Synthesis of the multialkali photocathodes by molecular beam epitaxy

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ABSTRACT

A compeletely new technique of growing $(Na,K)_3Sb$ multialkali photocathodes in the high vacuum facilities of the molecular beam epitaxy (MBE) is developed. The main principle of semiconductor technology is used: all sources are operated simultaneously and the vapour concentration of Na and K is well above of the stoichiometric one. The intensity flux control is provided with the help of a specially designed quadrupole masspectrometer as well as with the original procedure of atomic beams tomography. Fast baked effusion cells having low heat intertia have been designed. The photocathodes synthesis is provided onto monocrystalline sapphire substrates, on which the contact tungsten ring is eveporated. The choice of tungsten is determined by its small vapourization during the course of the substrate high temperature (1300°K) processing. It is important to note that the total cycle of the photocathode growing process does not exceed 15-20 minutes for the photocathode thickness of about 1000 Å. We have studied the influence of the substrate temperature on photoemission parameters. Quantum efficiency of the MBE grown photocathodes approaches to ten-forty percents at blue sensitivity edge. A qualitative emission theory of the MBE grown photocathodes is suggested.

INTRODUCTION

In spite of the evident success in fabrication of the negative electron affinity (NEA) photocathodes, the classical type photocathodes, namely the silver-oxygen-caesium (S1) and multialkali antimonide (S11, S20, S25, etc.) photoemitters still attract attention of the experimentalists due to their very high quantum efficiency in the blue edge (S20), and noticable infrared sensitivity up to 1.5-1.6μm (S1), and their long life time in photoelectron devices, We have started our own research in the physics of photoemission and photoemitters by choosing as a first step the multialkalai photocathodes. We understood that bulk and surface structure of these photocathodes depends on fabrication technology, as well as on their film growing procedure. In order to create reproducible technology for photocathode fabrication, we have used molecular beam epitaxy (MBE) technique in vacuum for all photocathode ingredients. In this paper we wish to present the first successful attempt in growing bialkali photocathodes by a very promising MBE technique.

EXPERIMENTAL INSTALLATION

Fig.1 presents the general view of the experimental set up which was developed by us for the multialkali photocathodes synthesis. In the growing chamber of our molecular-beam epitaxy installation, the vacuum was about 10^{-10} Torr. To obtain such a good vacuum is a quite sophisticated problem due to very high pressure of the residual Na and K vapours.In order to avoid this problem we have inserted Na and K samples inside the very thin tubes having less than one millimeter internal diameter. These tubes were blocked by the oxide films, which made it possible to heat the complete system up to 100°C without the presence of K and Na vapours.

For creation of K,Na and Sb molecular fluxes, the special fast baked, effusion cells having low heat inertia of approximately one minute were constructed. K and Na thin tube sources were installed inside these Knudsen cells.

The photocathode film deposition was monitoring in situ with the help of specially designed quadrupole masspectrometer. The latter instead if internal ionization volume was equiped with the external electron-beam ionization source.Additional monitoring was arranged by luminuoscence recording, arised due to electron impacts with the atoms of K,Na,Sb molecular beams.

PHOTOCATHODE FILMS GROWING PROCEDURE

Molecular beam epitaxial growing of Na_2KSb photocathodes starts from the short overheating of the elemental K and Na sources. This overheating helps to destroy the blocked oxide films. In the course of the film growth, the effusion cells temperature was kept as the following: Na - 493°K, K - 413°K, Sb - 713°K. For molecular beams shaping, the additional cryogenic panels, cooled to liquid nitrogen temperature were installed in the photocathode substrate vicinity. Photocathodes were deposited onto monocrystalline saphire substrates having

(0001) orientation. The contact tungsten ring is evaporated onto the saphire by a so-called "blowing up" technique. Tungsten was chosen because of its small vaporization during high-temperature training of the substrate at 1300 °K.

The optimum ratio among fluxes intensities can be achieved as the result of the photocathodes structure and photoemission parameters investigation "in situ". In our first experiments, the intensity flux ratio among Sb:Na:K was equal to 1:5:10. The growth rates were typically 1 Å/s. Thus, the overall growing period of the bialkali photocathode, having approximately 1000 Å thickness, was about ten-twenty minutes.

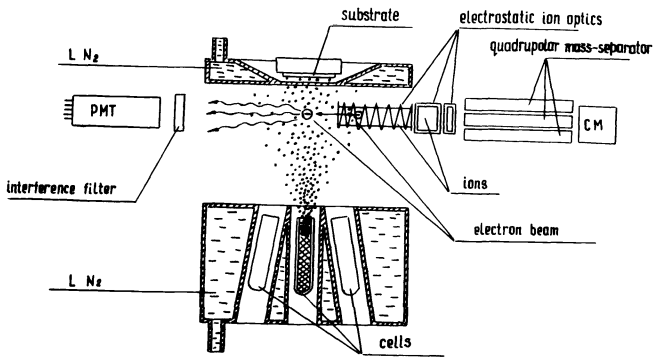


Fig.1. The experimental installation for the MBE growth multialkali photocathodes LN_2 - liquid nytrogen, PMT - photomultiplier, CM - control monitor

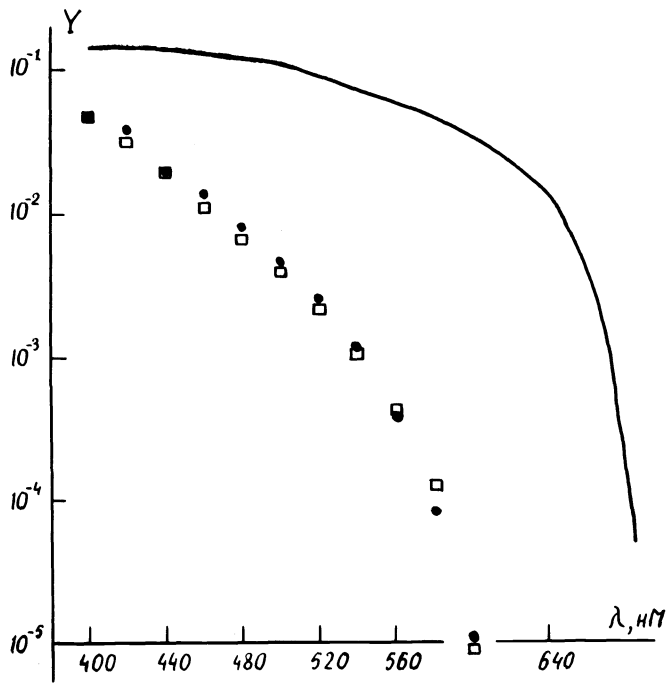


Fig.2. Quantum yield curve for the MBE grown bialkali photocathode

During multialkali photocathodes synthesis we have used one of the principal idea of the semiconductor technology, which assumes the simultaneous deposition of all ingredient molecular beams on the substrate. The substrate temperature during the photocathodes synthesis was in the range of 388 °K. Grown at this temperature, photocathodes films have exposed stable photoemission parameters for a period of months. But the MBE photocathodes which were fabricated at the higher substrate temperature have exhibited much poorer characteristics. The color of the epitaxial deposited films was yellow-brown with the reddish shade, in other words they have color which was quite similar to the color of traditionally fabricated multial-kali photocathodes.

We have measured the photoemission parameters of the grown photocathodes inside of the vacuum chamber just after finishing of the growing procedure. In order to provide this operation we have illuminated the photocathode through the quartz input window and the ring type photoelectron collector was installed in the close vicinity to the substrate. Intensity of the input radiation was absolutely calibrated with the help of standardized light detector. Fig.2 shows the typical spectral response curves for the MBE grown bialkali photocathodes. In this figure the experimental data presented by dots, and the theoretically predicted - by squares. At the right hand corner, the typical bialkali spectral response is presented. As one can see from the picture, the photoemission threshold for the MBE grown photocathodes is shifted towards blue side as comparing with the traditional response curves. This photoemission blue shift, is possibly connected with the n-type conductivity of MBE grown photocathodes.

PROPOSED PHOTOEMISSION MODEL

In order to explain the blue shift in MBE grown bialkali photocathodes with respect to the spectral response of the traditionally fabricated ones, we wish to suggest a simple theoretical model. We are assuming that our photocathodes has n-type conductivity. It is quite possible due to lack of elemental Sb inside the photocathode film in comparison with its normal stoichiometric configuration. It may be easily occured during the MBE fabrication process.

Our model (see Fig.3) takes into account the surface band-banding (E_s), as well as the

average energy loss of excited photoelectrons per length unit (q). The quantum photoemission yield obtained in such a model can be described by the following manner:

$$Y_\nu = \frac{1}{2}(1-R)\alpha_\nu \int_0^{x_0} \left[1-\left(\frac{h\nu - V_{eff}}{E_A}+1\right)^{-1/2}\right] e^{-\alpha_\nu \cdot x}\, dx,$$

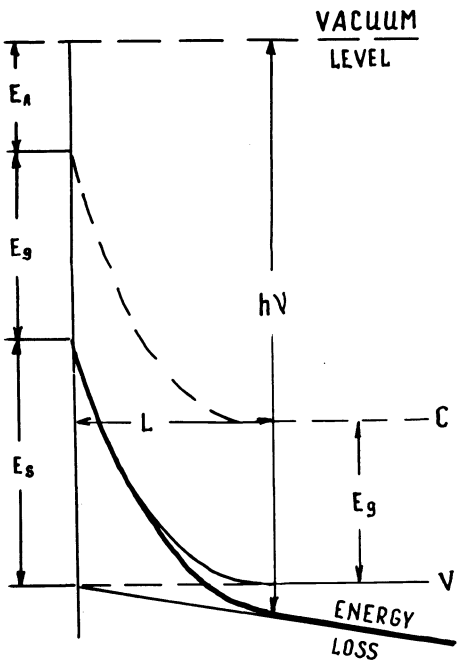
where R - is light reflection and α_ν - is the light absorption coefficients, ν - is the incident light frequency, h - Plank constant, x_ν - is the photoemission depth.

We will present the minimum energy needed for electrons to escape into vacuum depending on their depth of excitation as:

$$V_{eff}(x) = \begin{cases} E_A + E_g + E_s\left[1-(1-x/L)^2\right] + qx, & x \le L \\ E_A + E_g + E_s + qx, & x > L, \end{cases}$$

where E_A - is the electron affinity; E_G - is the inherent electron band gap; E_s - is the surface band-banding; L - is the screening length; x_ν - is the film depth from which "vacuum" electron is generated and which is defined by the following condition:

$$V_{eff}(x) = h\nu$$



Parameters E_G, E_A, E_s, q, L were variated for the following functional minimum searching:

$$\Phi = \sum_{i=1}^{N}\left(1-\frac{Y_{th}^i}{Y_{ex}^i}\right)^2,$$

where N - is the number of experimental values, Y_{th}^i - is the theoretical value of the quantum yield, Y_{ex}^i - is the experimental value of the quantum yield. The functional Φ minimum was realized under the following values of variables: E_G=1 eV; E_A=1.04 eV; E_s=0.6 eV; $q=7\cdot10^4$ kV/cm. These data are in a good agreement with the experimental ones which were taken earlier for usial bialkali photocathodes.[2]

Fig.3. The illustration of the band structure for n-type bialkali photocathodes, where energy losses taken into account

CONCLUSIONS AND ACKNOWLEDGEMENTS

Our first successful attempts to grow bialkali photocathodes by the MBE-technique confirm the evident advantages of this procedure for fast, reliable and reproducible production of efficient, classical type photoemitters. On the basis of the obtained results we are ready now to grow and investigate in more details not only bialkali but also multialkalai photocathodes. It means that the structure of the photocathode lattice as well as precise chemical components contain have to be searched. Another important question is to define the influence of molecular beams ratio during MBE process, and the conductivity type of the grown thin films. We are hoping that the suggested MBE growth technology for multialkali photocathodes is a very important new step after invention of these photocathodes by A.Sommer in 1955[3].

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