Optik 130 (2017) 806–812

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Study of cesium and oxygen adsorption on surface of GaAlAs photocathode in ultra-high vacuum chamber

Xinlong Chen [a,*], Guanghua Tang [a], Shumeng Wang [a], Benkang Chang [b]

[a] Nanjing Electronic Devices Institute, Nanjing 210016, China
[b] School of Electronic and Optical Engineering, Nanjing University of Science and Technology, Nanjing 210094, China

ARTICLE INFO

Article history:
Received 4 September 2016
Accepted 31 October 2016

Keywords:
Cesium and oxygen adsorption
GaAlAs photocathode
Electron affinity
Spectral response

ABSTRACT

The mechanism of cesium (Cs) and oxygen (O) adsorption on GaAlAs photocathode has been investigated. The models of Cs and O adsorption on GaAlAs surface are studied, and the electron affinity changing with Cs coverage on GaAlAs surface is calculated based on Topping model. The experiments of Cs activation on GaAlAs and GaAs are performed, and the Cs, O activation experiments with different heat cleaning temperatures are performed on GaAlAs photocathodes. The photocurrent and spectral response curves in the experiments are measured and analyzed. The results show that the Topping calculation of electron affinity changing with Cs coverage on GaAlAs surface is in consistent with the result of experiment, and the electron affinity nearly reaches the bottom of conduction band after the Cs activation. The GaAlAs phtocathode treated by 700 °C heat cleaning could obtain a good photoemission performance after Cs, O activation.

1. Introduction

As we known, negative electron affinity (NEA) semiconductor photocathodes have already been widely used in low-light-level image intensifiers, ultraviolet detection, photon-enhanced thermionic solar cell, and potential electron sources for the next-generation electron accelerators due to their high quantum efficiency, low energy spread, and high spin polarization [1–4]. Different with GaAs, InGaAs, and GaN photocathodes, GaAlAs photocathode is a potential photocathode for the next-generation electron accelerators and the marine detection due to the long lifetime and the controlled threshold wavelength [5,6].

For most III–V s emiconductor photocathodes, the activation of Cs and O plays an important role on the preparation of photocathode [7]. The surface could approach or achieve zero electron affinity after Cs activation, and obtain negative electron affinity by Cs and O activation. The photoelectrons generated in the body of photocathode would cross the Cs-O active layer and emit into vacuum. High quality Cs-O layer is conductive to make more photoelectrons escape to vacuum, the surface electron escape probability is often used to evaluate the effect of Cs-O active layer. So far, there are plenty of reports about GaAs photocathode in theory and experiment, and detailed studies about the adsorption of Cs and O on GaAs surface [8–11]. In contrast to GaAs photocathode, there are few studies about photoemission performances of GaAlAs photocathodes, much less the adsorption mechanism of Cs and O on GaAlAs surface.

* Corresponding author.
E-mail address: cxlnjust@163.com (X. Chen).

http://dx.doi.org/10.1016/j.ijleo.2016.10.124
0030-4026/

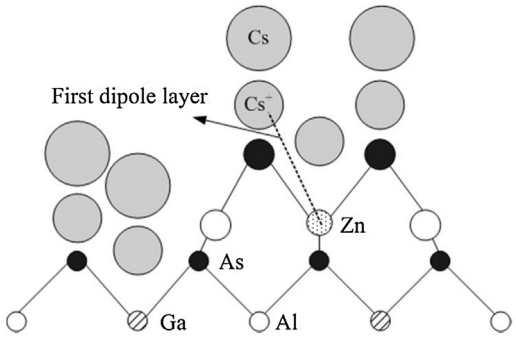

Fig. 1. GaAlAs(100) surface model after Cs adsorption.

In this paper, we focus on investigating the Cs and O adsorption mechanism of GaAlAs(100) photocathode in the ultra-high vacuum (UHV) chamber. The models of Cs and O adsorption on GaAlAs surface are built and the electron affinity changing with Cs coverage on GaAlAs surface is calculated based on Topping model. The experiments of Cs adsorption are performed on GaAlAs and GaAs surface. The Cs, O activation experiments with different heat cleaning temperatures are performed on GaAlAs photocathodes. The photocurrent and spectral response curves in the experiments are measured and analyzed.

2. Theoretical calculation

The 'yo-yo' activation technology was often used to prepare NEA photocathode, which Cs source was kept continuous and O source was introduced periodically [12]. There were lots of studies about GaAs(100) surface reconstruction model, which focus on GaAs(100) $\beta_2(2\times4)$ surface [13–15]. In contrast, the studies about GaAlAs(100) reconstruction were less. Yu et al. studied the properties of GaAlAs(100) $\beta_2(2\times4)$ surface [16,17]. The *p*-type GaAlAs material is often zinc (Zn) doping or beryllium (Be) doping. The GaAlAs surface models built in this paper are Zn doping. The atoms on the polar *p*-GaAlAs(100) surface have dangling bonds, which could react with Cs and form covalent bond. As we known, Cs is the most effective material to drop the surface electron affinity of semiconductor. For the GaAlAs(100) $\beta_2(2\times4)$ reconstruction surface, there exists several Cs adsorption positions, Cs atoms would rest on these positions and form the first dipole layer with the surface atoms. The GaAlAs(100) surface after Cs adsorption is shown in Fig. 1, where we presume the Zn atom replace the primary Ga atom.

In the process of Cs adsorption, the Cs on the GaAlAs surface loses 6 s outer valence electrons easily and turns to Cs^+ ion, which would combine with dangling bonds on the surface. In the *p*-GaAlAs surface, the Zn-centered cluster geometry has a big electronegative. The Cs^+ ion and Zn-centered cluster geometry form the first dipole layer, namely GaAlAs(Zn)-Cs, which would arouse the variation of electric potential and lower the surface electron affinity. When the Cs coverage on GaAlAs surface achieves a certain extent, the polarization and depolarization of dipoles would reach a balance. In this stage, the surface electron affinity reaches minimum and the GaAlAs photocathode has the best photoemission performance in the process of Cs adsorption. Following more coverage of Cs on the surface, the reaction of Cs-Cs would make the premier dipoles depolarized. The excess Cs atoms will form two dimension metal islands, which would cause the increasing of surface electron affinity and prevent the emitting of photoelectrons generated in the photocathode body.

For NEA photocathode, the surface dipoles induced by the atom adsorption will change the ionization energy of semiconductor. In comparison with Ga, Al, As and Zn atoms, the Cs atom has the minimum electronegative, but Cs has a large polarizability. The electron affinity changing induced by Cs adsorption follows the Topping model [18,19],

$$\Delta\chi = -\frac{e\rho n_{dip}}{\varepsilon_0}\left(1+\frac{9\beta n_{dip}^{3/2}}{4\pi\varepsilon_0}\right)^{-1} \tag{1}$$

where, ρ is moment of dipole induced by atom adsorption, e is electron charge, θ is atomic planar density, Θ is surface coverage, n_{dip} is product of θ and Θ of 1 ML adsorbent, ε_0 is dielectric constant, β is polarizability of adsorbed atom.

The moment of dipole is,

$$\rho = \Delta q(r_{Cs} + r_{sub}) \tag{2}$$

where, r_{Cs} and r_{sub} are covalent radius of Cs and substrate atoms respectively. Δq is the charge transferred to substrate atoms from Cs atoms, which could be obtained by the Pauling theory [20],

$$\Delta q = 0.16e|X_{sub} - X_{Cs}| + 0.035e(X_{sub} - X_{Cs})^2 \tag{3}$$

where, X_{sub} and X_{Cs} are electronegative of substrate and Cs atoms. According to Eq. (3), the contribution of Zn could be ignored because the proportion of Zn atoms in the GaAlAs surface is small. In the calculation, the electronegative of Ga, Al,