PHOTOEMISSION IN NANOSECOND AND PICOSECOND REGIMES OBTAINED FROM MACRO AND MICRO CATHODES*

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Summary

For Lasertron studies at LAL, results obtained from tests on different photocathodes are given below. Using respectively two Nd : YAG lasers (a nanosecond one and a picosecond one) we have determined the level and the intensity of pulsed photoemission and the photoelectric yield in UV, green and infrared lights.

We obtained a total current of more than 1 A with nanosecond width from a single W needle, and photoconversion yield of more than 1 was reached in green and UV lights.

In classical pulsed photoemission, obtained photoconversion yield from LaB_6 photocathode was of about 10^{-3} in higher fields.

1. Introduction

Photoemission from different photocathodes made with different materials has been realized to determine the best one which can deliver the maximum quantity of charges in a minimum time duration.

Cathodes of regular size -macrocathodes- made from lanthanum hexaboride or from tungsten, and of microscopical size -microcathodes-, as single needles or array of needles which upper radius is of about 500 Å were characterized.

The main goal of such studies is the development of a new microwave source, in S or more higher bands, switched by pulsed laser beam which can produce bunched electron beams with the same frequency as that of the light modulation.

The interest could be enhanced if high intensities in the range 100 to 1000 amperes peak value -and high accelerating voltages -10^5 till 10^6 volts- are reached ; in this situation, provided that the laser temporal distribution is roughly conserved in the electron beam, a high amount of power transported by the beam could be stored in RF cavities. Such device -lasertron- is under study in different laboratories[1,2,3]. These new microwave sources are needed by the development of high gradient accelerator structures in the range of 100 MV/m.

Such photoemission could lead also to the realization of photoemitted bunched beams which can be directly injected in RF Accelerators : this device could be of some interest in superconducting accelerators and free electron lasers.

In this article we shall give some results obtained in our experimental studies on different type of photocathodes in nanosecond and in picosecond regimes.

2. Experiments in nanosecond regime

2.1 Choise of photocathode material : LaB_6

The choice of LaB_6 as a photocathode material with normal size to produce pulsed photocurrents has been greatly facilitated by a good knowledge of this material[4] and the relatively weak work function when lowered till $\phi = 2.6ev$.

As a photoemitter LaB_6 presents a work function compatible with the $3.5ev$ value of the tripled frequency Nd : YAG laser. Lanthanum hexaboride has been studied essentially in thermoelectronic regime. High brightness LaB_6 guns have been already realized in 1974. Normalized brightness of $1.2 \times 10^{11} Am^{-2} rad^{-2}$ corresponding to continuous current densities of $220 A/cm^2$ were obtained[5].

2.2 Microcathodes emitters

For our experiments in ns regime we tested 2 differents single tungsten emitters W_1 and W_2 and an array of about 1000 carbon needles : such microemitters emit in field emission condition. Field emission starts when local field has a magnitude of some tenthes of volt per angström.

2.3 Nanosecond laser description

A trippled Nd : YAG laser made by Quantel was used as light source. It delivers single light beam pulses of 10 ns width with a repetition rate of 10 Hz. A nominal energy of 200 mJ in a 10 nanosecond pulse for 1.064 μm wavelength can be obtained. Laser light beam diameter does not exceed 5 mm, angular divergence is about 1 milliradian. Figure 1 shows photodiode response for UV light pulse of such laser.

2.4 Experimental conditions with ns laser

In our experiments, polycristalline sample of LaB_6 has been used in an ultra-high vacuum cell : high voltage feeding in this cell allows tests in classical emission and in field emission regimes. Figure 2 shows the photography of this experimental cell. Experimental working principle is shown on figure 3. Laser light power has been controlled in each case for $\lambda = 1.064 \mu m$, $\lambda = 0.532 \mu m$ and $\lambda = 0.355 \mu m$. Transmission light measurements showed that 10% of laser beam is reflected when entering the vacuum cell on the sapphire windows. Laser light energy per pulse has been varied for each wavelenght. Light incidence angle on the photocathode was of 45°.

3. Results

Photoemitted currents were observed either with a pico ammeter or with an oscilloscope.

3.1 Photocurrents obtained with LaB_6

With the LaB_6 photocathode, an example of a pulsed photocurrent obtained with a UV laser beam of $3.5 mJ$ energy and 10 ns about time duration is given on figure 4. Focussing of UV light on the LaB_6 cathode allowed significant enhancement of the emitted current and of the quantum yield. An example of the emitted photocurrents is given for different values of photonic density, on figure 5.

We may observe an important increase of the photocurrent time duration regarding the laser pulse. This enlargement may be explained by the space charge and by the local heating due to the incident light.

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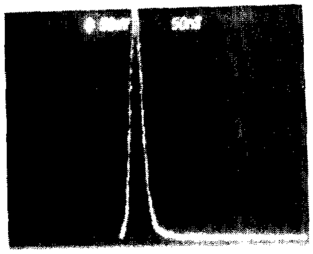

Figure 1 - Photocathode response for UV laser light (ns)

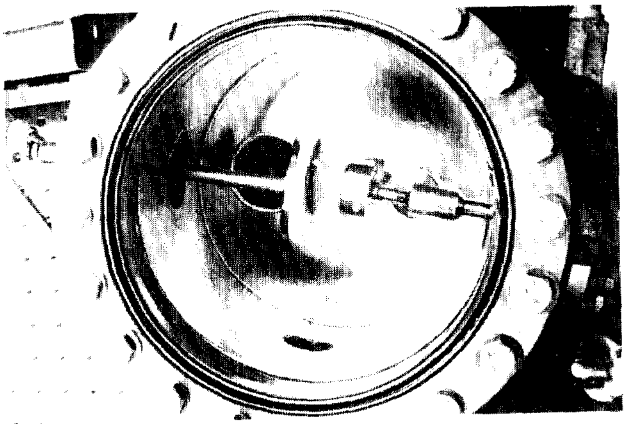

Figure 2 - Photography of the experimental cell

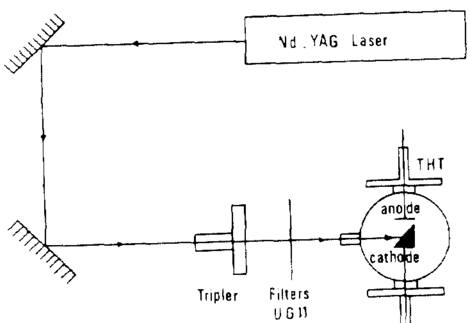

Figure 3 - Experimental working principle

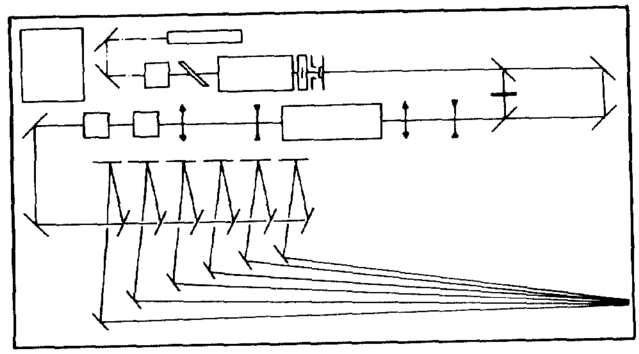

Figure 8 - Working principle of ps recurrent laser

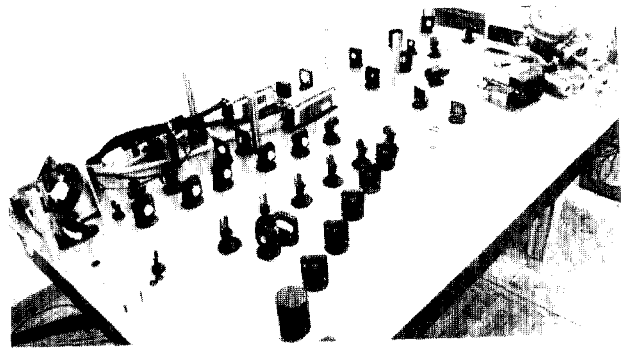

Figure 9 - Photography of the set up

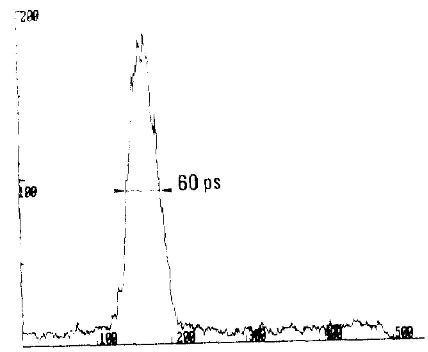

Figure 10 - Temporal distribution of the laser ps pulse observed with Thomson CSF streak camera $\rho = 60ps$ FWHM.

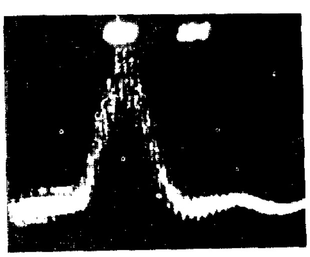

Figure 4 - LaB_6 photocurrent with UV light

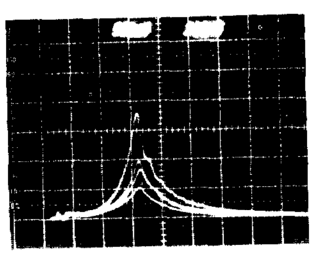

Figure 5 - Photocurrents with different photonic densities

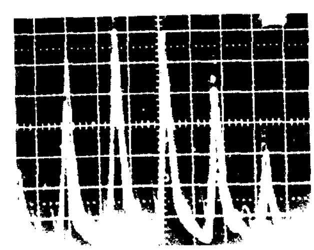

Figure 11 - Photoresponse in UV light obtained with ps laser on a photodiode of $1GHz$ bandwidth

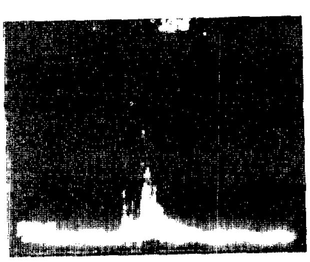

Figure 6 - W_1 needle photofield current (UV)

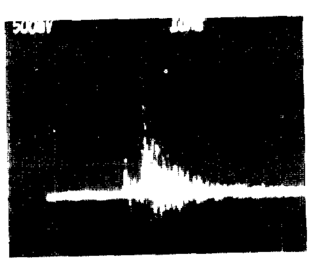

Figure 7 - W_1 needle photofield current (green)

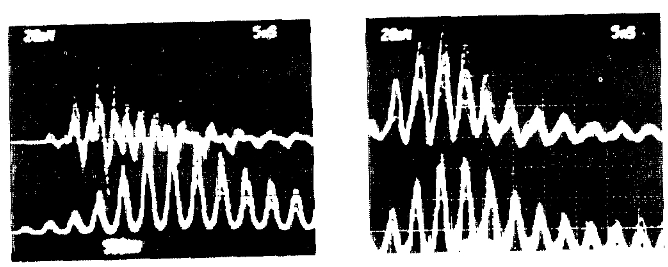

Figure 12 - An example of photofield current obtained with Nb_3Ti array needles.

Quantum yield -defined as the ratio of the produced electrons on the incident photons- evolved during the experiment from some 10^{-7} to some 10^{-3}.

Quantum yield enhancement is -in this case- the consequence of the LaB_6 surface cleaning photodesorption, thermodesorption of the impurities by the focussed light allowing work function lowering till 1 *ev* below the available UV light.

3.2 Photofield emission with ns laser

Pulsed photofield currents were obtained from W_1 and W_2 single needles and with the array of carbon needles at different energy levels, from $2 \times 10^{-6} J$ for UV pulse to $2 \times 10^{-3} J$ for IR pulse both for 10 *ns* laser pulses.

With needle W_1, we obtained photocurrents in UV light of $250 mA$ peak value and in green light of $2A$ peak value. Such results are represented on figure 6 and 7.

With needle W_2, we found practically the same results as with W_1 when using the same energies.

Using the array of carbon needles, obtained photocurrents reached $1A$ in UV light and $10A$ in green light for peak values.

Obtained quantum yields in photofield emission exceeded always unity in UV and green lights and reached 0.75 in infrared light.

4. Experiments in picosecond regime

4.1 Ps laser description

A trippled Nd : Yag laser, model $501 - DP5$ constructed by BMI[6], working in phase locked modes by saturable absorbent at 10 Hz rate, produces a train of elementary pulses of 35 *ps* each in the optimal conditions, with a chosen frequency modulation from 125 MHz till 3 GHz. On figure 8, we give the working principle of the ps laser ; figure 9 shows a photography of the set-up. The temporal distribution of the elementary light pulses has been observed successively with 2 different streak cameras : a Thomson CSF one and a Hamamatsu one. An example of this distribution is given on figure 10. Laser photoresponse has been observed in UV and in green lights with a 1 GHz bandwidth sensitive photodiode. Such photoresponse in UV light is represented on figure 11.

4.2 Experimental conditions

With the ps laser, we have tested only microemitter in field emission conditions ; we used the tungsten single W_2 emitter and an array of about 400 microemitters of $Nb_3\ Ti$.

In front of the photocathode, we have placed a fluorescent screen to observe either field emission pattern associated to each microemitter or geometrical appearance of such pattern in photofield conditions.

4.3 Photofield emission obtained with the ps laser beam

With W_2 needle using green light, pulsed currents of $2A$ peak value and $10A$ peak value were measured and corresponded to 4×10^{-5} and $10^{-4} J$ about respectively in the burst of 15 *ns*. Using ultra high violet light, pulsed currents of $0.2A$ and $0.8A$ peak values were obtained with $2 \mu J$ and $10 \mu J$ respectively.

With the array of about 400 filaments of $Nb_3\ Ti$ photons with $70 \mu J$ per UV burst gave peak currents of about $10A$ peak value. On figure 12 obtained photocurrents are shown in the presence of RF modes. These RF modes which are now under study, appear, when the obtained photocurrents are of the order of some amperes around the voltage field emission level.

5. Summary and Conclusions

The experiments reported here concern photoemission from LaB_6 photocathode with regular size and photofield emission from single or arrays of needles under *ns* or *ps* laser light beams.

In LaB_6 case focussing of photonic beam permitted partial cleaning of the surface and hence lowered the work function down to 1 *ev* about below the laser radiation energy. Such operation leaded to quantum yield enhancement till 10^{-3} instead of 10^{-7} previously observed before work function lowering.

Pulsed photofield emission using either *ns* or *ps* laser showed :

1. The existence of high photoemissivity performances in UV, green and IR lights for microemitters either single or array of needles.

2. Photocurrents of more than $1A$ in UV and $10A$ in green lights were obtained from single tungsten needle. These values increased till about $10A$ in UV, when an array of about 400 $Nb_3\ Ti$ needles was tested.

3. High quantum yields of more than one were often obtained in ultra-violet and green lights, and about 0.75 in infrared light.

This performance can be explained by the contributions of many effects as potential barrier lowering by Schottky effect also by tunnelling effect which greatly improve escape probability for excited electrons by the practical narrowing of the potential barrier ; it can be explained also by size effect of the microemitters which induces an enhancement of local static electric field and by different absorption phenomena. These results are encouraging for developping such photocathodes which are easier to control than any cesiated cathode and which are less sensitive to contamination and are not subject to alcaline adatom surface migration and desorption.

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