Ключові слова: лазерно-фотоіонізаційна технологія, виготовлення плівок, очищення напівпровідникових речовин, оптимальні схеми

Аннотация

ЛАЗЕРНО-ФОТОИОНИЗАЦИОННАЯ ТЕХНОЛОГИЯ И НОВАЯ ПРИНЦИПИАЛЬНАЯ СХЕМА УСТАНОВКИ ДЛЯ ПРИГОТОВЛЕНИЯ ПЛЕНОК ОСОБО ЧИСТОГО СОСТАВА НА АТОМНОМ УРОВНЕ

С. В. Амбросов

Разработаны новые схемы лазерно-фотоионизационной технологии контроля и очистки полупроводниковых веществ и приготовления пленок особо чистого состава на атомном уровне. Представлена новая принципиальная схема соответствующих установок.

Ключевые слова: лазерно-фотоионизационная технология, приготовление пленок, очистка полупроводниковых веществ, оптимальные схемы

Carrying out the effective methods for obtaining especially pure substances or their control and cleaning from admixtures (c. f. [1,2]) is considered as one of the actual problem of modern technology of the semiconductor and other materials. In particular, speech is about methods for control of the Al, B admixtures in Ge and other third group acceptor elements admixtures at the level of 10^{-8}-10^{-10}%. In some cases traditional analytic methods [1] or their modifications may provide the similar sensitivity. However, its sensitivity is limited by level of 10^{-7}%. Selective photo physics methods [2-9] allow developing a new approach to technologies of obtaining the pure substances at atomic level. 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 multi-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. [2]). 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 excitement 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 situation is more simplified for autoionization resonance's in the atomic spectra, but detailed data about characteristics of these levels are often absent. Main problems here are connected with difficulties of theoretical studying and calculating the autoionization resonance characteristics. In ref. [10,11] new optimal schemes for the laser photo-ionization sensors of separating heavy isotopes and nuclear isomers were proposed. We made 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 DC electric field ionization mechanism. To carry out modelling the optimal scheme of the *U* and *Tm* isotopes (nuclei) sensing, we used the optimal laser action model and density matrices formalism (c. f. [9-13]). In ref. [12] we carried out computer modelling the optimal schemes of laser photo ionization method for control and cleaning the semiconductor substances. At first we carried out modelling the laser photo-ionization scheme 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). New models of optimal realization of the first step excitation and further ionization of the Ga^+ ions in Rydberg states by electric field are proposed and optimal parameters of the photo ionization process are found. We have also calculated the optimal scheme for the laser photo-ionization technology of control and cleaning the substance on atomic level. As example it was carried out the photo ionization analysis of Al admixtures in Ge. 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 (c. f. [2-8]). 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 possible device for preparing the films of pure composition by means of the two-stepped selective ionization of atoms has been proposed by Letokhov [2]. Such scheme was not experimentally checked, however it is obvious that the two-stepped laser ionization scheme is not optimal one. The main feature and innovation of our scheme is connected with using the electric field ionization pulse on the last ionization step. Such an optimal scheme can be used as basis for devices for preparing the films of super pure composition during sedimentation of ions 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 propose the possible construction of scheme for preparing the films of super pure composition during sedimentation of ions. In fact our scheme generelizes the known Letokhov scheme [2], but it is significantly more effective.

The wide spread method for getting complex hetero-structures of super lattices type is a method of molecular epytaxy. At the same time one can note that it allows creating only 1D super lattices (the known example is layers $Ga_{1-x}Al_x$as of the width 10Å and GaAs of the width 60 Å with full number of layers around 100. The 3D hetero-structure super lattices can be created by means electromagnetic focusing and deflecting systems with using the photo-ionic beams of Ga^+, Al^+, As^+.

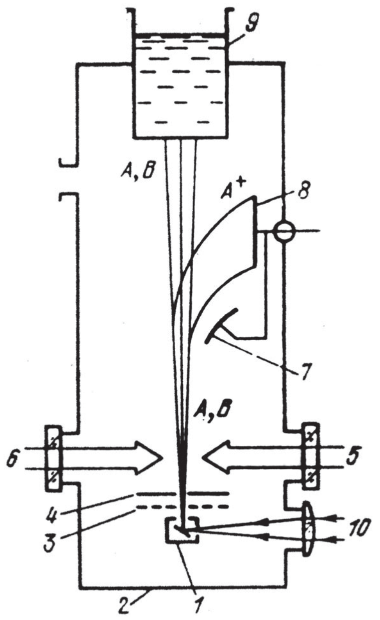

Fig. 1. Possible scheme for preparing the films of super pure composition during sedimentation of ions of A^+ kind, which are obtained by optimal method of selective photo-ionization of the A atoms in a beam in mixture with other atoms: 1 — source of atomic beam; 2- vacuum box; 3 — collector of non-selective ions; 4 — diaphragm; 5 — laser ray for the first step excitation; 6 — laser ray for second-step excitation to Rydberg states and ionization by external electric field; 7 — deflecting electrodes; 8 — sublayer; 9 –cold sublayers for freezing atoms; 10 — laser ray for vaporising the substance;

As it had been at first underlined in ref. [2], this opportunity of spatial control of the sedimentation of ions is of a great importance for semiconductor atomic technology of the materials in future. But the key topic is creation of the effective technology (profitable from commercial point of view).

Let us consider further laser photo-ionization method of obtaining the Ga^+ ions and optimal scheme for preparing the films of pure composition. We consider the ionization scheme of obtaining the Ga^+ ions, following to ref. [12]. The transition scheme is as follows; $4p^2P_{3/2}\rightarrow(\lambda_1=417{,}2$ nm$)\rightarrow 5s^2S_{1/2}\rightarrow(\lambda_1=420\text{-}440$ nm$)\rightarrow np^2P_{1/2.}$ (n=14-70). Modelling the optimal parameters for last process, i. e. ionization of the Rydberg states by electric field, can be carried out on the basis of methodise [9-12].

In figure 2 the results of the numerical modelling the Ga atoms separation process from the mixture on the basis of photo-ionization method and solving the corresponding differential equations system [12,13] are presented. 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 Ga. The δ -pulse provides maximum possible level of excitation (the excitation degree is about ~0,25; in experiment [2] with rectangular pulse this degree was ~ 0,1).

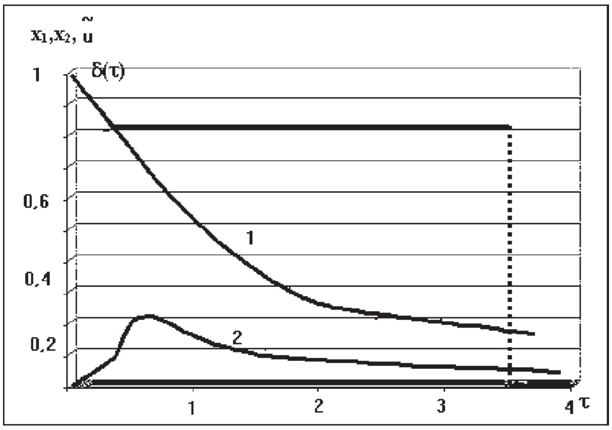

Fig. 2. Results of modelling Ga separation process from Ga-X mixture by the photo-ionization method (δ+dashed — laser pulse optimal form; curves x_1, x_2 are corresponding to populations of the ground and excited states).

In further the parasite processes such as spontaneous relaxation, resonant re- exchange can't change the achieved excitation level during a little time. The last step of the process is an ionization of excited atoms by the electric field pulse [9] (the field strength is 8,8 kV/cm). To get a high level of the optimality an electric field has to be switched on during the time, which is less than the excited state radiative decay time. In figure 3 we present the results of our calculating dependence of the ionization velocity for high excited atoms of Ga upon the electric field strength for states with quantum numbers n= 10-16,m=0,n2=n-1 [12]. The dashed line is corresponding to velocity of the radiative decay.

The decay of Ga atoms and ions in the high-excited state demonstrates the properties of the H-like systems at the qualitative level. But, there is quite significant quantitative difference. We have found that the ionization velocity for states with n>14 is more than the radiative decay velocity in electric

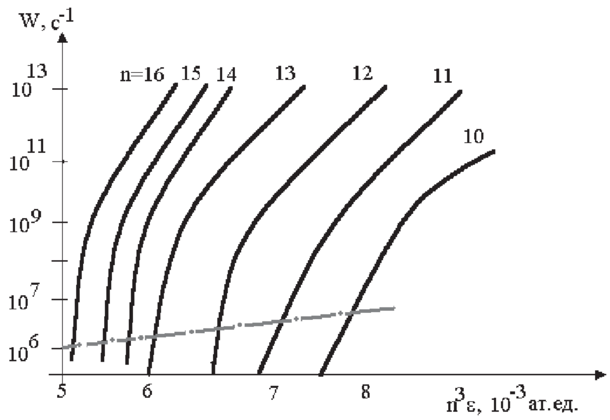

Fig. 3. Dependence of the velocity of ionization for high excited atoms of Ga upon the electric field strength for states with quantum numbers n=10-16, m=0,n_2=n-1.

field with strength E less than 15 kV/cm. Our estimate for the Ga atom ionization cross section is $1{,}5\cdot 10^{-13}cm^2$ that is higher than the corresponding cross section of ionization process by laser pulse in the two- stepped photo ionization [2] scheme ($\sim 10^{-17}cm^2$). Using δ-pulse provides a quick ionization, but the ionization yield will be less than 100% because of the sticking on intermediate levels. Experimentally obtained dependence of the critical ionization field strength E upon the effective quantum number n* is usually approximated by simple theoretical dependence $E_{cr}=(2n^*)^{-4}$. Our calculation results show that this is very approximate estimate and only consistent quantum calculation (c. f. [4,9] provides excellent agreement with experiment. In any case, 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.) could provide significantly more high yield and effectiveness of the whole process than the other known schemes [2]. So, we have considered new optimal equipment scheme for preparing the films of super pure composition during sedimentation of ions of the A^+ kind, which are obtained by optimal method of laser and electric field photo-ionization of the A kind atoms in the beam in mixture with other atoms.

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