A KINETIC MODEL FOR EXCIMER UV AND VUV RADIATION IN DIELECTRIC BARRIER DISCHARGES*

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AGENDA

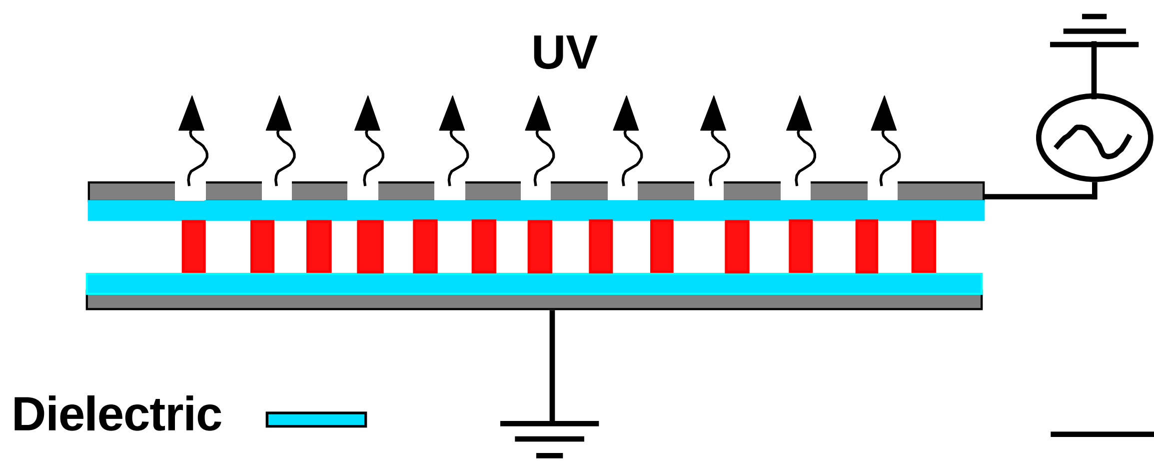
- Introduction
- Plasma Chemistry for Xe/Cl_2
- Description of the Model for Microdischarges
- Results for Microdischarge Mechanics and UV Radiation
- Concluding Remarks

DIELECTRIC BARRIER DISCHARGES

- Dielectric barrier discharges (DBDs) have shown promise as high intensity sources of UV and VUV radiation emitted by dimer and trimer excimers.

- These UV photons have a number of applications
  - Biological sterilization
  - Photochemical degradation of organic compounds in flue gases
  - Photo-induced surface modification and material deposition
  - Lithography

- DBDs are usually operated at high pressure on the order of 1 bar, so a number of microdischarge or breakdown channels are generated.
  - 2 mm - 5 mm gap
  - 10s Hz - a few kHz



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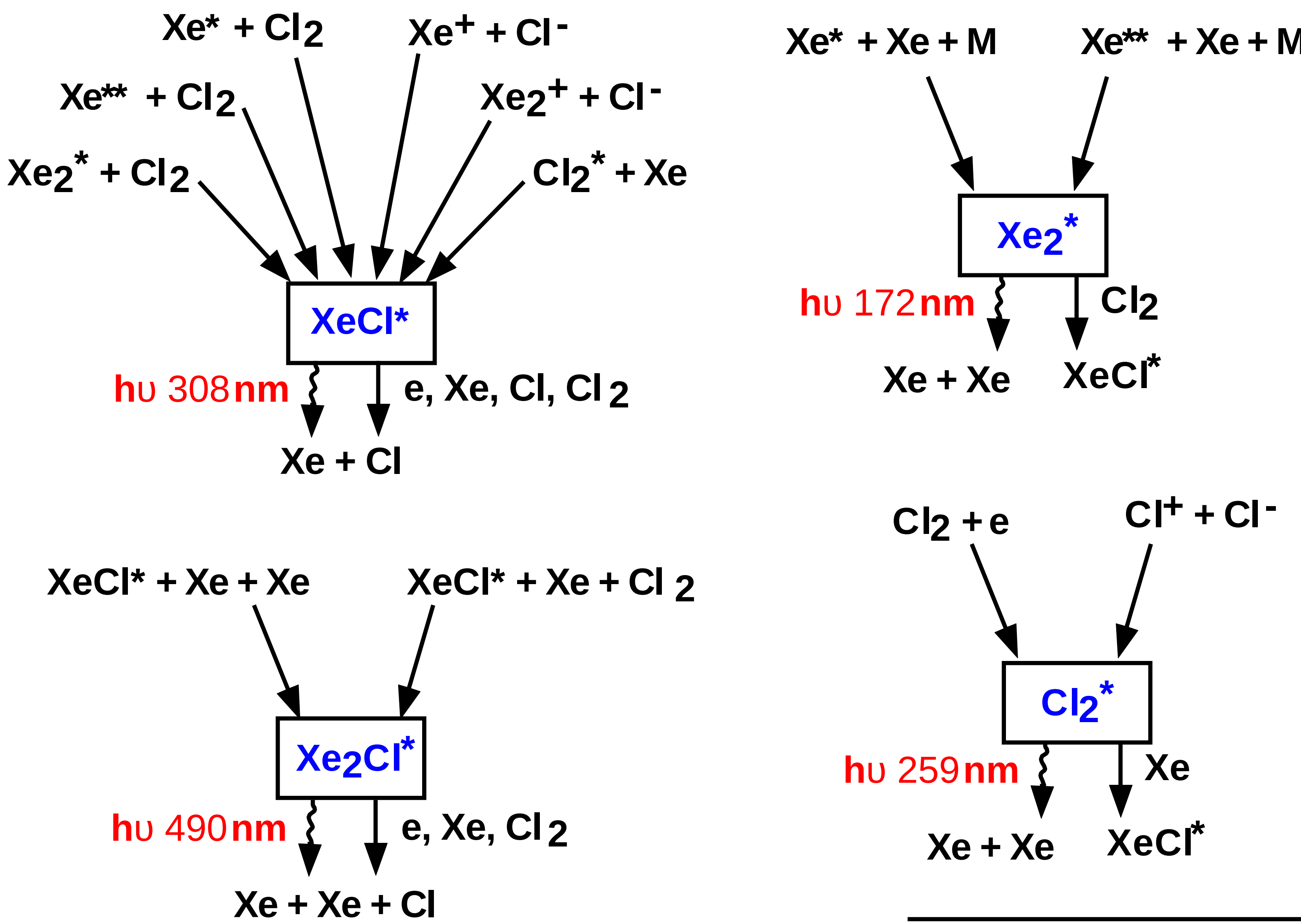
EXCIMER GENERATION IN Xe/Cl_2 DISCHARGE



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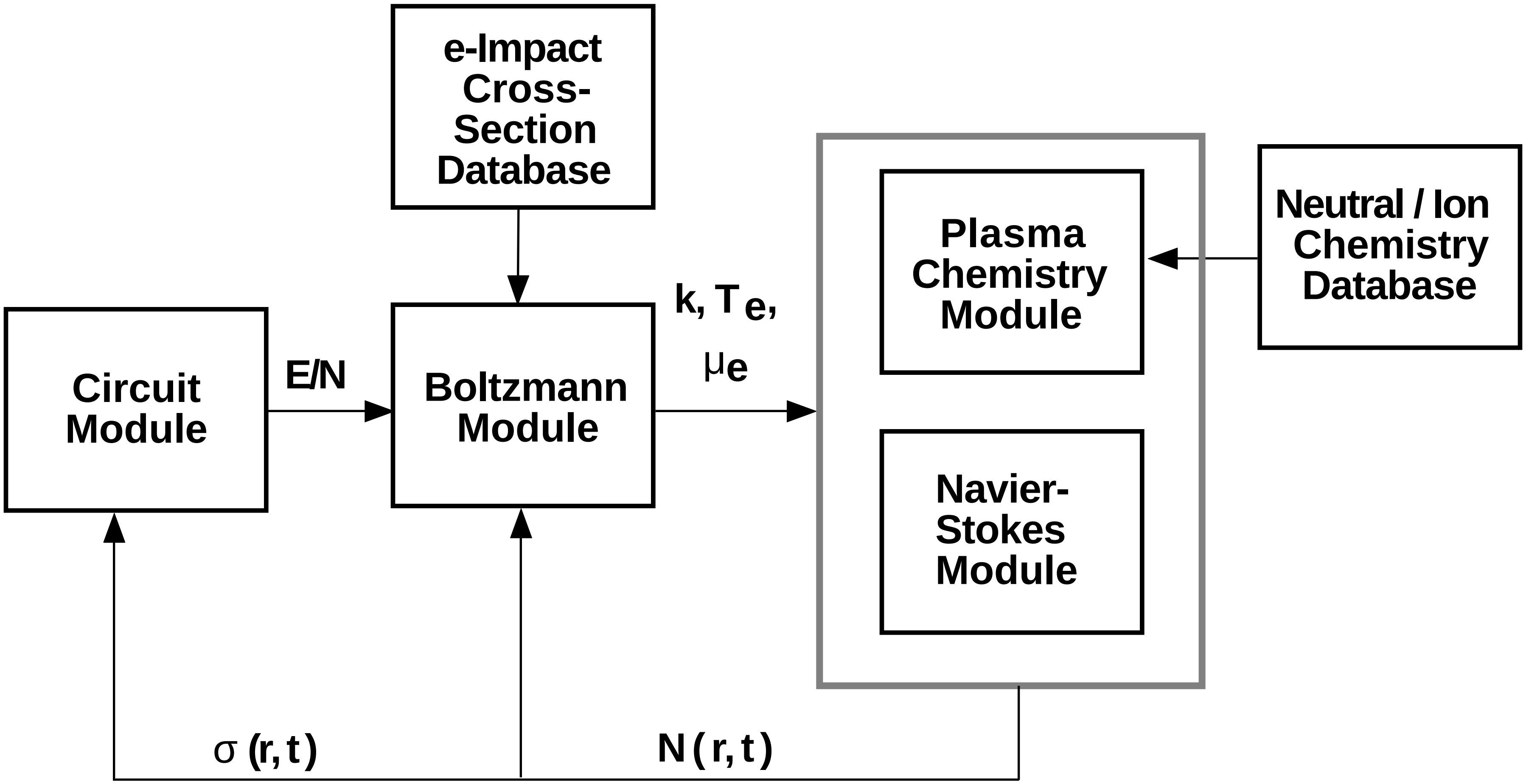
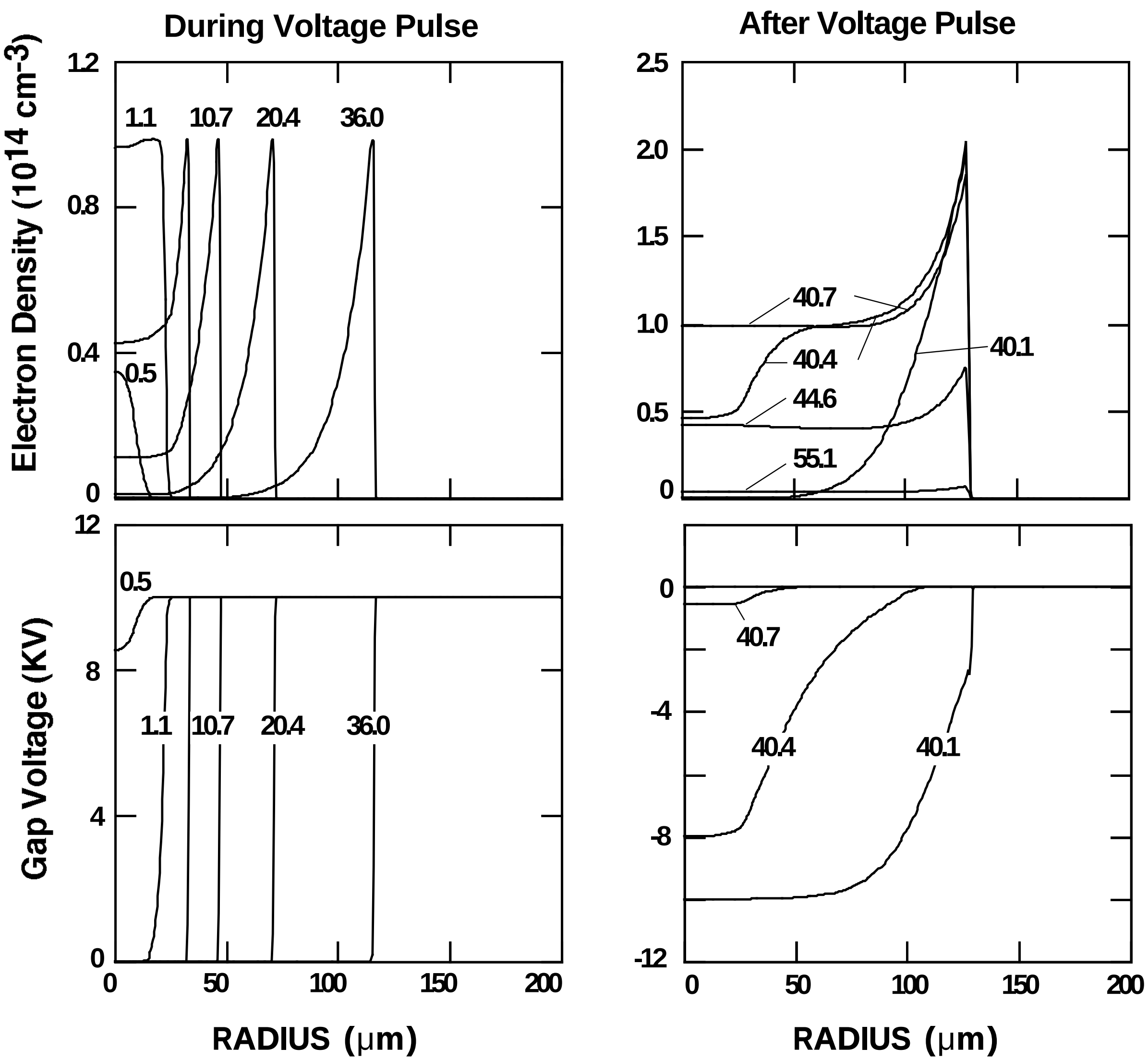
SCHEMATIC OF PLASMA CHEMISTRY AND HYDRODYNAMICS MODELS

- 1-d plasma chemistry and hydrodynamics models have been developed to investigate excimer radiation from dielectric barrier discharges in mixtures of xenon and chlorine.



MICRODISCHARGE IN $Xe/Cl_2 = 99/1$

- Cl_2 has a large rate of dissociative electron attachment at low E/N. The electron density shows an expanding avalanching shell for 1% Cl_2.
- An absolute low voltage region is produced in the core of the microdischarge during the voltage pulse, and around the edge after the pulse.



- $Xe/Cl_2 = 95/1$,

  Pressure: 0.6 atmosphere,

  Gas Temperature: 300 K,

  $V_o = 10$ kV,

  $\tau = 40$ ns,

  $\varepsilon = 5\ \varepsilon_0$

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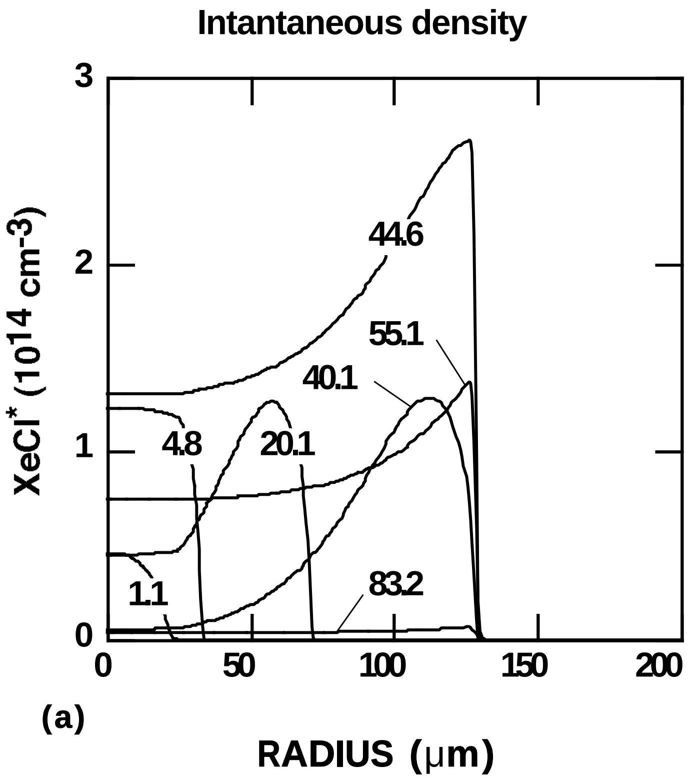
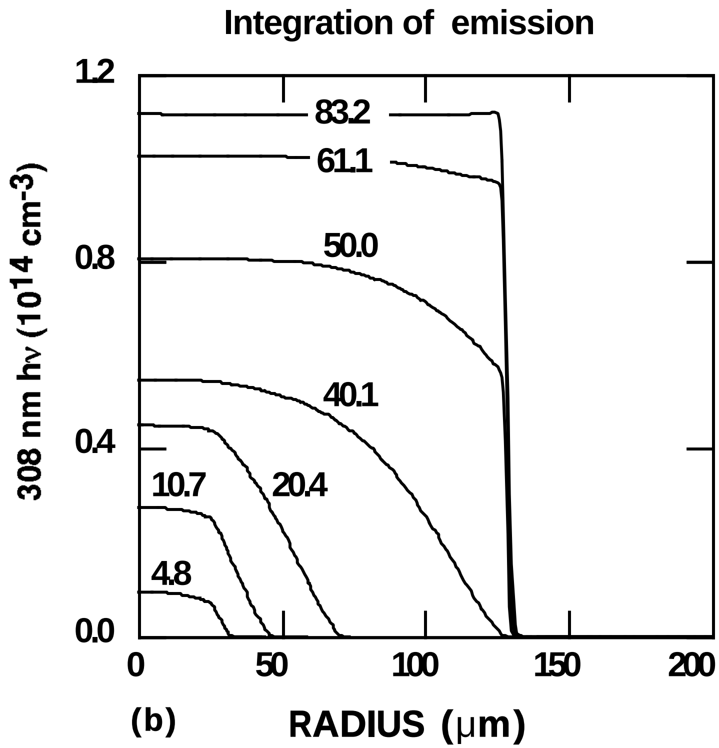
$XeCl^*$ AND 308 nm GENERATION IN Xe/Cl_2 = 99/1

- **The formation of the XeCl* excimer is delayed compared to electron generation.**
- **The total generation 308 nm photons is ultimately uniform across the microdischarge.**

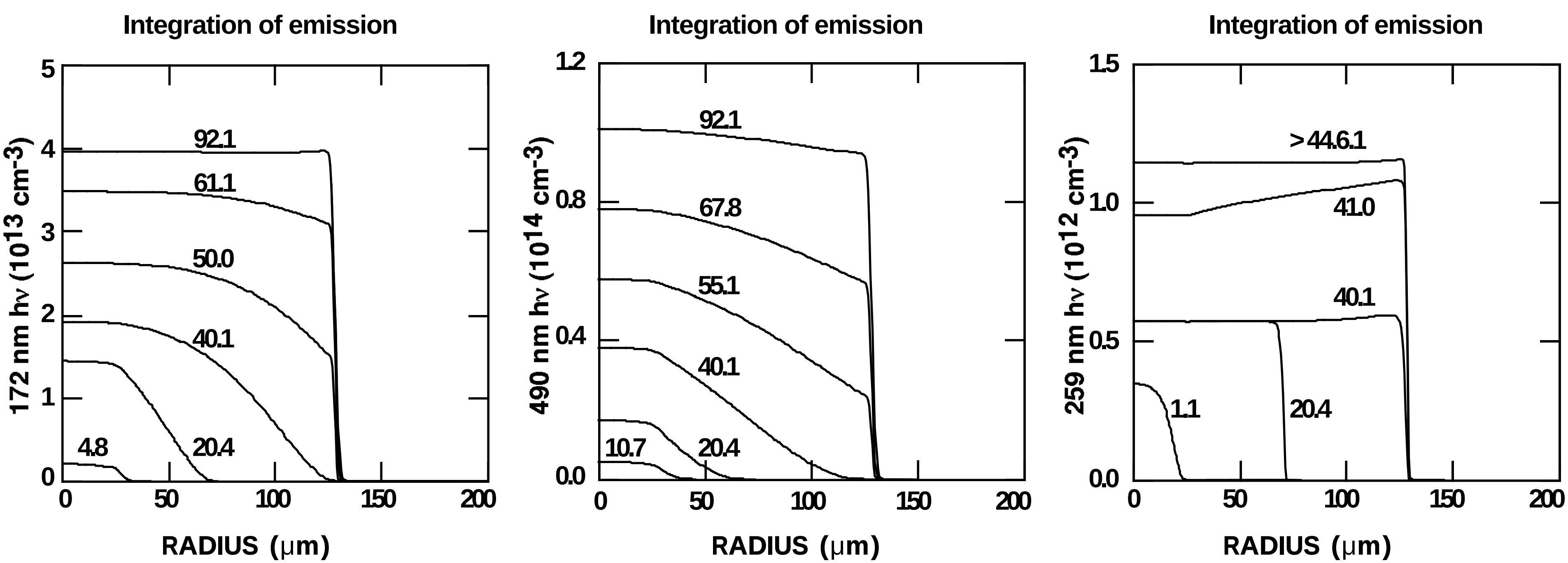




- **Xe/Cl_2 = 99/1, 0.6 atm, 300 K,**
  V_O = 10 kV, τ = 40 ns, ε = 5

OTHER PHOTONS IN Xe/Cl_2 = 99/1

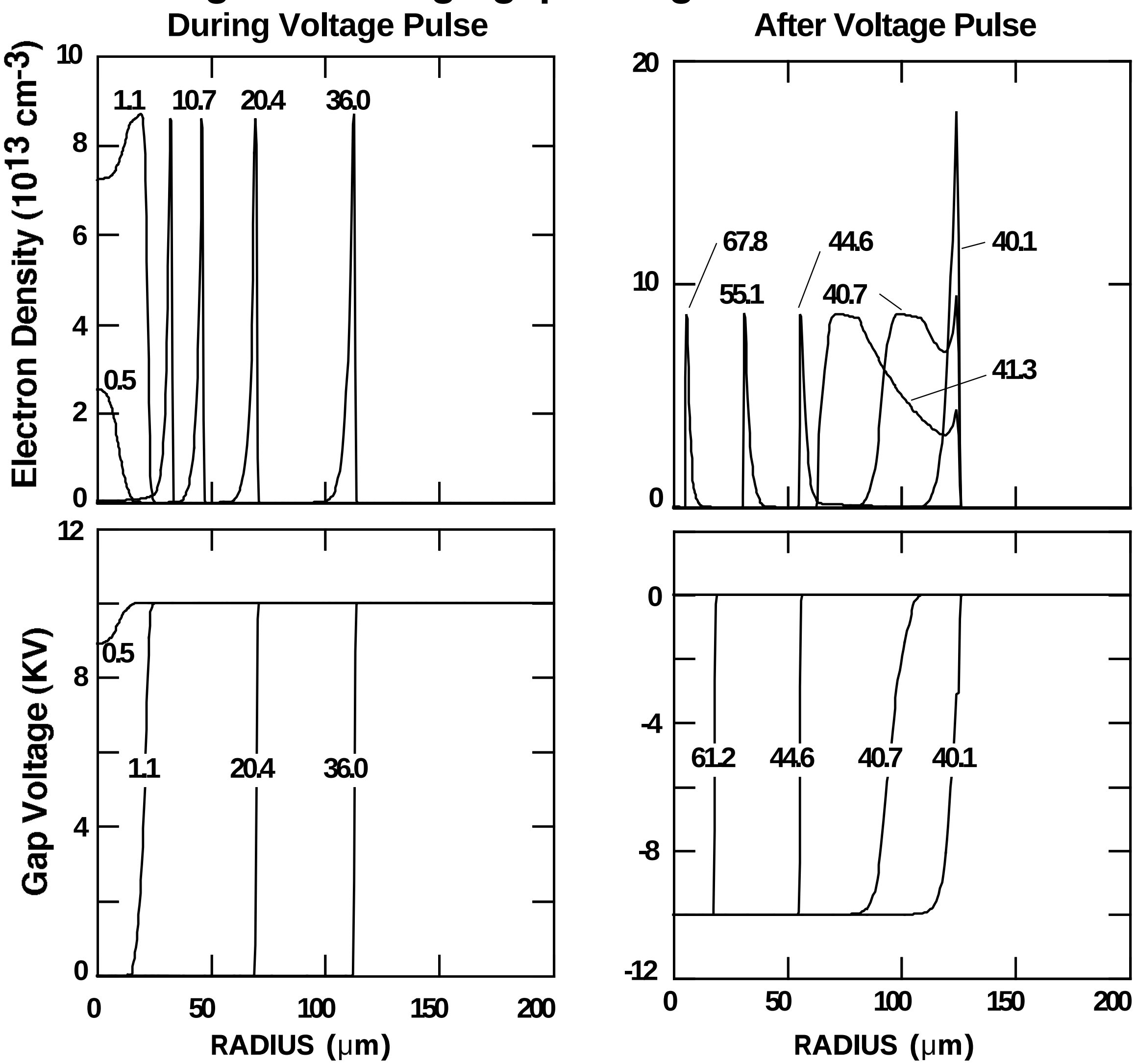
- Xe_2^* (172 nm) has a similar lifetime as XeCl*.
- Xe_2Cl^* (490 nm) has a long lifetime since its quenching rate is independent of the Xe pressure and only dependent on the Cl_2 density.
- Cl_2^* (259 nm) can be depleted by conversion to XeCl*.



- 1 atm, 400 K, V_o = 12 kV, τ = 40 ns, ε = 5

MICRODISCHARGE IN Xe/Cl_2 = 95/5

- Xe/Cl_2 = 95/5 drives the electron density to such low values in the core of the microdischarge during the pulse that there is not an immediate second avalanche in the core at the end ofpulse.
- After the pulse, the electron density shell propagates towards the center of the microdischarge due to high gap voltages in the core.



- Xe/Cl_2 = 95/5,

  Pressure: 0.6 atm,

  Gas Temperature: 300 K,

  V_o = 10 kV,

  τ = 40 ns,

  $\varepsilon = 5\ \varepsilon_0$

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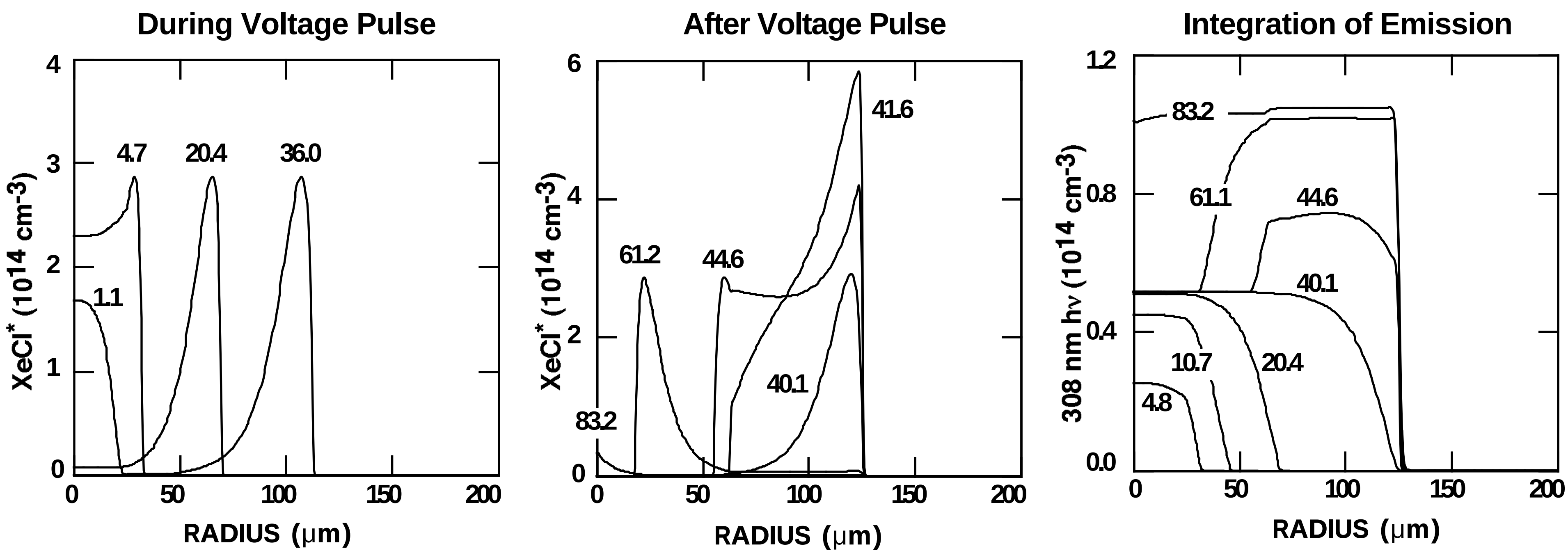
$XeCl^*$ AND 308 nm GENERATION IN Xe/Cl_2 = 95/5

- **$XeCl^*$ in the core of the microdischarge is regenerated as the second avalanche moves towards the center after the voltage pulse.**
- **The total number of 308 nm photons is similar to the case of Xe/Cl = 99/1.**



- **1 atm, 400 K, V_O = 12 kV, τ = 40 ns, ε = 5**

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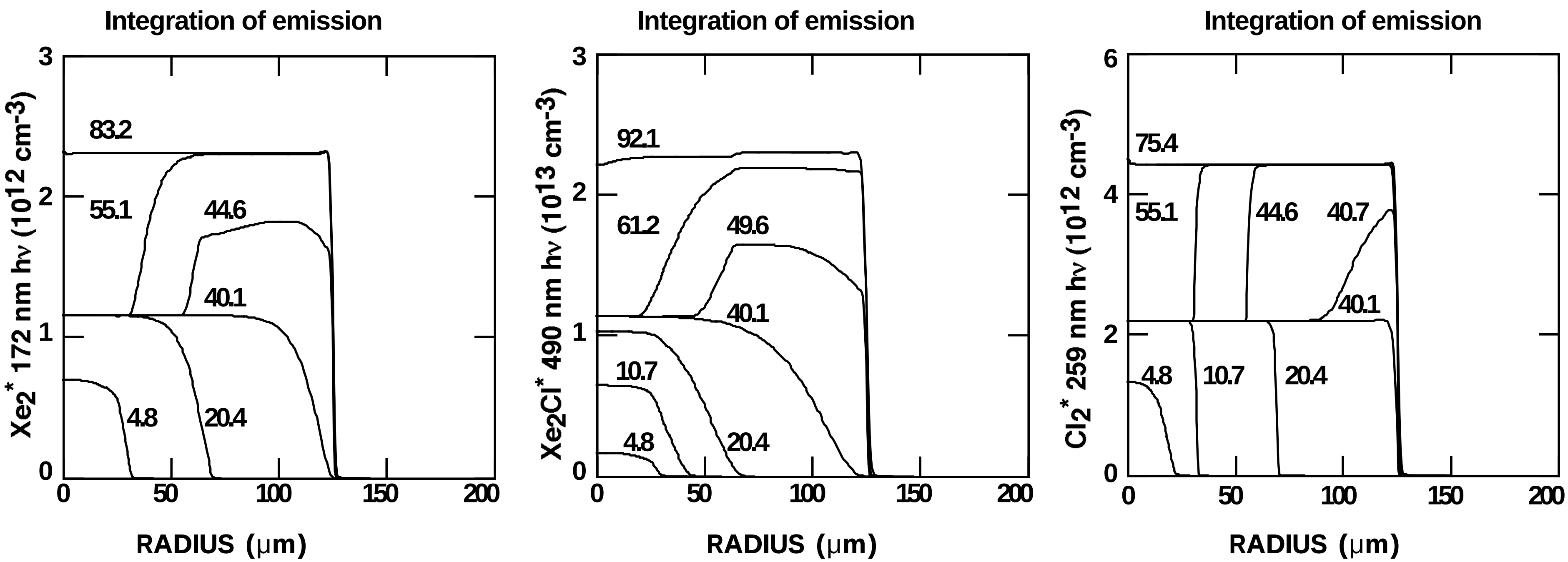
OTHER PHOTONS IN Xe/Cl_2 = 95/5

- For the 5% Cl_2 gas mixture, the generation of 172 nm and 490 photons dramatically decreases and the generation of 259 nm photons increases, compared to Xe/Cl_2 = 99/1.
- This trend is due to the fact that Cl_2 is very efficient at quenching Xe_2^* and Xe_2Cl^*, and the higher Cl_2 mole fraction is beneficial to generating Cl_2^*.



- Xe/Cl_2 = 95/5, 0.6 atm, 300 K,
  V_o = 10 kV, τ = 40 ns, ε = 5

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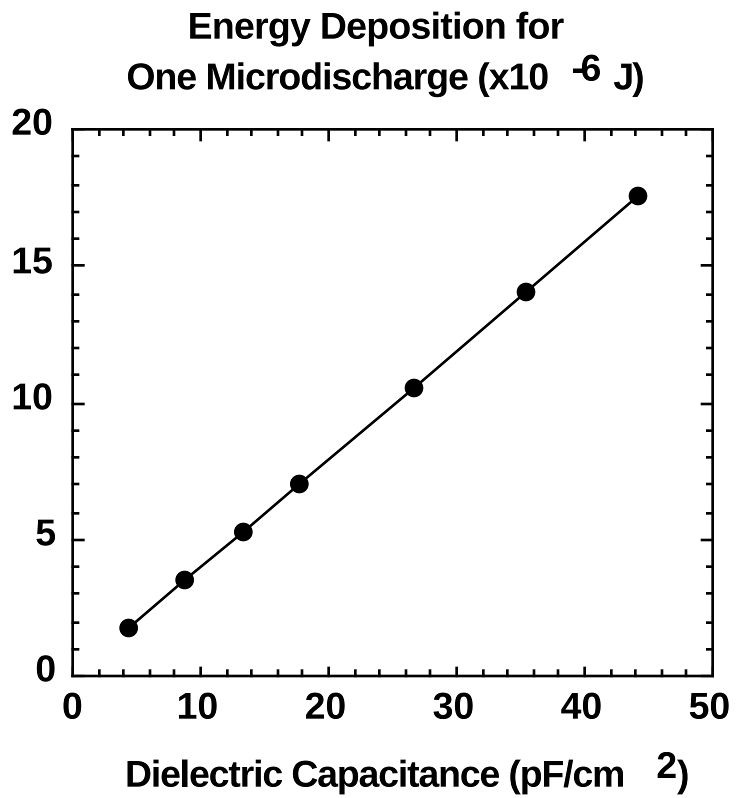
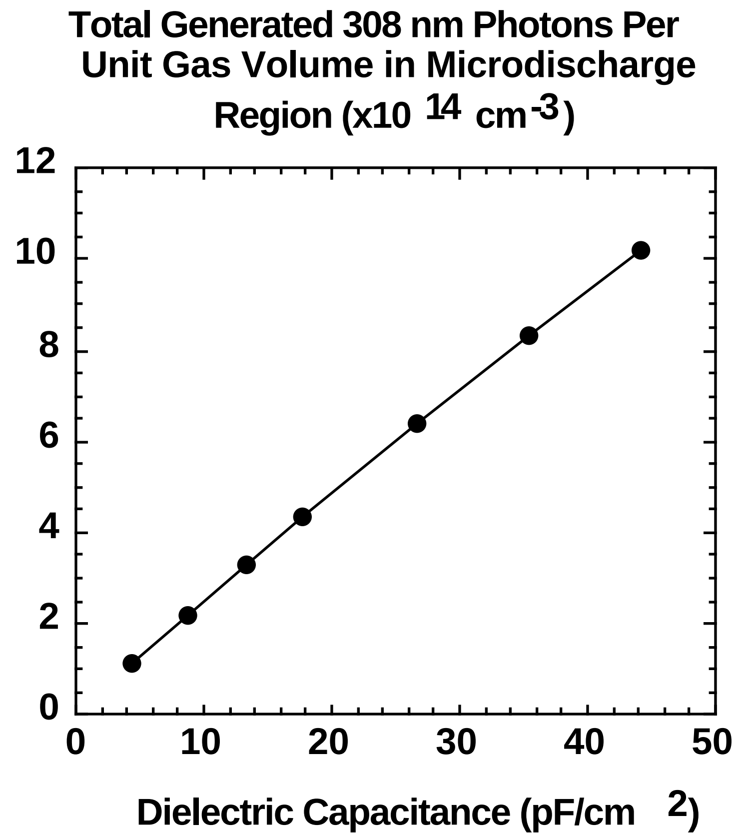
DIELECTRIC CAPACITANCE

- **With increasing dielectric capacitance, the energy deposition and generated photons linearly increase.**

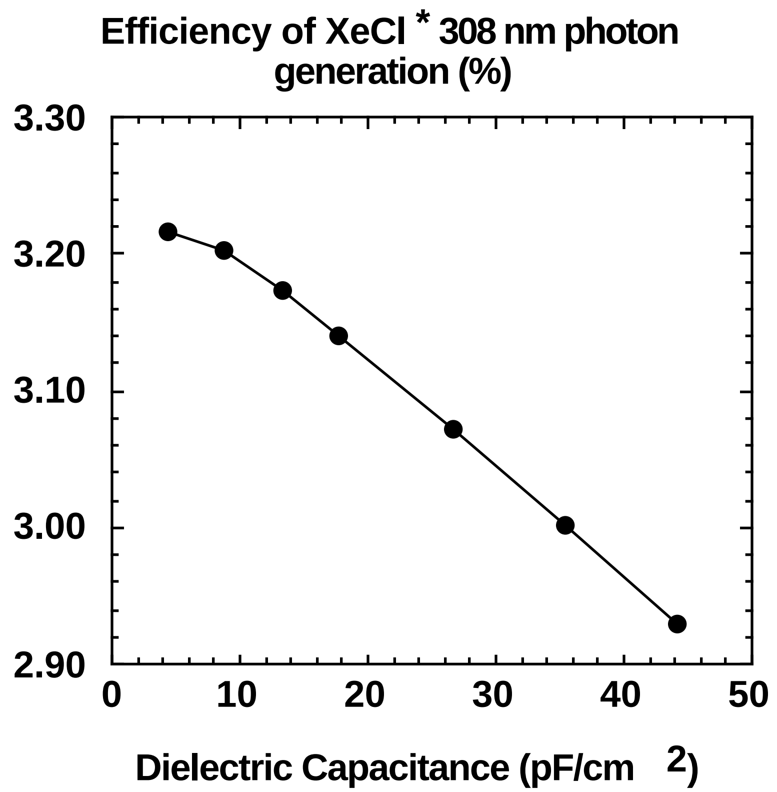


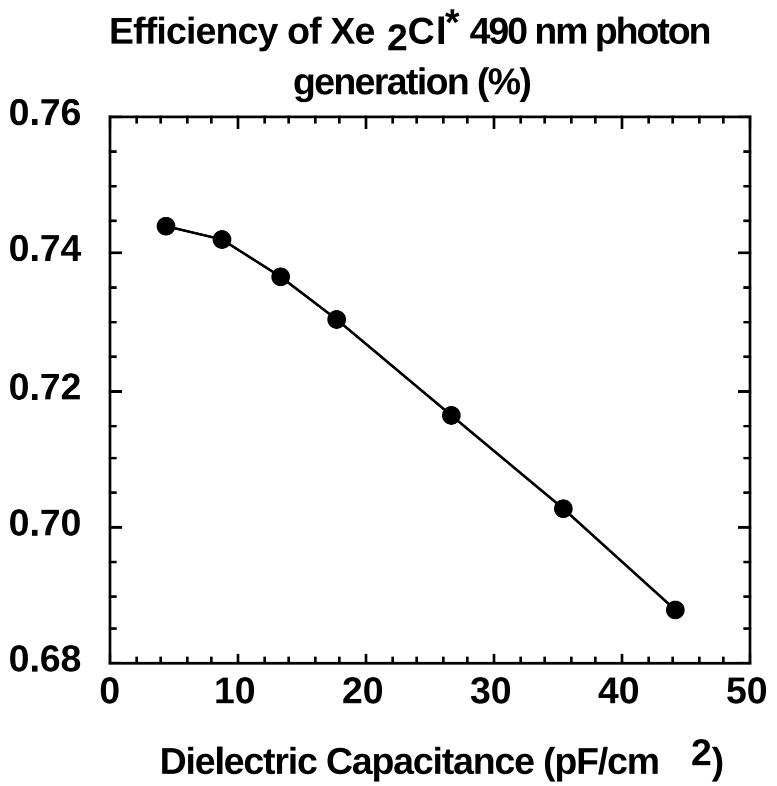


EFFICIENCY VS DIELECTRIC CAPACITANCE

- With increasing dielectric capacitance, the efficiencies of photon generation decrease.

- This is because large dielectric capacitance leads to high plasma density which has a stronger quenching effect.





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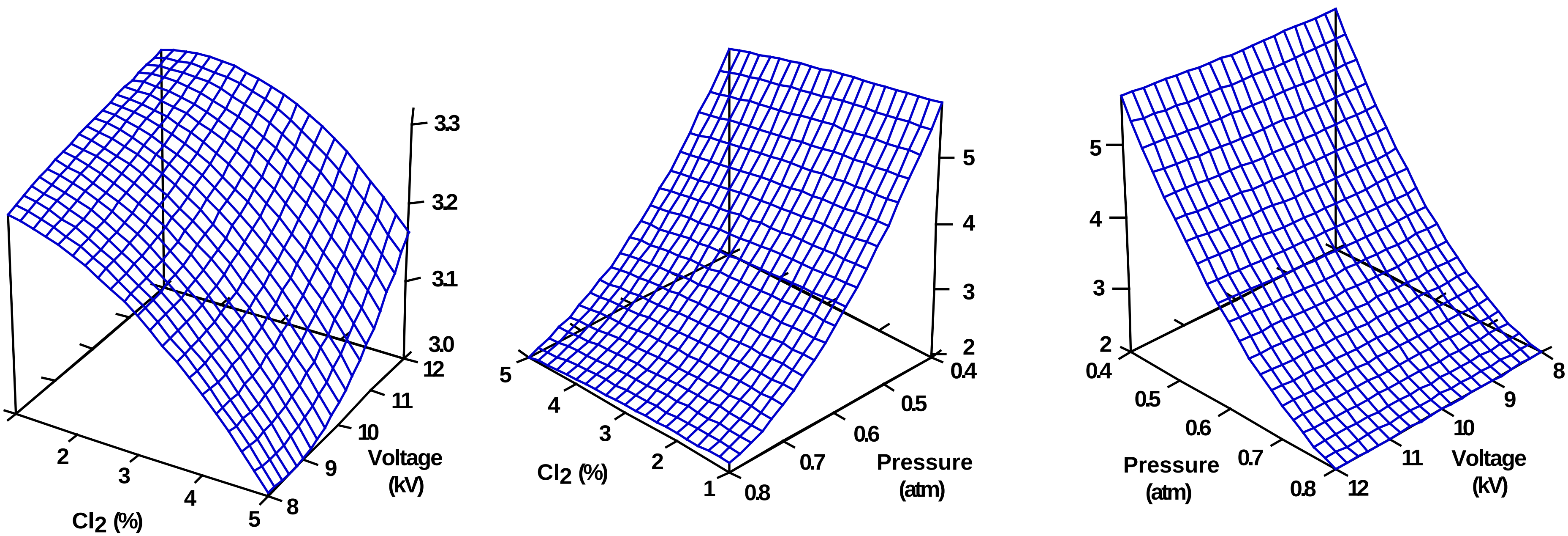
DOE ANALYSIS: EFFICIENCY OF $XeCl^*$ 308 nm PHOTON GENERATION

- The efficiency of $XeCl^*$ 308 nm photon generation is influenced largely by gas pressure and slightly by Cl_2 mole fraction and applied voltage.

Efficiency of 308 nm photon generation (%)



Pressure = 0.6 atmosphere

Applied Voltage = 10 kV

Cl_2 = 3%

$T_{gas} = 300\ K$, $\tau = 40\ ns$, $\varepsilon = 5$

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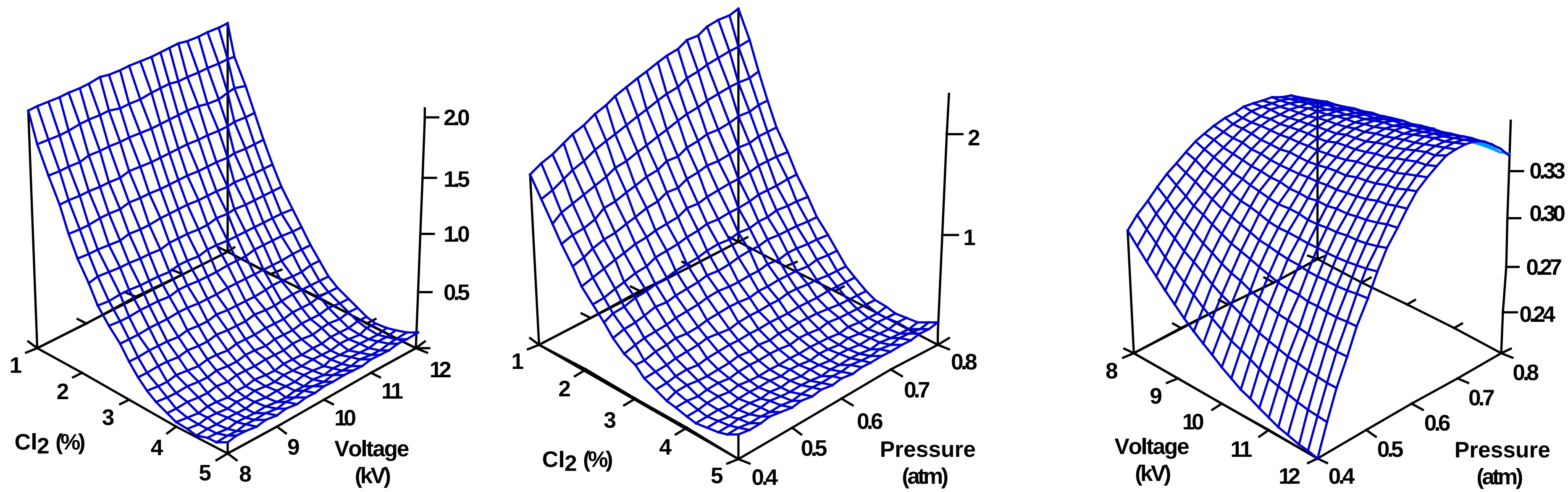
DOE ANALYSIS: EFFICIENCY OF Xe_2^* 172 nm PHOTON GENERATION

- **The efficiency of Xe_2^* 172 nm photon generation is influenced largely by Cl_2 mole fraction and slightly by gas pressure ratio and applied voltage.**

Efficiency of 172 nm photon generation (%)



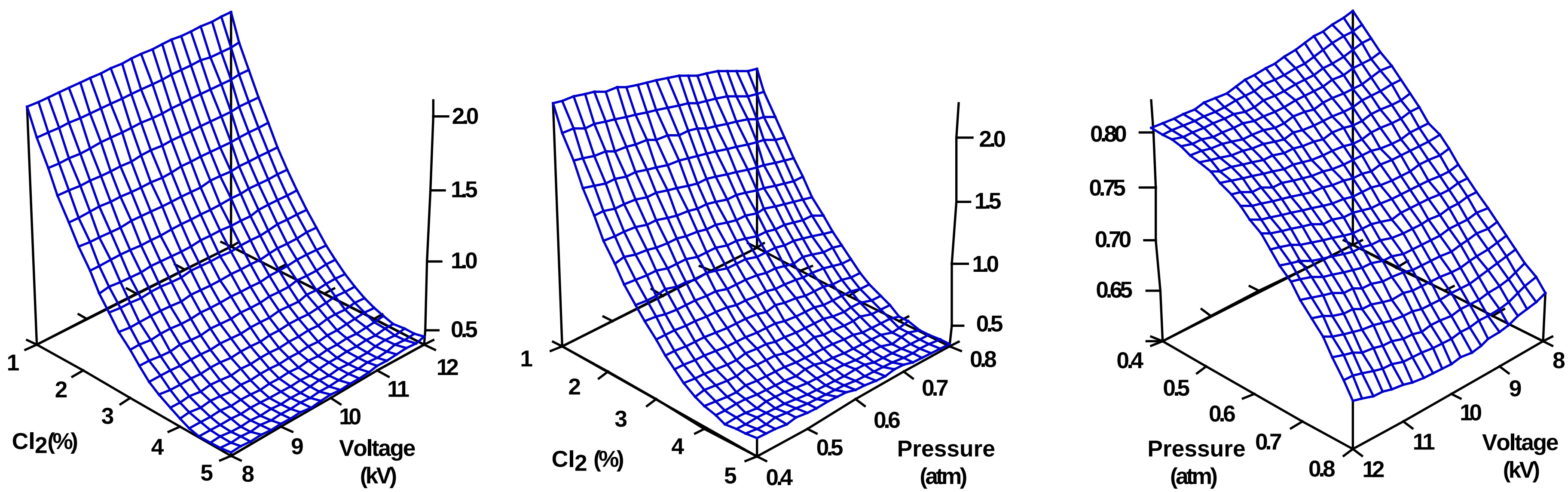
Pressure = 0.6 atmosphere **Applied Voltage = 10 kV** **Cl_2 = 3%**

T_{gas} = 300 K, τ = 40 ns, ε = 5

DOE ANALYSIS: EFFICIENCY OF Xe_2Cl^* 490 nm PHOTON GENERATION

- **The efficiency of Xe_2Cl^* 490 nm photon generation is influenced largely by Cl_2 mole fraction and slightly by gas pressure ratio and applied voltage.**

Efficiency of 490 nm photon generation (%)



Pressure = 0.6 atmosphere | **Applied Voltage = 10 kV** | **Cl_2 = 3%**

$T_{gas} = 300$ K, $\tau = 40$ ns, $\varepsilon = 5$

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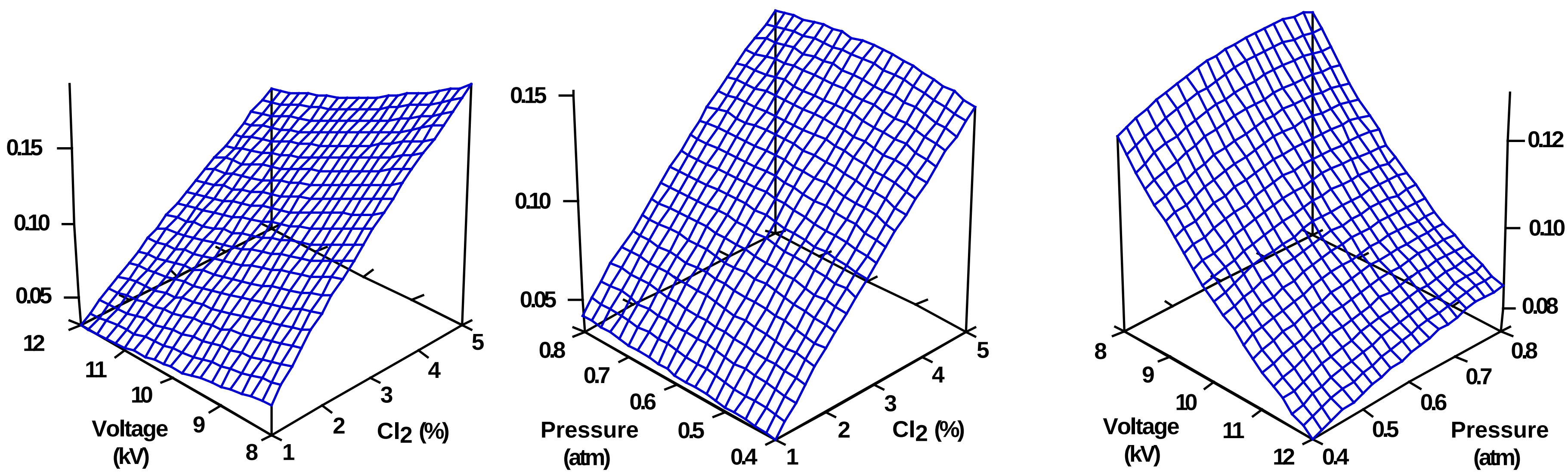
DOE ANALYSIS: EFFICIENCY OF Cl_2^* 259 nm PHOTON GENERATION

- **The efficiency of Cl_2^* 259 nm photon generation is influenced largely by Cl_2 mole fraction and slightly by gas pressure ratio and applied voltage.**

Efficiency of 259 nm photon generation (%)



Pressure = 0.6 atmosphere

Applied Voltage = 10 kV

Cl_2 = 3%

T_{gas} = 300 K, τ = 40 ns, ε = 5

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CONCLUDING REMARKS

- Microdischarge dynamics in dielectric discharge have been investigated for high intensity sources of UV and VUV radiation emitted by dimer and trimer excimers.

- In Xe/Cl_2 gas mixture, the electron density show a shell expansion during the pulse due to dielectric charging and attachment of Cl_2 at small radii at lower E/N.

- The strong attachment of Xe/Cl_2 = 95/5 leads to shell propagation to smaller radii after the pulse.

- Increasing capacitance of the dielectric increases the energy deposition and the total light generation with a slight loss in efficiency.

- The efficiency of 308 nm photon generation is influenced mainly by gas pressure, decreasing with increasing pressure, and the efficiencies of 172, 259 and 490 nm photon generation are most sensitive to Cl_2 density.