Design and Construction Optical Pumping System

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Abstract:

In this work the design and construction of optical pumping system was presented. The parameters of the pumping source to obtain discharge current density sufficient to shift the flash lamp spectrum towards uv portion of spectrum were measured.The current density was supplied to the flash lamp must be greater than 4000Amp./cm^2 to obtain the spectral range wavelength lies between 0.2 and 0.35μm. The current density was obtained by a capacitor 50μF, at 7KV discharge voltage. The applied electrical energy to the flash lamp was more than 1200 J, and the current density was around 5000 Amp./cm^2.The electrical parameters of the flash lamp were calculated. The impedance parameters(K_0) from the voltage and the peak current pulse was measured in range equal to 57, while the damping factor(α) was 1.3. The energy of the flash lamp was around 75% from the input electrical energy. The external trigger circuit was limited the increase the applied voltage, which is responsible for the damping factor.

Key words :Optical pumping system, flash lamp

Introduction:

The optical pumping for the laser active media can be achieved through a band width in the UV portion of the spectrum (285-288 nm), which lies in the spectrum range of the xenon flash lamp. To have an optical power enough to generate H_2 dissociation needed for producing population inversion in the active medium, it is important to use a flash lamp filled with xenon gas. Xenon gas is considered as the best inert gas utilized. It is generally chosen as the gas fill for flash lamps regarding its efficiency that converts (40%-60%) of the electrical input energy into radiation in the (0.2-1) μm regions. It can be increased by increasing the current density. In other words, the pumping efficiency of Xenon increases as the pressure increased in the range (450-3000) torr. The effect of an increase in gas fill pressure, is to reduce the mean free path of the electrons and atoms in the discharge, and thus to increase their collision frequency.The flash lamp which is shown in fig.(1), was employed to produce light spectrum suitable for pumping molecules in the active medium to dissociate at (285-288) nm[1].

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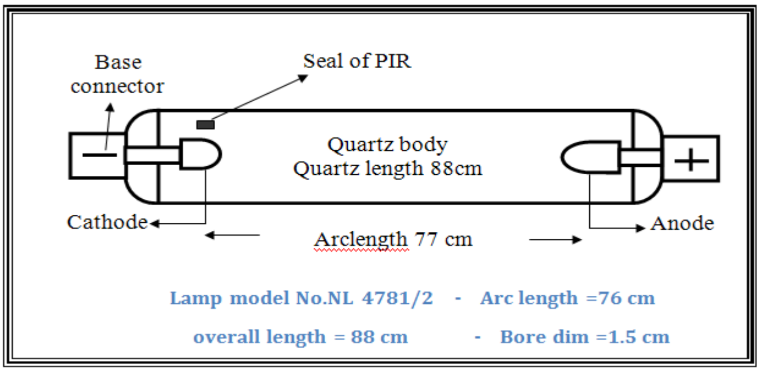


Fig.(1) The Xenon flash lamp[1]

The spectral output of Xenon flashlamp depends on current density, as the current density increases from few tens to few thousands of Amp./cm^2. The intensity in the portion of the blue and UV increases much more rapidly than that in the red and IR. The output spectral range of the XFL which is dependent on current density is shown in Fig.(2). Moreover, high current density shifts the spectral output toward the shorter wavelengths side [2].

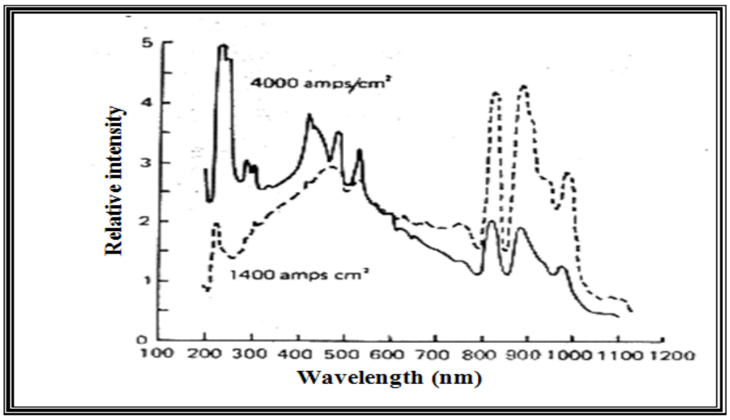


Fig.(2) The spectral emission from Xenon flash lamp operated in high current densities [2].

The intensity of the lamp output spectra depends on the material envelope of the lamp. The transmission properties of the flash lamp envelope will influence the spectral output. Usually, the envelope is fused natural silica, which transmits light between 0.2 and 4μm. Fig.(3) illustrate the relationship between the UV transmit wavelengths of different materials. Pure quartz glass was chosen for the flash lamp Xenon envelope designate by line B of the figure, which gives a high transmition for active pumping beam [3].

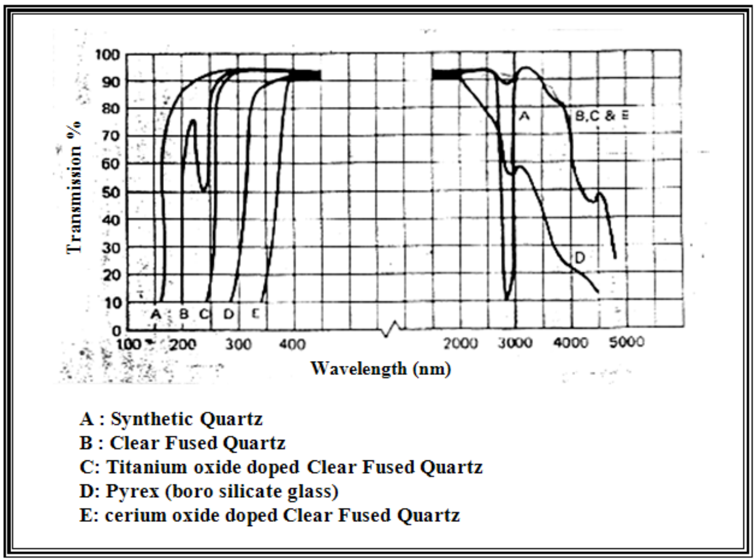


Fig.(3) Materials transmission curves for various envelope of flash lamps [2]

The Theoretical analysis of Electrical Design

This study was done to specify the design basics of the power supply for highly efficient operation necessary for achieving the required pumping. The following equation governs the (I-V) current-voltage characteristics for a flash lamp operates at high current range [3,4]:-

$$V = K_o i^{1/2} \quad \text{……. (1)}$$

where

V : is the voltage between two electrode for flash lamp (Volt)

i : discharge current (Amp)

K_o : impedance parameter (Ω. Amp ^{½})

$$K_o = K\ell / d \quad \text{…….(2)}$$

where:

K : is a constant which depends on the gas type and on the gas pressure only.

ℓ; d: are the length and diameter of the flash lamp bore respectively.

The impedance characteristics of the flash lamp determines the efficiency with which energy is transferred from the capacitor bank to the lamp, the lamp impedance parameter K_o can be calculated from eq.(2) [4].

$$K = 1.27\left(\frac{P}{450 torr}\right)^{0.2} \quad \text{at}$$

P = 450 torr

Respectively K_o or K is essentially the only parameter which is needed to describe the high-current electrical characteristics of a given flash lamp.

The resistance of the flashlamp for high-current region with the plasma filling the bore of the tube is obtained from the relation [5]:

$$V \approx R_L(i) i = \frac{\rho_i \ell}{A} i \quad \text{…… (3)}$$

where ρ_i is the specific resistivity of the xenon plasma, which is a function of the current density. A: is the cross-sectional area of the lamp, with relative to the voltage drop at the electrodes. The values of (ρ) for several values of (τ) are shown in table (1)[6].

Table (1) The values of (ρ) for several values of (τ)

ρ (Ω.cm)	τ (μsec)
0.015	$\tau \le 100$
0.02	$100 < \tau \le 1000$
0.25	$\tau > 1000$

In the operating regions of interest, the flash lamp resistivity for Xenon at 450 torr is related to the current density by (j), where [7]:

$$\rho_{(i)} = \frac{1.13}{j^{1/2}} \quad (\Omega.\text{cm}) \ldots\ldots (4)$$

The relationship is valid for current densities of approximately 400 to 10000 Amp/cm^2. The lamp resistance R_L is obtained by introducing eq.(4) into eq.(3):

$$R = \frac{\rho \ell}{A} \quad \ldots\ldots (5)$$

$$R_L(i) = 1.27\left(\frac{\ell}{d}\right) i^{-1/2} \ldots\ldots (6)$$

Comparing (3) with (1), we can obtain an expression for the flashlamp parameters K_o:

$$K_o = 1.27\frac{\ell}{d} \; (\Omega \text{ Amp.}^{1/2}) \quad \ldots\ldots (7)$$

The constant value (1.27) in equation (2) holds for 450 torr Xenon lamp. For other pressure values:

$$K_o = 1.27\left(\frac{P}{450}\right)^{0.2} \frac{\ell}{d} \quad \ldots\ldots (8)$$

The value of the capacitor is:[5]

$$C^3 = \frac{2E_o\alpha^4 t^2}{K_o^4} \ldots\ldots (9)$$

E_0=storage energy
α =damping parameter.
t =pulse duration.

The inductance L can be calculated from the following relation:

$$L = \frac{t^2}{C} \Rightarrow \frac{t_p^2}{9C} \ldots\ldots (10)$$

where:

L : total inductance in Henry.

C : capacitance in Farad.

The total flash lamp pulse duration (t)is:

$$t = \frac{1}{3} t_p \quad \ldots\ldots (11)$$

t : $\frac{1}{3}$ the desired pulse half width in second.

The energy initially stored in the capacitor is

$$E = \frac{1}{2} C V_o^2 \quad \ldots\ldots (12)$$

where:

E : storage energy in Joule.

V_O : initial voltage on capacitor band in Volt.

α : damping parameter for critically damped pulse.

The damping constant α can be calculated as follow:-

$$\alpha = \frac{K_o}{\sqrt{V_o Z_o}} \quad \ldots\ldots (13)$$

α should be 0.8 for critically damping pulse. The circuit impedance Z_o is given by:

$$Z_o = (L/C)^{\frac{1}{2}} \; (\Omega) \quad \ldots\ldots (14)$$

The peak current, for a critically damped current pulse at α = 0.8, is :-

$$I_{max} = \frac{V_o}{2Z_o} \qquad \text{……. (15)}$$

The current density (J) is:

$$J = \frac{I}{A} \quad \text{……. (16)}$$

The capacitor voltage decays exponentially from (V_o) to zero. The rise time (t_r) can be defined as the time required for the voltage or current to rise from zero to its maximum value. The rise time can be calculated by:

$$t_r = (CL)^{\frac{1}{2}} \qquad \text{……. (17)}$$

The rise time which is measured between the 10% and 90% points of the voltage is 0.5 t_r [8]. Vo must satisfy the relationship $Vo \leq 2Zo\ I_{pk}$.

The Trigger Circuit

In most of the flash lamps, the charged capacitors voltage is less than the required threshold voltage for the initiation of spontaneous flash lamp operation.

The discharges of the stored energy into the flash lamp are generally initiated by a high-voltage trigger pulse. The function of the trigger signal is to create an ionized spark streamer between the two electrodes, so that the main discharge can occur. The initial spark streamer is formed by the creation of a voltage gradient of sufficient magnitude to ionize the gas column. The trigger voltages of flash tubes are between 5 and 30 KV for short duration such as few microseconds. The outside wall of the flash lamp tube is wrapped with a tungsten wire.

There are three basic methods of triggering the flash lamps. Each of them achieve the same purpose. However, they are different in some characteristics according to the type of the employed lamp and to the application needed. These methods of triggering areas follows[9,10]:

1. External trigger.
2. Series (internal) trigger
3. Simmer (over volt operation) trigger.

We used an external triggering since it seems suitable at the beginning for our research. The circuit was used in this research to operate four flash lamps, each is connected to flash trigger by single trigger transformer This is to reduce the delay and the jitter time between the flashes. High voltage trigger (30 KV) supply to the flash lamps through the tungsten wire was wrapped around the flash lamps.

Many advantages have arisen out of using external trigger, namely: the reliability, simplicity and stability for long time of operation.

Results and Discussion:

The Xenon flash lamp emission covers a wide range of the electro-magnetic spectrum (0.2-2)μm. The pumping spectral range of our active medium lies between 0.2 and 0.35μm. Consequently, to obtain the desired wavelength range, the discharge current density which is supplied to the flash lamp must be greater than 4000Amp./cm^2 [11]. To obtain such values for current density a capacitor was chosen of around 50μF, at 7KV discharge voltage. Therefore, the input electrical energy to the flash lamp was more than 1000 J, and the current density was around 5000 Amp./cm^2.

An optical multichannel analyzer (type OMA-3) was used to get the relative intensity of the flash lamp as a function to the emitted wavelength which is drawn in Fig(4). This chart shows the increase in intensity in the range (280-288)μm which covers the absorption range of the active medium. The relative intensity of the flash lamp in the range (280-288)μm as a function of the applied voltage is shown in Fig.(5). It is seen obvious that at 7KV, the output intensity of the desired wavelength reaches a saturation value when a capacitor of 50 μF was used. The UV pulse shape of the flash lamp using a photomultiplier is shown in Fig.(6).

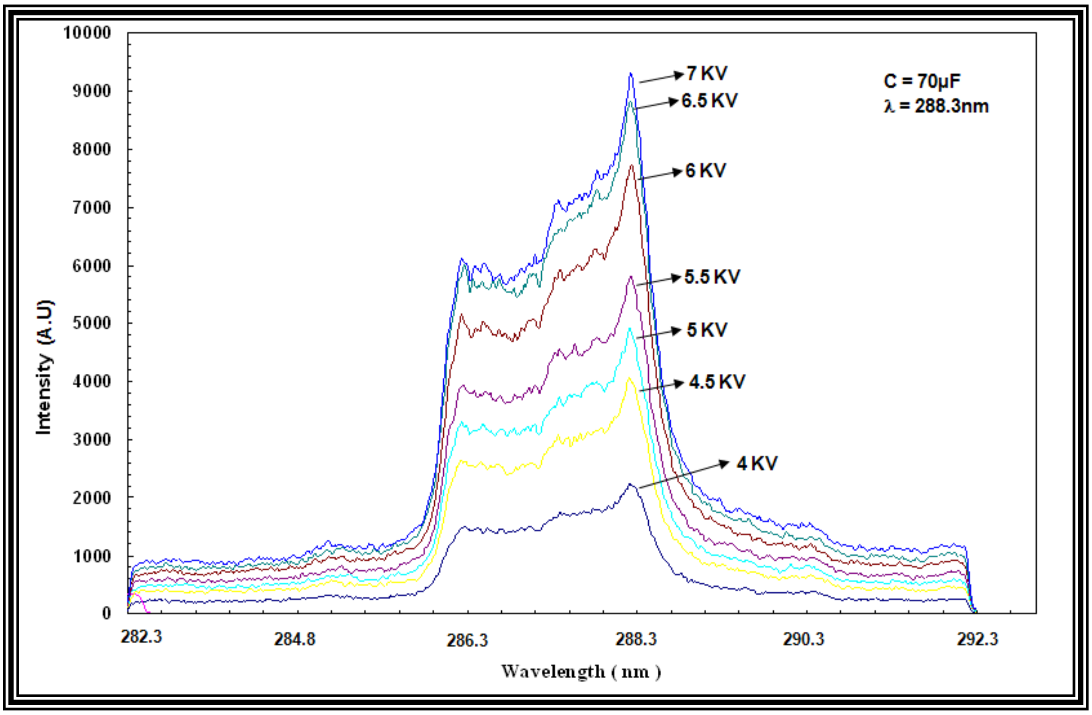


Fig. (4) Emission spectrum of the flash lamp at different voltages.

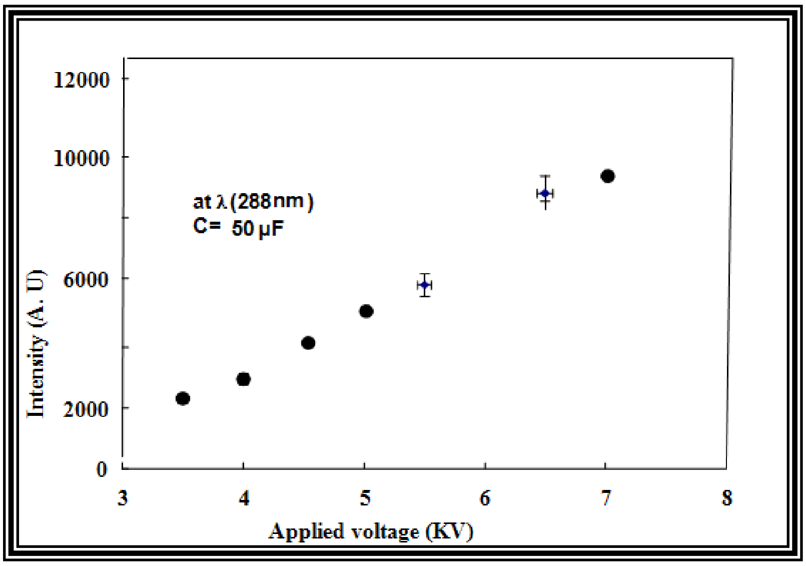


Fig.(5) The relation between the intensity (A.U) of the flash lamp as a function of the applied voltage.

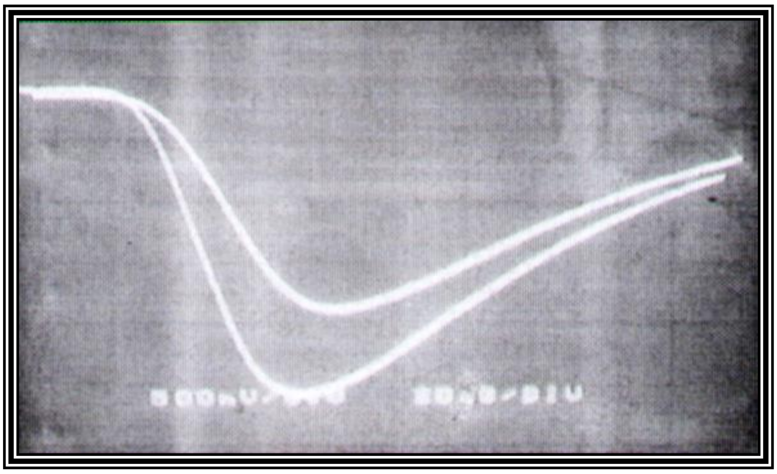


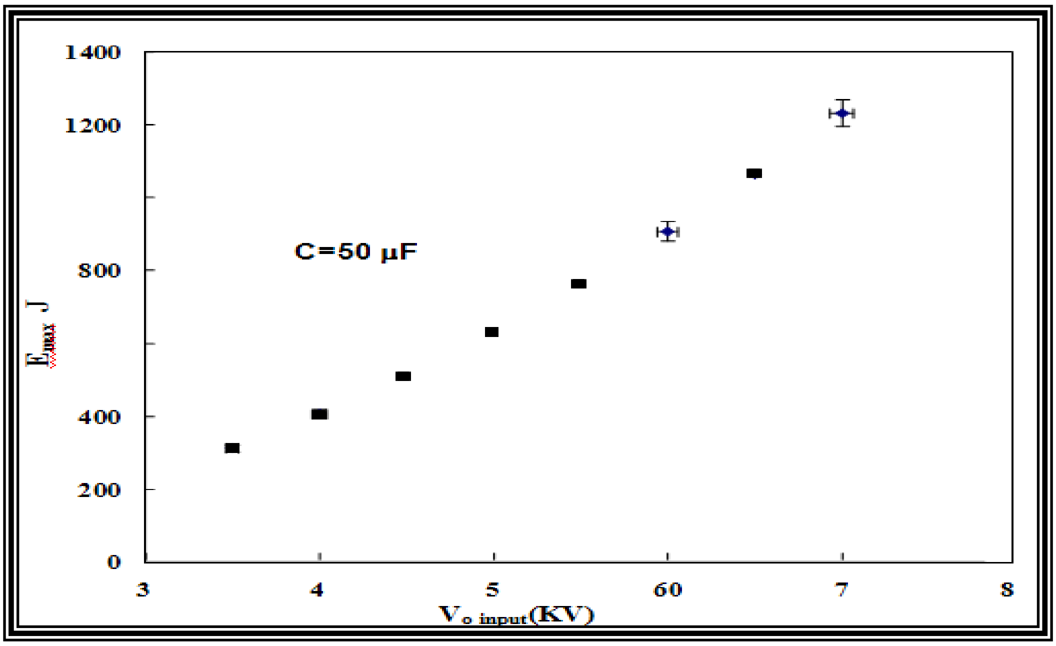
Fig.(6) the UV flash intensity of the flash lamp. The upper trace at voltage of 8.5KV. The lower trace at 10KV

The electrical parameters calculations of the flash lamp (NL4781/2), which was used in this research are illustrated in table (2). The measured value of (K_0) from the voltage and the peak current pulse was equal to 57, while the damping factor was 1.3. The value of (K_0) and (α) declares that the flash lamp is operated in the over damping case. This means that the delivered energy of the flash lamp is around 75% from the input electrical energy table (2) shows the damping factor(α) verses the input voltage. The use of external trigger circuit limitation increases the applied voltage which is responsible for the damping factor. This is because the increase in the applied voltage will reduce the damping factor to its optimum value (0.8). The relation between the electrical energy which is supplied to each flash lamp verses the input voltage for C =50μF is shown in figure (7). The energy reaches 1200J for v =7KV.

The current shape and the break down voltage profile, using current transformer (current prop AM 503 current prop amplifier) with oscilloscope (TS - 8123 storage scope) to record the pulses, is shown in Fig.(8)

Table (2) The optimum electrical parameters of the flash lamp.

$V_{o\ input}$ (volt)	Energy E_{input} $=(0.5)CV^2$ (J)	Peak current $I_{pk}=(0.5)(V_o/Z_o)$ (Amp.)	Current Density $J= I_{pk}/A$ (Amp./cm^2)	Damping Factors $\alpha= k_o/(V_o Z_o)^{1/2}$	Intensity (A.U.) λ_{288nm}
3500	306.25	5147	291	1.89	2242
4000	400	5882	3329	1.76	2960
4500	506.25	6617	3745	1.66	4080
5000	625	7352	4161	1.56	4932
5500	756	8080	4577	1.5	5822
6000	900	8823	4993	1.44	7741
6500	1056.25	9558	5409	1.38	8843
7000	1225	10294	5825	1.33	9316



Fig(7) The relation between the input energy of the flash lamp and applied voltage

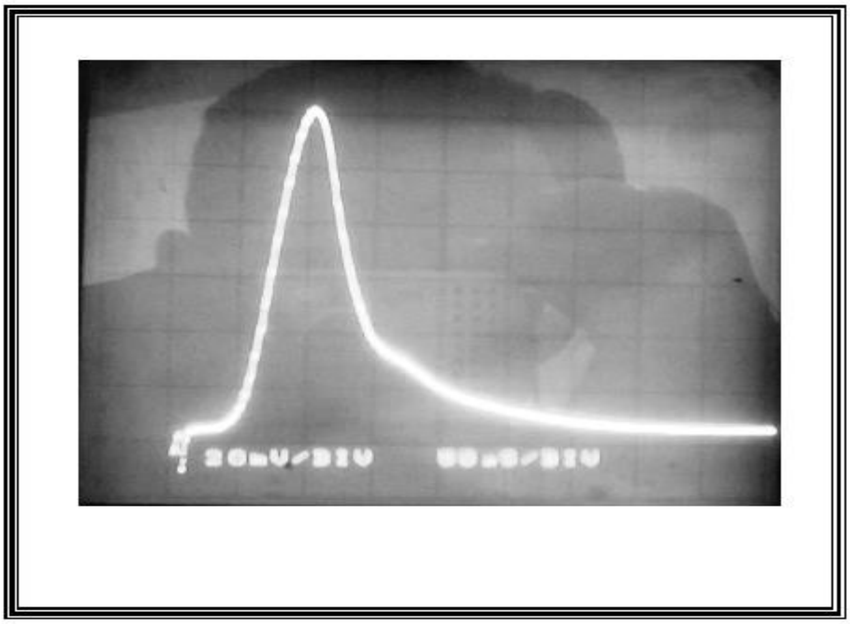


Fig. (8) The current pulse shape (1000 Amp./Div, 50 µsec/Div)

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تصميم وبناء منظومة ضخ ضوئي

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الخلاصة:

في هذا البحث تم تصميم وبناء منظومة ضخ ضوئي . حسبت معلمات مصدر الضخ لإزاحة منطقة الطيف الضوئي إلى المنطقة فوق البنفسجية . كثافة تيار التفريغ الكهربائي للمصباح الوميضي والذي يجب أن يكون قيمته اعلى من 4000 أمبير/سم^2 ومنطقة الطيف واقعة ضمن مجال الأطوال الموجية0.2-0.35 مايكروميتر. للحصول على تلك القيم من كثافة التيار تم استعمال متسعة ذات قيمة 50مايكرفاراد وفولتية تفريغ 7كيلوفولت. الطاقة الكهربائية المعطاة للمصباح الوميضي هي أعلى من 1200جول،وكثافة تيار 5000 أمبير/سنتميتر^2. تم حساب المعلمات الكهربائية للمصباح الوميضي .معامل الممانعة من قمة نبضة التيار والفولتية هي 57.بينما قيمة ثابت الانحلال هي 1.3 ان الطاقة المستلمة من المصباح الوميضي هي بحدود 75% من الطاقة الكهربائية المعطاة. ذلك التحديد الناتج من دائرة القدح الخارجية زاد من قيمة الفولتية المسلطة والمسؤول عن معامل الاضمحلال.