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S1 Photocathode image converter tubes

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Abstract

The S1 photocathode was the first cathode available for practical applications ; in spite of this its mechanism of photoemission has remained enigmatic.

S1 semi-transparent photocathode is the only one that can be used to study the 1.06 µm neodynium laser pulses of less than 10 ps duration. This recent application and the difficulties to manufacture stable and sensitive S1 photocathode at this wavenlength gave rise to new researches which aim is to have a better knowledge of this structure.

We first review the recent results obtained at the Paris Observatory (research sponsored by the CEA) and report on the lifetime in the 1-µm range of the photocathodes processed four years ago.

In a second part we will try to analyse the researches which have been investigated during these last ten years in different laboratories to determine the role of the main constituants (silver particles, Co oxydes) and their contributions to photoemission in order to improve the sensitivity and the stability of S1 photocathode.

Introduction

It is well known that the sensitivity of the S1 photocathode close to th. threshold is very unstable and decreases very quickly with time. Depending on the photocathode stability lifetime may vary from minutes to hours, up some years for the best image tube.

During the previous Congress on High Speed Photography and Photonics in August 1982 in San Diego we preser ed the work performed at the "Observatoire de Paris" for photocathodes desposition in standard image converter tube structures provided by R.T.C.

This paper will first present the performances of the latest tubes we have manufactured and the behaviour of tubes in which the photocathode has been evaporated three to four years ago and regenerated by rebaking several times.

Then, in order to understand the lack of stability of the S1 photocathode near the threshold ($\lambda > 900$ nm) and to explain the process of rgenerating the tube, we will summarize the different studies recently performed on the structure of this photocathode type.

General performances

During these past four years twenty S1 photocathodes were deposited in RTC structures (Fig. 1) following the method we described in a former publication (1) ; that is to say on SiO_2 conductive under coating generally called NESA substrate and with the basic processing scheme reported by A. SOMMER (2).

The table I summarizes the performances of the fifteen tubes with a significant sensitivity at 1,060 nm. We wrote down for each tube :
- the evaporation's date,
- the photocathode spectral sensitivity at 1,060 nm immediatly after its evaporation,
- the different photocathode's rebaking cycles being performed,
- the spectral sensitivity

- the spectral sensitivity after this previous regeneration,
- the latest measurement of the spectral sensitivity beeing currently checked out.

Of course all these tubes have been used in diagnostic experiments during all these four years period of time.

Tube's number	1	2	3	5	7	9	10	11	12	13	16	17	18	19	20
Evaporation's date	7/80	9/80	9/80	5/81	2/81	7/81	3/81	1/82	3/82	6/82	5/82	7/82	7/82	7/82	7/82
S(λ) at sensitivity after evaporation μA/W	250	175	165	110	50	165	180	130	630	190	160	160	110	190	
Rebaking cycles being performed	2	3	3	0	2	0	1	0	0	0	0	0	0	0	0
1st rebaking date	82	80	81		81		83								
1st rebaking 1060 nm sensitivity	130	170	165		60		70								
2nd rebaking date	84	81	82		84										
2nd rebaking 1060 nm sensitivity	76	170	60		30										
3rd rebaking date		81	81												
3rd rebaking 1060 nm sensitivity		70	0												
date latest measurement	84			84	84	84		84	84						
1060 nm sensitivity	76			35	30	7		2,5	25						

TABLE 1

This table emphasizes some interesting photocathodes behaviours :
- In any case the photocathode spectral sensitivity is very high immediatly after its evaporation and of the order at 150 μA/W.

If we are looking at the ten tubes older than two years, we can point out that :
- Only one of them lost its spectral sensitivity at 1060 nm (3).
- For the five unrebaked tubes the spectral sensitivity decrease rate at 1060 nm is very different from one tube to another. Tube n° 5 has still a sensitivity of 35 μA/W at this wavelength after three years.
- The spectral sensitivity at 1060 nm of the five remaining tubes was restored each time through a rebaking process.
  As an exemple, the first evaporated tube was rebaked four years later ant its spectral sensitivity at 1060 nm increased from 1 μA/W to 26 μA/W.

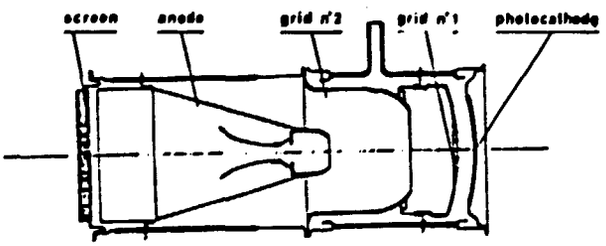

Figure 1 : Cross section of the P500S tube structure provided by R.T.C.

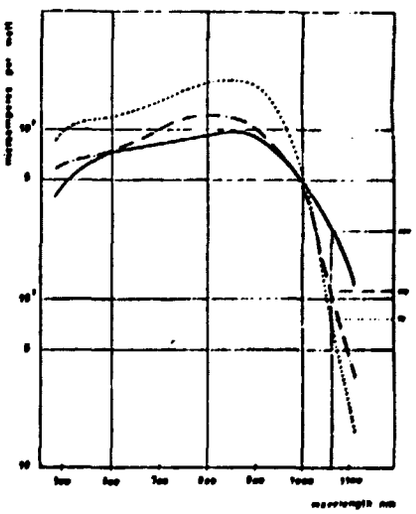

Figure 2 : Tube N° 1 spectral sensitivity
(— after evaporation, -·- after first rebaking, --- after second rebaking)

Nevertheless it appears the more the rebaking cycles are performed the faster sensitivity decreases. After each rebaking cycle the maximum of the spectral sensitivity curve gets higher and the threshold drift to the shorter wavelength. (See figure 2).

In conclusion we think that our S1 photocathode evaporation and rebaking process is under control concerning the spectral sensitivity at 1060 nm. The tubes keep a significant spectral sensitivity at 1060 nm during at least four years. Nevertheless the stability of the spectral sensitivity near the threshold stays the major issue.

In order to understand the grounds of this instability we have studied the abundant litterature reporting on the S1 photocathodes structures and the role of its different constituents in the photoemission process. We will now summarize some of the most interesting assumptions.

Understanding the S1 photocathode

A. SUMMER (2) pointed out in 1968 that among the photoemission materials with useful sensitivity to visible light the silver-oxygen-cesium photocathode was the only one with a non established chemical composition and no satisfactory information about its microscopic structure. As a result, the methods of preparing the material were largely empirical. Is that still the case today ?
What advances have been made in the understanding of the correlation between chemical composition, physical properties and photoemission ?

Generally accepted structure

Many studies over the years confirm that the AgOCs photocathode consists of silver particles up to about 200 Å in linear dimensions approximating to a spherical shape and distributed throughout a matrix 200 x 400 Å thick with a stoichiometry determined to be close to Cs_2O (2).

These results gave rise to different models to explain the quantum yield of the S1 photocathode. The more realistic one is the so called SOMMER BORZIAK model (Fig. 3) shows the corresponding band diagram.

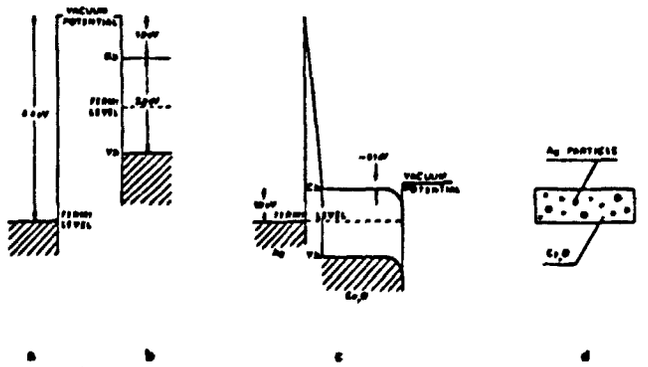

Figure 3 : Schematic energy band diagrams for
a) silver - b) cesium monoxide, c) silver dispersed in cesium monoxide

The data first given in Borziak's work has been substantiated by more recent studies.

In this model :
- the quantum yield from 3000 Å to shorter wavelengths is attributed to interband transitions in the CsO matrix ;
- the quantum yield between 3000 and 4000 Å is primarly due to light absorption in elementary silver ;
- between 4000 and 9000 Å the explanation is more speculative ; the emission is attributed to excitation of free electrons from the silver followed by tunneling to the conduction band of the cesium monoxide component and emission over the surface potential barrier which is probably decreased by band bending due to absorbed cesium.

In any case this model does not provide an explanation for the long wavelength which is the most interesting and useful characteristic of the S_1 photocathode.

The unsolved problems include the questions : whether any other oxides of Cs are present, whether unoxidized Cs is present, whether the silver must be present in the form of individual particles and, if so, whether the particle size is of critical importance.

New informations about the structure and deducted interpretations

Silver contribution

Dr. WU QUAN DE from the Pekin University has studied the structure of silver particles in the AgOCs photocathode by means of replies method and direct transmission observation in an electron microscope (3). He has observed that :

. A cathode with sensitivity at the near infrared contained :
- a lot of colloïdal particles, spherical in shape and smaller than 300 Å ;
- a few colloïdal particles between 300 and 1000 Å in size ;
- very rare flat granules larger than 1000 Å.

. In the same photocathode the structure and the distribution of the particles can be very different from one place to another. The size and distribution of particles depends on the silver quantity and the evaporation technique.

. At the activation temperature (140°C) the colloïdal particles can move inside the CS_2O compound. The small size particles move beeing easier at high temperature.

From this study they concluded (4) that the photoelectric emission of AgOCs photocathodes between 400 to 1100 nm is essentially due to the small silver colloïdal particles. From theoretical assumptions they developed formula to calculate the energy distribution, the photoelectric current and the quantum yield in terms of the physical characteristics of the photocathode. The calculations are in agreement with experimental measurements. Furthermore they determined that infrared light gives a photocurrent created by particles having an equivalent diameter of 31 Å. This result concerning the contribution of particles smaller than 50 Å in diameter in the quantum yield of the S1 photocathode between 400 to 1100 mm has been recently confirmed by Bates (6).

The role of cesium

. In the WU QUAN DE theory the quantity of free cesium has a strong effect upon the characteristics of the AgOCs cathode. Cesium atoms are located between the surface of the silver particles and CS_2O. They also lay on top of the CS_2O layer explaining the quantum yield between 1100 and 1800 mm. In both cases they lower the potential barrier.

. The oxidation of cesium on a silver substrate has been studied by C.W. Bates (6-7) using photoyield measurements and X-ray photoelectron spectroscopy. From these measurements he deduced that the structure of the AgOCs consists of silver particles dispersed in a matrix of CS_2O with a 20 x 30 Å thick layer of $CS_{11}O_3$ on top. The $CS_{11}O_3$ lowers the electron affinity at the surface so that the S1 is a negative electron affinity surface. This phenomena accounts for the threshold of ≈ 1.2 µm.
In conclusion these two recent theories confirm the role of the small colloïdal silver particles (≈ 50 Å) in the photoemission of the S1 photocathode up to approximately 1100 nm. For longer wavelength the photoemission is due to a superficial effect from cesium either in the form of oxide $CS_{11}O_3$ or as free cesium.

Interpretation of the instability of the S1 photocathode at 1060 nm

Considering the two theories outlined above the wavelength 1060 nm, our concern is just in the transition zone. We can suppose that both small silver particles and superficial effects due to Cesium contribute to the photoemission.

- If we assume cesium atoms present on the top of the layer, then these atoms are bed little by little by the inside walls of the tube and especially by the phosphor screen. This phenomena might explain the sensitivity decrease at 1060 nm. Indeed E.D. Sanoyet (8) has noted that in the new CCD streak tube they developped with the substitution of a CCD for the phosphor screen, they have solved the stability problem of the S1 photocathode.
At the Paris observatory we have an S1 photocathode in a small glass bulb that is more than 20 years old and which retains high sensitivity at 1060 nm.

- With the same assumption we can explain the rebaking process. During this rebaking process :

. Cesium is released from the inside parts of the tube and condenses at the surface of the photocathode explaining the recovery of the spectral sensitivity at 1060 nm.

. Part of this cesium migrate inside the layer. More over, refering to WU QUAN DE, small colloïdal silver particles move in CS_2O changing the distribution of Cesium on its surface and thus increasing the sensitivity at the shorter wavelength.

. With time and with subsequent rebaking cycles, the amount of Cesium able to be released gets smaller. The sensitivity at wavelengths above 1000 nm is definitely lost when no more free cesium is available.

Conclusions

We have achieved the deposition of twenty photocathodes in standard P 500S image converter tubes with a high manufacturing yield. These tubes keep a significant sensitivity at 1060 nm at least four years. The recent careful research of Dr WU QUAN DE confirmed partly by C.W. BATES provides insights into the insolved problems concerning the S1 photocathode structure. Our experimental observations can be explained by this new structure.

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