Phosphor Converted Xenon Excimer Discharge Lamps in Application – Chances and Challenges

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GEFÖRDERT VOM Bundesministerium für Bildung und Forschung

1. Phosphor converted Xe DBD lamps

Xenon excimer discharge lamps rely on the generation and the subsequent decomposition of Xe excimers in a dielectrically hindered discharge, often called “dielectric barrier discharge” or “silent discharge”.[1] Xe Excimers (compound of the words excited and dimer) emit electromagnetic radiation in the VUV region upon relaxation from electronically and vibronically excited states into the unstable dissociative ground state. Xe excimer emission consists of two emission bands peaking at 152 nm (1st continuum, dominant at lower pressure) and 172 nm (2nd continuum, dominant at higher pressure).[2] The implementation of energy conversion by applying inorganic phosphors as a coating promotes the lamp to an efficient UV-C/B emitting radiator for use in disinfection and POP depletion, offering several benefits:

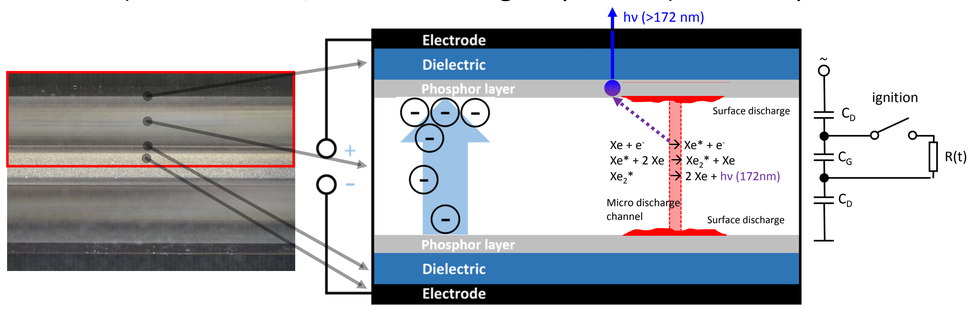
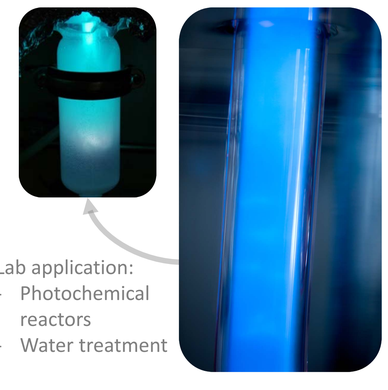


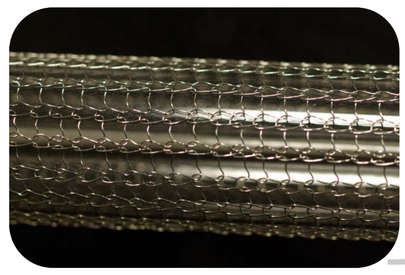
Fig. 1 Picture and schematic illustration of the set up of a phosphor converted Xe excimer discharge lamp.

- Free from heavy metals like Mercury
- Instant On/Off & pulsed operation possible
- Tailorable spectral output VUV—UV-C/B/A



Lab application:
- Photochemical reactors
- Water treatment

An YPO_4:Bi comprising Xe excimer lamp operated in H_2O



A switched off phosphor free 172 nm Xe excimer lamp comprising a stainless steel metal netting as outer electrode for operation in gaseous media. Phosphor application is as well possible.

Lab application:
- Spectroscopy
- Ozone generation
- Surface treatment

Fig. 2 Xe excimer discharge lamps for operation in water and air

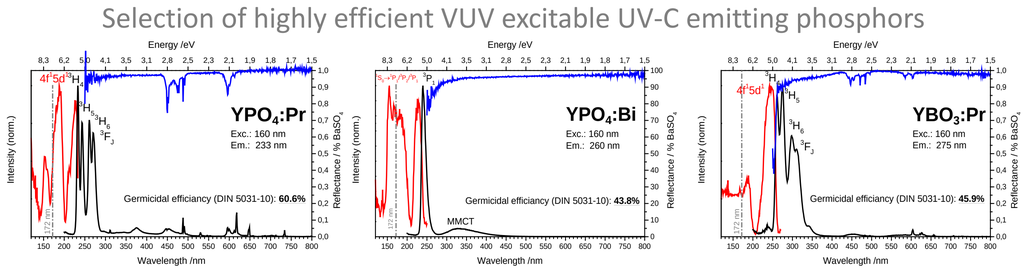
2. Application in UV induced Disinfection

Ultraviolet germicidal irradiation (UVGI) is the fraction of electromagnetic radiation which is capable of killing microorganism or inhibiting their ability to reproduce by causing defects within microorganism’s DNA photochemically.[3] For E. coli germicidal effectiveness of irradiation peaks in the UV-C at around 265 nm. Phosphor conversion renders Xe excimer discharge lamps suitable sources of UVGI.

Phosphor comprising Xe excimer discharge lamps can be used as efficient UV-C/B or VUV light sources in disinfection

The germicidal efficacy typifies a useful tool to evaluate a phosphor for its disinfection suitability

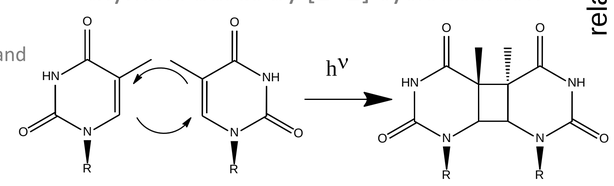
Selection of highly efficient VUV excitable UV-C emitting phosphors



$\lambda_{max}(YPO_4:Pr)$= 235 nm $\lambda_{max}(YPO_4:Bi)$= 241 nm $\lambda_{max}(YPO_4:Pr)$= 235 nm

Fig. 3 VUV excitation-, emission- and reflectance spectra of the UV-C emitting phosphors and YPO_4:Pr, YPO_4:Bi and YBO_3:Pr.

Photochemical dimerization of thymine bases by [2+2] cycloaddition



The application of certain phosphors or even phosphor blends yields:

- Application adaptable broad bended germicidal active irradiation in the UV-C/B/A range
- Innate Benefits of Xe excimer discharge: Hg free, pulsed op., instant on/off

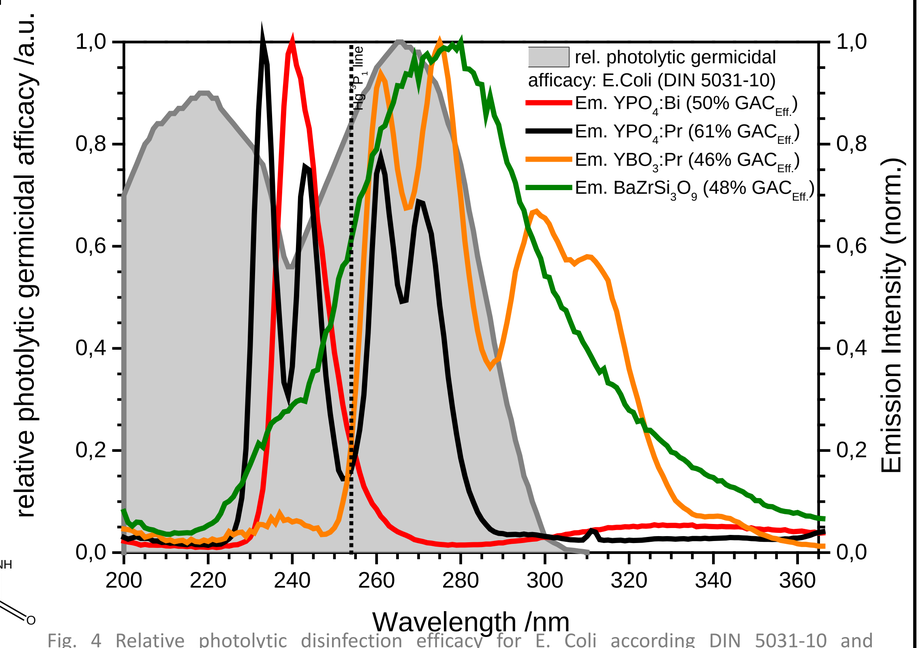


Fig. 4 Relative photolytic disinfection efficacy for E. Coli according DIN 5031-10 and photoluminescence emission spectra of YPO_4:Bi, YPO_4:Pr, YBO_3:Pr and $BaZrSi_3O_9$ at 160 nm excitation.

3. Application in Advanced Oxidation Processes (AOP)

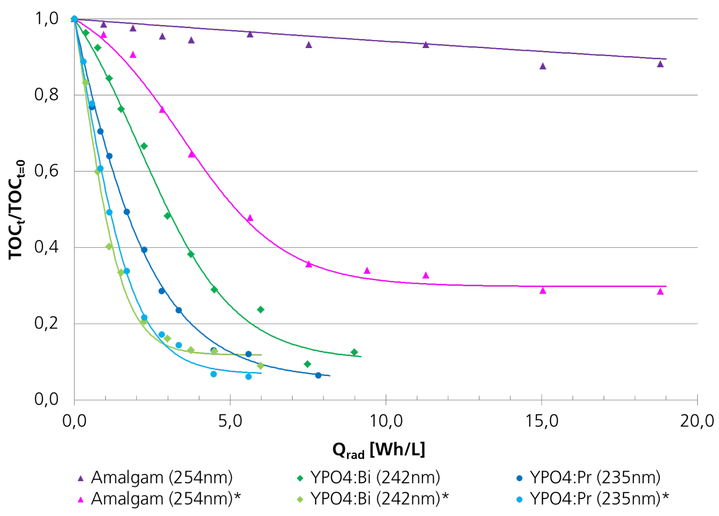


Fig 5: Degradation of sulfamethoxazole and intermediate products (measured as total organic carbon, TOC) during photolysis and photooxidation (*) using xenon DBD lamps with YPO_4:Bi, YPO_4:Pr in comparison to a standard amalgam lamp; Q_{rad} is the radiant energy per volume of processed aqueous solution.

Xenon DBD lamps with $YPO_4:Bi^{3+}/Pr^{3+}$ were tested for the degradation of the antibiotic sulfamethoxazole (20 mg/l).

According to fig. 5 almost complete mineralization is achieved in contrast to standard amalgam lamps when only radiation is applied (photolysis). With additional dosage of hydrogen peroxide (1 equivalent according to chemical oxygen demand) 70% mineralization is achieved with amalgam lamps (photooxidation). Mineralization with $YPO_4:Bi^{3+}/Pr^{3+}$ lamps is accelerated with hydrogen peroxide.

Radiant energy demand for photolytic mineralization of sulfamethoxazole is 20-60 times higher for only 20% TOC degradation with amalgam lamps in comparison to $YPO_4:Bi^{3+}/Pr^{3+}$ lamps (fig. 6).

Degradation of sulfamethoxazole with the photooxidation process requires 10 times more radiant energy with amalgam lamps than with $YPO_4:Bi^{3+}/Pr^{3+}$ lamps for reducing the TOC by only 70% (fig. 6).

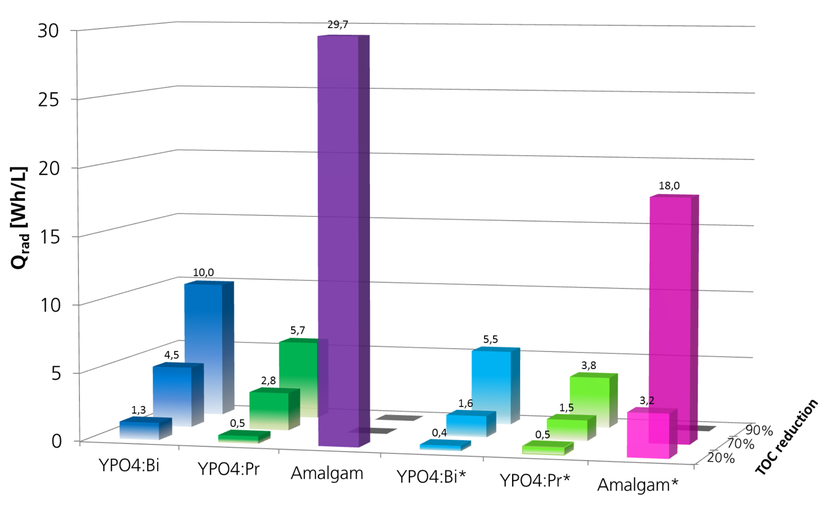


Fig 6: Comparison of the required radiant per volume of sulfamethoxazole solution for 20%, 70% and 90 % TOC reduction via photolysis or photooxidation (*) using xenon DBD lamps with YPO_4:Bi, YPO_4:Pr in comparison to a standard amalgam lamp; Q_{rad} is the radiant energy per volume of processed aqueous solution.

4. A Crucial Quality Criterion: Device Lifetime

Most phosphor converted Xe excimer lamps suffer from a fast aging involving dramatic loss of output intensity within a few hundreds of hours of operation. An YPO_4:Bi comprising lamp has lost 30% of its initial intensity after ~230 hours of operation (L70) as demonstrated by figure 5. It was figured out, that the lamp aging phenomenon is governed by aging of the applied phosphor. Detailed analytical survey of phosphor samples recovered from aged Xe excimer lamps included: VUV-spectroscopy, temperature dependent photoluminescence Spectroscopy, PXRD, ^{31}P-NMR, XPS and EPR.

Aging of an$YPO_4:Bi^{3+}$ comprising Xe excimer discharge lamp

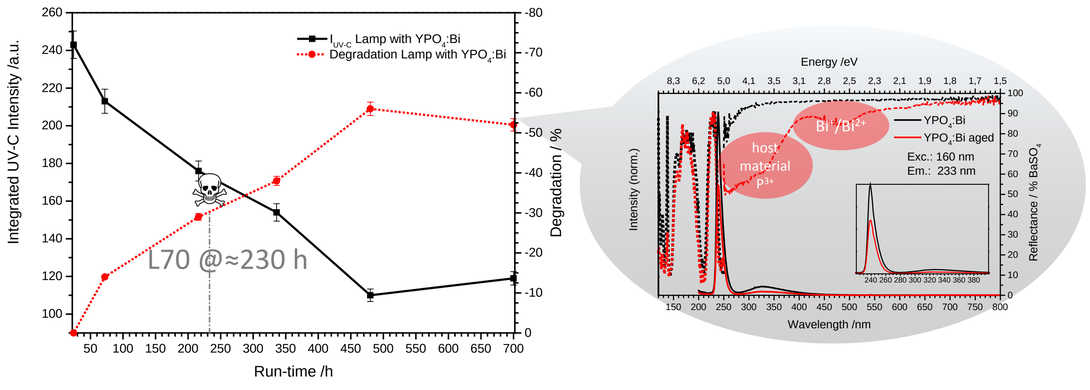


Fig. 7 Left: UV-C output vs. run-time for a YPO_4:Bi comprising Xe lamp; Right: Excitation, emission and reflectance spectra of untreated and aged YPO_4:Bi (after 700 hrs run-time).

The aging of a phosphor is dependent on the host structure and the introduced activator species. It consists of:

- Colour centre formation which leads to pronounced greying, measurable from 250 – 800 nm.
- Reduction of P^{5+} to P^{3+} when phosphates are applied as host structure, e.g. YPO_4:Bi which leads to the formation of distinct UV-absorption bands and a broad banded emission in the deep red originating from P^{3+} ([Ne]$3s^2$ electron configuration).

Measures to prevent aging

- Protective particle coating
- Sophisticated lamp design avoiding phosphor – discharge interaction

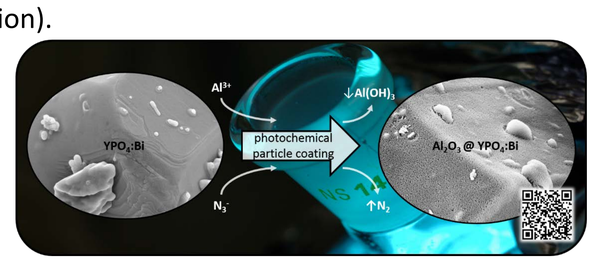


Fig. 8 Illustration of UV driven particle coating process [4].

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