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Research Article

Study on Quantum Efficiency Stability of Reflection-Mode GaN Negative Electronic Affinity Photocathode

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Abstract: The aim of this study is to analyze the decaying and recovering mechanism of the quantum efficiency for reflection-mode GaN NEA photocathode. One kind of reflection-mode GaN NEA photocathode is designed and grown in the laboratory. The quantum efficiency curves are obtained immediately and six hours later after the sample is fully activated, the quantum efficiency data at different wavelengths are acquired according to the two different quantum efficiency curves, Through the analysis of experiment result, the inner factors resulting in quantum efficiency decaying are discussed. Taking the factors into consideration, the method of supplementing Cs is applied in recovering the quantum efficiency, the quantum efficiency can be partly recovered. The reason that the quantum efficiency can not be completely recorvered is also anylized.

Keywords: Negative electron affinity, quantum efficiency, reflection-mode NEA

INTRODUCTION

Recently with the fast developing of the information technology and detection technology, the ultraviolet detection technology has gradually become an important photoelectric technique both in civil and military fields. Negative Electron Affinity (NEA) photocathode's activated by the coadsorption of cesium and oxygen found widespread application in modern night vision image intensifiers. Allen (1971) The GaN NEA photocathode with characteristics such as high quantum efficiency, low dark current, quick response speed and high stability make it the most important component in the ultraviolet detection equipment (Su *et al.*, 1982; Wada *et al.*, 1990; Machuca *et al.*, 2002). Therefore, it has a very promising application future in the optoelectronic field. The GaN NEA photocathode in these equipments should have high quantum efficiency; also the stability of the quantum efficiency is demanded. In order to further exert the superior quality of The GaN NEA photocathode, it is necessary to study the decaying and the recovering mechanism of the quantum efficiency.

The stability of GaN photocathodes in a vacuum system has been widely investigated. The lifespan of the photocathodes dramatically decreases with an increase in water pressure in the vacuum system. An excellent operating lifetime is related to low vacuum pressure. Some viewpoints point out that the degradation of the photocathode is mainly caused by the adsorption of harmful gases on the surface instead of the desorption of cesium (Terekhov and Orlov, 1995; Liu *et al.*, 1970), but whether it is true needs more evidence to support. Despite a long history of investigation about the stability of the photocathode, there are few reports concerning Cs influence on the stability of NEA GaN photocathode.

In this study, In order to prolong the lifespan of the GaN photocathode and analyze the decaying and recovering mechanism of the quantum efficiency for reflection-mode GaN NEA photocathode, one kind of reflection-mode GaN NEA photocathode is designed and grown in the laboratory,through measuring the quantum efficiency at different moment, the main reason leading to the quantum efficiency degradation of NEA GaN photocathodes is concluded, the method how to recover the quantum efficiency is put forward, meanwhile the reason that the quantum efficiency can not be completely recorvered is also anylized.

Experiment for the decaying and recovering of the NEA GaN photocathode's quantum efficiency:

Decaying experiment of quantum efficiency: A sample of p-GaN photocathode doping with Mg is produced in the laboratory, the doping concentration of the element Mg in the sample is 9.8×10^{18} cm^{-3}, the thickness of the activation layer is 1um. The structure of the sample is shown as Fig. 1. Before we measure the quantum efficiency of the photocathode sample, the sample must be activated in the vacuum chamber. In order to make clear what influence element Cs on the quantum efficiency, different from the traditional

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Table 1: The quantum efficiency six hours later after activation

Wavelength/nm	230	250	300	350	360	380	400
QE1 immediate after activation/%	36.92	31.08	20.85	10.81	7.47	1.17	0.21
QE2 six hours later /%	27.94	22.03	12.34	5.08	3.23	0.44	0.01
Ratio QE2/QE1	75.8%	70.8%	59.1%	47.0%	43.2%	37.6%	4.77%

Table 2: The quantum efficiency 6 h later after supplementing Cs

Wavelength/nm	230	250	300	350	360	380	400
QE1 immediate after activation/%	36.92	31.08	20.85	10.81	7.47	1.17	0.21
QE3 six hours later after supplement Cs/%	36.90	29.59	19.68	9.92	6.65	1.03	0.09
Ratio QE3/QE1	99.94%	95.20%	94.38%	91.76%	89.02%	88.03%	50%

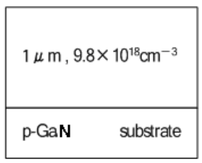

Fig. 1: The structure of the photocathode sample

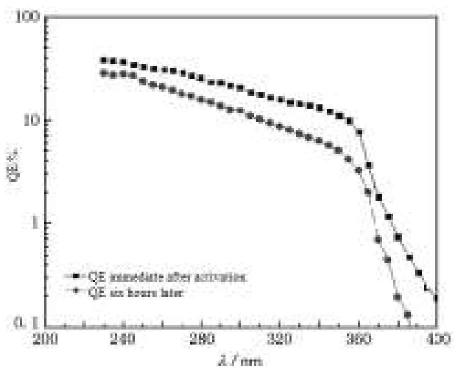

Fig. 2: The variation of the quantum efficiency after the photocathode is laid aside for 6 hours

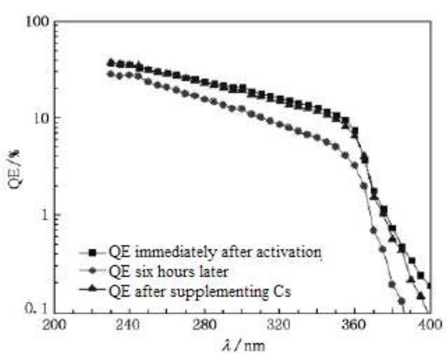

Fig. 3: The quantum efficiency curves of immediate activation, 6 hours later and supplementing Cs

activation mode, where the Cs source and the O source are turned on and off alternatively, the new activation mode which only turns on and off the O source alternatively but keeps the Cs source continuously is applied in this sample. In order to analyze the decaying situation of the quantum efficiency, the quantum efficiency is measured immediately and 6 h later after the activation, the two quantum efficiency curves are acquired. The variation situation of the quantum efficiency curves is shown as Fig. 2. After decaying for six hours, the quantum efficiency curve moves downward, this means the quantum efficiency of the photocathode decays obviously. The decline rate in the short wavelength region is smaller than that in the long wavelength region, which means the loss of the quantum efficiency in the short wavelength region is smaller than that in the long wavelength region.

The values of quantum efficiency at several wavelength points are listed in Table 1. All the quantum efficiency values are decreased when the GaN photocathode decays for six hours. The value at 230 nm decreases to 27.94% which is 75% of the value immediate after the activation; the values at 360 nm and at 400 nm are 43.2% and 4.77% of the original value respectively. Obviously the quantum efficiency decays more seriously in long wavelength region than in short wavelength region.

Recovering experiment of quantum efficiency: The decrease of the double dipole in the activation layer will lead to the decrease of the sensitivity of the photocathode; this kind of loss of the sensitivity can be partly recovered by supplementing Cs to increase the number of the double dipole. In order to investigate to how much extent the quantum efficiency can be recovered; the GaN photocathode which has decayed for six hours is supplemented with the element Cs, the result shows that the photocurrent improves with the supplement of Cs. The quantum efficiency values after supplementing Cs to the photocathode are listed in Table 2. From Table 2, we can see the quantum efficiency in the region from 230 nm to 350 nm can be recovered up to 92% of the original value, while from 350 nm to 380 nm the quantum efficiency can be recovered up to 88% of the original value.

The quantum efficiency curves under 3 different states are shown in Fig. 3. From Fig. 3, the quantum efficiency after supplementing Cs is almost recovered to the original value. This result expresses that supplementing Cs has a good effect on recovering the quantum efficiency.

RESULTS AND DISCUSSION

Decaying result discussion of quantum efficiency: According to the double dipole layer model which

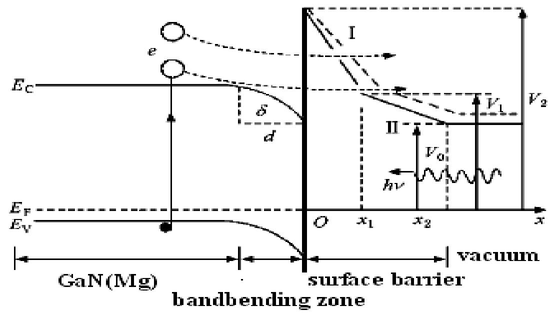

Fig. 4: The surface barrier and band structure before supplementing Cs and after supplementing Cs

formed by the element Cs and O, the number and direction of the double dipole [GaN(Mg:Cs)] and O-Cs in the activation layer have decisive function to the electronic escaping (Antypas *et al.*, 1970). After the photocathode is fully activated, during the decay course of the photocathode, the desorption of the element Cs in the surface of the photocathode will take place, also the surface of the photocathode can be adulterated by the impurity substance in the air, the reasons mentioned above can reduce the number of the double dipole in activation layer, the number of the electronic which can escape from the surface of the photocathode is cut down., naturally the quantum efficiency curve six hours later after the photocathode is activated moves downward. We can see from Table 1 and Fig. 1, the quantum efficiency decays more seriously in the long wavelength region than in the short wavelength region. With the wavelength increasing, the energy of the photo electronics decreases and the loss of the quantum efficiency increases. The reason leading to this result lies in the varying shape of surface potential barrier (Vergara *et al.*, 1995). The structure of the energy band and the surface barrier is shown in Fig. 4. In Fig. 4, the solid line represents the surface barrier immediately after activation, the dotted line represents the surface barrier six hours later after activation, obviously the width and the height of the surface barrier six hours later becomes wider and higher, so it is more difficult for the electron to penetrate into vacuum, naturally the quantum efficiency six hours later after activation is smaller than the value immediate after activation. Just because of the variation in width and height of the surface barrier, The longer the wavelength is, the weaker the energy of the electronic is, the quantum efficiency becomes smaller and smaller with the wavelength increasing (Ettenberg *et al.*, 1976).

In order to better understand the decay mechanism of the reflection-mode GaN photocathode, the quantum efficiency formula is given as formula 1 (James, 1974):

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

Many parameters can affect the quantum efficiency, P is the probability that the electronic can escape from the surface of the photocathode, α is the light absorption parameter, L_D is the electronic diffusion length, R is the reflection parameter of the photocathode, the α, L_D and R is decided by the material of the photocathode, so the real factor can affect the quantum efficiency is P. when the photocathode is laid aside for some while after activation, the desorption of Cs and the ambient impurity substance will deduce the double dipole formed in the activation layer, thus the surface barrier's width and height are changed, but P is the parameter representing the probability of electronic with different energy going through the surface barrier, the initial energy of the injected electronic and the height and width of the surface barrier can affect P, naturally the variation of P will change the quantum efficiency.

Reactivation result discussion of quantum efficiency: After supplementing *Cs* From Fig. 2, we can clearly see the recovering result after supplementing Cs, comparing the curve immediately after activation and the curve after supplementing Cs in Fig. 2, the quantum efficiency is almost recovered to the original value. From Table 2, the quantum efficiency at 230 nm and 235 nm are almost as same as the original value, but from 240 nm to 400 nm, the deviation between the recovered value and the original value becomes bigger and bigger, the quantum efficiency after supplementing Cs can not be recovered to the best value. When the photocathode is put aside for some while after activation, the quantum efficiency will decay obviously, the reason leading to this result lies in that the number of the effective double dipole become less, after supplementing Cs to the photocathode, the desorption of Cs is recovered, thus the number of the dipole is increased, naturally the quantum efficiency under the valve value 370 nm can be recovered up to 88% of the original value. Certainly the quantum efficiency can not be recovered to 100% of the original value, the reason is that the photocathode can absorb the impurity substance in the air, these impurity substance can take the empty position left by the desorption of Cs, so when re-supplementing Cs to the photocathode, even the Cs is enough provided, they can not take the position which has been taken by the impurity substance, thus the effective double dipoles are destroyed permanently. When the wavelength is under 370 nm, the quantum efficiency can be recovered up to 88% of the original value, this shows the desorption of Cs to the quantum efficiency loss outweighs the adsorption of the impurity substance. During the production of the photocathode, the pump keeps working to ensure the vacuum situation, so there is little impurity substance in the system, but the vacuum situation make the desorption easier.

On the other hand, after supplementing Cs, the ratio of the quantum efficiency immediate after activation against the quantum efficiency six hours later decreases with the wavelength increasing, which means the longer the wavelength is, the worse the recovering effect is. The variation of the potential barrier can contribute to this phenomenon. As shown in Fig. 3, the barrier can be partly recovered to the original level because of supplementing Cs, so the quantum efficiency can be well recovered, but because of the permanent destruction of the double dipole caused by impurity substance, the width and the height at the end of the potential barrier can not be completely recovered, as shown in Fig. 2, the quantum efficiency curve after supplementing Cs is between the other two curves.

CONCLUSION

According to the result of the decaying and recovering experiment of the reflection mode GaN NEA photocathode, the decaying and recovering mechanism of the GaN NEA photocathode are studied. According to the energy band structure, the shape of the barrier before decaying and after decaying and the quantum efficiency formula, the relationship between the decaying regular, the recovering result and the variation of the barrier is concluded. The result shows the loss of the quantum efficiency increases with the wavelength increasing, this is because the destruction of the double dipole change the shape of barrier I and barrier II, the variation of the barrier leads to the change of the escaping probability of electron at different wavelength point, thus the decaying extent of the quantum efficiency varies with the varying of the injection light wavelength. By supplementing Cs to recover the desorption, the quantum efficiency can be well recovered, but can not be completely recovered because of the impurity substance.

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