MgO PHOTOCATHODE FOR DC VACUUM-MICRODIODES TUNABLE THZ SOURCES

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Abstract - MgO, referred as a dielectric material has been proved experimentally to be a potential candidate as a cold photoemitter of futuristic DC Vacuum- microdiodes, which are to be employed as THz sources by showing photoemission in femto-ampere range without using any current amplifier, axial magnet field orFarady cup.For the empirical analysis, a commercialMgOsample with dimensions of 10×10×0.5mm, grown withorientation of <100> and polished as 1SP has shown a photocurrent which is measuredby using Keithly 2400source meter and 617 electrometer and is of the order of femto-amperes.For photoemission, an ultraviolet LASERemitting at a wavelength range of 325nm- 442nm (3.81eV-2.8eV, 100mW)is used in continuous wave mode as a photon injector. The photo-emitter is operated below its ablation limit($\leq$0.03W/mm^2) and anelectric field strength is changed from 0.06MV/m to 0.12MW/m. The empirical results showed an excellent agreement with the theoretically values and trends. Therefore, the selection of an MgO photocathode for making THz, DC Vacuum devices and systems promise a cost effective and robust approach for their possible future applications in the fields of sensing and pharmaceuticals.

Keywords - Photodetector, Continuous wave, Vacuum-microdiodes, THz sources.

I. INTRODUCTION

The photocathodes being an integral part of the phototubes are evaluated based upon their spectral response, operational lifetime, temporal response, saturation level, damage threshold, voltage hold-off, transverse energy spread of the emitted electron beam, dark current and the average current density [1]. The quantum efficiency of a photocathode with a particular work function that depends upon its growth parameters and surface treatment is a function of the photon energy (wavelength) of the corresponding incoming light [2]aswell. Theoretically, if photon energy of the incoming light is matched with the work function of the photocathode then photocurrent emission is possible [3]. It is observedexperimentally that with a light of wavelength such that if photon energy is more thanthe work function of the material, photoemission can take place easily and is a linear process[4].Also, in order to increase the value of the photocurrent, there is a requirement of high powers of the incoming light , even work function of the photocathode material and the photon energy of the incoming light are matched [5]. However, in this case the material operating condition should be ensured well below its ablation limits.

However, if the photons of the incoming light do not have sufficient energy i.e. even notsame as the work function of the material then the following multi-photon injection process (employment of high power pulsed operation below the ablation limits of the material);photoemission can occur but is anon-linear process and requires specialized measurement techniques to be adopted. One of the most common technique for the current measurement in such cases is, via employing interferometric time-resolved multiphoton photoemission spectroscopy (ITR-mPP)[6].

In order to make photocathodeslow-cost, robust, with longer lifetimes and high quantum efficiencies,different materials in either element form or compounds are tested. In each of these cases,photoemissionunder two conditions has remained under discussion.Itiseither from hot or cold photocathodes. In the former case , the photocathode is to be heated up but for the later, the work function is ensured to get matched with the incoming light without heating and in the presence of a sufficient electric field (to lower the potential barrier), under high vacuum conditions and with recommended surface treatment, photocurrent is emitted[7].

Photocathodes are categorized mainly as semiconductor, alkaline and metallic. Semiconductor photocathodes need surface treatment; GaAs needs to be cesiated to be able to respond in visible range of light and have a high quantum efficiency, for which a special dedicated chamber is required to avoid contamination[8]. This increases the costs of such phototubes. Furthermore, resultantlyampuled structures are formed, which if areleaked/broken then the quantum efficiency of the device drops below critical limits within few hours. The same is the issue with alkaline photocathodes, which are always ampuled and cannot be exposed to normal light for longer time, although their quantum efficiencies are high[9].

In order to fulfill the requirements of robustness, longer lifetimes and short response times, metallic photocathodes are well-known. One of their important application is in free electron LASERs.However, their quantum efficiency is low and is usually of the order of 10^{-4} at 266nm wavelength of the incoming light[10]. For such

wavelengths, commercially LASERs are employed. However, a customized LED and lens assembly can fulfill the requirements of the higher power at the required wavelength [11].

Furthermore, via recommended surface treatments, it is shown that quantum efficiency can be further enhanced. Such as, for the cases of Magnesium and Copper which are most commonly investigated metallic photocathodes due to their robustness, by specific surface treatments such as de-oxidization, ion etching along with employing high electric fields, the quantum efficiency of the photocathodes can be considerably enhanced[12, 13]. In this paper, anMgOsample whichacts as a dielectric material, by shining a light of 325nm (3.81eV) with a power of 100mW under continuous wave mode operation has shown a field emission. In this case, the electric field is changed from 0.06MV/m to 0.12MV/m and a vacuum level of 10^{-5}millibars is maintained.

II. THEORY

The quantum efficiency of a material with a particular work function is a function of the wavelength of the incoming light (shorter is the wavelength of the incoming light, more are the electrons to get emitted) and can be calculated by eq. (1):

$$QE = \frac{\text{Number of electrons produced } (N_{el})}{\text{Number of incident photons } (N_{ph})} \times (\varphi) \qquad [1]$$

In another form, the eq. (1) can be written as eq.(2):

$$QE = \frac{\text{Output current } (I(A))}{\text{Incident optical power } (P(W)} \times (\varphi) \quad [2]$$

"φ"is the work function of the photocathode and can be engineered. However, the number of electrons produced still depend upon the surface conditions of the photocathode and the on power of the incoming light, whether it is following the linear or the nonlinear process of photoemission. Via utilizing axial magnetic field, the transverse electron spread can be controlled. Moreover, with the Farday- cup precise current measurements can be performed to enable the determination of the exact QE of a photocathode.

The photocurrent also depends upon the geometrical parameters and the electric field applied. So, can be estimated by using “Child-Langmuir law” i.e. eq. (3)[14]:

$$N_{el} \sim 100 \times \frac{V(V)}{D(\mu m)} \times S(\mu m^2) \quad [3]$$

Here,"V" is the applied electric field,"D" is the distance between photocathode and anode(spacing) and "S" is the illuminated area of the photocathode.

III. EMPIRICAL ANALYSIS

3.1. Experimental setup and materials

Schematic of the setup is shown in Fig. 1. The structure is kept inside of a vacuum chamber with a vacuum level of 10^{-5}millibars maintained for the empirical analysis. LASER spot diameter is ~2mm on the surface of the photoemitter (MgO). Therefore, the power density at the surface of the photocathode is maintainedat 0.03W/mm^2 for the experiment. The distance between photocathode and the anode is kept fixed at 500µm. In order todrive electrons fromphotoemitter to the collector, the photocathode is driven with a negative potential and anode is applied with the positive potential.

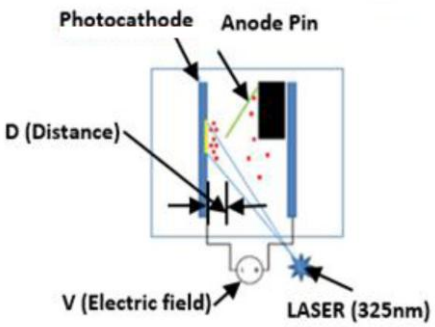


Fig.1. Schematic of the experimental setup for the photocurrent emission with anode as pin kept at distance 500µm above the photocathode.

Specifications of the MgOphotocathode, sample are given in Table 1.

Material	MgO	**Size**	10×10×0.5mm
Orientation	<100>	**Edge axis**	<001>
Polishing	SP1	**Work function**	3.66eV

Table1: MgO Wafer (Photocathode) specifications.

The input parameters for the empirical analysis are given in Table 2.

LASER	UV	**Wavelength Range**	325nm-442nm
Anode	Pin	**Material**	Steel
Area of the spot (R)	0.03mm^2	**Distance(D)**	500µm

Table 2: The Input Parameters of the setup for Photocurrent measurement.

The photocurrents are measured with the electric field varied from 0.04MV/m to 0.12MV/m.

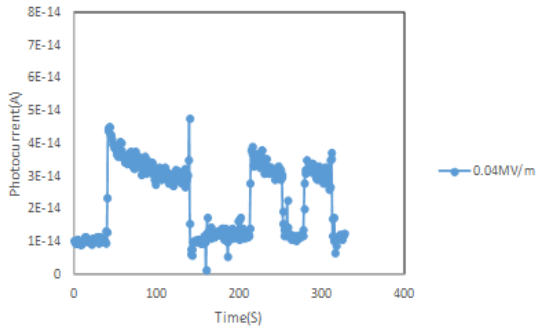
3.2. Photocurrent measurement

The quantum efficiency of the MgO photocathode is expected to be less than the pure magnesium metal i.e. of the order of 10^{-7} at 325nm wavelength of the

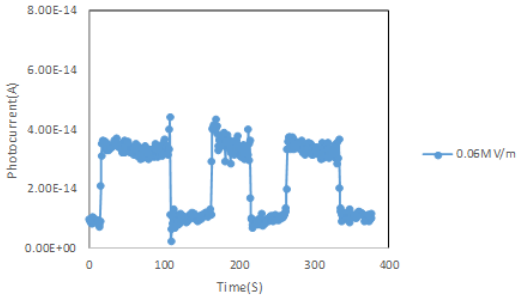
incoming light. Therefore, the output current with 100mW of the LASER power is estimated as to be in the range of Pico-amperes (pA). So, an electrometer is used for the photocurrent measurement.

The field emission results obtained at 0.04MW/m, 0.06MW/m and 0.12MW/m of the electric field values are shown in Figs. 2(a, b, c and d). It can be observed from Fig. 2(a, b and c) that with increasing the electric field the photocurrent is increasing and is of the order of 10^{-14}. The peaks and valleys in photocurrent spectrums for each of the cases correspond to "light" and "no-light" conditions respectively.Under each of the field conditions, the sample was exposed for 300s to "light" and "no-light" conditions. No heating effects were observed under "light" conditions even the samples were exposed for a long time.

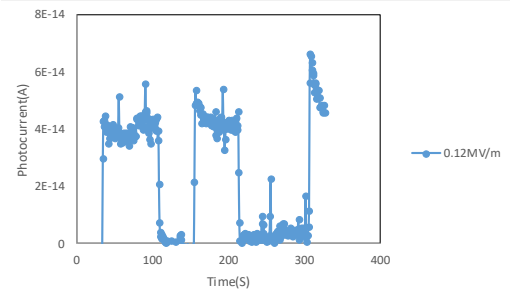
It can be noticedfrom Fig. 2(d) that for an electric field of 0.12MV/m, there is a sudden increase in photocurrent but no saturation is observed. This points towards the fact that the sample can be exposed to even higher electric fields and correspondingly higher values of the photocurrents can be obtained andthe photoemission can be regarded as a cold photocathode emission.



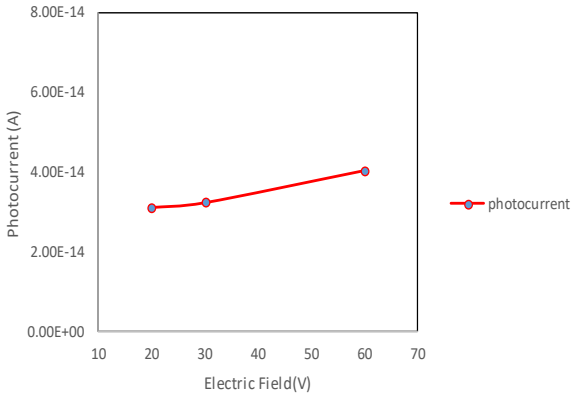
(a)



(b)



(c)



(d)

Fig.2. Photocurrent as a function of time for (a) 0.04MV/m, (b) 0.06MV/m, (c) 0.12MV/m and (d) increasing photocurrent as a function of electric field.

IV. RESULTS AND DISCUSSION

The empiricaland predicted datafor MgO material are well in agreement. The difference,however is attributed to the loss due to surface conditions and reflections. Other reasons may be due to the absence of axial magnetic field and Faraday cup which are essential parts of the photocurrent measurement setup due to their vital role in converging, directing and collection of the electron beam. Also, the LASER light used was outside the chamber, which may cause light loss due to free space coupling due to which the quantum efficiency is low.However, the increasing photocurrent trend pointstowards two important facts to be noticed. Firstly, the increase in photocurrent followed the theory that increasing the electric field causes the increase in their values and secondly, the trend is nonlinear which exactly follows the predicted trend (Child-Langmuir law) with the sample operated far below the ablation limit.

V. CONCLUSIONS

In this paper, MgOis reported as a cold- photoemitter. The measured photoemission and correspondingly the quantum efficiency was low as predicted. It is due to, as results were obtained with LASER in continuous mode, without any recommended surface treatments, axial magnet orFaraday cup. Therefore, it is proposed here that in future, with all above conditions met properly the photocurrent and correspondingly the quantum efficiency of the photocathode can be enhanced.

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