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Laser induced white lighting of tungsten filament

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The sustained bright white light emission of thin tungsten filament was induced under irradiation with focused beam of CW infrared laser diode. The broadband emission centered at 600 nm has demonstrated the threshold behavior on excitation power. Its intensity increased non-linearly with excitation power. The emission occurred only from the spot of focused beam of excitation laser diode. The white lighting was accompanied by efficient photocurrent flow and photoelectron emission which both increased non-linearly with laser irradiation power.

1. Introduction

Earlier, numerous experiments were reported on broad band white emission induced by irradiation of micro- and nano-scaled objects (dielectrics, semiconductors, graphene foams) placed in vacuum with CW infrared (IR) lasers. Costa et al. [1,2] have reported a sustained white emission of silicon nanopowders in vacuum. A number of experimental works was reported for rare earth doped crystalline powders [3–9]. An intense white lighting was recently reported for IR laser irradiation of graphene ceramics [10] and graphene foam [11]. It was demonstrated that white light emission was accompanied by very efficient photoconductivity, field emission and photoelectron emission. An interaction of femtosecond laser pulses with tungsten tips were reported by Yanagisawa et al. [12]. A strong multiphoton electron emission was observed from nanoscale tungsten tips by Kruger et al. [13]. Interaction of femtosecond laser interaction with metallic tungsten was investigated by Fujimoto et al. [14]. The authors have observed multiphoton and thermally enhanced photoemission from a tungsten metal surface.

In this work we present the studies of tungsten filament irradiated with a focused beam of CW infrared laser diode. It was found that a tungsten filament emits very intense white light. The mechanism of phenomenon was discussed in terms of current enhanced multiphoton ionization.

2. Experimental

The experiments were performed using the tungsten filament (TF) from a commercial incandescent light bulb. The filament in light bulb was irradiated with CW infrared laser diode operating at 808 nm and 975 nm. To detect the intensity of emission the Avantes USB2000 CCD camera was used. The kinetics of tungsten emission were measured using the oscilloscope LeCroy WaveSurfer 400 – Hamamatsu photomultiplier tube R928P system. The excitation laser beam was focused at the spot diameter 170 μm what corresponds to ~10^4 W/cm^2 for laser diode power 2 W. Keithley 2400 SourceMeter was used for photoconductivity and electron emission measurements.

3. Experimental results

The white light emission spectra of laser irradiated tungsten filament placed in vacuum are shown in Figs. 1 and 2. The experiments were performed using two different laser excitation wavelengths 975 nm and 808 nm. The laser excitation beams were focused at the spot about 170 μm. The white light emission occurred in a form of light cone from the spot of incident laser beam with tungsten surface. The peak intensity was centered at 600 nm and did not shift with laser power. The laser induced white emission (LIWE) intensity I_{LIWE} was measured as a function of excitation laser power *P*. The power dependence of LIWE intensities for both excitation wavelengths are plotted in Fig. 2a and c. It can be note that the white emission intensity demonstrated the threshold behavior since it started to increase rapidly after exceeding

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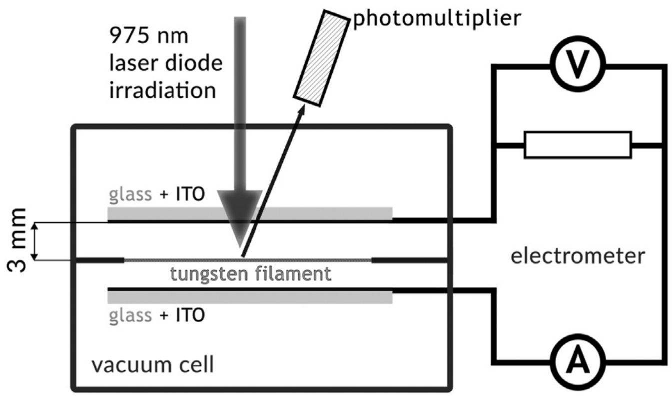

Fig. 1. Experimental setup for electron emission, optical spectroscopy and photoconductivity measurements. For optical spectroscopy measurements, the ITO electrodes were removed and a different irradiation source (808 nm) was used additionally. For photoconductivity measurements, wiring connected to source/electrometer was attached to the filament.

characteristic laser power magnitudes 0.2 W and 0.4 W for 975 nm and 808 nm, respectively. The integral LIWE intensity increased with incident laser power and can be approximated by the power function. The double log dependences of white light integrated intensity on laser excitation power are shown in Fig. 2b and d.

The observed linear plots after exceeding the threshold were well scaled according to the power law formula $I_{LIWE} \propto P^{N}$, where the order parameter N was determined to be 3.78 nm for 808 nm excitation and 5.05 nm for 975 nm excitation.

The LIWE process is characterized by the build-up time dependent on the excitation laser density and decay times of white lighting. The kinetics of tungsten filament initiated by laser irradiation was measured the rise (growth of emission) and decay times of the process. The kinetics of emission is dependent on laser irradiation power. The rise time decreases with excitation power from 230 ms for 800 mW to 61 ms for 2000 mW (see Fig. 3a). The reverse dependence is observed the decay time of white lighting after switching off the excitation laser - the decay time increases with excitation power from 4.72 ms for 800 mW to 6.85 for 2000 mW (see Fig. 3b). The rise time was longer more than one order than the decay time. The long build time of white light emission may be associated with threshold behavior of phenomena, but very short decay time of emission may suggest that the nature of white light generation is different than temperature emission. It should be stressed that after reaching the maximum of intensity the lighting process was sustained process by several hours. Similar magnitudes of rise and decay times were obtained using as excitation 808 nm laser diode.

Since the LIWE lighting has occurred only from illuminated spot on the surface of tungsten filament it seems to be interesting to observe the process resulting from excitation by two laser sources simultaneously at two different separate points on filament surface. The resulting LIWE spectra measured with individual excitation by 808 nm and 975 nm laser diodes as well as the effect of simultaneous excitation are presented in Fig. 4. The spectra were measured at excitation power of 1 W of each laser diode.

The intensities measured for single laser beam pumping excitation were of comparable magnitudes. The measured total intensity measured for simultaneous excitation by two laser diodes exceeded the sum of intensities measured separately for both cases of single laser excitation by approximately 15%. As shown in Fig. 2, the relation between the excitation power and the resulting emission intensity is non-linear and this specific case of a synergistic effect of simultaneous excitation by two light sources, where the measured intensity is neither the linear sum of intensities measured individually nor is it corresponding to a twofold increase of optical excitation density, is subject to further investigation.

4. Discussion

These magnitudes could be referred to the first Townsend coefficient defined as the multiplication number of electrons (e^{-}) released from metallic surface. They may be related to the work

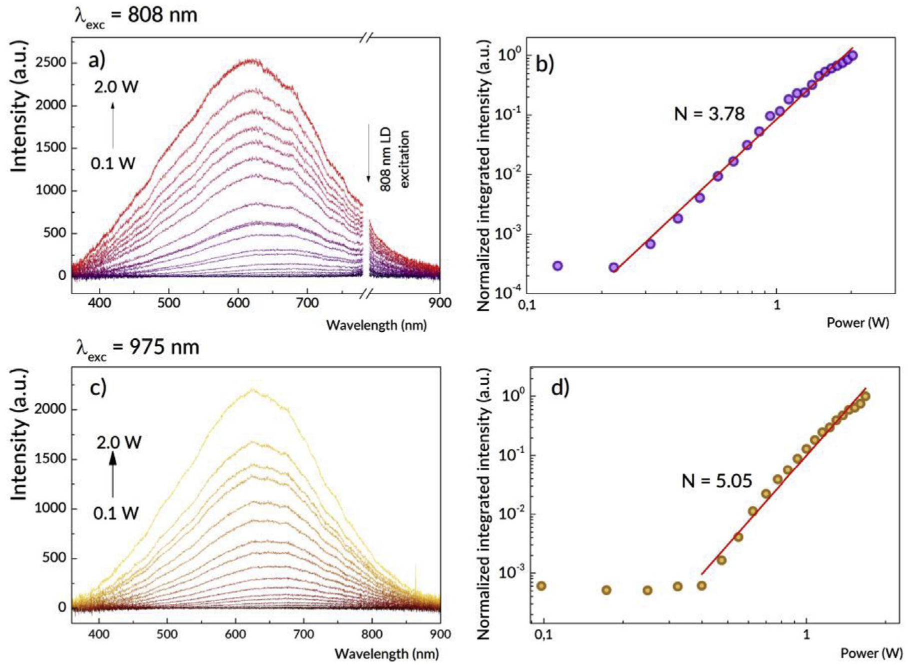

Fig. 2. The white light emission spectra of tungsten filament irradiated with focused beam of CW infrared laser diode operating at 808 nm (a) and 975 nm (c). The log-log power dependence of white light emission of the laser irradiated tungsten filament under 808 (b) and 975 nm (d) LD excitation.