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PHOTOEMISSION FROM Ag, Cu, AND CsI

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PHOTOEMISSION FROM Ag, Cu, AND CsI

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ABSTRACT

Photoemission characteristics of three different cathodes, CsI, Ag film and Cu were investigated. CsI, upon irradiation by 213 nm, 10ps laser pulse yields a quantum efficiency of 4% at 0.2 μ J input energy. The saturation mechanism observed at higher input energies require further investigation. Ag film, upon irradiation by 630 nm, 300 fs laser emit prompt photoelectrons after absorbing 2 photons. There was no evidence of optical damage of the film up to 10¹¹ w/cm². At low intensities, photoemission from Cu is a simple ν -e⁻ interaction, the nonlinearity of the process depending strongly on trace impurities. At higher intensities, there appears to be a change in the emission mechanism.

INTRODUCTION:

In recent years there has been considerable interest ¹⁻³ in using photoemission technique to generate high quality, low emittance and high brightness electron beams for high energy colliders and short wavelength free electron lasers. These applications call for a high quantum efficiency (~1%), rugged, long life-time photocathode material that is capable of operating in 10⁻⁸ Torr pressure, using a simple, short pulse laser. So far no single photocathode material has met all these requirements simultaneously. Our investigation of CsI was motivated by its capability to meet most of the above requirements. There are also other applications such as the switched power high brightness gun ⁴ and positron production by e⁻- γ and γ - γ interaction ⁵ that require electron bunches of subpicosecond duration. Our investigation of Cu and Ag using femtosecond laser pulses were motivated by these applications. In the subsequent sections the results of experiments with CsI irradiated by 266 nm and 213 nm laser pulse of ~ 10 ps duration and Ag film and Cu irradiated with 630 nm laser pulse of 300 fs are discussed.

MEASUREMENTS ON CsI USING PS LASER PULSES

EXPERIMENTAL ARRANGEMENT:

Preparation of the CsI photocathode was as follows. Bulk CsI was vapor deposited on diamond turned Cu to a thickness of 8000 Å, transported in an evacuated container and the electrodes were assembled together with minimum exposure to air. The anode was a hollow cylinder of 6 mm inner diameter, the opening nearest to the cathode covered with a copper mesh of 70 lines/inch. The electrodes, spaced apart by 1 mm, were then set in the vacuum cell and baked at 100 - 140°C overnight.

The anode can be biased up to a voltage of 10 kV, but normally maintained between 2 to 4 kV to limit the possibility of high voltage breakdown in vacuum.

The laser used to irradiate the CsI was an actively and passively mode-locked Nd-YAG laser operating at $1.06\text{ }\mu\text{m}$, with $\sim 25\text{ mJ}$ energy in 25 ps duration. Radiation at $0.266\text{ }\mu\text{m}$ and $0.213\text{ }\mu\text{m}$ were obtained using different nonlinear crystals. It was possible to obtain up to 1.5 mJ in 12 ps and $100\text{ }\mu\text{J}$ in $\sim 10\text{ ps}$ at wavelengths $0.266\text{ }\mu\text{m}$ and $0.213\text{ }\mu\text{m}$, respectively. The two wavelengths were separated using a fused silica prism and only one of the wavelengths was directed to illuminate the cathode. A small percent of the laser beam was deflected to a calibrated photodiode to monitor the energy of the irradiating beam. The photoemission signal was extracted from the cathode and displayed on the oscilloscope after passing it through a charge sensitive preamplifier and a shaping amplifier when needed. Fig. 1 illustrates the experimental lay-out.

MEASUREMENTS WITH $0.266\text{ }\mu\text{m}$ RADIATION:

The dependence of the charge on the input laser energy was determined by varying the laser energy and observing the corresponding charge emitted and the results are displayed in Fig 2. The slope of this logarithmic plot, an indicator of the number of photons involved in the process, indicates that the photoemission at this wavelength is a single photon process and the quantum efficiency is $\sim 2 \times 10^{-6}$. Considering the facts that the absorption coefficient of CsI at this wavelength is $\sim 1.7\text{ cm}^{-1}$,⁶ the thickness of the CsI in our sample is $8000\text{ }\text{\AA}$ and the substrate is copper whose quantum efficiency at this wavelength is very close to this measured value, the observed photoelectrons could have originated from the substrate and not from CsI. However, this fact needs to be verified by varying both the thickness and the material of the substrate. The capability of these electrons to tunnel through the CsI layer also needs to be investigated.

MEASUREMENTS WITH $0.213\text{ }\mu\text{m}$ RADIATION:

Fig.2 also illustrates the intensity dependence of the photoelectrons at $0.213\text{ }\mu\text{m}$ radiation. The slope of the plot indicates that photoemission at this wavelength requires two photons. The quantum efficiency at $0.2\text{ }\mu\text{J}$ incident laser energy is $\sim 4\%$. However, as the laser energy approaches $\sim 1\text{ }\mu\text{J}$, the electron yield appears to saturate and become independent of the incident laser energy. This saturation is unlikely due to space charge effects as evidenced by the voltage dependence data. Fig. 7. Similar effect has been observed on cesium activated GaAs⁷ and has been attributed to the formation of plasma and subsequent modification of the work function. The validity of this explanation for CsI is currently under investigation. Measurements at both wavelengths agree with results from other laboratories⁸.

MEASUREMENTS WITH SILVER USING FEMTOSECOND LASER PULSES:

The preparation of the silver cathode was similar to that of CsI. 3100 Å thick silver was evaporated on a diamond turned Cu mirror. The cathode was transported in an evacuated cell and the electrodes were assembled and mounted in the vacuum cell. As before, the anode was a hollow cylinder, but with the opening nearest to the cathode covered by a 40 lines/inch nickel mesh. The electrode gap was 1 mm.

The laser used in these experiments was an amplified colliding pulse mode-locked (CPM) laser. The output characteristics of the laser are as follows: wavelength was 630 nm, energy was 1 μJ, pulse duration was 300 fs, focused spot size, FWHM, on the cathode was 100 x 70 μm².

Figs. 3 and 4 illustrate the intensity and the voltage dependence of the electron emission respectively. As can be seen from the intensity dependence data, photoelectric emission at this wavelength is a two photon process. The data taken with the unamplified CPM and the amplified CPM mesh smoothly without any normalization indicating the absence of any other nonlinear mechanism. The maximum current density measured with this cathode was 4000 A/cm². The maximum charge extracted was limited by the available laser energy. The measured quantum efficiency was low, however, it has been proven⁹ that at grazing incidence, the presence of the electric field of the (p- polarized) laser enhances the quantum efficiency to a level comparable to that of a single photon process, which is ~10⁻⁵ electrons per incident 2 eV photon for Ag.

The slope of the voltage dependence curve (Fig. 4) is high, implying strong modification of the work function due to Schottky effect. The slopes of these curves for various input laser intensities scale with the input intensity linearly, supporting the evidence for the two photon process.

The pulse duration of the electron bunch was measured using the autocorrelation technique. The laser beam was split into two equal halves, passed through delaying optics, and recombined on the target. One beam was delayed with respect to the other by translating its delaying optics with a fine stepper motor. The electron signal was measured as a function of the delay and displayed in Fig. 5. The autocorrelation trace of the laser pulse is also displayed along side for reference. As can be seen from Fig. 5 the electron pulse duration is comparable to the laser pulse duration. Due to the low signal to noise ratio encountered in these measurements, it is not possible to verify the origin of the slight broadening of the electron pulse length. The silver film was not optically damaged even at intensities of 10¹¹ W/cm².

MEASUREMENTS WITH COPPER USING FEMTOSECOND LASER PULSES:

The experimental arrangement for these measurements were similar to that for silver. Fig. 6 illustrates the intensity dependence of the photoemitted electrons. Experiments with two different copper samples indicate that nonlinearity of photoemission from copper under visible radiation is significantly affected by trace embedded and surface impurities. The presence of CuCl could provide a long lived intermediate state¹⁰ and cause a 3 photon process to appear as a 2

photon process and the presence of trace amounts of Si could change the process from two photon to a single photon process. At low laser intensities, the photoemission requires two photons for the sample without trace amounts of Si and one photon for the sample with traces of Si. For a number of Cu samples investigated, as the laser intensity increased beyond 10^{10} W/cm², the number of photoelectrons increased abruptly by thousandfold. The sharp onset of this behavior and the amplitude fluctuation of the laser energy precluded using autocorrelation technique for pulse duration measurements. However, the lower limit on the pulse duration can be estimated. For Ag, the onset of space charge limited photoemission was at 100 fc and the corresponding measured pulse duration was $\approx$ 250 fs. For copper, even at a charge of 100 pc, the space charge limit is not reached for similar electrode geometry. Hence, the pulse duration of the electrons have to be larger than 250 ps. The time resolution of our measurement system is 1 ns and the oscilloscope traces did not indicate pulses longer than 1 ns. Hence the pulse duration of this bunch must lie between .25 and 1 ns, much longer than the laser pulse duration. Similar behavior from copper with longer pulse duration has been observed previously ¹¹ and attributed to the formation and expansion of plasma from the copper surface. The short pulse behavior is being analyzed at present.

CONCLUSIONS

Photoemission from CsI indicates that quantum efficiencies exceeding 1% could be obtained from rugged materials. The operating wavelength, although high, is not too difficult to achieve. Since CsI is an insulator, the number of available electrons may not be as high as a metal cathode. Hence the capability of CsI to yield short bunch electron charges $\gg$ 1 nC has to be investigated in detail. Photoemission measurements on Ag and Cu using femtosecond laser pulses indicate that high current electron pulses in short bursts are achievable with reasonable quantum efficiency. However, further studies, such as effects of electromagnetic fields associated with the laser, non-uniform heating of the electron, plasma production, and emittance characteristics are required before adopting it in other applications.

REFERENCES

1. J. S. Fraser, R. L. Sheffield, E. R. Gray, P. M. Giles, R. W. Springer, and V. A. Loeb, Proceedings of the 1987 Particle Accelerator Conference, Washington, D.C., 1987, p. 1705
2. K. Batchelor, H. Kirk, J. Sheehan, M. Woodle, and K. McDonald, Proceedings of the European Accelerator Conference, Rome, Italy, 1988, p.954
3. J. Madson, CERN, Private Communication
4. R. B. Palmer, Proceedings of the Switched Power Workshop, Shelter Island, U. S. A., 1988, BNL 52211, p. 263
5. R. B. Palmer, Presented at this Workshop

6. P. Avakian and A. Smakula, Phys.Rev. 120, 2007, (1960)
7. Max Zolotarev, SLAC, Private Communication
8. G. Suburlucq, CERN, Private Communication
9. J. P. Girardeau-Montaut, C. Girardeau-Montaut, S. D. Moustazis and C. Fotakis, Submitted for publication in Phys. Rev. Lett.
10. W. F. Krolikowski, Ph. D. Thesis, Stanford University, 1967, p. 231
11. X. J. Wang, T. Tsang, H. Kirk, T. Srinivasan-Rao, J. Fischer, K. Batchelor, P. Russell, and R. C. Fernow, J. Appl. Phys., 72, 888, (1992)

FIGURE CAPTIONS

1. Experimental arrangement.
2. Intensity dependence of photoelectrons from 8000 Å thick CsI on diamond turned Cu. The bias voltage was 3.5 kV across 1 mm gap. o: laser wavelength is 266 nm and spot size is 3 mm diameter. Δ: laser wavelength is 213 nm and the spot size is elliptical with major and minor axes 2.5 and 2 mm respectively.
3. Intensity dependence of photoelectrons from 3100 Å thick Ag on diamond turned Cu. o: are using unamplified CPM of pulse duration 100 fs Δ: are with amplified CPM of pulse duration 300 fs.
4. Applied field dependence of photoelectrons from 3100 Å thick Ag on diamond turned Cu with laser energy as a parameter. m is the slope of the line and the ratios listed are m_1/m_2 .
5. Autocorrelation signals of (Δ) electrons and (+) laser. The real width is autocorrelation width/ $\sqrt{2}$ for a Gaussian profile.
6. Intensity dependence of photoelectrons from diamond turned Cu cathode. The bias voltage was 2.5 kV across 2.75 mm gap. The laser pulse duration was 250 fs and the focal spot size was 70 x 100 μm^2 FWHM.

Figure 1. Experimental Arrangement

Figure 2. Intensity dependence of photoelectrons from 8000 Å thick CsI on diamond turned Cu. The bias voltage was 3.5kV across 1mm gap.
 O: laser wavelength is 266nm and spot size is 3mm diameter.
 Δ: laser wavelength is 213nm and the spot size is elliptical with major and minor axes 2.5 and 2 mm respectively.

Figure 3. Intensity dependence of photoelectrons from 3100 Å thick Ag on diamond turned Cu.
 O: unamplified CPM laser of pulse duration 100 fs
 Δ: amplified CPM laser of pulse duration 300 fs

Figure 4. Applied field dependence of photoelectrons from 3100 Å thick Ag on diamond turned Cu with laser energy as a parameter. m is the slope of the line and the ratios listed are m_1/m_2 .

Figure 5. Autocorrelation signals of (Δ) electrons and (+) laser.

Figure 6. Intensity dependence of photoelectrons from diamond turned Cu cathode. The bias voltage was 2.5kV across 2.75 mm gap. The laser pulse duration was 250 fs and the focal spot size was 70 x 100 μm^2 FWHM.

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