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Photoemission optogalvanic studies with copper as target electrode

K.C. Ajithprasad, V.P.N. Nampoori *, C.P.G. Vallabhan

Laser Division, School of Photonics, Cochin University of Science and Technology, 682 022 Cochin 22, India

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Abstract

Photoemission optogalvanaic (POG) effect has been observed by irradiating copper target electrode, in a nitrogen discharge cell using 1.06 μm and frequency doubled 532 nm Nd:YAG laser pulse. Measurement of the nature of the variation of POG signal strength with 532 nm laser fluence confirms the two photon induced photoelectric emission from copper. However, using 1.06 μm laser pulses thermally assisted photoemission is observed.

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1. Introduction

Keeping one of the electrodes of a discharge cell as the target electrode, for irradiation with a laser beam the impedance of a discharge can be changed through photoelectric emission. This impedance change due to photoelectric emission in the presence of a discharge is known as the photoemission optogalvanic (POG) effect [1,2]. The POG effect is analogous to the optogalvanic (OG) effect [3,4], but the OG effect is a resonant phenomenon while POG is a nonresonant one. Also the POG effect is possible for all radiation wavelengths below a threshold value while the normal OG effect arises only when resonant radiation is absorbed by the discharge. Photoemission can take place under multiphoton excitation also [5,6]. The study of the POG effect is an efective method for the understanding of the properties of discharge plasma and for the surface characterization of the target electrode. When radiations of longer wavelengths are used for photoemission from the target electrodes, along with multiphoton excitation, thermal effects will also become noticeable. If the photon energy is slightly less than the workfunction of the target material, the intense optical field corresponding to the pump beam will modify the workfunction, thereby increasing the probability of electron tunnelling through potential barrier. Such studies have been carried out by picosecond and femtosecond laser pulses [5]. Optical field effects are found to generate electron yield from copper with p-polarized light rather than with s-polarized light. Work reported so far describes photoemission from targets in the absence of discharge using UV laser radiations as the pump beam. The present paper deals with the observation of the a OG effect from copper target using 1.06 μm and frequency doubled 532 nm radiation from a Nd:YAG laser.

* Corresponding author. Tel.: +91-484-855441; fax: +91-484-5324495; e-mail: @cochin.ernet.in.

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2. Experimental set-up

The discharge cell used in this experiment (Fig. 1) consists of a glass tube of 1 cm diameter socketed into two metal caps made of stainless steel. The separation between the ends of the caps is 3 cm and they act as electrodes. One end of the cylindrical cap is provided with a glass window while a copper target is fixed inside the metal cap at the other end of the discharge tube. The separation between the copper target and other end of the electrode is 4.5 cm. Suitable side tubes for continuous flow of gas into the cell are provided. The schematic of the experimental set up is given in Fig. 2. The discharge is excited using a low noise high voltage power supply (Thorn EMI PM 28 B). A ballast resistance of 66 kΩ is also included in the circuit. Pulsed radiations of 1.06 μm and frequency doubled 532 nm (pulse width 10 ns and repetition rate 10 Hz) from the Nd:YAG laser (Quanta Ray DCR-11) are used to excite the POG signal from the copper target. The signal developed across the load resistor is fed to a digital storage oscilloscope (Iwatsu DS-8621, 200 MHz) through a blocking capacitor (0.1 μF). The signal amplitude is measured directly from the oscilloscope trace.

3. Results and discussions

The discharge in the cell was maintained at a pressure of 180 μbar of nitrogen gas. Dc voltage

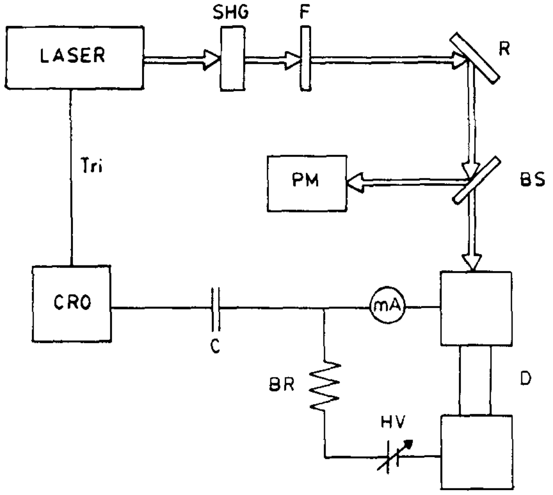

Fig. 2. Schematic of the experimental set-up (SHG – second harmonic generator, F – harmonic separator, R – reflector, BS – beam splitter, PM – power meter, D – discharge cell, BR – ballast resistance).

was applied across the cell keeping the copper target electrode as cathode. The target was irradiated with unfocussed laser pulses.

Since the workfunction of copper is 4.4 eV [7], and the energy corresponding to 532 nm radiation is ~ 2.3 eV, we expect a two photon induced photoemission from copper on irradiation with this wavelength. Variation of the observed POG signal as a function of laser power for different discharge voltages is given in Fig. 3. The signal strength increases

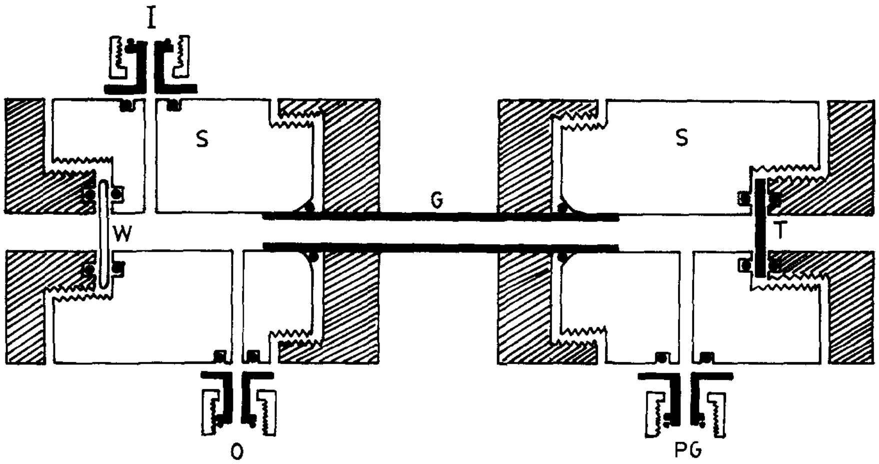

Fig. 1. Geometry of the discharge cell used. W – glass window, S – steel cap, G – glass tube connector, T – target, I – gas inlet, O – gas outlet, PG – pressure gauge.

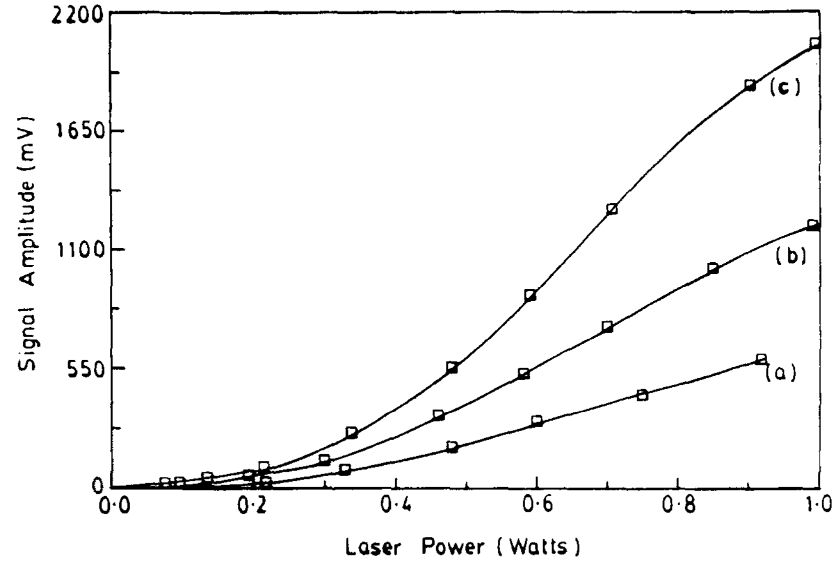

Fig. 3. Variation of signal amplitude versus laser power: (a) 600 V, (b) 700 V, (c) 800 V.

with laser power as well as with applied voltage. At lower laser power the POG signal strength is almost the same irrespective of the applied voltage, but at higher laser power the POG signal increases with applied voltage. Electric fields at metal surfaces reduce the image and ion fields, and thereby cause reduction of the workfunction [8] and hence an enhancement in the POG signal. At lower laser power, recombination of photoelectrons with positive ions limits the POG signal. However, at higher laser power, a much larger number of photoelectrons will be generated such as to surpass the recombination

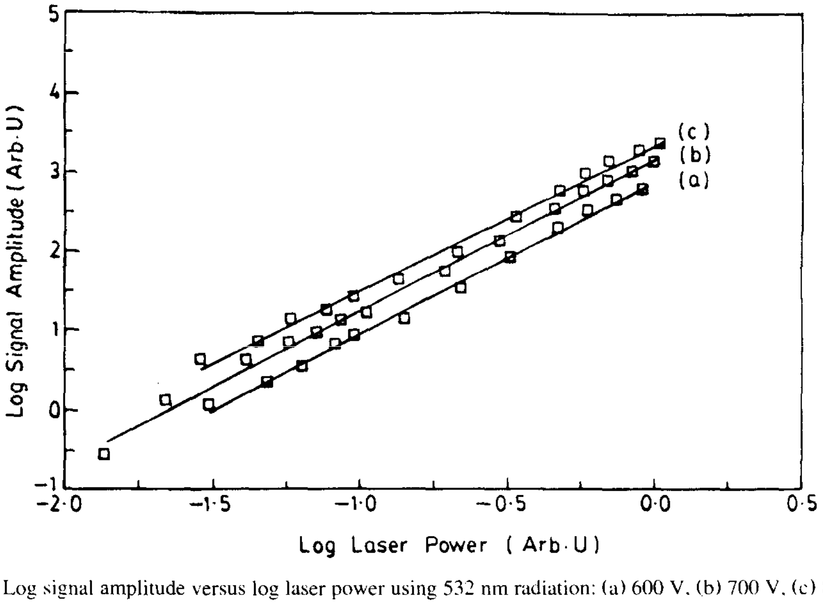

Fig. 4. Log signal amplitude versus log laser power using 532 nm radiation: (a) 600 V, (b) 700 V, (c) 800 V.

rate and hence an increase in the POG signal may be expected. The log–log plot of laser power versus POG signal yields a slope of 2 (Fig. 4) which confirms the two photon processes taking place for different discharge voltages.

Irradiation of the target with 1.06 μm radiation also gives POG signals. In 1.06 μm radiation induced photoemission also we observe an enhancement in the POG signal with laser power and discharge voltage (Fig. 5). We expect a four photon process, similar to the two photon induced POG signal from copper using 0.532 μm radiation, since the energy corresponding to 1.06 μm radiation is only 1.16 eV. However, energy versus signal strength shows a slope of $\sim > 2$ (Fig. 6). That is, we observe a near quadratic dependence of signal strength as

$$S = bI^2. \tag{1}$$

That is photoemission from copper using 1.06 μm radiation is also mostly due to two photon process similar to the observation with 532 nm radiation.

Yen et al. showed that the current density for an n-photon photoemission can be written as

$$J_n = K[(1-R)]I_0]^n$$

where R is the reflectivity, I_0 is the incident laser power and K is a constant. When infrared radiations are used as pump beam thermally assisted photoemission process is possible. According to generalized Fowler–Dubridge theory [9] the total photoelectric current can be written as

$$J = \sum_{n=0}^{\infty} J_n(r, t) \tag{2}$$

where

$$J_n(r, t) = a_n \left(\frac{e}{h\nu}\right) A(1-R)^n P^n(r, t)^2 T(r, t) F \times \left(\frac{(nh\nu - \phi)}{K_B T}\right) \tag{3}$$

where R, A, P, ϕ, a and T are the sample surface reflectivity, Richardson coefficient, laser power, workfunction of the sample, sample dependent constant and sample temperature respectively. $F(x)$ is the Fowler function. J_0 represents pure thermionic emission, J_1 represents one photon induced photoemission and J_2 gives the two photon induced photoemission etc.

The mismatch of workfunction and photon energy using 1.06 μm laser radiation implies that the resulting process is a thermally assisted two photon POG effect. The thermionic process due to heating of sample by laser pulse does indeed cause electron emission from the target complementing the multiphoton excitation eventually constituting to the POG

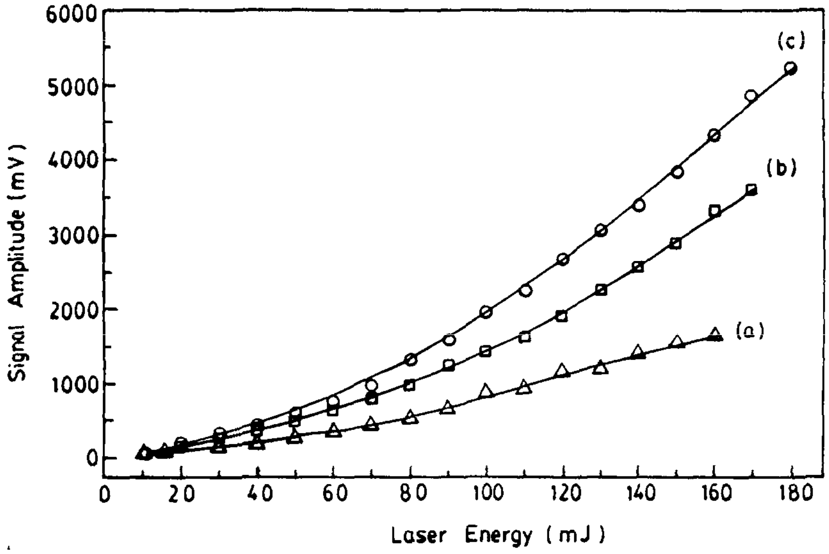

Fig. 5. Signal amplitude versus laser energy using 1.06 μm radiation: (a) 800 V,(b) 900 V, (c) 1000 V.

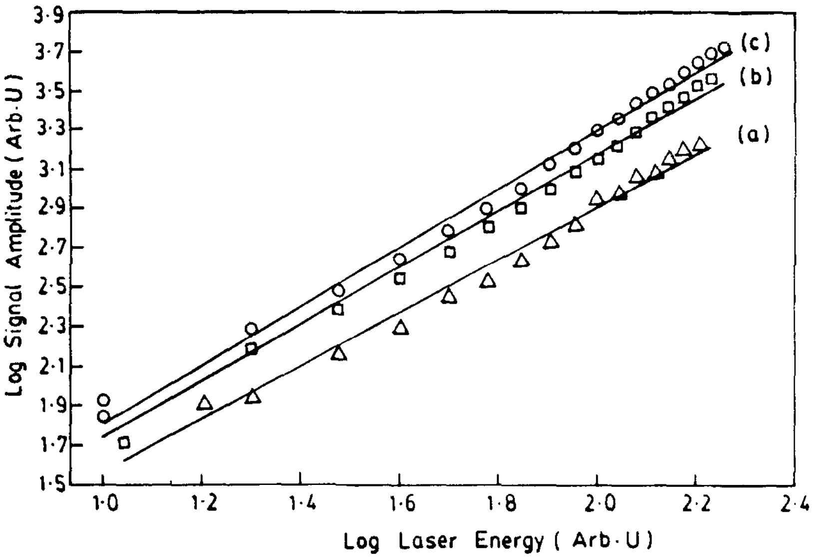

Fig. 6. Log signal amplitude versus Log laser energy: (a) 800 V, (b) 900 V, (c) 1000 V.

signal [10]. Heating of the target by intense laser pulses produce electrons with energies above the Fermi level, so that emission from the tail of Fermi distribution can take place (Fig. 7) with the absorption of fewer than four photons. This masks the fine details of the photoelectric effect. The thermionic emission current is entirely governed by the temperature of the cathode surface, which depends on the absorbed power. Heating of the copper cathode surface disturbs the equilibrium between electron and the lattice and this should effect strongly the thermionic emission because of the low specific heat of the degenerate electron gas. The laser power dependence of POG effect therefore deviates from a simple power law.

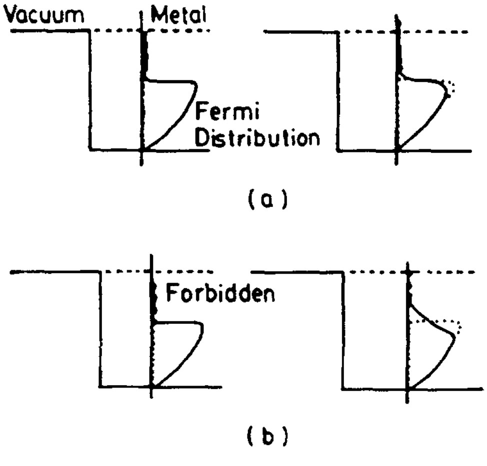

Fig. 7. Schematic representation of (a) two photon emission with 532 nm radiation and (b) thermally assisted multiphoton emission with 1.06 μm radiation.

In conclusion, we have observed two photon induced photoemission from a copper target using 532 nm radiation, whereas the POG effect with 1.06 μm radiation thermionic emission contribution becomes very predominant which eventually masks the photoelectric emission components.

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