

S20 photocathodes grown by molecular-beam deposition

N. Massegu, A. Konrath, J.M. Barois, P. Christol and E. Tournié

S20 photocathodes have been grown by solid-source molecular-beam deposition (MBD). The unactivated absorbing layer exhibits a maximum response of 29 mA/W at 430 nm while the photocathode shows a sensitivity and a quantum efficiency of 74 mA/W and 22% at 430 nm. This corresponds to a white sensitivity of 200 $\mu\text{A}/\text{lm}$ which is already comparable to commercial S20 photocathodes. In addition, the MBD fabrication cycle takes five times less time than the actual industrial process.

Introduction: Photocathodes (PKs) are key components for many imaging systems, in particular for night vision systems, most of them relying on residual-light amplification. In these tubes, electrons are generated by light absorption in the PK, emitted into vacuum, and multiplied in a micro-channel plate before hitting a phosphor screen to form the image. Most imaging sensors are based on second generation PKs (SG-PKs) where the absorbing layer is a multi-alkali Na_2KSb compound semiconductor with a bandgap near 1.1 eV deposited onto a transparent glass window. This layer is subsequently activated by a Cs-based surface treatment to decrease the electronic affinity and ease the escape of electrons into vacuum [1]. The window is then sealed to its tube under vacuum to prevent any contamination of the extremely reactive alkali antimonide compound. Different application fields require different types of SG-PKs which differ essentially by the thickness of the absorbing layer. For example, so-called S20 PKs are ~ 20 nm thick and are typically used for scientific applications in photomultiplier or in streak tubes to detect high speed events where nanosecond or picosecond temporal resolution performances are essential.

All commercial SG-PKs are fabricated by using a complex chemical vapour deposition (CVD) process where alkali metals are obtained from dedicated dispensers based on alkali chromates and reducing agents, while antimony is produced by resistive heating of metallic Sb-beads [2]. Although well established, this process suffers from a slow deposition rate (~ 0.01 nm/s) and a lack of composition control. It is thus appealing to try to elaborate these PKs with an ultra-high vacuum (UHV) technique such as molecular-beam epitaxy (MBE) which allows a control down to the monolayer level and is routinely used to develop and produce high performance optoelectronic devices [3]. However, only a few attempts have been reported till now, and the PKs always exhibited performance orders-of-magnitude lower than those obtained by CVD [4–6]. This may arise from (i) the difficulty in getting high purity alkali precursors, (ii) the high reactivity of alkali metals, and (iii) the high reactivity of alkali antimonide compounds which makes SG-PKs extremely sensitive to any contamination.

In this Letter we show that high-performance S20 PKs can be elaborated by molecular-beam deposition (MBD), a technique directly derived from MBE.

Experiment: All PKs have been fabricated on standard glass-windows used by Photonis in their industrial CVD process. The experiments have been carried out in a modified Compact 21 MBE reactor developed by Photonis, UM2 and Riber. Especially, the deposition chamber is interlocked to a UHV process chamber where the windows can be vacuum-sealed to their tubes after PK deposition. Note that this procedure prevents any *ex situ* characterisation of the as-deposited alkali antimonide layers. High purity (99.99%) Na, K and Cs elements have been used as alkali sources. Special effusion cells have been designed to avoid any contamination of these metals. MBE-grade Sb has been evaporated from a standard MBE cell.

Two series of samples have been grown, one with only the Na_2KSb absorbing layer, and one with the complete PK, i.e. where the absorbing layer is activated by a Cs treatment. All tubes have been characterised *ex situ* with a photo-response setup using a calibrated lamp. The colour temperature of this lamp has been adjusted to 2856 K, the temperature which is conventionally used to measure white sensitivity values. This system is identical to the one which is used to measure commercial tubes produced by Photonis.

Results and discussion: The principle of operation of MBD and MBE reactors is identical. However, the use of amorphous substrates during

MBD prevents epitaxy taking place. The critical point is to adjust the relative Sb and alkali fluxes in order to obtain the desired compound. In addition, depending on the precise growth conditions, *in situ* reflection high-energy electron diffraction indicates that the resulting film microstructure lies somewhere between amorphous and polycrystalline. Best results in terms of sensitivity are obtained with the highest crystallinity. Activation is performed by soaking the Na_2KSb layer with a Cs flux.

We show in Fig. 1 the photo-response of a Na_2KSb layer alone and of an activated layer. The bare layer shows a maximum responsivity of 29 mA/W at 430 nm while the PK exhibits a peak responsivity of 74 mA/W at 430 nm. Activation thus allows a gain by more than a factor 2 on the peak responsivity. In addition, the cutoff wavelength is much longer for the PK than for the layer (900 nm against 700 nm). This shows that the activation process does play its role and decreases dramatically the electronic affinity at the surface.

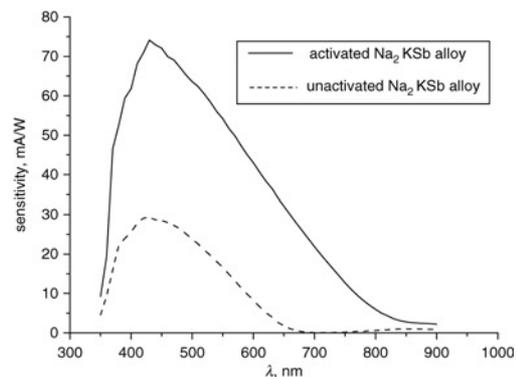


Fig. 1 Spectral responses given by activated and unactivated MBD grown S20 photocathodes

Fig. 2 compares the photo-response of a Photonis commercial S20 PK with that of an MBD-grown PK. Both PKs have a white sensitivity of ~ 200 $\mu\text{A}/\text{lm}$. The two curves superimpose perfectly for wavelengths longer than 550 nm. At shorter wavelengths, however, the MBD PK performs much better. UV-blue photoelectrons are generated very close to the window. They need to cross the whole layer while keeping enough energy for being extracted in vacuum. The higher performance of the MBD PK at short wavelength demonstrates that the Na_2KSb material is of much higher structural quality when grown by MBD compared to CVD. In addition, our PK colour is very uniform over the surface, which indicates an excellent composition and thickness uniformity in contrast to CVD-grown PK. Finally, note that the deposition rate is about five times higher in MBD compared to CVD.

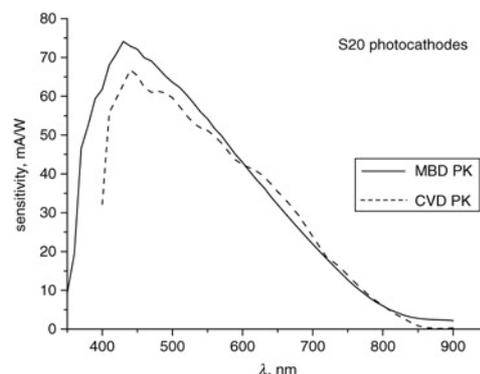


Fig. 2 Comparison of spectral responses of standard commercial Photonis S20 grown by CVD and S20 grown by MBD technique

Conclusion: We have shown that high-performance S20 PKs can be elaborated by MBD with a process which is much less time-consuming and more reproducible than the industrial CVD process. This opens a new route for the fabrication of high performance second generation PKs.

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