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Title: APPLICATIONS OF DIELECTRIC BARRIER DISCHARGES

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ABSTRACT

Dielectric barrier discharges (DBDs) in oxygen and air are well established for the production of large quantities of ozone and are more recently being applied to a wider range of plasmachemical processes. Here, the application of DBDs for ozone synthesis, the non-thermal oxidation of volatile organic compounds (VOCs) in air, the generation of incoherent (V)UV radiation and surface processing (etching, ashing) is presented.

- The main plasmaphysical features of sinusoidally-driven DBDs (transient, filamented, non-thermal plasmas at atmospheric pressure) are described, and a simple plasmachemical reaction pathway for ozone synthesis are is given.
- Experimental results on the degradation of VOCs (2-propanol, trichloroethylene, carbon tetrachloride), as well as byproduct formation is presented for stand-alone DBD treatment, as well as for simultaneous (V)UV illumination of the discharge. Illumination of the discharge with (V)UV can change the plasmachemistry by enhanced formation of certain species of radicals - and thereby change byproduct formation - but also can change the discharge physics, known as the Joshi effect.
- As an example for generation of excited dimers and exiplexes for the production of incoherent UV light, experimental results on a XeBr* excimer UV light source are presented. Effects of the total and partial pressure of a Xe/Br_2 system, the gap spacing and the applied driving frequency on the UV radiant efficiency are shown.
- For the application of DBDs for surface processing, experimental results of photoresist ashing on Si wafers using DBDs in oxygen are shown function of gas pressure, gap spacing and applied frequency.

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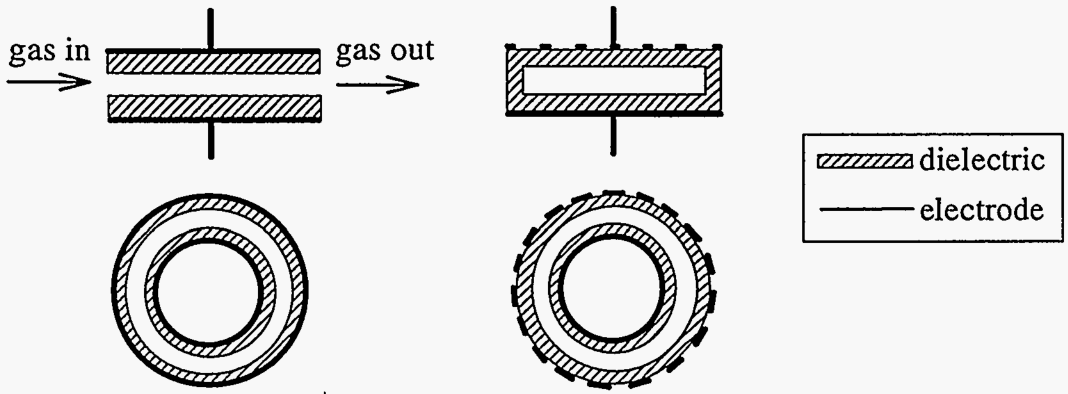

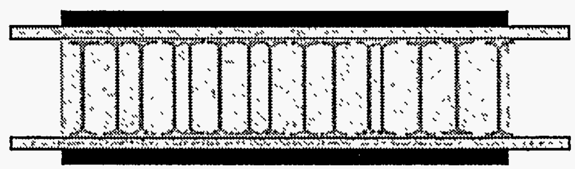

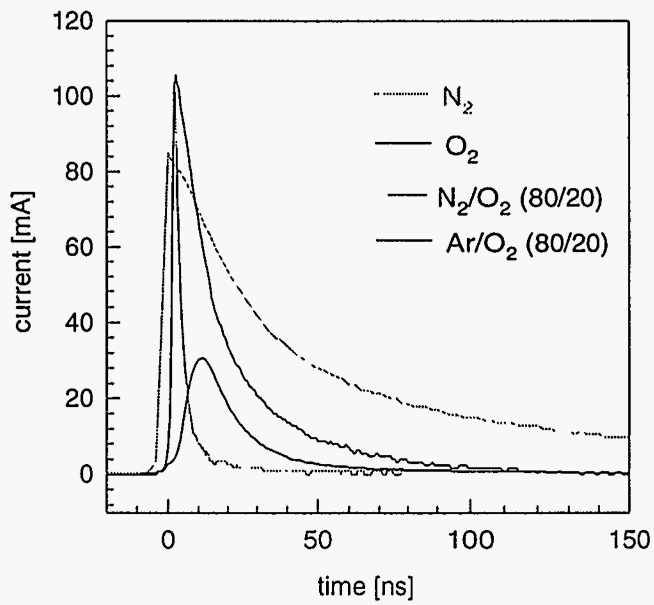

Materials: metalic electrode
(plate, mesh,
paste, electrolytes)
dielectric
(glass, quartz, ceramic)

Gap distance: 1 - 10 mm

Gas pressure: atmospheric
(but also from 50 to 3000 Torr)

Applied voltages: 1 - 100 kV sinusoidal
(1 Hz to < 1 MHz)
steep-rising (ns/kV)

Discharge characteristics: transient (1's to 100's of ns)
non-thermal
microdischarge formation
(filamentation)
large area discharge
kA/cm^2 discharge current density
electron temperature 1...10's eV
(mean electron temperature
in air typically 3 - 5 eV)
plasma density 10^{13} - 10^{15} cm^{-3}

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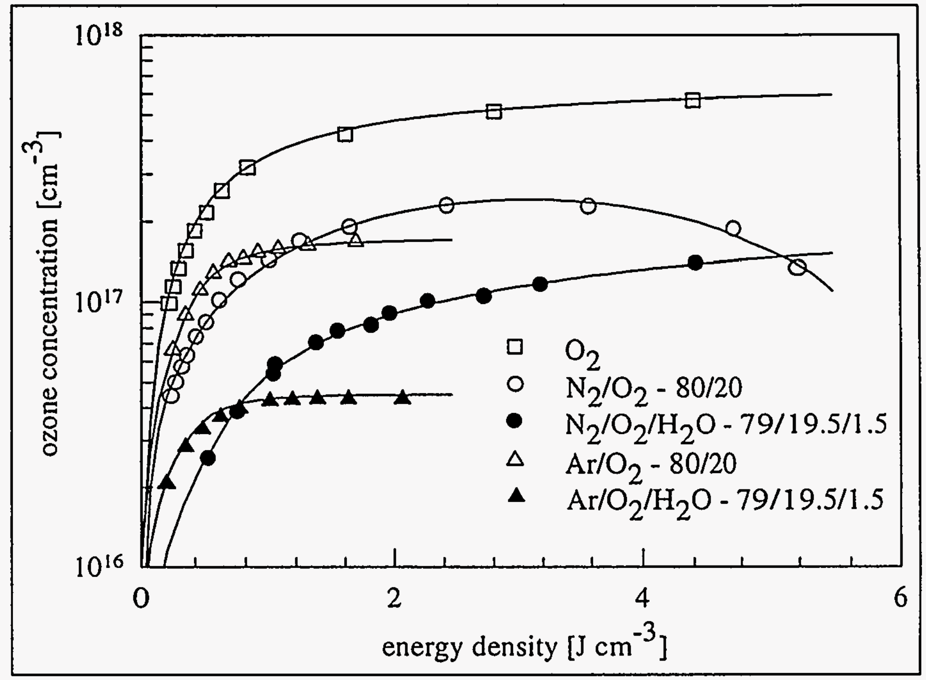


Herzberg system

$e^- + O_2(X^3\Sigma_g^-) \longrightarrow e^- + O_2(A^3\Sigma_u^+)$

$O_2(A^3\Sigma_u^+) \longrightarrow O(^3P) + O(^3P)$

Schumann-Runge system

$e^- + O_2(X^3\Sigma_g^-) \longrightarrow e^- + O_2(B^3\Sigma_u^-)$

$O_2(B^3\Sigma_u^-) \longrightarrow O(^1D) + O(^3P)$

($O(^3P)$ or) $O(^1D) + O_2(X^3\Sigma_g^-) + M \longrightarrow O_3(^1A) + M$

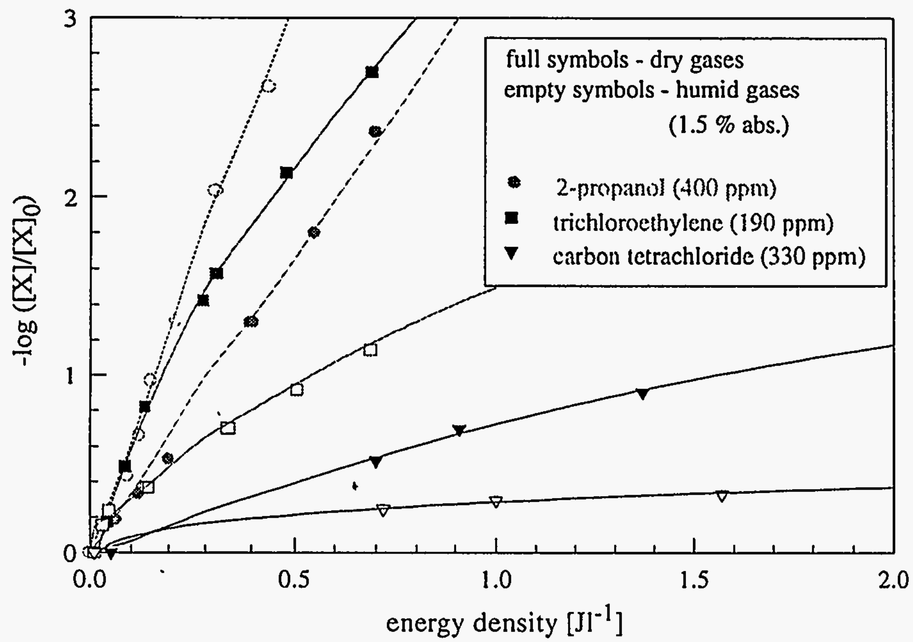
$k = 5.7 \times 10^{-34}\ cm^6\ s^{-1}$ for $M = O_2$

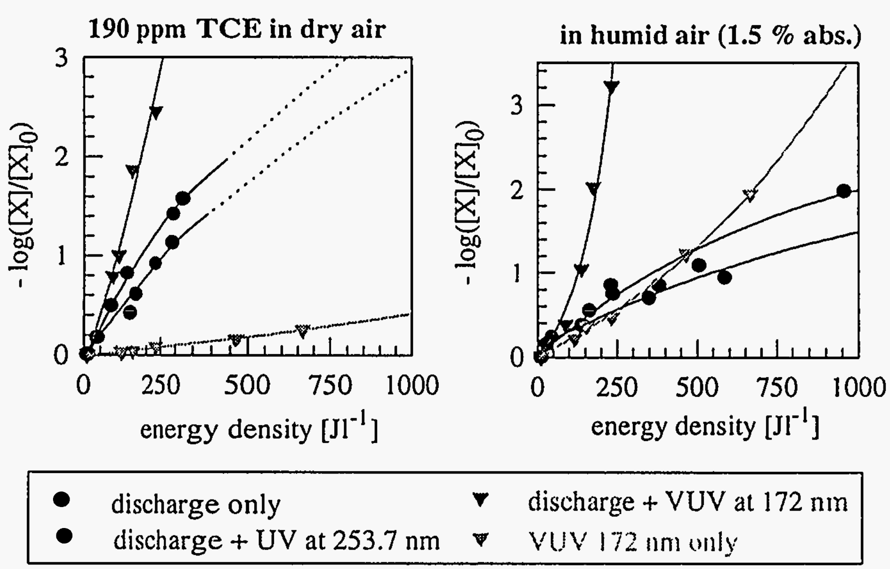
$k = 5.1 \times 10^{-34}\ cm^6\ s^{-1}$ for $M = N_2$

but also $O^{\cdot}$ scavanging by N_xO_y formation

$k = 3.6 \times 10^{-34}\ cm^6\ s^{-1}$ for $M = Ar$

$O(^1D) + H_2O \longrightarrow 2\ OH$





VOC + radical

$(O(^1D), O(^3P), O_2(a,b), O_3, H, F, Cl, etc.) + O_2$

$\longrightarrow$

byproducts + radical + O_2

$\longrightarrow$

$CO_2 + H_2O$ (+ HCl or HF)

generally: $k_{O,\,OH} >> k_{O_3}$

Idea:

increase atomic oxygen concentration by photolysis of (unutilized) ozone

Hartley band

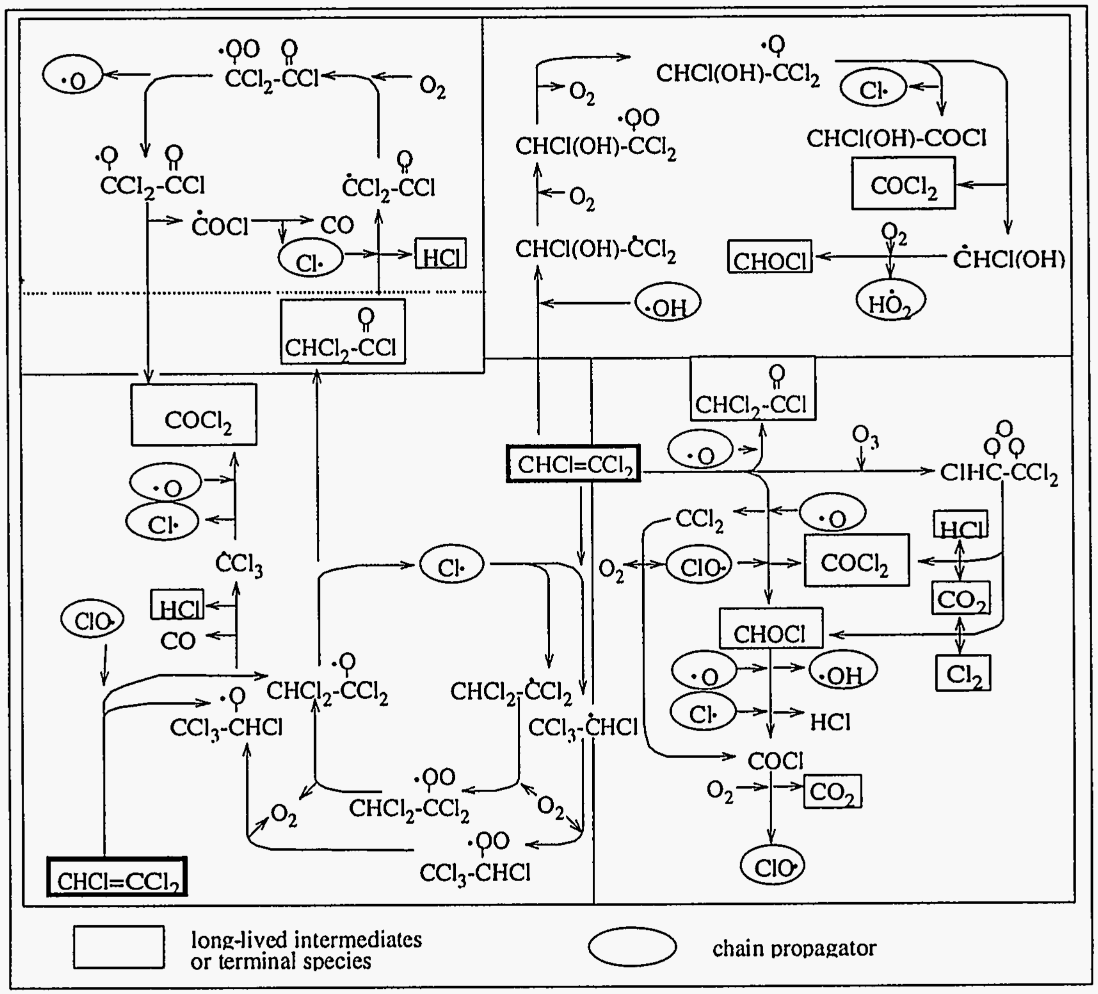
$$O_3 + h\nu \xrightarrow{253.7\text{ nm}} O_2(^1\Delta) + O(^1D)$$

VUV band

$$O_3 + h\nu \xrightarrow{172\text{ nm}} O_2(b^1\Sigma) + O(^1D)$$

5 W_{DBD} and 2.57 W_{UV} / 1.97 W_{VUV}

Main reaction scheme in TCE removal



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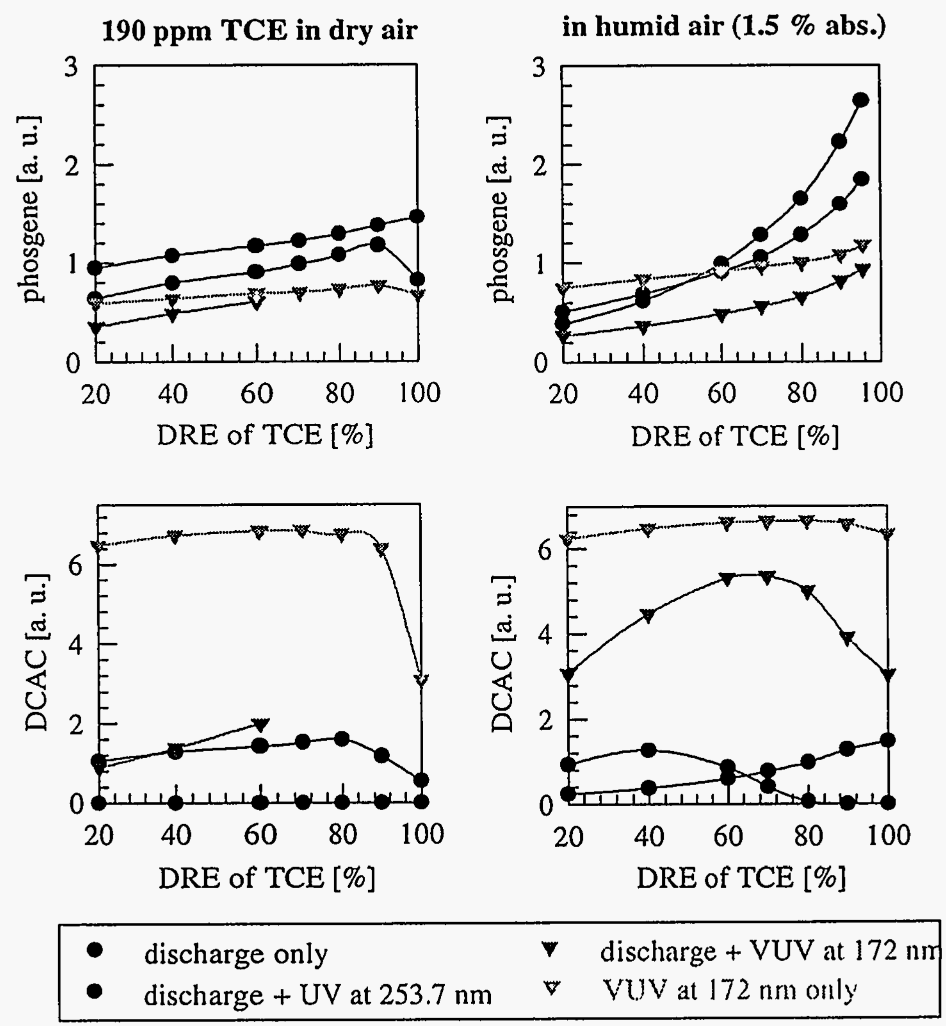
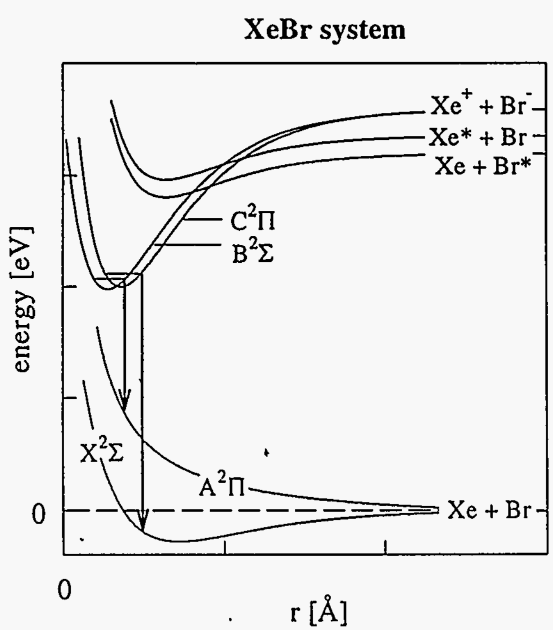
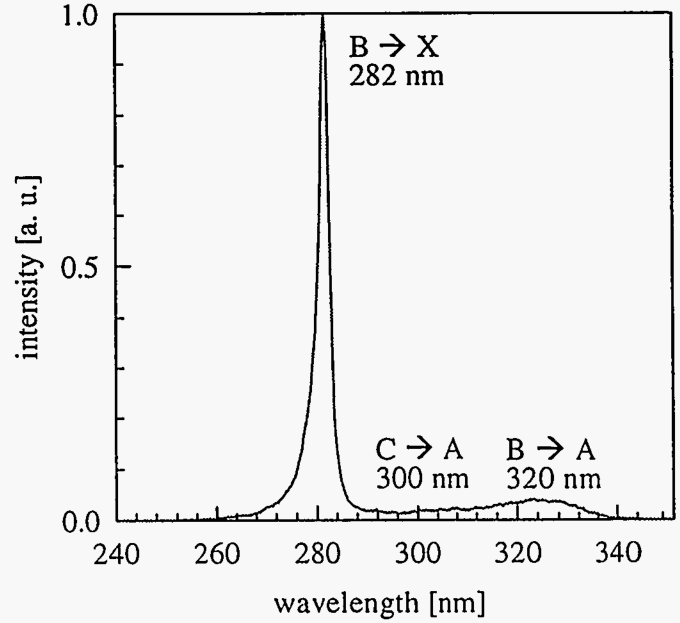
Byproduct formation in combined (V)UV/DBD treatment of TCE





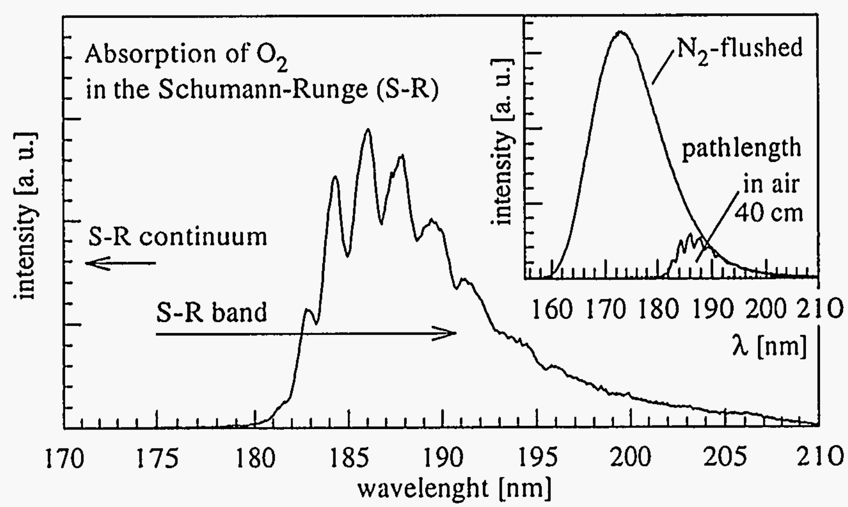


$$e^- + Br_2 + M \longrightarrow Br_2^- + M$$

$$Br_2^- + M \longrightarrow Br + Br^- + M$$

$$e^- + Xe \longrightarrow Xe^+ + 2\,e^-$$

$$Xe^+ + Br^- + M \longrightarrow XeBr^* + M$$



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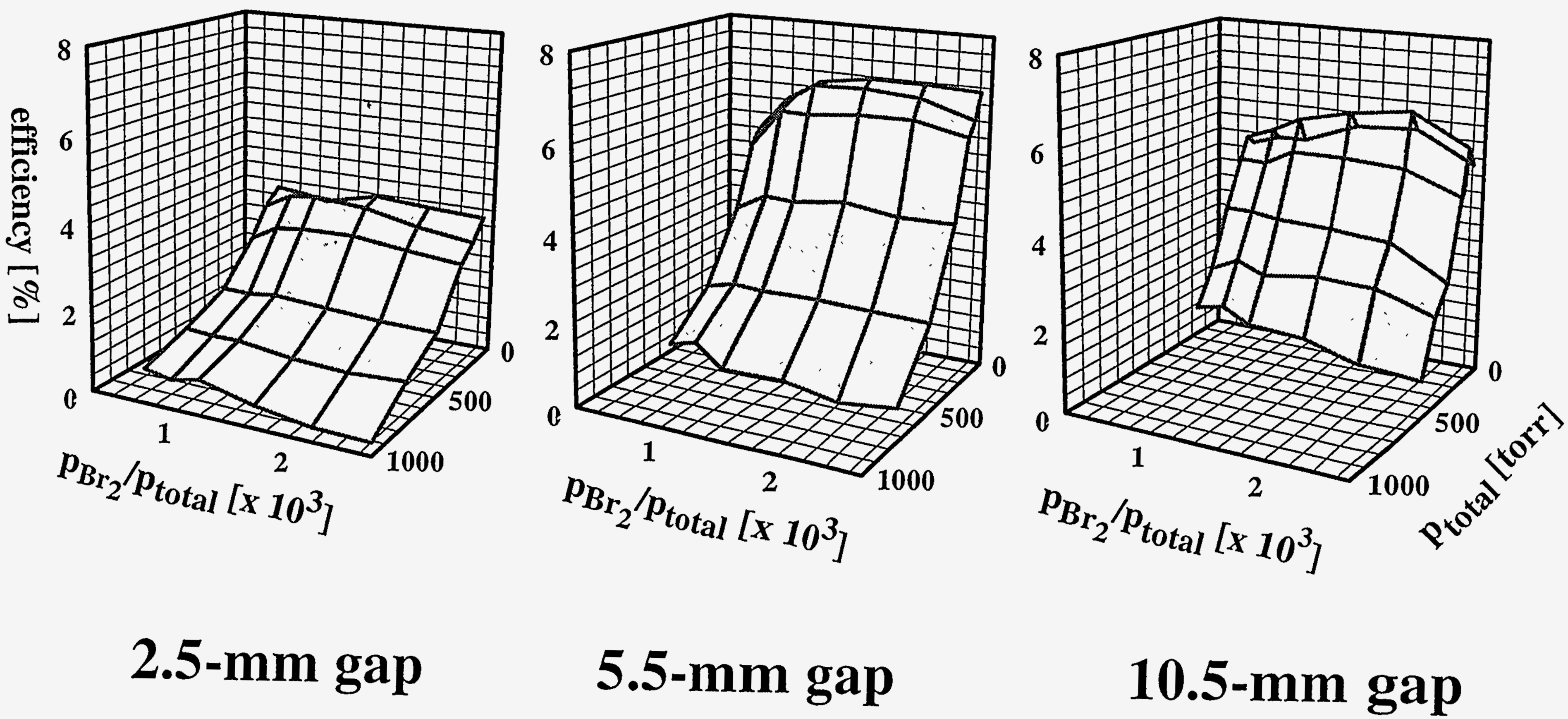
UV Efficiency of XeBr* (B-X, C-A, B-A)



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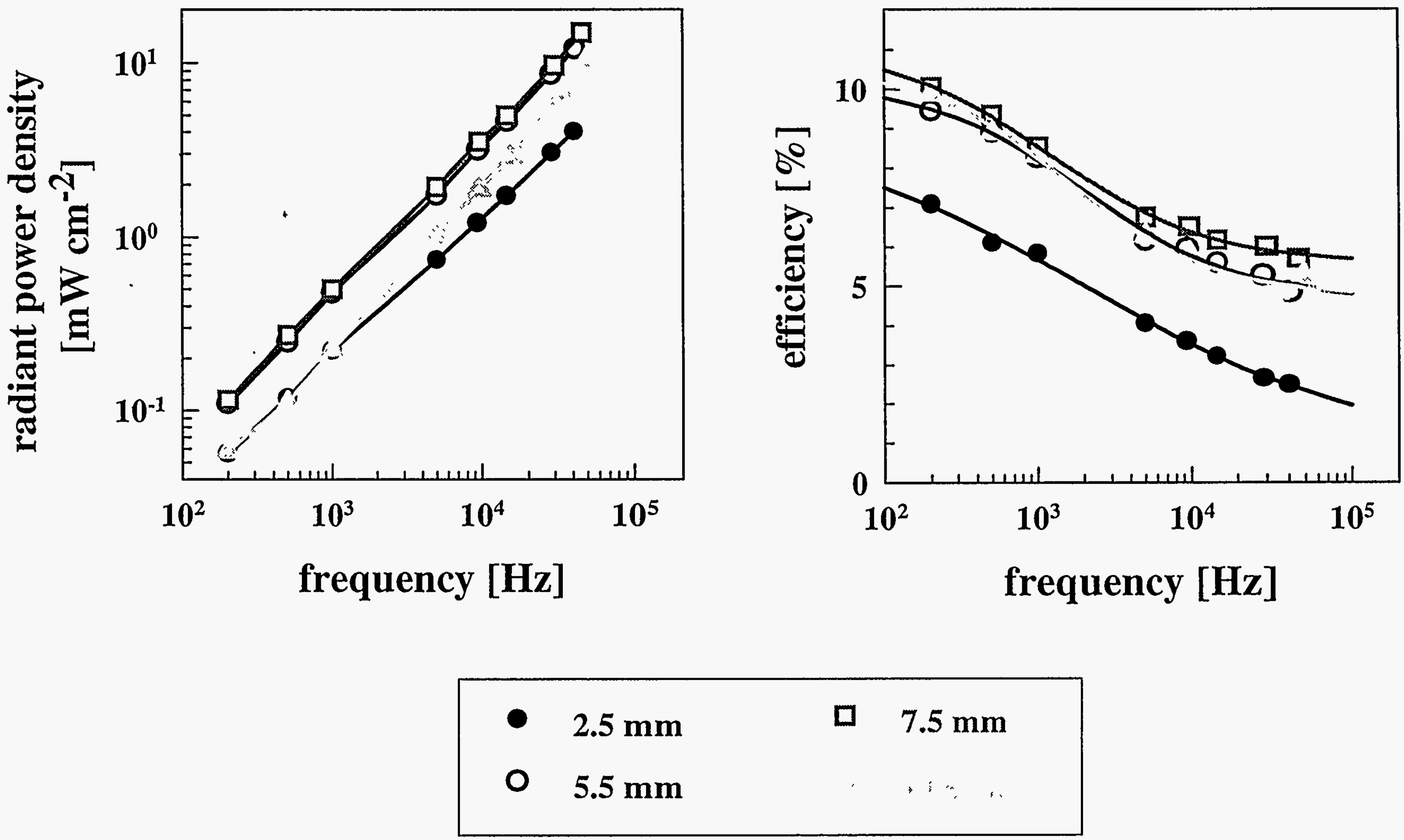
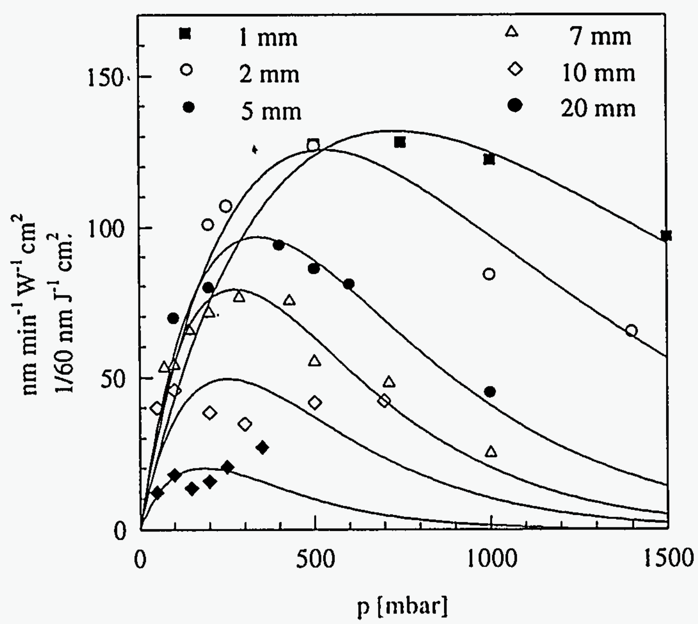
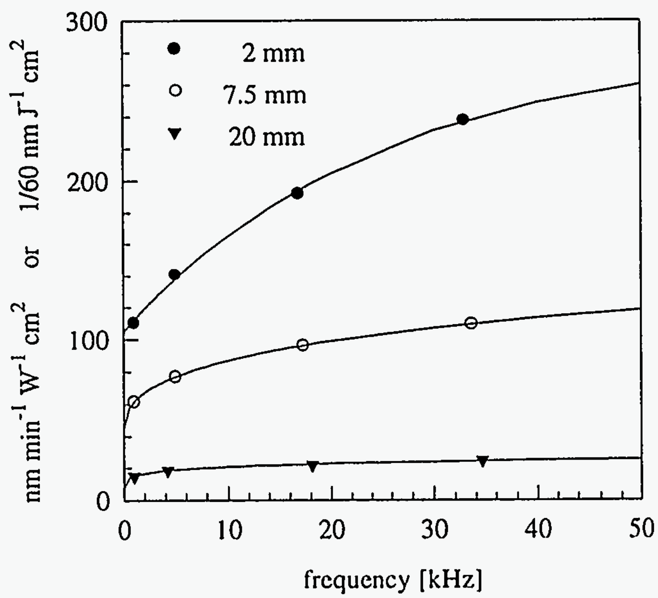
Frequency Effects



Photoresist (Novolak) ashing with DBDs in O_2





SUMMARY AND CONCLUSIONS

Exemplary results of the application of dielectric barrier discharges (DBDs) for the generation of ozone, flue gas treatment, the generation of incoherent (V)UV light and the ashing of a photoresist are presented. In all applications it is shown that a critical feature of the DBD is to produce non-equilibrium plasmas at atmospheric presure. The optimization of each system is indicated by changing parameters like energy density, gas mixture and pressure, gap spacing and frequency.

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