Rapid Communication

In-situ multi-information measurement system for preparing gallium nitride photocathode*

Fu Xiao-Qian(付小倩)[a)b)], Chang Ben-Kang(常本康)[a)†], Qian Yun-Sheng(钱芸生)[a)], and Zhang Jun-Ju(张俊举)[a)]

[a)] *Institute of Electronic Engineering and Optoelectronic Technology, Nanjing University of Science and Technology, Nanjing* 210094, *China*

[b)] *School of Information Science and Engineering, University of Jinan, Jinan* 250022, *China*

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We introduce the first domestic *in-situ* multi-information measurement system for a gallium nitride (GaN) photocathode. This system can successfully fulfill heat cleaning and activation for GaN in an ultrahigh vacuum environment and produce a GaN photocathode with a negative electron affinity (NEA) status. Information including the heat cleaning temperature, vacuum degree, photocurrent, electric current of cesium source, oxygen source, and the most important information about the spectral response, or equivalently, the quantum efficiency (QE) can be obtained during preparation. The preparation of a GaN photocathode with this system indicates that the optimal heating temperature in a vacuum is about 700 °C. We also develop a method of quickly evaluating the atomically clean surface with the vacuum degree versus wavelength curve to prevent possible secondary contamination when the atomic level cleaning surface is tested with X-ray photoelectron spectroscopy. The photocurrent shows a quick enhancement when the current ratio between the cesium source and oxygen source is 1.025. The spectral response of the GaN photocathode is flat in a wavelength range from 240 nm to 365 nm, and an abrupt decline is observed at 365 nm, which demonstrates that with the *in-situ* multi-information measurement system the NEA GaN photocathode can be successfully prepared.

Keywords: gallium nitride, photocathode, *in-situ* multi-information measurement

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1. Introduction

A gallium nitride (GaN) photocathode is a so-called solar-blind negative electron affinity (NEA) photocathode with characteristics such as high quantum efficiency, low dark current, quick response speed, and high stability. Therefore, it has very promising applications in the optoelectronic field such as ultraviolet detection and photon-counting.[1−9] How to achieve the effective NEA state is a key point in GaN photocathode preparation. Since heat cleaning and activation in an ultrahigh vacuum (UHV) environment are the two decisive factors during preparation, collecting as much information as possible will definitely help us to form some rules for successfully preparing NEA GaN photocathodes and also make the preparation more stable and repeatable. Therefore, according to our former photocathode preparation system[10−12] and considering the special properties of GaN material, we construct an *in-situ* multi-information measurement system, through which we can obtain lots of key parameters to control preparation, as well as to attain an NEA GaN photocathode successfully.

2. System organization

This *in-situ* measurement system is composed of four main parts: light sources, a UHV chamber, multi-information measurement and control circuits, and a computer as shown in Fig. 1.

Here, we use two light sources to fulfill the activation and spectral response measurement, respectively. The former light source is a deuterium lamp for measuring the photocurrent of GaN, which can produce a continuous spectrum from 160 nm to 400 nm. The latter is a xenon lamp for testing spectral response, which has a larger wavelength range (from 190 nm to 1100 nm), and can be used not only for GaN but also for other III-V semiconductors such as GaAs and InP. The light

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†Corresponding author. E-mail: bkchang@mail.njust.edu.cn

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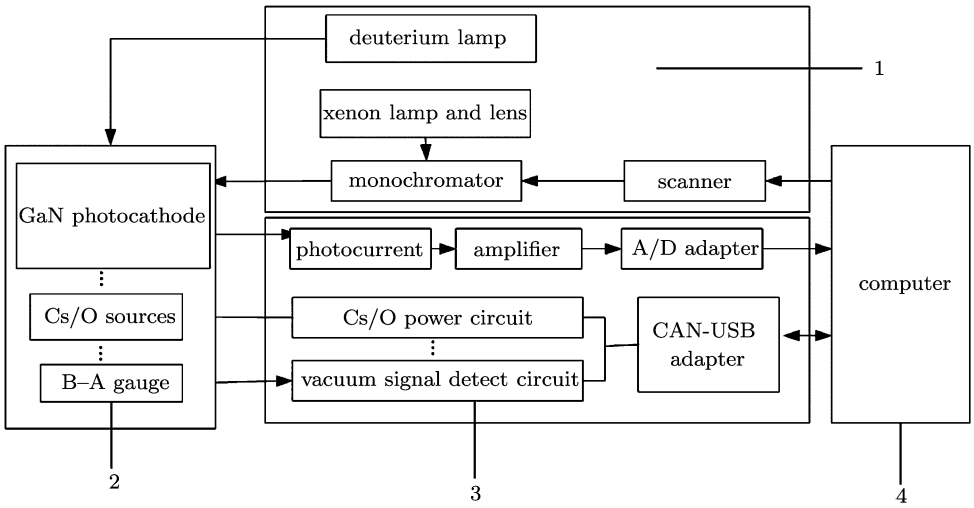


Fig. 1. Schematic diagram of a multi-information measurement system for a GaN photocathode (1. light sources, 2. UHV chamber, 3. multi-information measurement and control circuits, 4. computer).

from the xenon lamp first passes through a monochromator, which is connected with a scanner controlled by the computer. Therefore, the computer can control the spectral range (230 nm–400 nm) of the xenon lamp light.

The UHV chamber, where GaN samples are heated and activated, is equipped with a mechanical pump, a turbo pump, a splash ionic pump, and a titanium sublimation pump, and its highest degree of vacuum can reach 3.3×10^{-8} Pa. A magnetic transmission pole is used to transfer the sample between the apparatuses. Meanwhile, the tungsten–halogen lamp for heating the photocathode, the thermocouple for temperature measurement, the Bayard–Alpert gauge for vacuum measurement, and Cs and O sources are all included in this part.

The multi-information measurement and control circuits are connected as a distributed data test and control network based on a controller area network (CAN) bus. This part is responsible for gathering and processing the signals from the apparatuses placed in the UHV chamber, and transferring the signals to the computer, thereafter the apparatuses are controlled by the computer. During heat cleaning, the temperature and the degree of vacuum in the UHV chamber are measured. The measured data are transferred into the computer, which instantly draws an on-line curve with these messages and helps to evaluate the effect of heat cleaning. When the sample is activated, the Cs doser and O doser are powered by two digital potentiometers which are controlled by a microcontroller through a relay. The collected photocurrent is first processed by the amplified circuits and A/D adapter and then transmitted to the computer.

In addition, X-ray photoelectron spectroscopy and a quadrupole mass spectrometer are used to analyse residual components on the sample surface and to evaluate the stability of the GaN photocathode in the activation chamber.

The interface created by using the software Visual C++ 6.0 can be used to visually control and measure the multi-information during cathode preparation. Therefore, the preparation effect can be evaluated and the relevant characteristics can be obtained very conveniently.

3. Measurement and discussion

When the heat cleaning is started, the GaN sample is first transferred to the heating platform in the UHV chamber by a magnetic transmission pole. The temperature indicator controls the tungsten–halogen lamp to irradiate the photocathode surface, then the data of temperature measured by the thermocouple and the data of vacuum degree obtained by the B–A gauge are transferred into the computer. Therefore, those data can be instantly drawn on the computer screen as shown in Fig. 2.

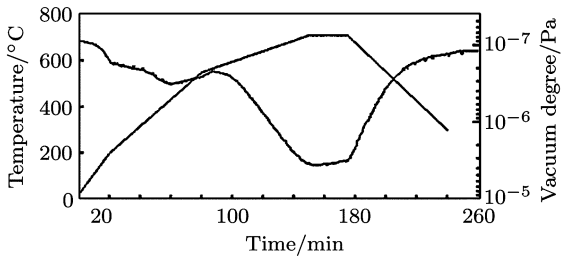


Fig. 2. *In-situ* vacuum and temperature measurement curves during heat cleaning of the GaN sample.

From this figure, we can see three temperature turning points at 200 °C, 600 °C, and 700 °C, respectively. At the beginning, the halogen lamp is controlled to heat the sample with a linear temperature increase. The temperature increases quickly to 200 °C, and then gradually to 600 °C. Meanwhile, the degree of vacuum declines gradually in the temperature range (0 °C–600 °C). And then an abrupt reduction of the degree of vacuum is observed when the heat temperature is increase from 600 °C to 700 °C. The temperature is kept constant for about 30 min and the vacuum degree is also maintained at about 7×10^{-5} Pa. Finally, with the fast temperature decreasing, the degree of vacuum of the chamber increases abruptly back to a high level. This procedure shows that the desorption of most residues from the surface takes place at about 700 °C, which is in good accordance with the results from other researchers.[13,14] Such a profile as shown in Fig. 2 appears in almost all the samples in our experiments, which means that once we obtain such a kind of vacuum–temperature curve, we do not have to test the surface residue with X-ray photoelectron spectroscopy (XPS). In most cases, XPS inevitably introduces some other residue into the surface again. The profile can help us to evaluate the surface condition very quickly and can be used as a new method to judge whether the surface is atomically clean, with the sample untouched.

After heat cleaning and achieving an atomically clean surface, activation starts when the surface temperature of the GaN sample cools down to about 60 °C, during this process the Cs activation is continuous and the O activation is intermittent.

First, the Cs source power is switched on and adjusted down to a minimum position, and then it is controlled by the computer. Under the control of a computer, the power value increases to a specific value and this value is kept unchanged for some time during which we can observe that the *in-situ* photocurrent increases gradually and then comes down to the first crest. When the current declines for about 10 min, O activation starts with a minimal O current. As O current increases gradually, a great enhancement of GaN photocurrent happens at a certain O current value. We keep this O current unchanged for a while and then stop the O exposure, under which the observed photocurrent continues to increase until the second crest occurs. The O source is switched on again when the photocurrent decreases to about 90% of the second crest. When the next crest occurs, the O source is switched off again. This procedure continues until the last two photocurrent crests are almost the same and then the activation is finished. Recent experiments have shown that when Cs current and O current are 1.66 μA and 1.62 μA, respectively, the ratio of which is about 1.025, the photocurrent is greatly enhanced. However, the optimal Cs/O ratio still needs to be investigated in further experiments.

Here, a deuterium lamp is used to serve as an ultraviolet (UV) light source, and the power incident on the GaN surface is about 30 μW. The photocurrent is amplified by the circuits, and an A/D adapter is used to convert the signal into digital form, which is transferred to the computer. Thereafter, the computer draws the *in-situ* photocurrent curve as shown in Fig. 3.

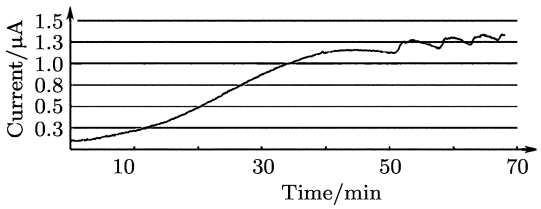


Fig. 3. *In-situ* photocurrent curve during activation of a GaN sample.

After activation, we start to test the spectral response or quantum efficiency with the xenon lamp. The light from the xenon lamp passes through a grating monochromator which is controlled by a scanner, and then the monochromic light in a certain wavelength range from 230 nm to 400 nm is directed to the GaN photocathode surface. The photocurrent is stored as a digital signal by the computer. By using the software the spectral response curve is instantly drawn on the screen as shown in Fig. 4.

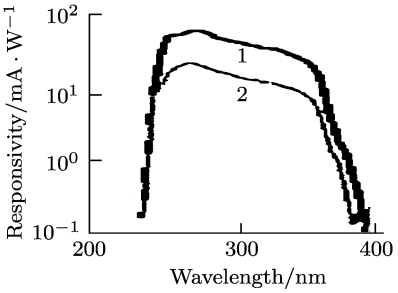


Fig. 4. Two *in-situ* spectral response measurement curves of a GaN photocathode sample.

The spectral response wave shows that the GaN photocathode has a flat response in a wavelength range from 240 nm to 365 nm, and a good sharp cut-off frequency property at a wavelength of 365 nm, which

indicates that a UV GaN photocathode with NEA is successfully obtained.

4. Conclusion

Based on the specific characteristics of GaN, we explore multi-information measurement technology and develop an *in-situ* multi-information measurement system for preparing a GaN photocathode. This system can fulfill the *in-situ* measurement of the degree of vacuum and temperature during heat cleaning, the photocurrent, Cs current, O current during activation, and the spectral response and quantum efficiency after activation. The measurement results show that the optimal heat cleaning temperature for a GaN photocathode is about 700 °C. With the vacuum–temperature curve, we develop a method of quickly evaluating the heat cleaning efficiency of a GaN photocathode. During activation, by drawing *in-situ* photocurrent waves, we find that the photocurrent increases greatly when Cs current and O current are 1.66 μA and 1.62 μA, respectively, in recent experiments. The optimal ratio of Cs current to O current still needs further investigation in this system. The spectral response shows that after activation, the GaN photocathode has a very good sharp cut-off wavelength characteristic at about 365 nm. This system plays an important role in the preparation and the evaluation of a GaN photocathode and also other III-V semiconductor photocathodes.

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