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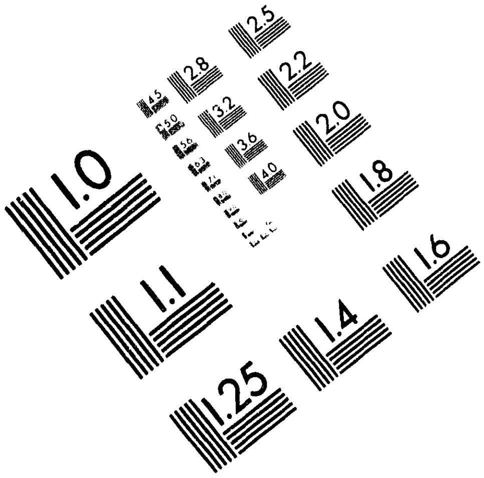
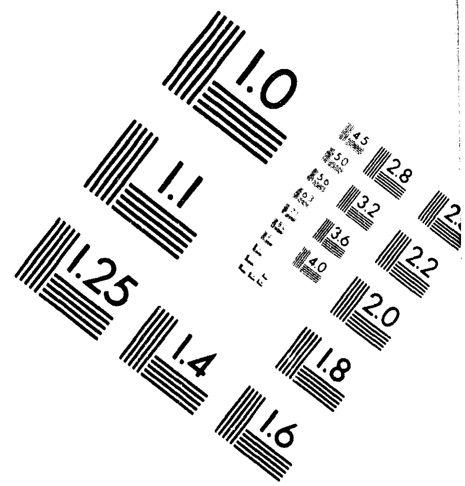

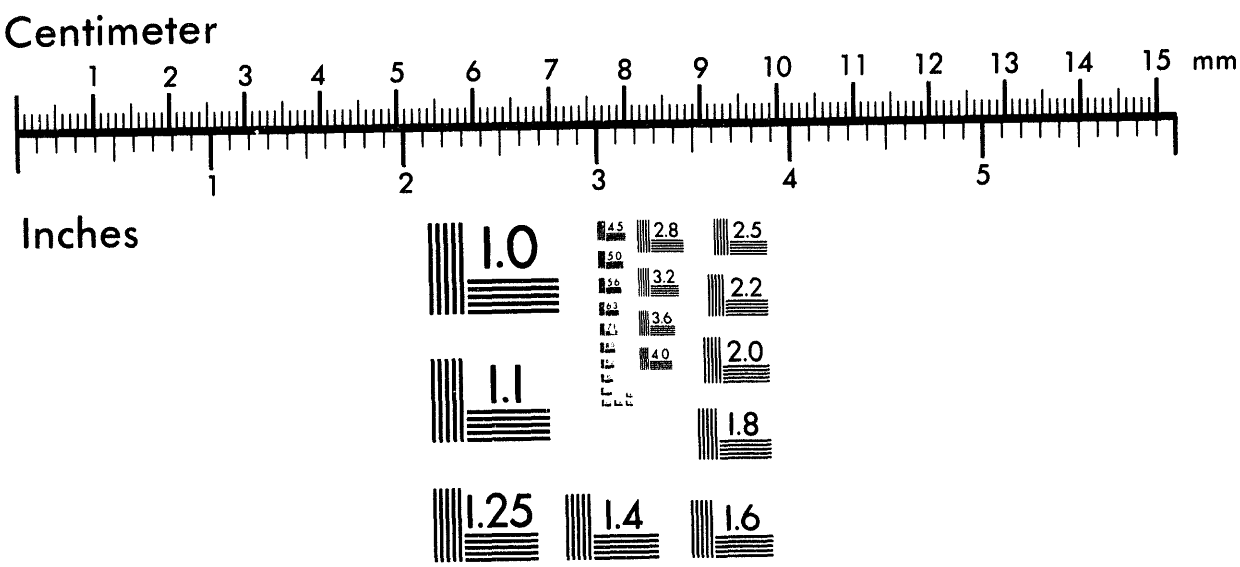

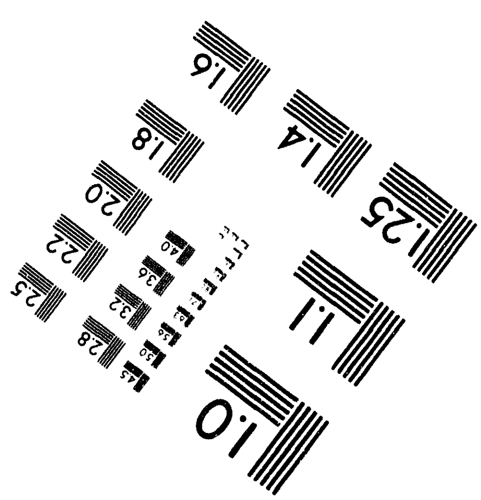
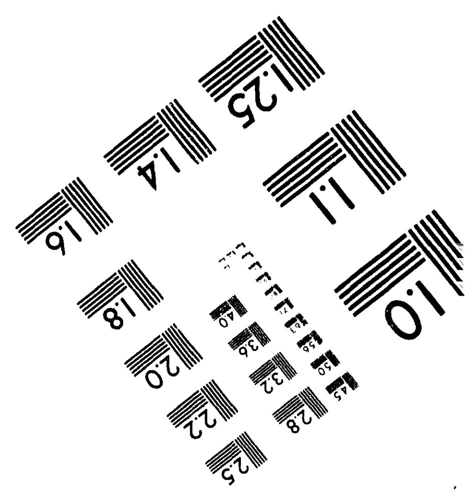

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Title: Nonlinear Response of the Photocathode of an X-ray Streak Camera to UV Light

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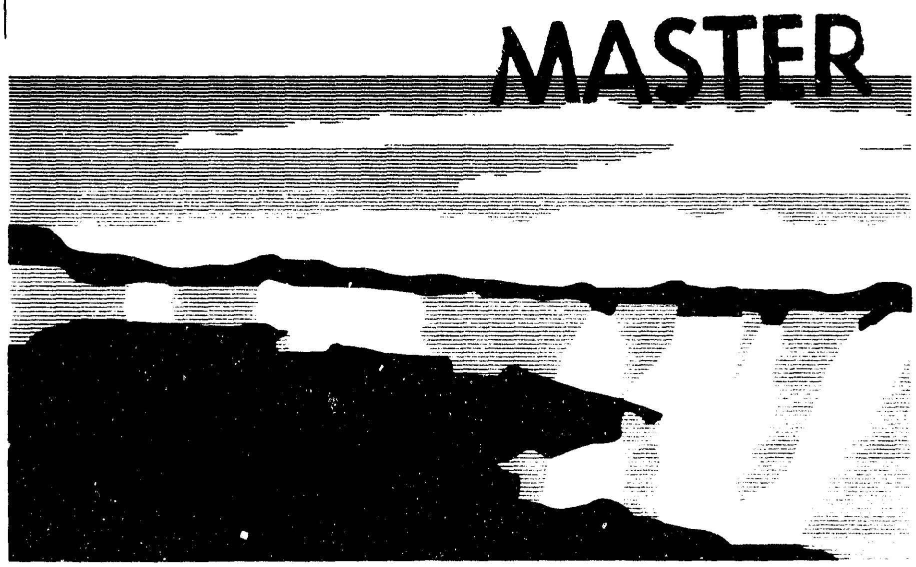

Los Alamos
NATIONAL LABORATORY

Nonlinear Response of the Photocathode of an X-ray Streak Camera to UV light

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ABSTRACT

We have found that a potassium-iodide photocathode of an x-ray streak camera responds to UV light at λ=308 nm. The photocathode surface work function, 6.5 eV, is larger than the 4 eV energy of the UV photon, hence the source of the response is interesting. We will present results on the response of a transmission type potassium-iodide photocathode to the UV light from a λ=308 nm, subpicosecond XeCl laser and from a λ=326 nm HeCd laser. We will test for the non-linearity of the yield to measure of the number of photons that are needed to be absorbed before a signal is recorded. We will present data on the effect of the UV irradiance on the yield, as well as on the temporal width of the recorded signal. We will give an explanation of the observation and its effect on the dynamic-range response of the streak-camera. We will show that the response is linear with the incident irradiance, up to an incident irradiance of 10^8 W/cm^2 and we will explain the observation.

Keywords: Potassium iodide, photocathode, streak camera, ultraviolet response.

2. INTRODUCTION

While measuring the x-ray emission from a laser produced plasma, we had a need to monitor the incident laser irradiances at λ=308 nm on the same streak-camera. The response of the streak camera to the x-rays was the driving factor in choosing a photocathode. In contrast to previous attempts,[1,2,3] where only a timing fiducial was needed, the shape of the laser pulse needed to be measured. Other factors also influenced the choice of a photocathode: the streak camera was exposed to air quite often, the photocathode had to be changed often depending on the x-ray region of interest, the photocathode had to be solar blind and the photocathode had to work in the transmission mode. Of the metal photocathodes, only the alkali metals Barium, Cesium and Lithium have work functions below 3 eV. However they are not suitable from the handling point of view[4]. Semiconducting and alkali antimonide photocathodes also have low work functions and high quantum yields but also suffer from exposure to repeated cycling from vacuum to air. Alkali-iodides, though suitable for handling, have a work function greater than 6.2 eV. Fortunately, in a different setup, we had noticed that a Cesium Iodide photocathode, with a work function of 6.2 eV, responded to the UV irradiation from a KrF laser at λ=248 nm with a 5 eV photon![5] and Rockett[3] observed a response at the frequency of a quadrupled glass laser, λ=266 nm. A similar response from potassium bromide was reported[6] at 308 nm, well below its work function of 8 eV. While the cesium iodide did not require intense radiation to get a response at λ=248 nm, it did require 1 mJ/cm^2 at λ=266 nm. The response of the potassium bromide photocathode required a focused laser to solicit a response. It has been suggested that the source of the response in all these cases is a two photon process, in which two photons simultaneously eject one electron. An alternative explanation is the single photon response from F-centers due to defects in the alkali halide photocathode structure[4]. The behaviour begs an important question, is the response linear or is it nonlinear due to two-photon photoelectric effect? If the response is linear, then the regular interpretations of the recorded streak width apply. If the response is nonlinear, then we have to interpret the streak camera response carefully because the recorded streak-widths would be narrower than the actual incident laser pulse-width.

Assume that N_e , the number of electrons produced, is related to N_p ,the number of incident photons, as:

$$N_e(t)=a\,N_p(t)^k \qquad (1)$$

where k is the order of the non-linearity. For example, if two, three, four .. UV photons are required to produce an electron then k=2, 3, 4, ... respectively. For an incident Gaussian laser pulse, of width t:

$$N_p(t)=A\,e^{-(t/\tau)^2} \qquad (2)$$

the electron response will be:

$$N_e(t)=a\,[\,Ae^{-(t/\tau)^2}\,]^k\; = a\,A^k\,e^{-(t\sqrt{k}/\tau)^2} \qquad (3)$$

and the electron pulse will be Gaussian with a width $\tau/\sqrt{k}$. For a Gaussian instrument function of width τ_i, the recorded pulse width τ_r will be:

$$\tau_r^2=\tau_i^2+(\tau/\sqrt{k})^2. \qquad (4)$$

For a multiphoton absorption the recorded width is thus narrower than for a linear response. One sees the importance of measuring k in the interpretation of the measured pulse width. If the pulse shape is not Gaussian, then a more general treatment is necessary to interpret the measurement from the recorded trace.

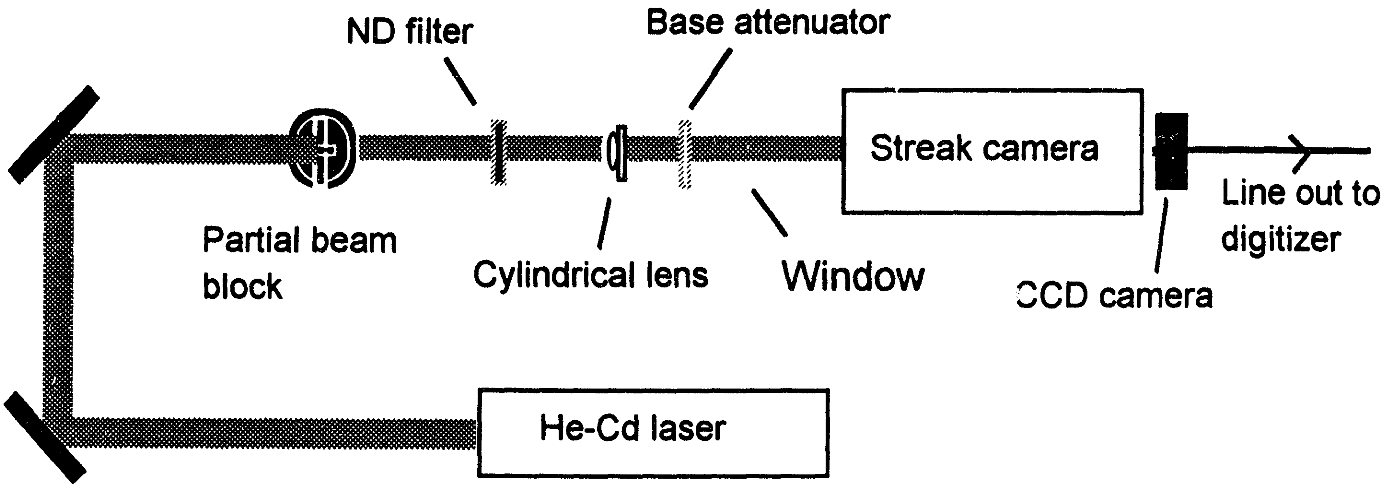

Fig. 1. A schematic of the experiment using the HeCd illumination.

3. DESCRIPTION OF THE EXPERIMENTAL APPARATUS

We have measured the non linearity of the response using two different x-ray streak cameras with two different photocathodes and with three different methods. The first setup used a continuous HeCd laser with an emission wavelength of 326 nm to examine the low irradiance regime. The streak camera was used in the focus mode, and the data were recorded in digital form using a CCD camera with a frame store digitization. In the second setup a 270 fsec XeCl laser was used to examine the temporal response of the camera in the streak mode and at higher irradiance. In the third method the streak camera was used in the focus mode, but illuminated by the pulsed XeCl laser. The photocathode[7], in each case, is constructed from a 120 nm thick KI film deposited on a 12 nm Aluminum conducting layer which in turn is deposited on a 150 nm thick Lexan substrate. The KI, on a transmitting photocathode that is connected to a -15 kV supply, faces an extraction grid that is connected to an -11.5 kV supply. The electric field in the extraction region is 30 kV/cm. At the input slit, 100 μm in width, agraduated series of calibrated attenuators covered one half of the slit. Thus we recorded on every shot a reference beam as well as the attenuated beam.

3.1-HeCd Illumination:

A HeCd laser was used for a low irradiance illumination of the photocathode where the streak camera was used in the static mode, also called the focus mode, Figure 1. The maximum laser irradiance was estimated at 4×10^{-2} W/cm^2. The response from the streak camera was recorded by an intensified CCD camera and digitized into 256 levels. Since the response of the streak camera photocathode and the laser irradiance were not uniform, we chose to examine the response across 10 bands of the image. For each band we examined 30 different measurements, and we fitted S, the response, as a polynomial function of the irradiance I. The fit that with the lowest uncertainty has the functional form:

$$S = a_0 + a_1 I^{\alpha} \quad (5)$$

The mean fit for α was found to be 0.997 with a standard deviation of the mean of 0.012. The probability that the response is second order is less that .001 and the response is clearly linear, see figure 2.

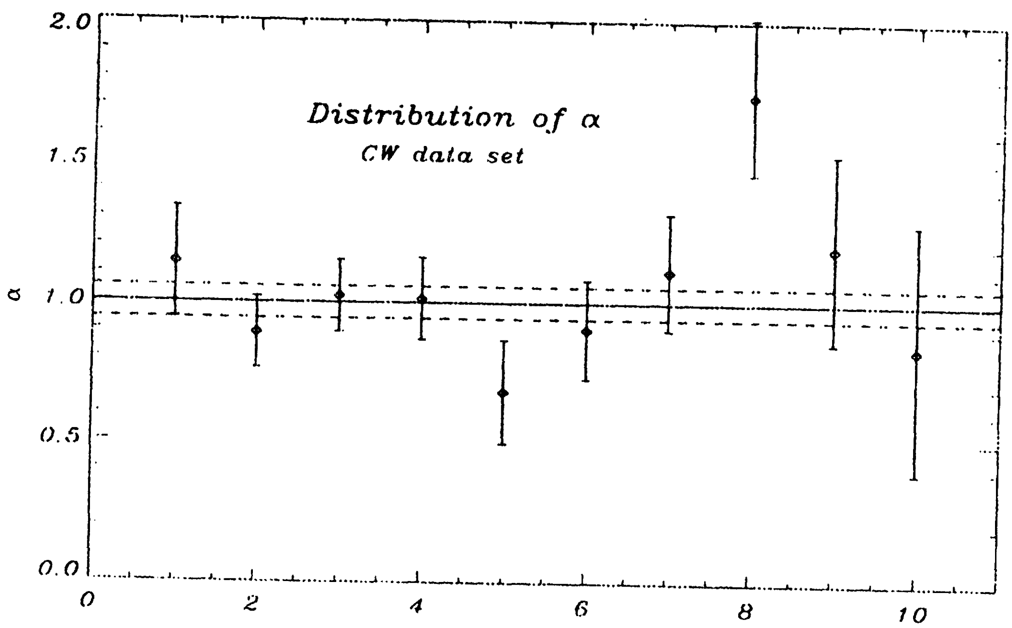

Figure 2. Summary of all the fits to the exponents. Each measurement set corresponds to 30 measurements.

3.2-XeCl Illumination [Streak Mode]:

A subpicosecond XeCl laser was used for high irradiance illumination [Figure 3]. The peak irradiance averaged 10^8 W/cm^2 and was generated by a fluence of 6 10^{-5} J/cm^2 from a λ=308 nm laser with a pulse width of 270 fsec. This irradiance is quite high, relative to the constant illumination data, and two photon process are much more probable than at the lower irradiances. In this experiment, calibrated neutral density filters were used to attenuate one half the beam, and the response was recorded on hard film. Each image contained two recordings: the attenuated and the non-attenuated beam. Since each recording was in response to a different illuminating pulse, with a varying pulse energy, we chose to analyze the data in a different manner than for the continuous illumination case. We analyzed the ratio of the signals from different parts of the screen. Thus using equation (1), the response of the non attenuated beam is:

$$S_0=a\, I(t)^k \tag{6}$$

and the response from the part of the beam that was attenuated with a neutral density filter of transmission 10^{-nd} is:

$$S_{nd}=a\, [\, 10^{-nd}\, I(t)\, \beta\,]^k \tag{7}$$

where we have used β, a multiplier for the irradiance, to indicate that a different part of the beam is being sampled. The ideal ratio would be :

$$R= S_{nd} / S_0 =[\, \beta\, 10^{-nd}\,]^k \tag{8}$$

We used the fit:

$$R=A\, [10^{-nd}\,]^k \tag{9}$$

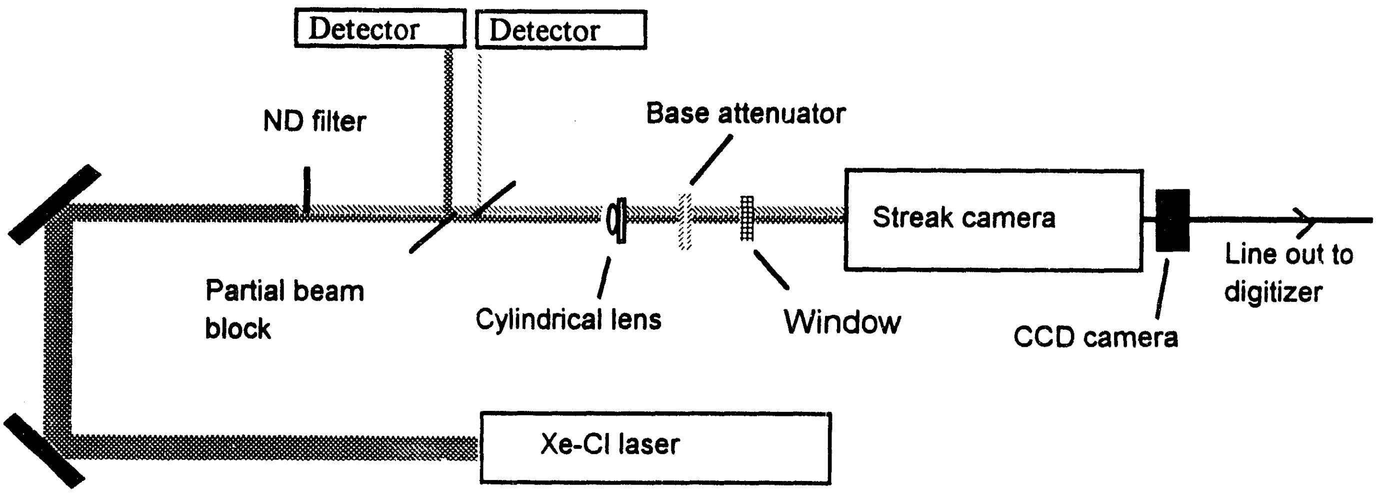

Fig. 3. A schematic of the experiment using the XeCl illumination in the streak mode.

The data was noisy, but the best fit of the parameters was A, k= 0.81, 1.01 with standard deviations 0.134 and 0.2 respectively [see figure 4]. The value of k is consistent with a linear response. We expect A to have the values 1. The value of a is close to the expected value indicating that the method is correct. The large variance of A, and its difference from 1, indicate that the two regions of that were sampled did not have equal illumination. Because the coefficient a did dependent on k as well, the fit shows that the regions were illuminated with a ratio of 0.8 when the attenuation was absent, and the response is linear. A plot of a forced second order response [see figure 5] over the data demonstrates that a quadratic response falls far from being a two photon process.

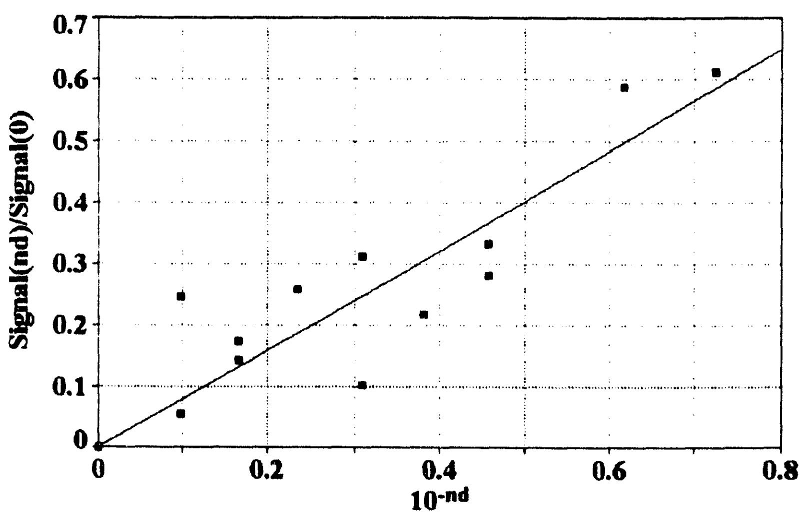

Figure 4. A best fit to the pulsed streaked data using a power function, $Y = a\ x^k$, where $a = 0.81 \pm 0.134$ and where $k = 1.01 \pm 0.2$.

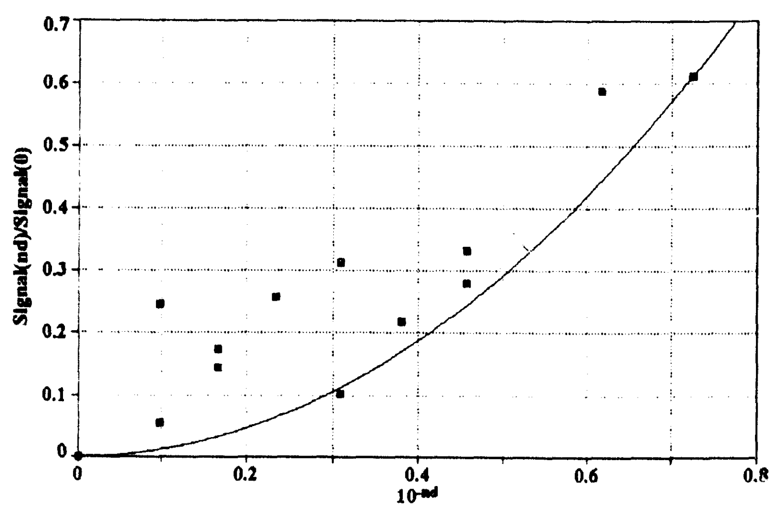

Figure 5- A forced fit to the pulsed streaked data using a square law response, $Y = a\ x^2$.

3.3-XeCl Illumination [Focus Mode]:

A subpicosecond XeCl laser was used for high irradiance illumination [Figure 6]. The peak irradiance averaged 10^8 W/cm^2 . and was generated by a fluence of 6 10^{-5} J/cm^2 from a λ=308 nm laser with a pulse width of 270 fsec. Part of the beam that focused on the photcathode was split and directed onto a CCD camera that monitored the incident beam. The camera was used in the framing mode. Thus we could monitor the laser beam as well as monitor the irradiance at each position across the photcathode slit, on a single shot basis . The recorded signals, at one photocathode position, were fitted against the incident signal from the corresponding laser position, as in the previous section. The results in Figure 7 show that the best fit is again a linear fit.

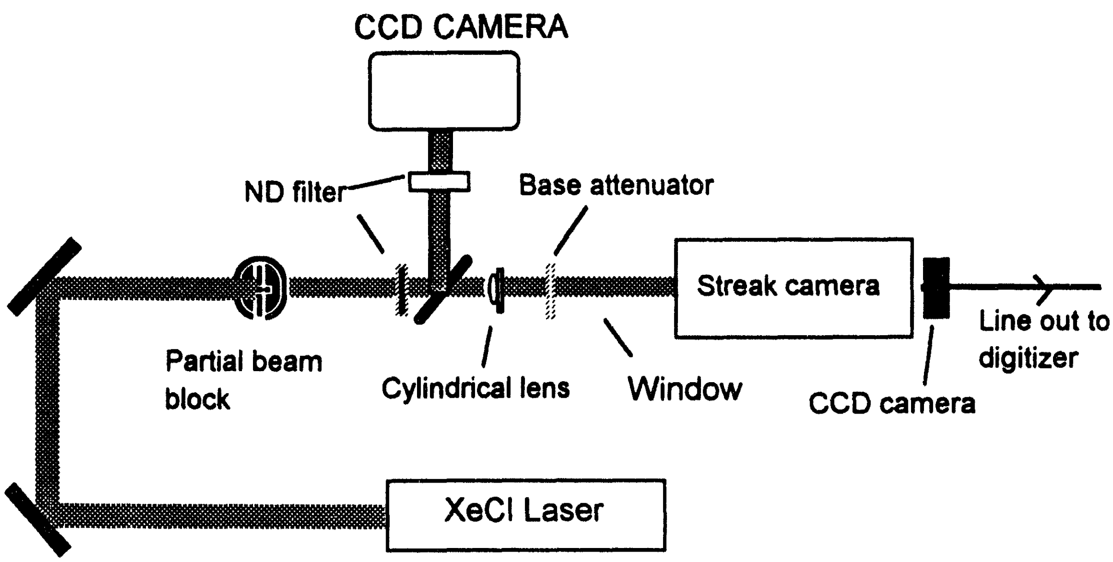

Figure 6. A schematic drawing of the setup for the static measurement of the pulsed laser illumination

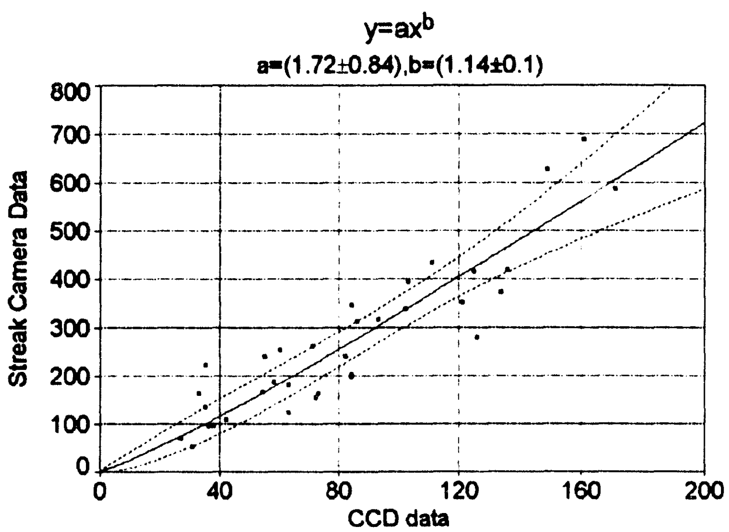

Figure 7. A fit of the high irradiance laser illumination data. The dotted lines are the 90% confidence limits of the fit.

4. DISCUSSION

The early results[4] for the intrinsic response for KI Vs photon energy showed a sharply decreasing response below 8 eV, appearing to approach an asymptote around 7.4 eV, which was taken to be the work function of KI. Later work by Apker[8,9] showed that direct ejection of electrons from color centers could eject photoelectrons with a yield of 10^{-4} electrons/photon for a broad band of photons with energies between 2 and 7 eV. The color centers were excited by illumination with 5.63 eV photons , before irradiation by the lower energy photons. Direct exciton-induced emission with quantum yield of 10^{-3} electrons/photon could also exist at photon energies of 6 eV where an F-color center is excited. In the present case we have found that the emission occurs even in the absence of an irradiation that causes the color centers, or the excitons to be formed. In addition, the electron emission was instantaneous, without the 10 minute decay time of the photo emission response that Apker and Taft had measured. This behaviour may rule out the F-center as a source of the present photoelectrons. However, L-band absorption[10], though less efficient than F-center induced emission, may be a possible source of the present observations. We have considered the effect of the lowering of the photoelectric threshold by the extraction field. To lower the threshold by 4 eV one requires a static field of about 10^9 V/cm. The applied macroscopic fields were of the order 30 kV/cm, and one would require few angstrom size features to cause such microscopic fields. A last possible explanation, is that the photoemission is not from the KI but from the conducting aluminum layer that existed below the KI photocathode. We can rule out this possibility because the threshold for aluminum metal is 4.2 eV, again requiring two photon for emission.

5. SUMMARY

We have measured the linearity of the response of a potassium iodide photocathode to 308 nm irradaiation. We found that the response is linear for irradiances below 10^8 W/cm^2 . The response was solicited without the help of lower wave-length irradiation which generates F-centers and may be produced by the L-band photo absorption.

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