Xenon iodide exciplex lamp as an efficient source for the UV surface cleaning and water decontamination

M. Guivan[1], H. Motomura[2], M. Jinno[2]
[1]Department of Quantum Electronics, Uzhgorod National University, Pidgirna 46, Uzhgorod, Ukraine
[2]Department of Electrical and Electronic Engineering, Ehime University, Matsuyama, Japan
e-mail: m_guivan@rambler.ru

Résumé

In this study a good cleaning effect of glass surface and sterilization action was achieved with the DBD-driven XeI* exciplex lamp. The main part (~76%) of the lamp output was due to the *B*→*X* transition of XeI* exciplex at 253 nm. The contribution of an atomic iodine emission in the range of 178–207 nm has been confirmed. Germ reduction experiments with the XeI* excilamp have been carried out in a water flow reactor.

Introduction

Conventional technology for disinfection by UV irradiation is based on low-pressure mercury lamps. The development of a new mercury-free UV lamp is very important due to the environmentally unfriendly nature of mercury. The excilamps (excimer or exciplex lamps) based on mixtures containing xenon and iodine vapours emitting mainly due to XeI($B^2\Sigma_{1/2} - X^2\,\Sigma_{1/2}$) at $\lambda = 253$ nm are considered to be the efficient sources in the UVC (200–290 nm) range. Recently, the sterilization action of a DBD-driven XeI* excilamp operated with a Xe/I_2 mixture has been reported for the inactivation of *Bacillus Subtilis* spores in a steady state mode [1]. In this study, we report the investigation of XeI* excilamp operated with the Xe/I_2 mixture and using it for the UV surface cleaning and UV inactivation of *Bacillus Subtilis* spores in a water flow reactor.

Results and discussion

In these experiments we used the dielectric barrier discharge (DBD) lamp in coaxial design consisting of two quartz tubes and electrodes, which were applied to the inner surface of the smaller tube and the outer surface of the outer tube [1]. The exciplex lamp was excited using a custom built power supply, producing bipolar pulses with peak-to-peak voltage $U = 0$–4.4 kV, $f = 21.5$–115 kHz, provided the highest XeI* UV output at a frequency of 60 kHz. The emission spectra in the VUV–UV range (170-400 nm) were measured with the VM-502 0.2 m vacuum monochromator (Acton) equipped by a PMT R928 (Hamamatsu) with a scintillator. The radiation power of the excilamp in absolute units was measured by a UV power meter C8026 (Hamamatsu Photonics K.K.) equipped with a calibrated H8025-254 sensor head (210–350 nm).

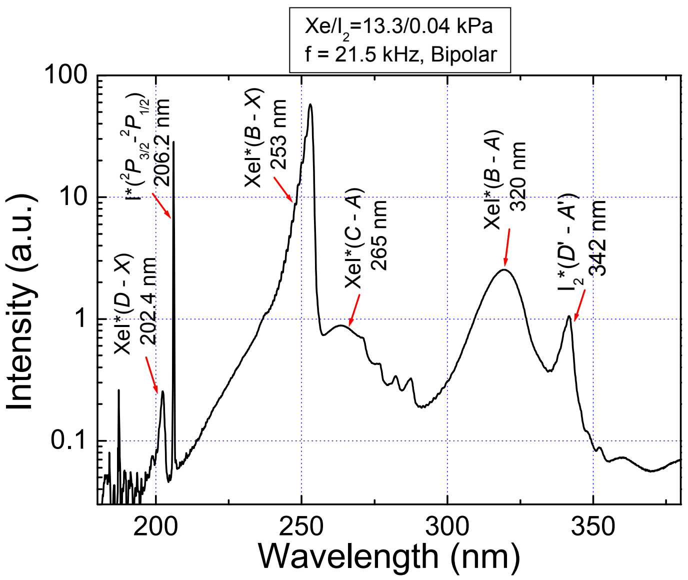

Fig. 1: UV emission spectrum of the XeI* excilamp. Y axis is in a logarithmic scale in order to show the low-intensity features.

The emission spectrum of the XeI* excilamp, operated with a Xe/I_2 = 13.3/0.04 kPa mixture, in germicidal region (180–300 nm) includes atomic iodine I* radiation in the range of 178–188 nm (178.3, 179.9, 183.0, 184.4, and 187.6 nm) and at λ = 206.2 nm, XeI*($B \to X$, $\lambda_{max} = 253$ nm), XeI*($C \to A$, $\lambda_{max} = 265$ nm) exciplex emission, weak traces of XeI*($D \to X$, λ_{max} = 202.4 nm) and I_2*($F \to B$) in the range of 270–280 nm (Fig. 1). Moreover, the XeI($B \to A$, $\lambda_{max} = 320$ nm) and I_2($D' \to A'$, $\lambda_{max} = 342$ nm) emission was also registered. The radiation of the atomic iodine and XeI*($B \to X$, $C \to A$) coincides with the absorption maxima of DNA nearly at 200 and 260 nm so it can be efficiently used for UV sterilization. It should be noted that very often a sterilization efficiency curve is shown with one maximum around 260 nm mainly due to the small penetration depth in water for UV emission with λ<220 nm. However, the main target for the UV sterilization is DNA and the short wavelength part (175–210 nm), which is transparent for air and the quartz bulb of the lamp, can be efficiently used in the case of a setup with a thin water layer, and for air or food package sterilization.

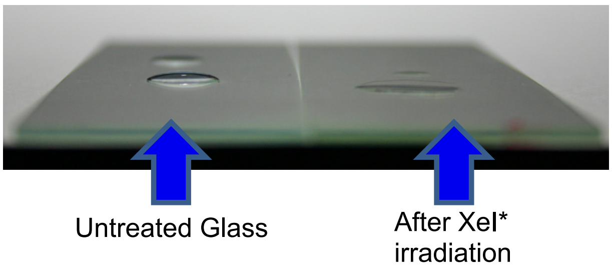

Fig. 2: Glass plates w/o treatment (left) and after 1 min. UV irradiation by means of XeI* exciplex lamp (right).

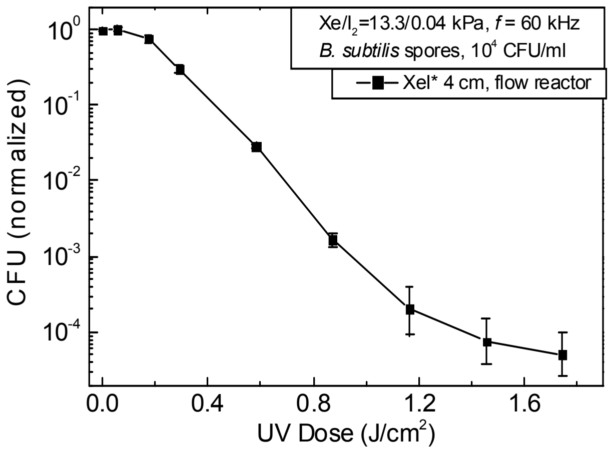

Fig. 3: Normalized number of CFU (*B. subtilis*) as a function of UVC energy from XeI* excilamp. Distance to the lamp: 4 cm, 1 Liter of flowing water.

The glass plates were chosen as the test objects for the UV surface cleaning. It can be seen from the figure 2 that after 1 minute irradiation the water drop on the glass surface has a contact angle about three times less in comparison with the untreated surface. It means, the UV radiation from the XeI* lamp destroyed the oil film on the surface and can be used for the UV cleaning.

Figure 3 shows the changes in the normalized number of CFU in the water flow reactor as a function of the cumulative UV dose of XeI* exciplex lamp, emitted during the UV treatment. One experiment was carried out when the volume of irradiated water was covered with a plate preventing the penetration of foreign microflora from outside, and another one – without a cover. Almost the same CFU reduction was observed in both measurements. The higher UV doses, needed for inactivation of *B. subtilis* spores in the water flow reactor in comparison with the steady state mode [1], can be explained by the short reaction time. This is also the possible reason for the presence of a threshold at about 0.1 J/cm^2 in CFU reduction. Taking into account the water flow circulating velocity, the cross section ratio of the tubing and the water layer on the plate, and the plate length, we can estimate that the total exposure time of the same portion of water is about 49 s for a 30 min irradiation, since the processing time of water per single pass in the water flow reactor is 0.3 s and the same portion is irradiated 162 times during 30 min irradiation. Then, using the data of [1], we can calculate that the UV dose, which reaches the same portion of water, does not exceed 40–42 mJ/cm^2. This is close to the energy range of the steady state mode. Note that it is possible to improve the reactor design placing the lamp along the water stream and using a set of the exciplex lamps. Thus, the latter experiment has shown the possibility to use the XeI* exciplex lamp (or a set of the lamps) for water decontamination in flow systems.

Summary

The sterilization action of the DBD-driven XeI* excilamp was tested on the inactivation of *B. subtilis* spores. A reduction by more than 4 orders of magnitude of CFU in *B. subtilis* spores was achieved in a water flow reactor and the D-value was about 0.4 J/cm^2. An additional effect of the I* radiation at 206 nm and in the VUV range (178–188 nm) was confirmed. This research demonstrates that the DBD-driven XeI* excilamp can be used for the UV cleaning and inactivation of microorganisms not only in a steady state mode, but also in movable systems (drinking water treatment or food package sterilization).

References

[1] H. Motomura, M.M. Guivan, M. Jinno, Int. Light Sources Workshop LSW 8, Jhong-Li, Taiwan (2009) I-O-1.