Multialkali photocathodes grown by MBE technique

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ABSTRACT

A new technique of bialkali photocathodes growth by molecular beam epitaxy (MBE) has been developed. The photocathode film was deposited onto the substrate from molecular beams produced by simultaneously operating molecular sources of Sb, Na and K. Thus suggested procedure is noticeably differed from the classical one. Growth rate was about 1 A/sec and complete cycle of photocathode fabrication was 15-20 minutes. A special ultra high vacuum (UHV) chamber for MBE of multialkali photocathodes has been designed. The chamber is a part of UHV system consisting of an analysis vessel supplied with Auger and ESCA electron spectrometer and low energy electron diffractometer (LEED), the MBE chamber itself and a chamber for cold sealing of photocathodes with device body through indium ring. The system gives a possibility to carry out investigations of multialkali photocathode physics and to produce commercial devices. Developed technique can be used for fabrication of vacuum devices including streak tubes.

1. INTRODUCTION

In spite of developing solid light detectors image converting tubes containing photocathode are widely used in both scientific work and standard TV systems because of their high time resolution and low noise level. Recent time there is evident success in fabrication of the negative electron affinity (NEA) photocathodes, but the classical type of photocathodes, namely multialkali antimonide photoemitters[1] still attract attention of the scientists due to their great quantum efficiency[2] and their long life time in photoelectron devices.[3] We have started our own investigation in physics of photoemission and photoemitters by choosing as a first step the bialkali $(Na,K)_3Sb$ photocathodes.

$(Na,K)_3Sb$ photocathodes is the basic one for the most successful multialkali (Na-K-Cs-Sb) photocathodes. This photocathode also has very good performances even at rather high environmental temperature (up to 150^0C). The Na-K-Sb system, also called the S-24, is considered to be the fundamental one for different type of multialkaline photocathodes and constitutes the bulk of the S-20 thin film.[4]

It is well known that bulk and surface structure of these photocathodes depends on fabrication technology, as well as on their film growing procedure. Now two types of different technology is known for multialkali photocathodes fabrication[5]:

1) Initial evaporation of Sb base layer of variable thickness, followed by activation by alkali metals.

2) Initial formation of K_3Sb cathodes by "coevaporation" of Sb in K vapor, followed by activation similar to the one used in (1).

While method (1) is still used extensively in the production of photoelectron devices it appears that more modern technology (2) has now more adherents and may give generally better sensitivities.

We suggest a new technology for fabrication of (Na,K)3Sb photocathodes. The photocathode film is deposited onto substrate from molecular beams produced by simultaneously operating molecular sources of Sb, Na and K.

In this report we wish to present the first successful attempt of growing (Na,K)3Sb photocathode by very promising MBE technique.

2. EXPERIMENTAL SET UP

Fig.1 present the general view of the experimental set up which was developed by us especially for the synthesis of photocathodes. A special ultra high vacuum (UHV) chamber for MBE of photocathodes (such as S-24, S-20, S-25) has been designed. The growth chamber is a part of UHV system, consisting of an analysis vessel supplied with Auger and ESCA electron spectrometer and low energy electron diffraction (LEED), the MBE chamber itself and chamber for cold sealing of photocathodes with device body through indium ring. In the growing chamber shown in fig.2 of our molecular beam epitaxy installation the vacuum level was about 10^{-9} Torr. Metallic sodium and potassium have been inserted inside thin tubes, having a small internal diameter (less then 0.5 mm). This tube were blocked by oxide films, which made it possible to bake out the complete system up to 100^{0}C without presence of K and Na vapors.

For creation of Na, K and Sb molecular flux, the special fast baked, effusion cells having low heat inertia of approximately one minute were constructed. Potassium and sodium sources were installed inside these Knudsen cells. Flux of potassium, sodium, antimony were monitored with the help of quadruple mass-spectrometer.

For molecular beam shaping, the additional cryogenic panel, cooled down to liquid nitrogen temperature, were installed in the photocathode substrate vicinity.

The last vacuum chamber is supplied with specially designed facilities for pumping and baking out the body of devices and with press in order to produce photoelectron vacuum devices. Developed technique can be used for fabrication of vacuum devices including streak tubes.

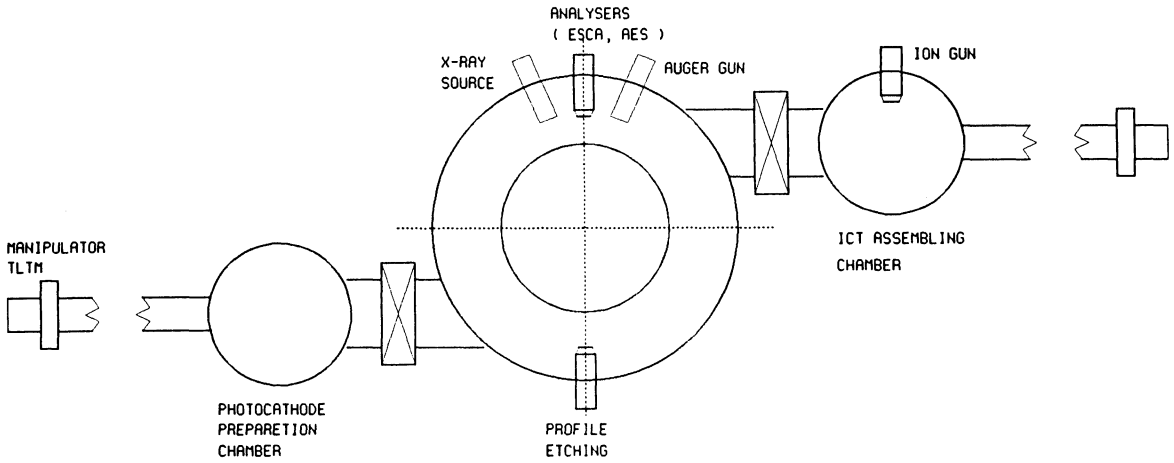

Fig.1. Experimental set up

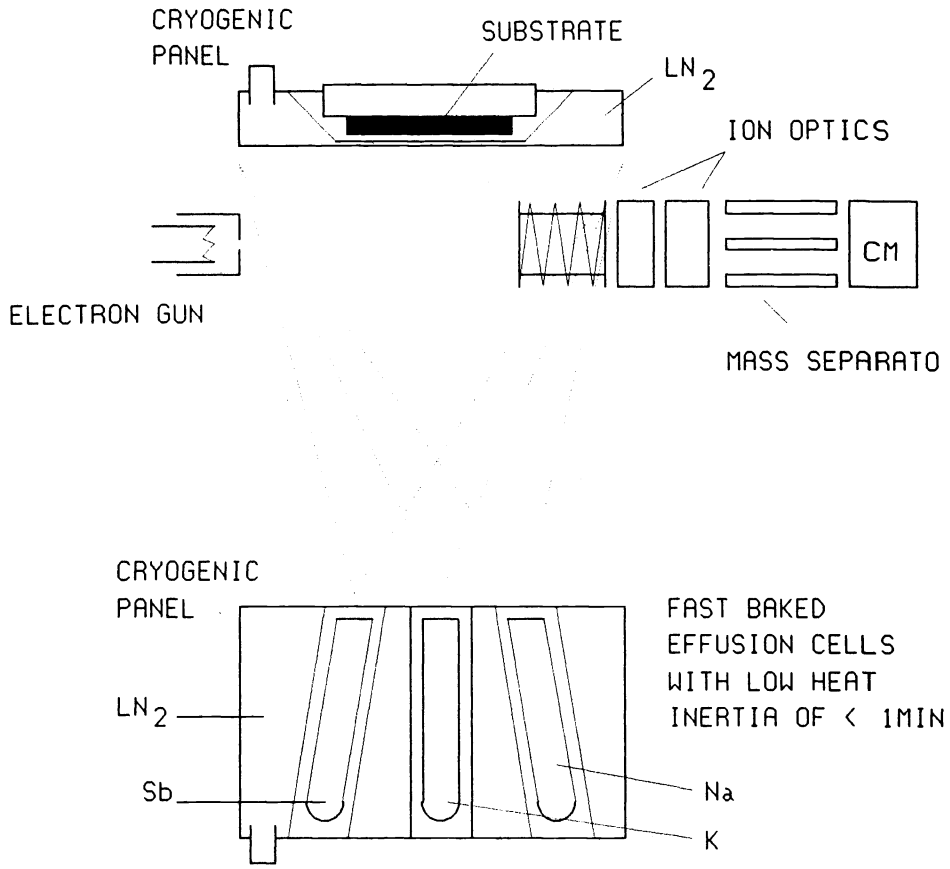

Fig.2. Growth chamber

3. PHOTOCATHODE FILMS GROWING PROCEDURE

Molecular beam epitaxial growth of photocathode starts with short overheating of elemental sodium and potassium sources. This overheating helps to break the blocking oxide films.

The effusion cells temperatures were kept as following: Potassium (Na) - 220^0 C, Sodium (K) - 140^0 C, Antimonide (Sb) - 440^{0}C. Photocathode was deposited onto monocrystalline sapphire substrate having (0001) orientation. The contact tungsten ring was evaporated onto sapphire by so-called "blowing up" technique. The choice of tungsten is due to its small vaporization during high-temperature training of the substrate at 1000^0 C.

In fig.3 you can see some spectral curves of photocathodes prepared at various ratio between flux intensities at various temperatures of the substrate.

1. Sb:Na:K equal to 1:4:5 Ts~150^0 C.
2. Sb:Na:K equal to 1:4.5:7 Ts~150^0 C.
3. Sb:Na:K equal to 1:5:7.5 Ts~115^0 C.
4. Sb:Na:K equal to 1:10:15 Ts~115^0 C.
5. $(Na,K)_3Sb$ photocathode fabricated by the conventional technique.[2]

In fig.4 you can see the spectrum of residual gases and Na, K and Sb during the photocathode film growth.

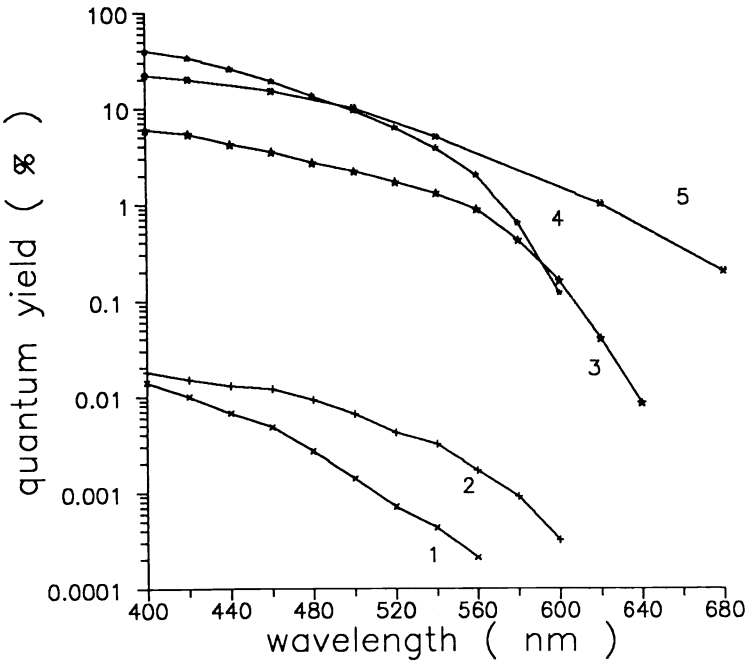

Fig. 3. Spectral curves of photocathodes $(Na,K)_3Sb$

The best sensitivity of the photocathode was achieved when the flux intensities ratio Sb:Na:K was equal to 1:10:15. The growth rate was typically ~1Å/s. Thus the whole growing time of a photocathode which was approximately 1000 Å thick was about 10 - 20 minutes versus to 3 - 4 hours in conventional technology.

During photocathodes synthesis, we have used the simultaneous deposition of all ingredient molecular beams on the substrate. The substrate temperature during photocathode synthesis was about 115° C. Photocathode films grown at this temperature have exposed stable photoemission parameters during period of month. But the MBE photocathodes, which were fabricated at higher substrate temperature have exhibited much poor characteristics.

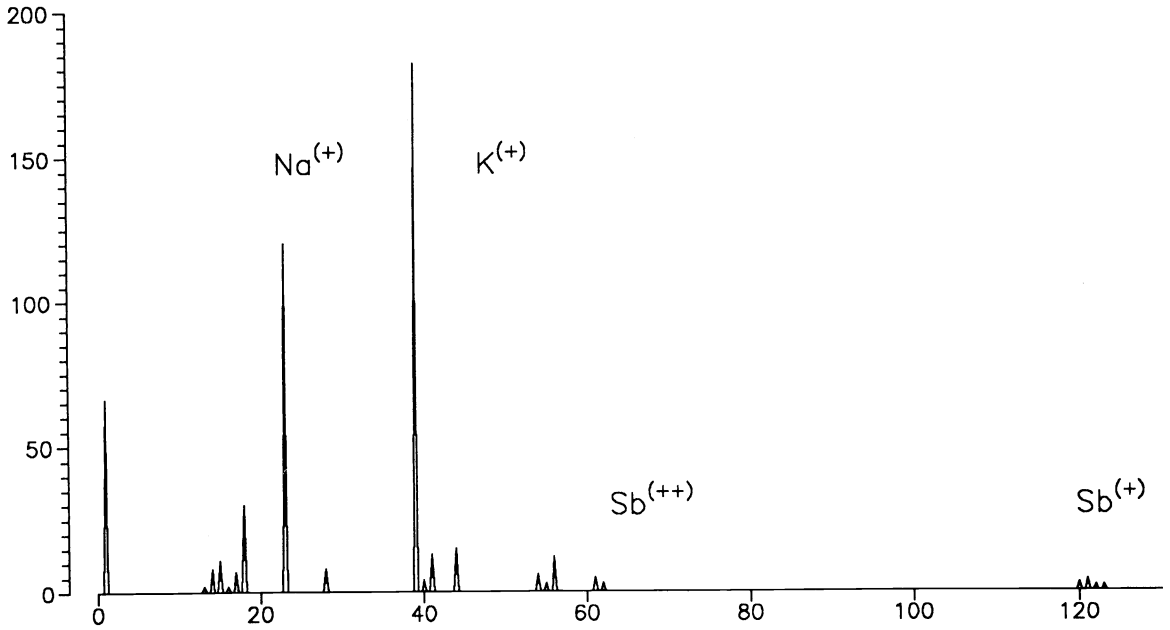

Fig. 4. Spectrum of residual gases and Na, K, Sb during the film growth

The colour of the epitaxially deposited film was yellow-brown with reddish shade, in other words it has the colour of traditionally fabricated multialkali photocathodes.

Fig.3 shows the spectrum response curves for MBE grown photocathodes. These photocathodes have high quantum efficiency at 400 nm wavelength. One can see quite noticeable shift of these photocathodes quantum yield into the blue region. This effect may be explained by the lack of elemental Sb (antimonide) in bulk of the photocathode film in comparison with its normal stoichiometric configuration. It is easily occurred during MBE fabrication process and photocathode in this case has n-type conductivity in contrast to the traditional method of preparing of the photocathode where it always has p-type conductivity.

4. CONCLUSIONS

The main purpose of this work was to show the possibility of growing semiconductor film consisting of Sb and alkali metals by MBE technology. Our first successful attempts to grow photocathodes by MBE-technique show evident advantages of this procedure for fast, reliable and reproducible production of efficient classical type photoemitters.

This MBE growth process may be computer controlled in real time. Thus it differs this method from the conventional one which is very difficult to automize. Computer ensures the complete safety of the technological procedure and helps to provide reproducible results.

5. REFERENCES

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