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S-11 and S-20 Photocathode Research Activity

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S-11 and S-20 Photocathode Research Activity*

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Abstract

The S-1 semi-transparent photocathode is the only one that can be used to study the 1.06 μ m neodymium laser pulses of less than 10 ps duration. We first reviewed the recent results obtained at the Paris Observatory (research sponsored by the CEA), and then we tried to determine the role of the main constituents and their contributions in photoemission.

Introduction

Processing techniques for S-11 and S-20 have been developed for film research purposes at the Lawrence Livermore National Laboratory.

A processing station was built in order to provide a reliable system for the production of stable films with quick fabrication turn-around time. Furthermore, it is also an apparatus that is readily accessible in performing basic electrical and optical measurements on photocathode films.

Experimental set-up

The photocathode processing system was designed to be very simple and very convenient for production of stable films with quick fabrication turn-around time as shown in Figure 1. The system consists of four major components, the vacuum chamber and its associated vacuum pump, the headers for evaporating the source metals, the power sources, and the calibration instruments. The vacuum system (shown in Figure 2) is a compact Varian type with a pump rate of 5-liter/second. It gives an ultimate pressure better than 10^{-8} Torr. The glass vacuum chamber (Figure 3) holds three metal gasket vacuum flanges. One is connected to the vacuum pump via a cold trap. The other two flanges allow an easy and complete cleaning of the chamber after each series of experiments. They also hold multi-head headers. Figure 4 shows the eight pin header used for evaporating the source metals. The antimony source is a bead of pure solid antimony melted on a platinum coated molybdenum wire previously degassed in a neutral atmosphere. To preclude antimony deposition on areas other than target (thus minimizing errors in photoemission current measurements) a shield is located around the bead. The alkali sources, potassium, sodium and cesium are metal dispensers and are heated electrically. They are made of an alkali chromate and a reducing agent such as zirconium. By initiating the reducing reaction at high temperatures, the alkali metal is generated in situ. The quantity of released alkali metal is generated in situ. The quantity of released alkali metal is adjusted by the current value (about 0.5 to 7-A).

An oven (surrounding the vacuum chamber) is used to process the evaporated materials into a photocathode. The oven temperature is increased up to 150°C depending on the processing method. The antimony and alkali metal evaporation rate is known by the optical transparency of the evaporated film and its photoemission current value. For this purpose the photocathode substrate can be viewed and illuminated at both sides through the two vacuum chamber lateral windows as shown in Figure 5. A photomultiplier is used to measure the transmitted light emitted by a quartz iodine lamp located in the oven itself. The photoemission current is measured using the antimony bead (and its associated shield) as an anode while the remaining twenty pins are maintained at 300 volts.

The photocathode spectral sensitivity is recorded by using a single pass monochromator (instead of the quartz lamp) and a standard photomultiplier for the absolute calibration.

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Fig. 1. Layout of the equipment.

Fig. 2. Vacuum System.

Fig. 3. Test envelope.

Fig. 4. Schematic of the eight pin headers.

Fig. 5 Schematic of the monitoring and measurement equipment

Photocathode substrate. (Figure 6)

The substrate is a flat, 30-mm diameter, 2-mm thick 7052 Corning glass plate. Twenty 0.5-mm Kovar pins are inserted into this glass plate. Holes are ultrasonically drilled 2-mm apart and the metal pins are fused to the glass at 800°C in a graphite block. The flat surface is polished and a pattern of 20 spaced rectangular shaped metallic bars (centered on each pin) are evaporated through an appropriate mask. Finally, the pins are spot welded to the corresponding header pins and checked out before setting up the substrate into the vacuum chamber.

Fig. 6. Schematic of the substrate.

Photocathode processing

A very thorough cleaning is given to the glass envelope, flanges, headers and substrate. This procedure removes alkali hydroxides that are created by exposure of these components to the atmosphere. The antimony bead and the alkali channels are subsequently degassed by baking them.

We studied two types of photocathodes. The S-11 photocathode (Cs_3Sb) was deposited with two different methods. The first one (described by A. Sommer) is commonly used in industrial fabrication. The second one is used at the Paris Observatory. It gives more stable photocathodes which can be transferred to another vacuum chamber without any change in sensitivity. In the context of our studies, the main point is the fact that the cesium is evaporated at the end (first method) or at the beginning (second method) of the evaporation process, and consequently, the interface substrate photocathode might be different depending on the cesium reaction with the substrate.

Two different methods are also used to deposit S-20 photocathode in alkali photocathode (Cs-Na-K-Sb). The first one is very conventional and was developed by A. Sommer. The second one is similar but with numerous modifications. In particular, there is no need for an initial antimony layer deposition.

Experiments and results

We were looking for different answers:

1. Does the spectral sensitivity depend on the substrate type and on the evaporation process? In other terms, is it possible to create an intermediate compound between the substrate and the photocathode film? If yes, an abnormal transmitting or reflecting spectral sensitivity change should be observed.
2. If an intermediate compound interface is created, do the pin contacts stay ohmic? In other terms, is the I-V characteristic curve still linear?
3. Is it possible to implement a MOSFET structure and modulate the photoemission current through the insulated gate?

Evaporation process optimization

Some preliminary evaporation allowed us to optimize the photocathode processing schedule (taking into account the configuration of the glass chamber) and to set up the monitoring instrumentation. Figures 7 and 8 show the spectral response of two S-20 photocathodes. The volume resistivity of the photocathode is calculated from the formula:

$$\rho = R d e / L$$

where R is the film resistance between the contacts A-B (as shown in Figure 4), L is the film length, d is the film width, and e is the film thickness. An approximate value of the thickness can be determined by comparing the curve shapes of the measured optical reflectance as a function of the wavelength (3) and (4). For example, measurements made on cathode No. 3 give an estimated thickness of 40-nm. In fact this value is too low to get a good optical sensitivity in the I. R. range. A better processing schedule gives rise to thicker photocathode (90-nm) with better spectral sensitivity at 750-nm (Figure 8).

Fig. 7. Spectral sensitivity of thin (40nm) S-20 photocathodes.

Fig. 8. Spectral sensitivity of a thick (90 nm) S-20 photocathode.

Spectral sensitivity versus substrate type for S-11 and S-20 photocathodes

The Figure 9 shows the substrates that were used. It is made of seven different evaporated metals (aluminum, nickel, palladium, platinum, gold, chromium and silver).

Optical measurements were made with a light spot smaller than the width of the bar. For each of the photocathodes, the uniformity was checked at different points along the bar. At the same time, we also measured the reflected light from each bar. The variance between the measurements on the eight aluminum bars was about 10%, thus indicating a fairly uniform photocathodes (S-20 or S-11) over the entire substrate area. Table 1 and 2 summarize reflectivity of the results for the S-20 and the S-11 photocathode. The following observations can be made:

1. The photoemission is different from one metal substrate to another. The difference can be explained partially upon the variation of the reflected light from the different metal substrates.
2. The most surprising result is the lack of spectral sensitivity of S-20 and S-11 photocathodes deposited on a palladium substrate. In fact, we strongly believe that an intermetallic compound was created and consequently affected the reflectance characteristics of the palladium substrate.

We have two confirmations of this assumption looking at the silver and gold substrate behavior.

When the silver substrate is superficially oxidized the corresponding S-20 photocathode spectral sensitivity (Table 1) is very low as for a palladium substrate. This phenomena didn't appear for a non-oxidized silver substrate and a S-11 photocathode (Table 2).

Fig. 9 Schematic of the substrate with seven different evaporated metal bars.

λ_{nm}	Glass		Al		Au		Ni		Pr		Cr		Ag		Pd	
	Δ	R	Δ	R	Δ	R	Δ	R	Δ	R	Δ	R	Δ	R	Δ	R
450	56	23	57	24	54	26	50	19	48	27	41	29	20	8	19	25
500	37	28	47	29	36	29	37	22	37	28	37	27	14	8	12	30
550	24	32	41	29	23	41	30	21	31	28	33	26	11	9	8	34
600	16	37	37	27	18.3	43	23	18	24	28	36	22	9	10	7	38
650	9	40	22	21	14	43	14	16	15	21	16	17	8	10	3	41
700	4	50	14	16	7	49	6	16	6	19	6	15	3	10	1.5	52
750	2.5		6		4		3		3		3		2		0.9	

Spectral sensitivity of a S20 photocathode with an oxidized silver substrate.

λ_{nm}	Glass	Al	Cr	Ni	Pr	Ag	Pd	Au
	Δ mA/W	Δ mA/W	Δ mA/W	Δ mA/W	Δ mA/W	Δ mA/W	Δ mA/W	Δ mA/W
400	43	47	44	38	41	47	19	18
450	30	35	30	30	32	32	18	13
500	29	32	29	25	27	27	13	11
550	16	17	15	12	14	14	7	5.7
600	3	4	3	2.5	3	3	1.6	1.2

Spectral sensitivity of a S11 photocathode with a non-oxidized silver substrate.

I-V Characteristic curves versus substrate/photocathode type and evaporation process

We used the previously described processing methods and measurement techniques. I-V curves were measured between the metal substrate pins, either between two pins in contact with the same metal or one pin connected to an aluminum bar and the other connected to a different metal substrate. The results are surprising: none of the S-11 photocathode I-V characteristic curves are linear (Figure 10) contrary to the S-20 photocathode observations (Figure 11). In other words, we don't have ohmic contacts between the pins in a S-11 photocathode. Furthermore, these results do not appear to be associated with the photocathode processing technique. Indeed, we observe a cesium reaction with the metal during the very first evaporation. Hence, we used the method where the antimony layer is initially deposited with a simple twenty aluminum bar pattern substrate. We obtained similar shaped I-V curves and the same resistance values in the previous measurements.

Fig. 10. I(V) measurement of S11 photocathode.

Fig. 11. I(V) measurement curves for a S-20 photocathode.

MOSFET structure

We attempted to configure a MOSFET structure by evaporating 400-nm thick SiO_2 layer over each odd numbered metal bar to form the insulated gate as shown in Figure 12. Caution in the cleaning and the deposition was taken to avoid a "leaky" SiO_2 film. Finally, a S-20 photocathode is evaporated and processed according to the "Sommer" technique.

With SiO_2 aluminum substrate, the spectral photosensitivity decreases but remains high in the I. R. region (.650 nm) (Table 3).

Figure 13 shows the I-V characteristic curves between the even and odd numbered pins with both linear and nonlinear characteristics. Back-plate photoemission modulation experiments were also made on the isolated strip with a light spot focused on the metal strip and a modulated voltage of a few volts applied on the corresponding pin. As shown in Figure 14, some significant changes in the I-V characteristic curves were observed; however, no significant photoemission variation was measured probably because of the dielectric leakiness in the SiO_2 film.

Fig. 12. Schematic of the substrate with a MOSFET structure.

Table 3

λ_{nm}	Al	Al + SiO_2
450	37	28
500	30	23
550	23	16
600	20	12
650	14	8
700	4	4

Spectral sensitivity of a S20 photocathode with a SiO_2 /aluminum substrate.

Fig. 13. I-V measurement of S20 photocathode with a MOSFET structure.

Fig. 14. I-V measurement of S20 photocathode with a MOSFET structure and a backplate photoemission modulation.

Conclusions

S-20 and S-11 photocathode processing techniques have been developed for film research purposes at Livermore. The processing station has proven to be reliable in the production of stable films with quick fabrication turnaround time; also, it has provided an apparatus that is readily accessible in performing basic electrical and optical measurements on these films. This paper has shown the system capability as well as some characteristics of these films. The photocathode film characteristics are being evaluated and will be used for developing physical models for energy band-bending effects at the photocathode-glass interface.

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