Optik 125 (2014) 6040–6043

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Study on the sensitivity decrease of reflection-mode GaN NEA photocathode

Jiangtao Fu*, Guoqiang Zheng, Songchun Zhang, Huahong Ma

Institute of Electronic Information Engineering, Henan University of Science and Technology, Luoyang 471003, People's Republic of China

ARTICLE INFO

Article history:
Received 28 October 2013
Accepted 2 June 2014

Keywords:
GaN photocathode
Spectral response curve
Incident wavelength
Potential barrier
Energy distribution

ABSTRACT

The experiment result discloses that the sensitivity of the reflection-mode NEA GaN photocathodes decrease with time after activation. Through analyzing the experiment result, it is found that the changes of the element content in the surface of the cathodes play an important role in the decrease course of the sensitivity. In order to explain the above result, a surface model of the reflection-mode NEA GaN photocathodes is put forward. By using this model, the inner mechanism leading to this result is that the dipoles direction changes because the harmful gases are adsorbed in the surface of the photocathodes.

1. Introduction

Negative electric affinity (NEA) GaN photocathodes made by the coadsorption of cesium and oxygen alternatively on the surface have many superior characteristics such as high quantum efficiency, low dark current, good spectrum response and low energy spread, so they have a vast application in the field of low light intensifier, spin polarization electron source and so on [1–4]. The NEA GaN photocathodes are produced under the "three-step" photoelectric emission theory put forward by Spicer, according to this theory, the quantum efficiency formula of the NEA GaN photocathodes can be deduced through solving the diffusion equation of the unequilibrium carriers. Because the GaN photocathodes are negative electric affinity photocathodes, the escape probability in the quantum efficiency formula is generally thought to have nothing to do with the incident photo wavelength [5,6]. But when applying the theoretical quantum efficiency formula to analyze the spectrum response of the GaN photocathode, there is always a deviance between the theoretical result and the experimental result. From the angle of fitting the experimental data with theoretical data, the relationship between them is concluded.

2. Experiment

A kind of uniform doping structure reflection-mode GaN sample was grown on the high quality p-type GaN oriented substrate with Be doping by molecular beam epitaxy (MB7/30/2014E). The thickness of the emission layer is 1.4 μm and the doping concentration is $1 \times 10^{-19}\,\mathrm{cm}^{-3}$. Before activation, the chemical cleaning of the sample is finished at first, after chemical cleaning the sample is placed into the heating position of the UHV system quickly, when the vacuum pressure in the system is lower than 1×10^{-17} Pa, the heat cleaning is carried out to purify the sample, the high temperature and the low temperature are 650 °C and 410 °C, respectively, the duration of the high temperature and the low temperature are 55 min and 15 min respectively. After heat cleaning, when the sample is cooled down to 60 °C and the vacuum pressure in the system recover back to 1×10^{-17} Pa, then the two-step "yo-yo" activation technique is applied to activate the sample. After activation, the spectral response is measured through the spectrum response measuring instrument and the result is shown as Fig. 1. In Fig. 1(b), curves 5 and 2 represent the spectral response one hour and two hours later after low temperature activation respectively, curve 6 represents the spectral response right after low temperature activation. Comparing with curve 6, curves 5 and 2 drop down very clearly. In the process of the low temperature activation, the O–Cs dipoles are damaged because of the desorption of Cs, the spectral response decreases continuously, especially the spectrum response decrease more quickly in long wavelength band. This phenomenon shows the escape probability

* Corresponding author.
E-mail address: fjtmengnan302@sina.com (J. Fu).

http://dx.doi.org/10.1016/j.ijleo.2014.06.096
0030-4026/© 2014 Published by Elsevier GmbH.

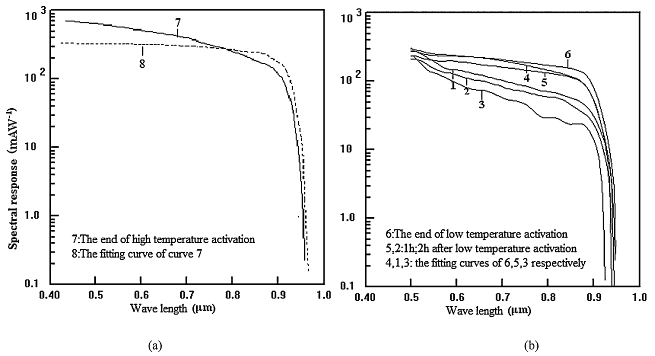

Fig. 1. Spectral response curves and fitting curves: (a) high temperature activation and (b) low temperature activation.

within different wavelength range is different; otherwise the dropping tendency of the spectral responses should be the same.

3. Relationship between escape probability and quantum efficiency

The escape probability P is the probability that the electronic can escape from the surface of the photocathode into the vacuum through tunneling through the surface potential barrier, so when the photon excited electrons reach the surface of the photocathode, their energy distribution and transmission rate will decide the value of P. Generally speaking, when the hot electrons excited by the photons transit from the valance band to the conduction band, they will lose some of their energy because of the scattering effect of the phonons and fall into the range within several Kt of the conduction band bottom, the energy distribution of the electrons satisfy the Fermi–Dirac distribution when they reach the band bending region. When the electrons pass the band bending region and get to the surface of the photocathode, their energy distribution $n(E)$ is calculated by Barterlink [7–9]. When the electrons arrive in the surface of the photocathode, they must tunnel through the surface potential barrier into the vacuum, all the electrons can only get into the vacuum with a transmission rate because of the surface potential barrier, the transmission rate $P(E)$ of the electrons with different energy can be acquired through solving the electron wave function equation [10], then the escape probability P can be decided by the transmission rate $P(E)$ and the energy distribution $n(E)$. Actually the escape probability P is the average value of the transmission rate of the electrons with different energy [9].

From the analysis above, the excited electrons quickly fall into the range within several Kt of the conduction band bottom, so their energy distribution does not have too much difference which means the energy distribution $n(E)$ is independent on the energy of the incident photons, the only factor that can affect the energy distribution $n(E)$ is the surface potential barrier, according to such conjecture, the quantum efficiency formula of the reflection-mode GaN photocathode can be acquired through the diffusion equation on the basis of the "three-step" model by Spicer [5,6,11]:

$$QE = \frac{P_\alpha L_D}{1+\alpha L_D}(1-R) \tag{1}$$

where P is the escape probability, α is the light absorption parameter, L_D is the electronic diffusion length, R is the reflection parameter of the photocathode.

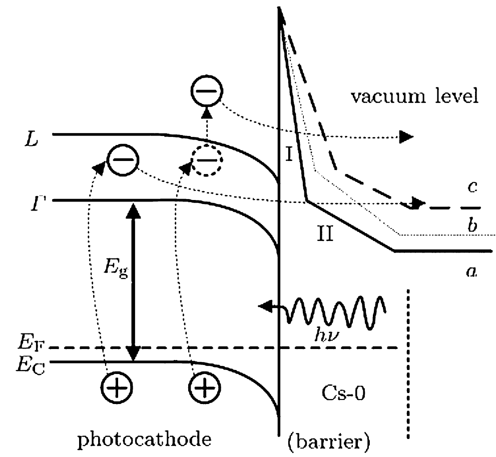

Fig. 2. Band structure of GaN photocathode.

4. Relationship between escape probability and the incident wavelength

By applying the theoretical quantum efficiency formula (1), the data fitting of the experimental curves are carried out.

The electron diffusion length L_D can first be decided through fitting the experimental curves 2, 5, 6 and 7 within the wavelength ranging from 800 nm to 880 nm,the fitting results of the four curves have good consistency and the value is 1.8 μm, then the fitting curves of the four experimental curves are acquired by using 1.8 μm in formula (1) as shown in Fig. 1. The fitting curves do not match the experimental curves very well. This mismatch discloses the inconsistency between the experiment result and the theoretical formula.

The reason leading to the inconsistency is the assumption that the escape probability independent on the incident wavelength cannot be applied for the NEA reflection mode photocathodes. In the reflection mode photocathodes, the light incident surface and the electrons emission surface are the same, so the photon excited electrons are mainly produced near the emission surface, then some electrons may escape into the vacuum before they fall into the bottom of the conduction band, this procedure can be realized through two different ways: one hand, the electrons in the conduction band can be thermalized at the bottom of the conduction band through relaxation, but the thermalization length is generally dozens of nanometers, so some electrons with high energy can escape into the vacuum with the hot electrons form; on the other hand, the photon excited electron first transmit from the valence band to Γ valley of the conduction band, before they escape into the vacuum, some electrons may have the energy high enough to be scattered into the L valley of the conduction band, some of these electrons in the L valley can directly escape into the vacuum, the photon excited electrons with energy lower than the L valley but higher than the minimum of Γ valley will probably escape into the vacuum in the shape of hot electrons. With the increase of the incident wavelength, the energy distribution of the electrons will move to the high energy direction. Some experiments have proved this result [12–15].

The surface band structure of the photocathode is shown as Fig. 2. The surface potential barrier is composed of two straight lines with different slopes: barriers I and II which is based on the double-dipole model. The dot lines b and c in Fig. 2 represent different barrier shapes under different situations [6,8,9]. In the process of activation, after first exposure to Cs, the surface potential barrier is just a approximate straight line, with continuously exposure to Cs