Multialkali Thin Photocathodes for High Brightness guns

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Abstract

R&D on high quantum efficiency (QE) alkali antimonide photocathode is in progress at Milano in the context of the ARES-TTF (Tesla Test Facility) program.

An advanced photocathode preparation system is fully operative and we are now able to produce routinely thin (20 ÷ 30 nm) high QE KCsSb stable photocathodes with 4 % < QE < 6 %, for a photon wavelength of 543 nm.

The spectral response of the produced photocathodes is measured together with the spatial distribution of the quantum efficiency over the photoemitter area.

The influence of the composition of the preparation chamber residual atmosphere on the photocathode lifetime has been investigated.

A high voltage DC gun (150 kV) that will be used to test photocathode at high current density is under development.

1. INTRODUCTION

In this paper we present the R&D activity, in progress at Milano in the context of the ARES TTF program [1], devoted to the preparation and characterization of alkali antimonide thin photocathodes to be eventually used inside a superconducting (SC) RF high brightness gun, such that proposed for the TTF injector 2 [2].

The general requirements of a photocathode to be used as the electron source inside a laser driven RF SC gun are extensively reported elsewhere [3-6]. For the sake of completeness they can be summarized as in the following:

- fast response time (≤ 1 ps),
- high current density capability (≥ 500 A/cm^2),
- reasonable lifetime (at least a few hours),
- negligible field emission,
- high QE (≥ 1 %) for a photon energy lower than the Nb work function (Φ = 4.6 eV),
- thickness < 30 nm, to take advantage of the proximity effect. This is needed because of the high dielectric losses of the KCsSb material at cryogenic temperature.

2. PHOTOCATHODE PREPARATION SYSTEM

A photograph of the Milan advanced preparation system is shown in Fig 1. Its main features are:

- Powerful pumping system, based on the combination of sputter ion pumps (SIP) and room temperature not evaporable getter (NEG) modules (ST707 SAES [7]). For a base pressure of $3 \cdot 10^{-11}$ mbar, the 90 % of the residual atmosphere is hydrogen. the other 10% being dominated by methane. The partial pressure of reactive gases - such as H_2O and O_2 and CO_2 - is negligible (< 10^{-12} mbar).

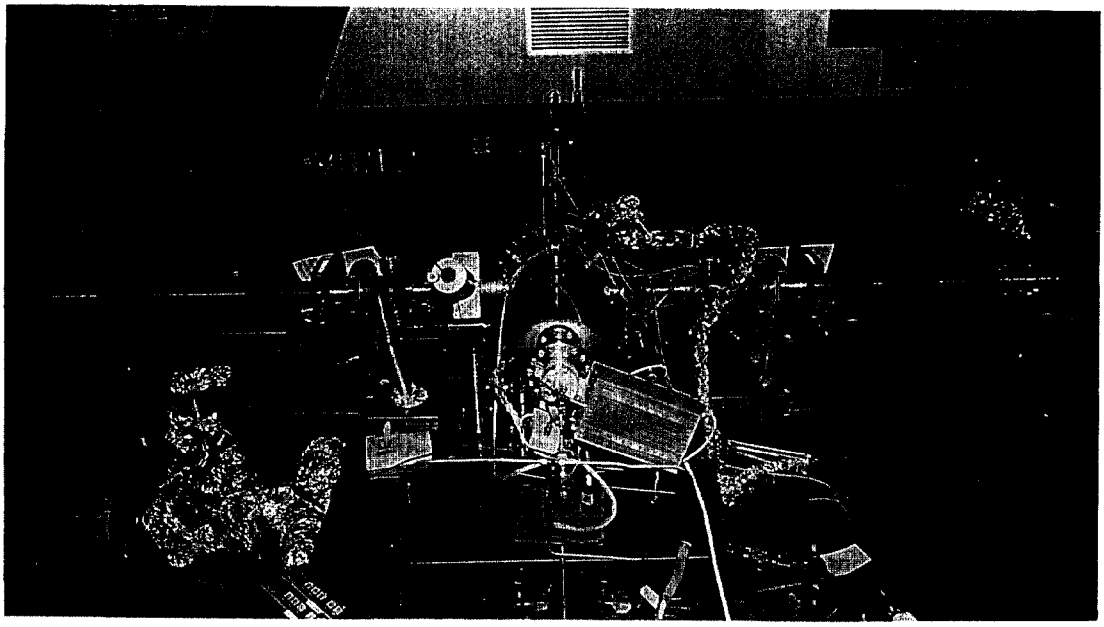

Fig. 1. The photocathode preparation system.

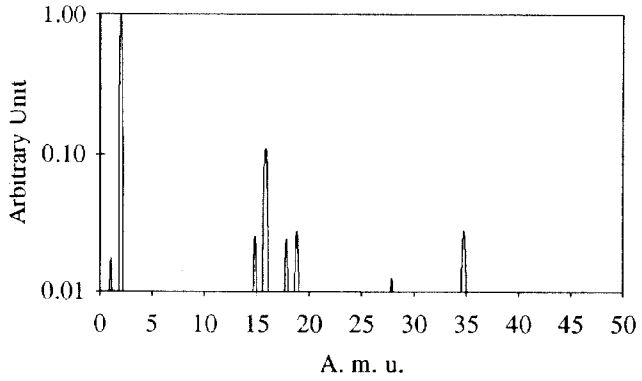

Fig. 2. Preparation chamber residual gas composition, for a total pressure of $3 \cdot 10^{-11}$ mbar.

- Load - lock for the insertion of the antimony and alkali metal sources: the change of the sources can be done without breaking the vacuum of the chamber.
- Load - lock for cathode transfer to a storage and transport system pumped by a SIP (battery powered) and a NEG pump. In the next future photocathode will be transferred, using this device, to the surface analysis apparatus of the Dep. of Physics of the University of Modena [8]. The transport system developed at Milan has been accepted, by the European Network for "High current photoemission", as the standard to exchange photoemitter samples. The same load-lock system will be used for the photocathode transfer to the high voltage photocathode test facility which is under development at Milano.
- Fully automated photocathode preparation following recipes which have been previously developed: a LabVIEW program controls all the process parameters (e.g. deposition rates and thickness, cathode temperature, ecc).
- Four low power CW lasers (one Ar ion and three HeNe) are used for the measurement of the emitter spectral response. The wavelengths available together with the relative power are shown in Table 1.

Table 1.
Wavelength of the radiation used for the QE measurements and relative maximum power.

λ [nm]	456	476	488	514	543	594	633
P [mW]	1.9	5.7	40	40	1.5	3.0	10.0

- An optical scanning system (scanned area is a square of 30 mm) to perform a measurement of the spatial distribution of the QE all over the cathode surface. This measurement can be done using the wavelengths reported in Table 1. The acquisition of the cathode photocurrent together with the control of the motion of the mirrors is done via a PC (LabVIEW). The typical time for the acquisition of a QE distribution (729 measurements) is 30 minutes.
- A two steps (pressure is first reduced to 50 mbar), high accuracy, gas injection system ensures the controlled exposition of the photoemitters to different gases (oxygen, methane, carbon monoxide and carbon dioxide). In this way we investigate cathode activation and poisoning.

3. EXPERIMENTAL RESULTS

A typical preparation procedure of a SbKCs cathode can be divided in four main steps:

- cathode substratum is baked to 450 °C for 30 minutes.
- an antimony layer of 5 nm is than evaporated on the substratum surface, maintained at 120 °C.
- a potassium layer of 3 ÷ 4 nm is deposited on Sb layer.
- finally cesium is evaporated with a deposition rate of about 1 nm/min. Once the photocurrent is close to saturation, the temperature is reduced, while the Cs deposition is maintained for a few minutes.

During the cathode preparation both current extracted from the photocathode and thickness of the evaporated layer are monitored. The dark current, i.e. the alkali metal dispenser thermionic emission, is continuously monitored and automatically subtracted from the current measured by the picoammeter.

A typical preparation procedure of a KCsSb cathode is shown in Fig. 3, where the thicknesses of the antimony, potassium and cesium layers are shown together with the cathode temperature and photocurrent (laser power: 0.85 mW @ 543.5 nm).

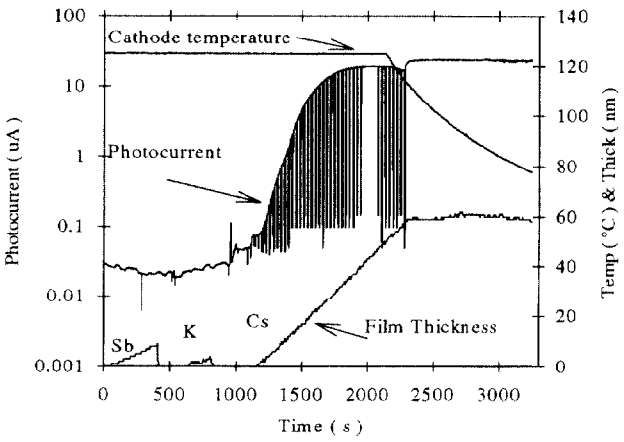

Fig. 3. Preparation procedure of a KCsSb cathode: see text for more details.

The total thickness of the KCsSb photocathode prepared following this recipe has been estimated to be few tens of nanometers, that is in good accordance with the demand of a "thin cathode" forced by the operation inside an SC RF

cavity [4]. This estimation has been confirmed at the SeSAMO Laboratory (University of Modena), where such a cathode has been prepared in situ and than analyzed, using the AES technique (with deep profile). Thanks to this collaboration we have also investigated the photoemitter production process and the influence of the substrate characteristics on the photoemitter properties: the results so far obtained are discussed in a specific paper presented at this conference [8].

Usually we obtain photoemitters with a good uniformity in QE spatial distribution (within 10 % @ λ = 543 nm). A typical QE distribution is shown in Fig. 4 while the cathode spectral response is shown in Fig. 5.

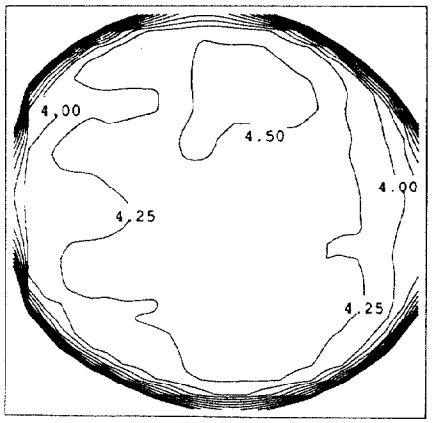

Fig. 4. QE spatial distribution over a KCsSb photocathode (30 mm diameter, λ = 543 nm).

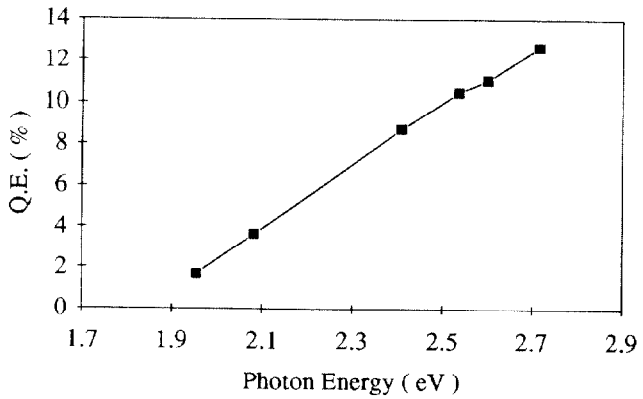

Fig. 5. Spectral response of a KCsSb photocathode.

In order to evaluate cathode sensitivity to different gases, we successively exposed a KCsSb cathode to methane, carbon monoxide, carbon dioxide and oxygen. During these measurements we monitored both the cathode QE and the partial pressure of the admitted gas. Figure 6 shows the results of this measurement, the amount of the admitted gas being measured as the time integral of the gas partial pressure. Partial pressure of the admitted gases was monitored with a residual gas analyzer. The effect of the methane is similar to that of carbon monoxide.

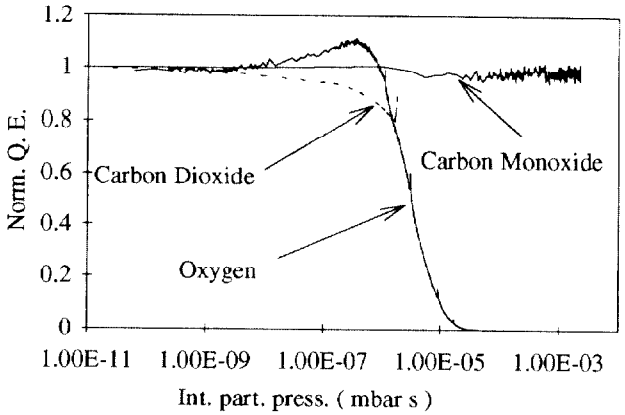

Fig. 6. Poisoning of KCsSb cathode with different gases.

Photocathode is rather insensible to an exposition to CH_4 or CO atmosphere. Conversely O_2 and CO_2 produce a rapid poisoning, evidenced by the decrease of the photocathode QE. The well known increase of the cathode QE due to the absorption of small amount of oxygen is clearly visible [9].

4. CONCLUSION

Thin KCsSb high QE photocathode has been produced and characterized. Moreover "in situ" prepared photoemitters has been analyzed, using AES, at the SeSAMO lab. of the University of Modena. In the next future, by means of a portable storage and transport system, will be possible to analyze either photoemitters produced in the preparation system or photoemitters used in the DC HV test facility. We believe in fact that the strategy of applying surface analysis techniques is fundamental to go over the alchemy of alkali antimonide preparation and to ensure a better understanding of the photoemitter poisoning effects.

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