

Sources of Spontaneous Narrow-Band uv and VUV Radiation

D.V. Schitz, V.F. Tarasenko, V.S. Skakun, M.I. Lomaev and S.M. Avdeev

Institute of High Current Electronics SB RAS, Akademichesky Ave. 2/3, Tomsk, 634055, Russia,

Phone: 7(382-2) 491-412, Fax: 7(382-2) 491-410, E-mail: schutz@loi.hcei.tsc.ru

Abstract – Pre-production models of excilamps developed in the laboratory of optical radiation are described; main characteristics of radiators and their power supplies, portable UV-excilamps of the barrier or capacitive discharges, and also powerful VUV-excilamps of the barrier discharge which can be used for cleaning or modifying material surfaces are presented.

1. Introduction

Excilamps are a kind of gas-discharge lamps radiating in UV- or VUV-spectral region due to the decomposition of excimer molecules (excited dimer – excimer, in the case of a molecule consisting of equal atoms, Ar_2^* for example) or exciplex molecules (excited complex – exciplex, in the case of a hetero-nuclear molecule, XeCl^* for example) [1]. According to the gas composition and conditions under which the electrical discharge is effected, exciplex/excimer is formed in accordance with different mechanisms (the Harpooning reaction, the ion-ion recombination). The spontaneous decomposition of excimer or exciplex molecules into separated atoms is accompanied with radiation of light quantum typical for this molecule. Such type of radiation sources provide photon energy from 3 to 10.5 eV, that is sufficient to apply excilamps practically to all known photoprocesses in which UV and/or VUV radiation is required.

Due to extraordinary properties of excilamps, their appearance on the world market of science technologies has been met with considerable interest [2]. Originality of excilamps consists in the next:

- ✓ simple device construction (in comparison with excimer lasers);
- ✓ unlike mercury, hydrogen and thermal sources of spontaneous UV or VUV radiation, the main part of the radiation power of excilamps driven by the capacitive or the barrier discharges (up to 80 %) is concentrated in a band of $B \rightarrow X$ transitions (see Fig. 1) with 10 nm FWHM [3], because of this, excilamps can be used in applications where selective influence of radiation on investigated object is required [4, 5];
- ✓ it is possible using excilamps to irradiate at once large area of an object;
- ✓ working gas of excilamps does not contain metal vapors such as mercury and cadmium, that is why it is easy to recycle excilamps after ending of their lifetime.

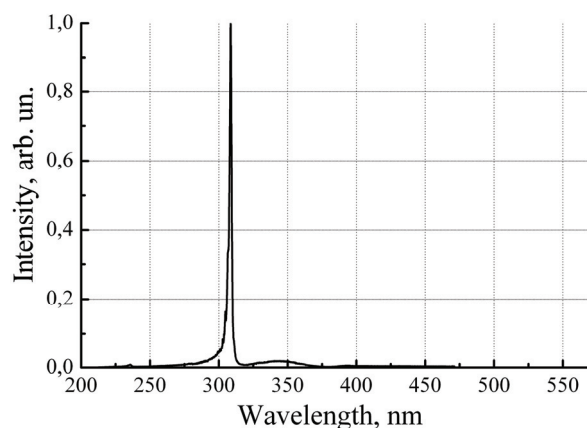


Fig. 1. Radiation spectrum of the XeCl-excilamp driven by the barrier discharge

2. Power supplies for excilamp excitation.

As shown in Figure 2 a power supply consists of four main parts: a rectifier, a power factor corrector (PFC), a half-bridge converter and a step-up transformer. The rectifier consists of an on-off switch, a fuse, an EMI filter and a diode bridge rectifier. PFC is a device to improve power factor and reduce total harmonic distortion (THD) and to stabilize the voltage on a bulk storage capacitor. This circuit operates from AC 95÷230 V and delivers DC 400V on a bulk storage capacitor with typical power factor over 0.98 and THD of 8%. A half-bridge converter feeds from the bulk storage capacitor. The converter consists of two metal-oxide-semiconductor field-effect transistors as switches controlled by a pulse-width modulator and a transistor driver. A load of the bridge converter is a step-up transformer with a ferrite of E-type core. High-voltage pulses with repetition rate 20÷100 kHz occur at the output of the step-up transformer at transistor switching. Secondary winding of a high-voltage transformer is connected with a potential electrode of an excilamp. The airflow produced by a fan cools transistors and a bulb of the excilamp. The excitation power of the described power supply construction is in range 20÷300 W.

The circuit of supplies with the output power up to 1kW is similar to the circuit given above, but more powerful components such as fast insulated gate bipolar transistors and low-inductive capacitors build in a full-bridge circuit are used. The operation of powerful supplies for excilamp excitation was described in [6].

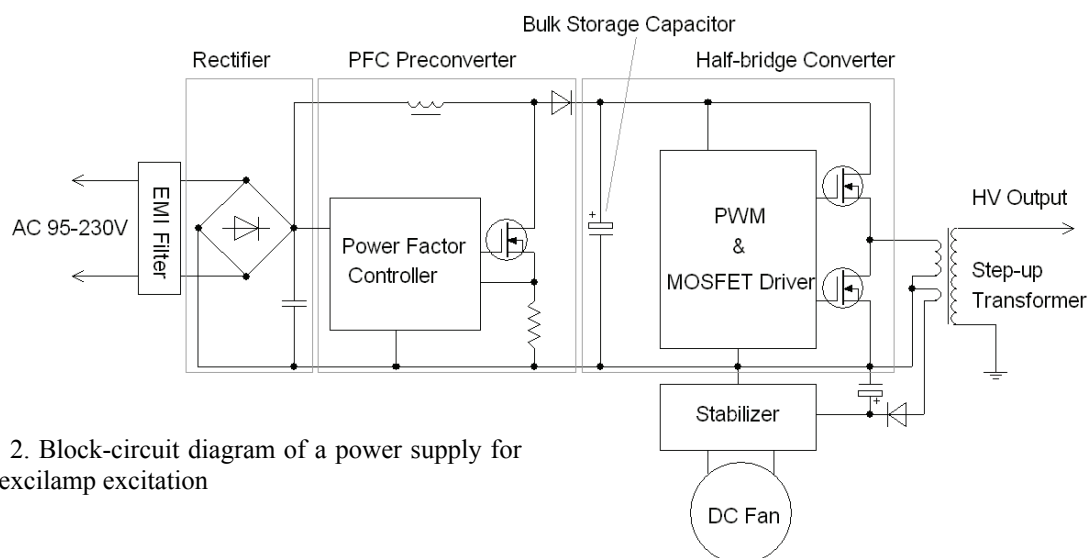


Fig. 2. Block-circuit diagram of a power supply for the excilamp excitation

3. Powerful excilamps.

Complex investigations of influence of the excitation power, the pulse excitation shape and the value of a discharge gap on the efficiency of exciplex molecule radiation were carried out [7, 8]. KrCl-, XeCl- and XeBr-excimer lamps with the average UV power of radiation up to 100W (specific UV power 100mW/cm²) were developed on the basis of obtained data. Excimer lamps of the barrier discharge have coaxial construction. A grounded reflector electrode is inserted into the inner quartz tube and the water flow cools the inner tube. From the outside the tube is covered with a metal mesh electrode which is connected to the high-voltage output of the power supply.

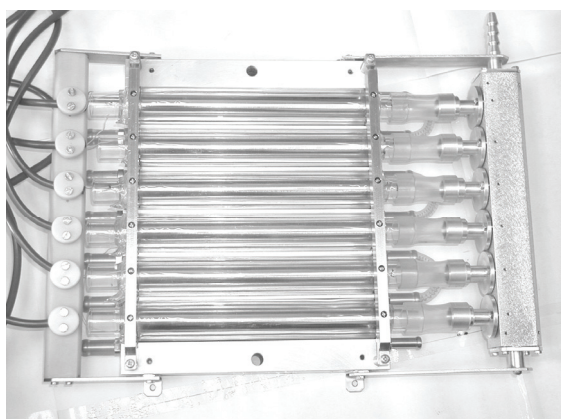


Fig. 3. Xe-excimer lamp with the high specific power of radiation

Powerful excimer lamps of the barrier discharge were also developed in the laboratory of optical radiation. A Xe-radiator consists of 6 equal quartz bulbs of coaxial construction installed on the aluminum plate (Fig. 3). An electrode made from aluminum-magnesium foil is inserted into each bulb. The outer electrode in the form of half-cylinder made from

Al:Mg-foil which is put along the outer tube of the bulb. The other part of the bulb is covered with the metal mesh (transmission coefficient ~90%). Such construction of reflectors is called "half-reflector". Radiation surface of the device is 400 cm². The water and cold air cool bulbs.



Fig. 4. Photochemical reactor with a power supply on the basis of the one-barrier Xe-excimer lamp

Xenon excitation is carried out with the power supply, forming bipolar pulses of the voltage with the amplitude 6kV at the frequency 200 kHz. The excitation power is 350W for each of six bulb radiators. The specific radiation power in VUV region of spectrum achieved 120 mW/cm².

On the basis of scientific investigations published in [9], one-barrier Xe-excimer lamps with a high-curvature cathode and a large area of radiation surface were developed. The length of a quartz bulb covered with a grounded metal mesh was 1200 mm and a diameter –

20mm. A stainless steel wire was employed as a cathode. The specific radiation power of xenon dimer was $25\text{mW}/\text{cm}^2$. A reactor was made on the basis of this lamp to irradiate liquids or gases (Fig. 4). The Xe-excilamp was inserted into a metal tube with fittings to pump liquid or gas.

Sources of VUV radiation are widely used for cleaning of surfaces in microelectronics including the sources with windowless construction [10]. Here, irradiated objects are situated in the same gas which a discharge gap of the excilamp is filled. Such sources are usually employed for excitation of Ar- or Kr-dimer because of the short-wave radiation $<150\text{ nm}$ which is absorbed by different optical media, but windows from LiF-, CaF_2 -, MgF_2 -crystals are very expensive and usually too small. Moreover only LiF-crystals have the low coefficient of absorption for the excilamp on Ar-dimer ($\lambda\sim 126\text{ nm}$).

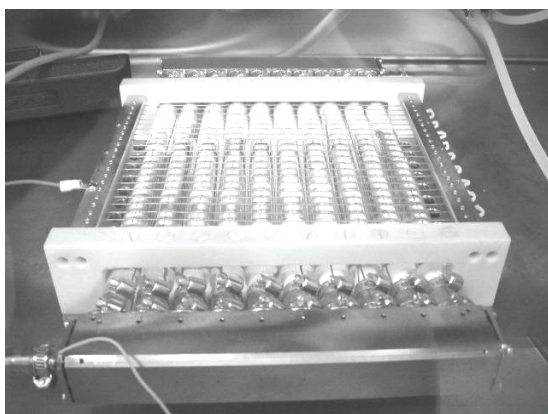


Fig. 5. Windowless excimer lamp

Windowless construction of an excilamp includes: 10 quartz tubes through which the water-flow is carried out; a cathode made from 21 metal sticks installed perpendicular to quartz tubes (Fig. 5). Area of radiation surface of the excilamp is $23 \times 23 = 529\text{ cm}^2$.

The surface barrier discharge in some rare gases was obtained using the windowless excilamp and the efficiency of radiation of dimer Ar_2^* ($\lambda\sim 126\text{ nm}$) and Kr_2^* ($\lambda\sim 146\text{ nm}$) $\sim 25\%$ and 45% of Xe_2^* dimer ($\lambda\sim 172\text{ nm}$) was achieved.

4. Portable UV excilamps.

If it is necessary to irradiate small area ($10\text{--}100\text{ cm}^2$) the use of powerful excilamps with large area of radiation is ineffective. Having scientific experience of investigations and developments of excilamps of the barrier and capacitive discharges, we have created portable excilamps [11].

The high voltage is used to ignite the barrier or the capacitive discharges. A radiator is inserted into a metal box together with a power supply and a air cooling system in order to provide a safety operation of excilamps (Fig. 6).

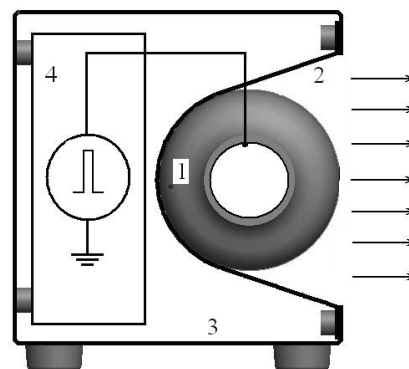


Fig. 6. Arrangement of components of the barrier discharge portable excilamp. 1 – radiator, 2 – supplementary reflector, 3 – box, 4 – power supply

A radiator 1 has coaxial construction with a half-reflector and radiation of the excilamp is directed to the limited solid angle using a supplementary reflector 2 [12]. Photos of portable XeBr-excilamps with the radiation power 4W and 1W are represented in Fig. 7.

The wavelength of excilamp radiation depends on gas mix composition and an operating molecule respectively. Excilamps on KrCl^* ($\lambda\sim 222\text{ nm}$), XeCl^* ($\lambda\sim 308\text{ nm}$), XeI^* ($\lambda\sim 253\text{ nm}$), XeBr^* ($\lambda\sim 282\text{ nm}$), KrBr^* ($\lambda\sim 206\text{ nm}$), Xe_2^* ($\lambda\sim 172\text{ nm}$), Br_2^* ($\lambda\sim 289\text{ nm}$), Cl_2^* ($\lambda\sim 258\text{ nm}$). The average UV power of excilamps put in a box depending on dimensions of a radiator and a reflector is from 0.5 W to 4W. The weight of excilamps is from 0.8 to 2 kg.



Fig. 7. 4W and 1W portable XeCl-excilamps

Portable XeCl-excilamps ($\lambda\sim 308\text{ nm}$) can be used in medical applications [13]. The radiation spectrum of the portable excilamp represents mainly the band radiation of $\text{B}\rightarrow\text{X}$ transitions of XeCl^* molecule with a maximum at 308 nm and a short-wave wing of the band of $\sim 30\text{ nm}$. More than 90% of radiant energy lies in the active spectrum of UVB radiation working for psoriasis curing. The last makes the XeCl-excilamp to be the unique source of radiation suitable for psoriasis photocuring. Moreover these excilamps do not produce ozone.

We have also developed a portable excilamp in a similar box with a capacitive discharge lamp as a radiator (Fig. 8). As a rule, bands of B→X, D→X and C→A transitions are present in radiation spectra of exciplex molecules excited by the capacitive discharge, but the most intensive is the B→X transition.

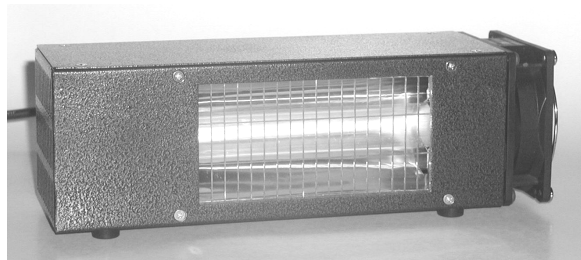


Fig. 8. Portable XeCl-excimer lamp of the capacitive discharge.

The construction and spectrum particularities of the radiator of capacitive discharge excimer lamps are described minutely in [14]. In order to prevent casual contact with a HV electrode of the lamp radiation was extracted through the stainless steel grate.

Portable excimer lamps of UV radiation directed to bottom were created to investigate influence of UV on biological objects [4, 5, 15], processes of photochemical reactions [16] and disinfection [17] (Fig. 9, 10).

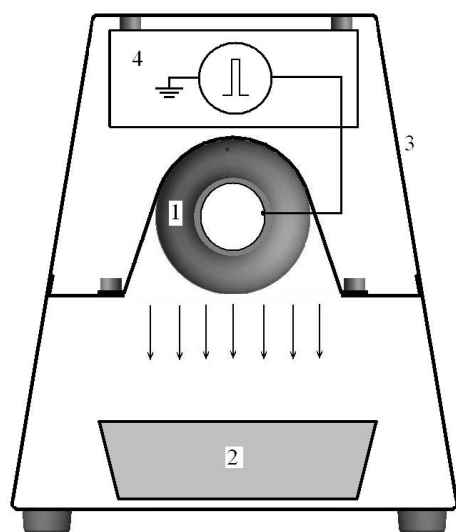


Рис. 9. Arrangement of components of the barrier discharge portable excimer lamp. 1 – radiator, 2 – irradiated object, 3 – box, 4 – power supply

Air flow produced by two fans installed on flanks of the excimer lamp box cools a radiator.

A series of wavelengths of such excimer lamps is the same that for portable excimer lamps with front direction of radiation and the radiation power is 5÷10W.



Fig. 10. Portable XeBr-excimer lamp of the barrier discharge

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