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The influence of surface barriers on the photoemission characteristics of AlGaN photocathodes

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ABSTRACT

In order to research the photoemission characteristics of AlGaN photocathodes with different surface barrier structures, AlGaN photocathodes with varying Al composition were grown by MOCVD. The atomic composition of the photocathode surface was measured by Ar^+ ion sputtering and XPS. We find that the C atoms only exist at the surface, but O atoms are present up to 6 nm from its surface. The photocathodes were cleaned and activated with different processing methods, and the result show that the quantum efficiency value of Cs/O activated AlGaN photocathodes were about 42% higher than that of Cs-only activated AlGaN photocathode. Through thermal cleaning at 850 °C and Cs/O activation, the maximum quantum efficiency of the AlGaN photocathode was 49.39% at 240 nm. Through simulation of the electronic energy distribution, we determined that the surface barrier I structure formed by [AlGaN: Mg-Cs] dipoles at the photocathode surface was mainly affecting the surface electrons escapes probability and determining the photocathode quantum efficiency. The surface barrier II structure formed by [Cs-O] dipoles at the photocathode surface determined the photocathode performance, and also affected the electronic energy distribution concentration.

1. Introduction

The AlGaN photocathode has been a key photoelectric conversion unit in solar-blind photodetectors and ultraviolet (UV) ray responder due to its low dark current and high stability [1–3]. Also AlGaN the photocathode was a potential electronic source in the light source, the light modulated traveling wave tube and the terahertz laser for its concentrated electronic energy distribution. As a result the quantum efficiency and the electronic energy distribution of AlGaN photocathode have been important parameters for evaluating the vacuum device performance. At present, AlGaN photocathodes are activated by Cs/O alternation [4–7]. The Cs and O atoms adsorption efficiency and surface cleanliness of the photocathode directly determines the surface barrier structure [8,9]. The smaller the surface barrier width and the lower the vacuum energy level is, the greater possibility for the electrons to emit to the vacuum, and this possibility was positive related to the electronic energy. Therefore, the surface barrier structure of the AlGaN photocathode determines the energy distribution of the emitted electrons and the photocathode performance, but this has rarely been reported.

When the electrons move to the photocathode surface from the internal emission-layer, their energy steadily decreases due to scattering in the AlGaN crystals, as phonon scattering and ionized impurity scattering. Although the scattered energy

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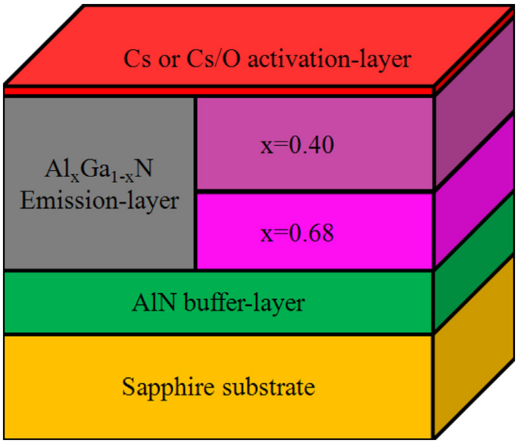

Fig. 1. A schematic diagram of the AlGaN photocathode structure. The buffer-layer and emission-layer were grown by MOCVD, and the activation-layer was deposited during preparation processing in an ultra-high vacuum system.

of the electrons differs, most of the electronic energy is concentrated over a certain range. Because high energy electrons have a greater chance into escape to the vacuum than low energy electrons, the energy destitution of the emitted electrons continuously changes with the surface barrier structure of the AlGaN photocathode. Therefore, the surface properties of the activated AlGaN photocathode represent its photoemission performance potential. In this paper, reflection-mode AlGaN photocathodes with the same structure were cleaned and activated with different technologies. The surface barrier structures of the photocathode surfaces were analyzed from the viewpoint of surface atomic composition and Cs/O activation processing. From the electron transport process, the electronic energy distribution was simulated for different surface barrier structures, and the relationship between electronic energy distribution and photoemission characteristics was reviewed.

2. Experimental

The activated AlGaN photocathode was composed of a substrate, buffer-layer, emission-layer and activation-layer, as shown in Fig. 1. The AlN buffer-layer was grown on double-side polished (0001) sapphire, its thickness and Mg doping concentration was 200 nm and 5×10^{17} cm^{-3}, respectively. In order to improve the emission-layer crystal quality and increase electrons transport, the emission-layer was composed of double layers, and the Al composition was 0.68 and 0.40 for each layer, and the thicknesses was 20 nm and 80 nm. The Mg doping concentration was 5×10^{18} cm^{-3}. The buffer-layer and emission-layer of the AlGaN photocathode were grown by MOCVD. The activation-layer was deposited onto the photocathode surface during the preparation processing in an ultra-high vacuum system.

Because O atoms could affect the photocathode surface cleanliness and affect Cs adsorption, it is necessary to know the O atom content and its distribution near the surface. The atomic composition located near the surface of the AlGaN photocathode was measured using a monochromatic Al $K\alpha$ X-ray radiation ($h\nu$ = 1486.6 eV) by XPS in a PHI 5000 VersaProbe II system. After the atomic composition of the surface was tested, Ar^+ ion sputtering was introduced to etch the photocathode surface at the same position with a step size of 2 mm × 2 mm. The etching processing time was 15 s, and the ion energy was 4 kV. XPS analysis was then carried out after the Ar^+ ion sputtering. The etching process was repeated until the photocathode surface contaminants were reduce reduced to zero.

The contaminants at the AlGaN photocathode surface will change its surface properties and reduce Cs atom adsorption efficiency. So it is reasonable to clean the AlGaN photocathode samples and makes them an atomically clean surface. Four AlGaN photocathode samples were taken in this experiment with size 10 mm × 10 mm and named sample 1, 2, 3 and 4, respectively. The first chemical cleaning step was to remove the samples surface organic compounds using acetone and carbon tetrachloride. Then, the samples were cleaned by bathing in KOH solution for 50 s and in a sulfuric acid mixed solution for 10 min [10]. The concentration of the KOH solution was 1 mol/L. The sulfuric acid mixed solution was prepared by H_2SO_4, H_2O_2 and deionized water at a 2:2:1 ratio. Finally, the sample surface was rinsed with deionized water before dewatering in alcohol.

After the samples were cleaned in chemical solution, the samples were mounted in an ultra-high vacuum system. The samples 1 and 3 were thermally cleaned at 710 °C, and the samples 2 and 4 were thermally cleaned at 850 °C. The heating rate was 4 °C/min from room temperature to the maximum value. The cooling rate was fixed at 7 °C/min from the maximum temperature to 300 °C, and then allowed to cool naturally to room temperature.

Cs/O activation was the last step of the photocathode preparation. The samples 1 and 2 were activated by Cs-only. The sample 3 and 4 were activated by alternating Cs and O. A deuterium lamp was used as the activation light source. The preparation was deemed complete when the photocurrent no longer increased. Then the spectrum responses of the AlGaN photocathode samples were measured with monochromatic light ranging from 240 nm~310 nm.