PORTABLE EXCILAMPS

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Abstract

The excilamps are simple gas-discharge sources of spontaneous narrow-band ultraviolet (UV) and vacuum ultraviolet (VUV) radiation due to the decomposition of excimer molecules. Sources of radiation of such type provide energy of photons from 3 to 9.87 eV, which is sufficient for application of excilamps practically in all known photoprocesses in which UV and/or VUV radiation is necessary. Having scientific experience of investigations and developments of excilamps of barrier and capacitive discharges, we have created portable excilamps with a UV/VUV radiator and a power supply in one box for irradiation of small size surfaces. Portable excilamps developed in the Laboratory of Optical Radiation (LOR) are described; the main characteristics of radiators and their power supplies, portable UV- and VUV-excilamps of a barrier discharge are reported. Application areas of portable excilamps are listed in the present paper.

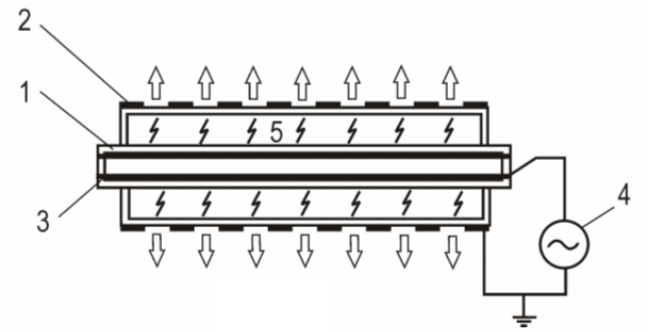
Key words: *ultraviolet radiation, gas-discharge sources, spontaneous radiation, barrier discharge, portable excilamp, high-voltage power supply*

1. INTRODUCTION

The excilamps are simple gas-discharge sources of spontaneous narrow-band ultraviolet (UV) and vacuum ultraviolet (VUV) radiation due to the decomposition of excimer molecules (excited dimer – excimer, in the case of a molecule consisting of equal atoms, for example, Ar_2*) or exciplex molecules (excited complex – exciplex, in the case of a hetero-nuclear molecule, for example, XeCl*) (Lomaev et all., 2003). Sources of radiation of such type provide energy of photons from 3 to 9.87 eV, which is sufficient for application of excilamps practically in all known photoprocesses in which UV and/or VUV radiation is necessary.

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

- ✓ simple device design (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 capacitive or barrier discharges (up to 80 %) is concentrated in the band of B→X transitions with 10 nm FWHM, because of this, excilamps can be used in applications in which a selective effect of radiation on an investigated object is required;
- ✓ it is possible to use excilamps to irradiate at once a large area of an object (in one step);
- ✓ operating 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.



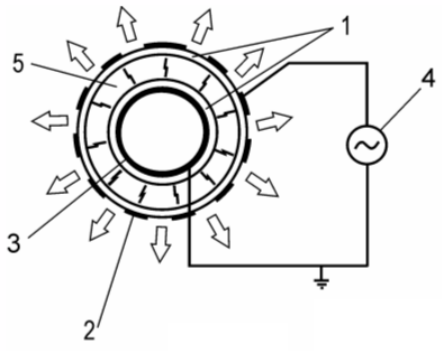


Fig. 1a. Longitudinal section of a radiator. **Fig. 1b.** Cross-section of a radiator.

1 – quartz tubes, 2 – grid electrode, 3 – reflective electrode, 4 – power supply, 5 – discharge.

Use of powerful excilamps with a large area of radiation is ineffective to irradiate a small area (10-100 cm^2). Portable excilamps are developed with the aim to receive the homogeneous and plane front of one or several radiations with a small area of irradiation for use in a lab environment. Design of portable excilamps means join of a radiator, a power supply and a cooling system in one box. The idea of creation of portable UV or VUV radiators is not new and is widely used in the world, but not portable excilamps. The leader of development of portable excilamps with various optical features is the Laboratory of Optical Radiation of SB RAS.

Excilamp radiators are represented two coaxial quartz tubes of different diameters soldered at ends. The reflector *6* is placed on a coaxial radiator in one half-plane to receive radiation, and the grid electrode *2* is used to extract radiation (Fig. 1.)

2. EMISSION SPECTRA OF EXCILAMPS

An important characteristic of excilamps is their emission spectrum. Contrary to the case of mercury, hydrogen, and thermal sources of spontaneous UV and VUV radiation, the emission spectra of excilamps consist of comparatively narrow bands of B→X-, D→X-, and C→A-transitions of the corresponding molecules. Since the main fraction of the radiation power of capacitive- and barrier-discharge excilamps (up to 80%) is contained in the bands of the B→X-transitions and the half-height width of these bands does not exceed 10 nm, the latter can be used in applications in which a selective action of radiation on the object under study is required (Lisenko and Lomaev, 2002).

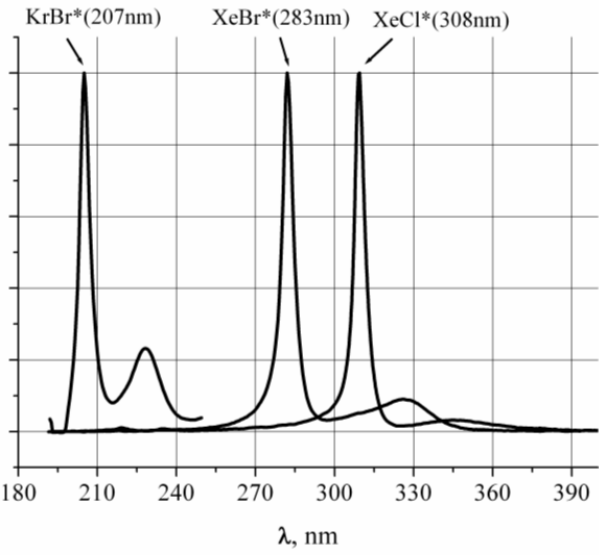


Fig. 2. Spectra of exciplex lamps.

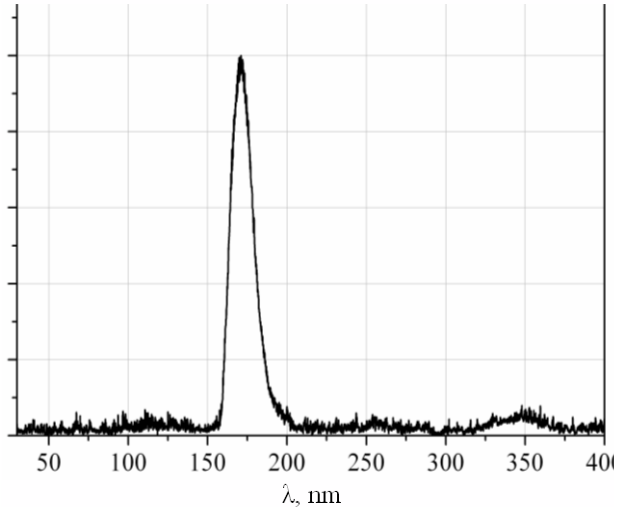


Fig. 3. Spectrum of a xenon lamp.

Figure 2 shows typical emission spectra of exciplex lamps and wavelengths of potable excilamps are listed in Table 1.

Table 1. Operating molecules and wavelength of portable excilamps.

Operating molecule	Wavelength of the maximum of spectral distribution, λ, nm
Xe_2*	172
I_2*	342
Br_2*	289
Cl_2*	259
KrBr*	207
KrCl*	222
KrI*	190
XeBr*	283
XeCl*	308
XeI*	253

spectra are reported in the paper.

The emission spectra of barrier-discharge excilamps consist of highly pronounced bands of the B→X-transitions and weak bands of the C→A-transitions. The D→X bands are usually absent, and the half-height width of the B→X bands for the B→X transition are 1.6, 1.9, 1.8, 3.3, and 1.6 nm for KrCl*, XeCl*, XeI*, XeBr*, and KrBr* excilamps, respectively.

The emission spectra of an excilamp of a barrier discharge on xenon dimers have a simpler structure (Fig. 3). In this case, the emission spectra contain the B→X band with the maxima at 172, 289, and 259 nm that has approximately the half-height width 9.6, 6 and 8 nm at average pressures for Xe_2-, Br_2-, and Cl_2-excilamps, respectively.

So, with changing operating gases or gas mixtures in excilamps, it is possible to generate narrow-band radiation of excilamps with a necessary wavelength at maximum (see Tab. 1), therefore the main characteristics of portable excilamps except

3. POWER SUPPLIES FOR EXCILAMP EXCITATION

As shown in Fig. 4 a power supply consists of four main parts: a rectifier, a power factor corrector (PFC), a half-bridge converter and a step-up transformer.

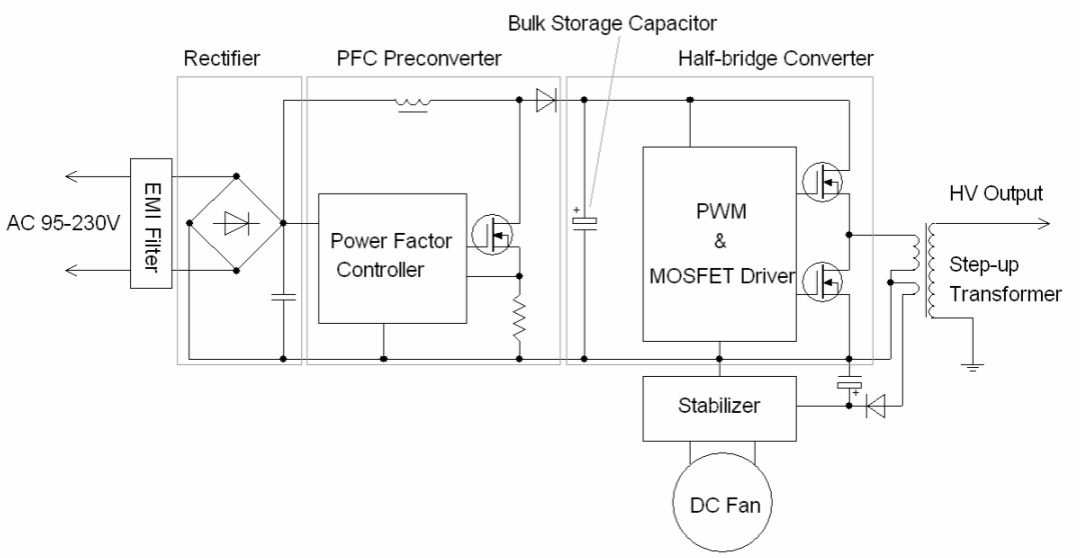


Fig. 4. Block-circuit diagram of a power supply for excilamp excitation.

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 AC95-230V and delivers DC400V 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 (MOSFET) 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 switching of transistors. 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 design is in range 20-800W.

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 (Lomaev et all., 2003).

4. PORTABLE UV EXCILAMPS

Fig. 5 shows a portable excilamp in section. A radiator is inserted into a metal box together with a power supply and an air cooling system. Use of excilamps with a radiator separated from a power supply, may cause electric injury, as high voltage is used to ignite barrier discharges. Design of

portable excilamps (as in Fig. 5) means high voltage feeding the radiator does not take out from the metal box that provides a safety operation of excilamps.

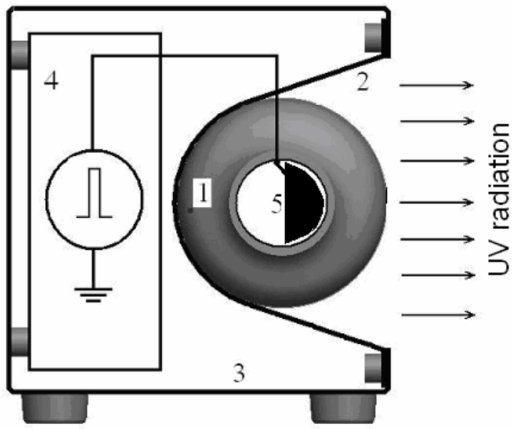


Fig. 5. Arrangement of components of the barrier-discharge portable excilamp.
1 – radiator, 2 –reflector, 3 – box, 4 – power supply, 5 – inner halved electrode.



Fig. 6. 4W and 1W portable XeCl-excilamps.

To produce radiation in one half-plane we use a unique patented design of a bulb with electrodes for portable excilamps. A radiator 1 has a coaxial design with a reflector and radiation of the excilamp is directed to the limited solid angle (Sosnin et all., 2004). Due to an inner electrode *5* halved, the discharge is located only in one plane of an excilamp bulb. Such design of electrodes has high efficiency of the radiation output in one half-plane in comparison with design with a solid electrode, because a part of radiation is screened by this electrode. Photos of portable excilamps with the radiation power 4W and 1W are presented in Fig. 6.

Portable excilamps of UV radiation directed to bottom were created to investigate influence of UV on biological objects, processes of photochemical reactions and disinfection (Fig. 7, 8). Cooling of a radiator is carried out by the airflow produced from two fans installed on flanks of the excilamp box.

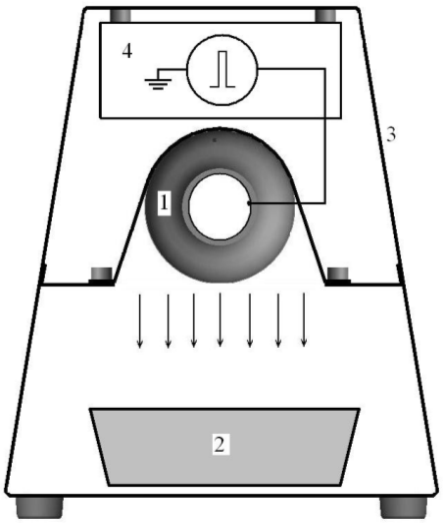




Fig. 7. Arrangement of components of the barrier-discharge portable excilamp. 1 – radiator, 2 – irradiated object, 3 – box, 4 – power supply. (left)

Fig. 8. Portable XeBr-excilamp of a barrier discharge. (right)

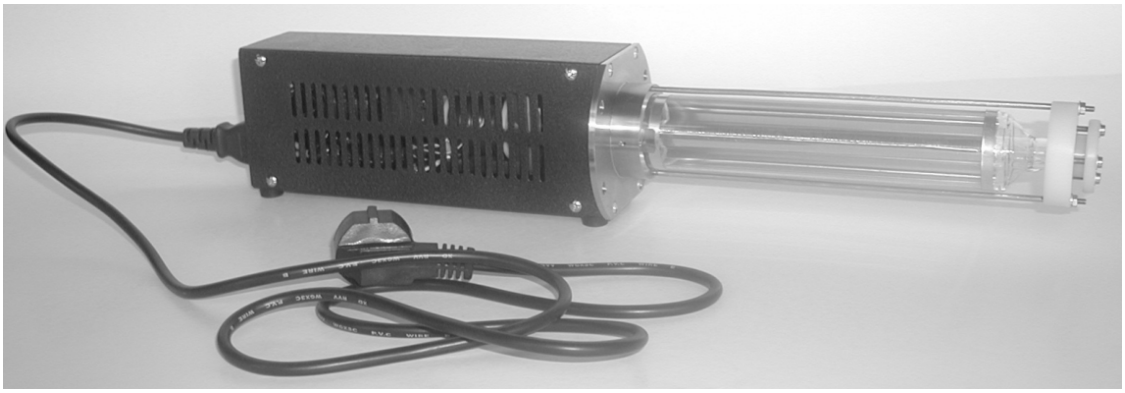


Fig. 9. VUV excilamp with a hermetic flange.

As known VUV light is absorbed by molecules of oxygen, so VUV irradiation is not possible in the air. To transmit VUV light to an irradiated object it is necessary to reduce maximum distance from a radiator to the object (to irradiate closely), or to use a special chamber filled with a rare gas.

Fig. 9 shows a Xe-excilamp with a hermetic flange that operates in a vacuum- or a gas-filled chamber. The power of VUV radiation is 1 W. The emission spectrum of xenon is shown in Fig. 3. Krypton is added to xenon to broad the emission spectrum in a short-wave area. Diameter of a radiator is 30 mm, its length – 190 mm, its weight with a power supply is 1.1 kg.

6. PHOTOREACTORS

Portable photoreactors using barrier-discharge excilamps have been also developed in the Laboratory of Optical Radiation. On the basis of scientific investigations published in (Lomaev et all., 2004), one-barrier Xe-excilamps with a high-curvature cathode and a large area of radiation surface have been developed. The length of a quartz bulb covered with a grounded metal mesh was 1200 mm and

a diameter – 20 mm. A stainless steel wire was employed as a cathode. The specific radiation power of xenon dimer was 25 mW/cm^2 (λ = 172 nm). A reactor was made on the basis of this lamp to irradiate liquids or gases (Fig. 10). The Xe-excilamp was inserted into a metal tube with fittings to pump liquid or gas.



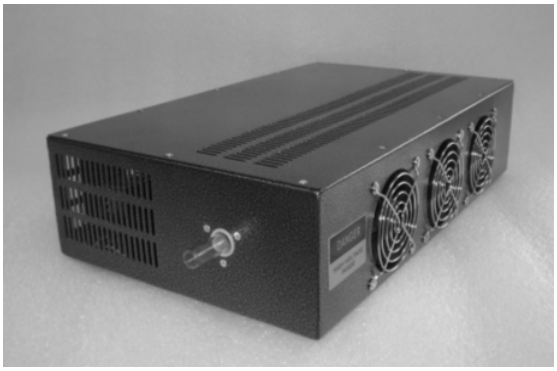


Fig. 10. Photochemical reactor with a power supply on the basis of the one-barrier Xe-excilamp. (left)
Fig. 11. Portable photoreactor with replaceable tubes of liquid or gas flow. (right)

At irradiation of some liquids or gases there is problem of contamination of a quartz surface of radiators. The portable photoreactor with replaceable tubes for liquid or gas flow has been developed in LOR. A power supply and a radiator are placed in one box (Fig. 11). From box sides there are holes to insert a quartz tube which passes through a radiator. Radiation directed to a bulb axis is taken out through a grid electrode and through a quartz tube for gas or liquid irradiation.

7. POWERFUL PORTABLE EXCILAMPS

A unique design excilamp with a large aperture has been developed in LOR. Power excilamps are cooled as a rule by deionized water or other liquid cooling agent that complicates considerably the device. We used a powerful air flow from several fan blowers and a special configuration of electrodes for cooling of the excilamp shown in Fig. 12. Radiation, as well as in previous excilamps, was taken out in one half-plane with the specific power to 30 mW/cm^2 at the aperture 70x6.5 cm. Hence the full power of excilamp radiation directed to one half-plane was 13.5 W. The excilamp is provided by a timer *4* which helps to set time of expositions accurate within 1 s. The radiator is fixed by means of two holders *5* on bulb ends, and high voltage and a grounder are made in the form of connectors. Thus, the user can easily and quickly replace a radiator without special tools. Power consumption of the excilamp from AC network is 600 W, its weight - 8 kg.

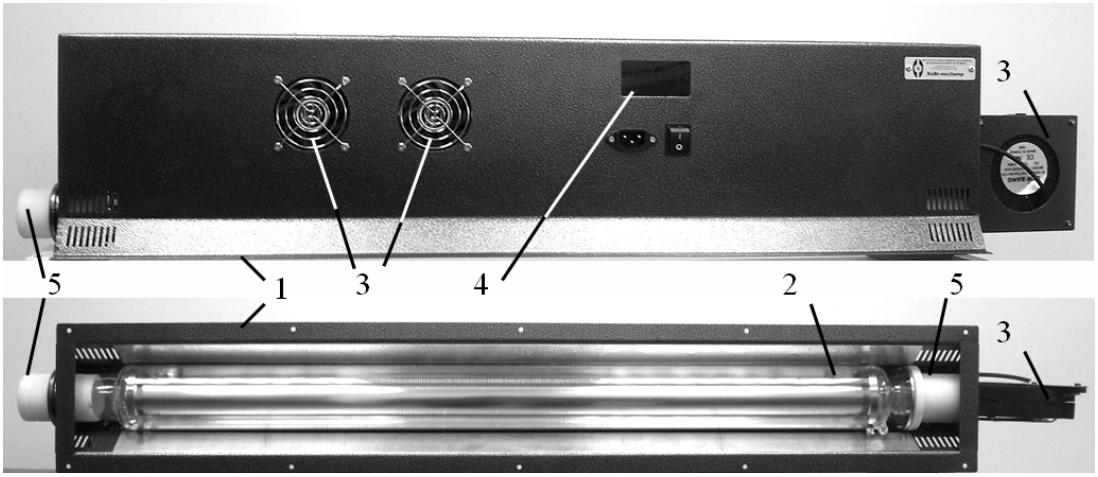


Fig. 12. Large-aperture portable excilamp. 1 – box, 2 – radiator, 3 – cooling system, 4 – timer, 5 – holders of a radiator.

8. APPLICATIONS OF PORTABLE EXCILAMPS

The excilamp technology offers a great number of applications in photoscience. We allocate the following tendencies in the development of excilamps and accompanying technologies (Kogelschatzet all., 1999):

►progress of excilamp applications in photomedicine (phototherapy, photoimmunology etc.). For example, portable XeCl-excilamps (λ~308nm) can be used in medical applications (Dmitruck et all., 2005), because of their radiation spectrum that represents mainly the band radiation of B – X-transitions of XeCl* molecule with maximum at 308 nm and shortwave wing of the band of ~ 30 nm. More than 90% of radiant energy lies in the active spectrum of UVB radiation working for psoriasis curing. The last makes XeCl-excilamps to be the unique sources of radiation suitable for psoriasis photocuring;

►inclusion of excilamps in multicomponent analytical systems (e.g. in the chromatography apparatus);

►applications of excilamps in photochemistry of gas mixtures at elevated pressures. When solutions of organic and inorganic substances are irradiated, the following stages take place: 1) absorption of light quanta, 2) primary photochemical processes, and 3) dark (secondary) processes between the substances formed at stage 2. It often happens that, implying the whole cycle that terminates in decomposition, a photomineralization process is considered that can generally be written as

$C_nH_mX_z$ ($h\nu$, O_2) → nCO_2 + (m-z)/2 H_2O + zHX,

where X is heteroatomic organic molecules that are transformed into the corresponding mineral acids HX (HNO_2, H_2SO_4, HCl, HNO_3, etc.). In the foreign literature, such photochemical processes and technologies related to them have been named Advanced Oxidation Processes (AOPs), and less used alternative names Advanced Oxidation Technologies (AOIs) and Enchanced Oxidation Processes (EOPs). A specific feature of the photochemical activation of a

substance is its selectivity as compared to the thermal activation, as radiation interacts only with the substance that absorbs it;

►substitution of mercury-containing lamps in existing apparatus (e.g., for water and air disinfection and purification, UV-curing of coatings) by excilamps;

►UV- sterilizers on the basis of excilamps (Lomaev et all., 2006);

►applications of excilamps in photosynthesis, e.g., for synthesizing vitamin D;

►for solving ecological problems, e.g., for photochemical decomposition of industrial waste;

►for thin films deposition;

►for cleaning of semi-conductor surfaces;

►use of narrow-band excilamps in photobiology may help to obtain new data on the interaction of UV radiation with biosystems of various natures.

Excilamps have and will certainly find wide use in modern science and industry applications.

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