Microplasmas : sources of high pressure, non-thermal plasmas

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1. Microplasma configurations
   => MicroHollow Cathode Discharges (MHCDs)

2. Properties of MHCD's

3. Micro Cathode Sustained Discharges (MCSD)
   and their properties

Microplasma configurations

Lab-on-chip =>

(Karanassios, Spectrochim Acta B, 2004)

• Microfabricated ICPs - Iza and Hopwood, PSST, 11 229 (2002)

• Capacitively coupled microplasmas - Yoskiki and Horiike, Jpn J Appl Phys 40 L360 (2001)

• Microstrip (microwave-induced) plasmas : Iza and Hopwood, IEEE Trans Plasma Sci, 31 782 (2003)

Plasma display panels =>

(J.P. Boeuf, J Phys D Applied Phys 36 R53, 2003)

•Arrays of individually addressable microplasmas in a dielectric barrier discharge configuration

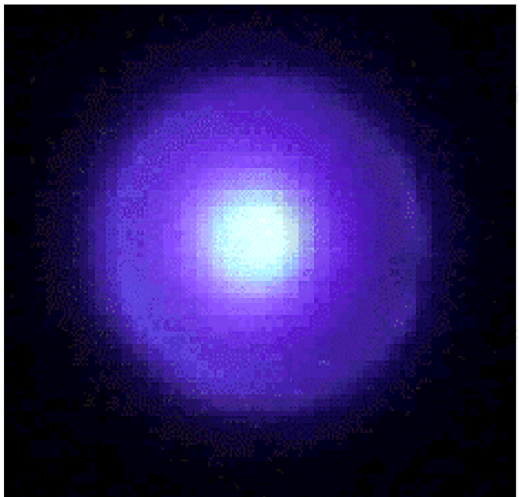
•….(International workshop in Microplasmas)

Microplasma configurations

Discharges in microcavities

• *Stabilization of high-pressure plasmas is easily achieved if the plasma is confined to small volumes (large surface/volume).*

MicroHollow Cathode Discharge

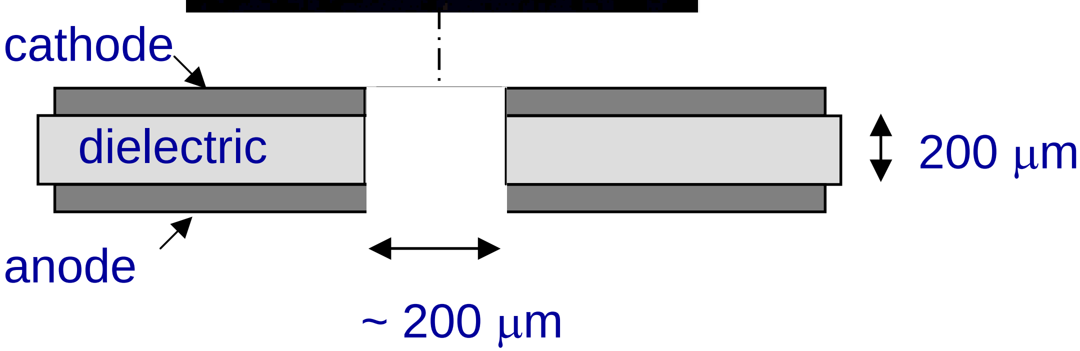


Low voltage operation (~>200 V)

Scaling to higher volumes :

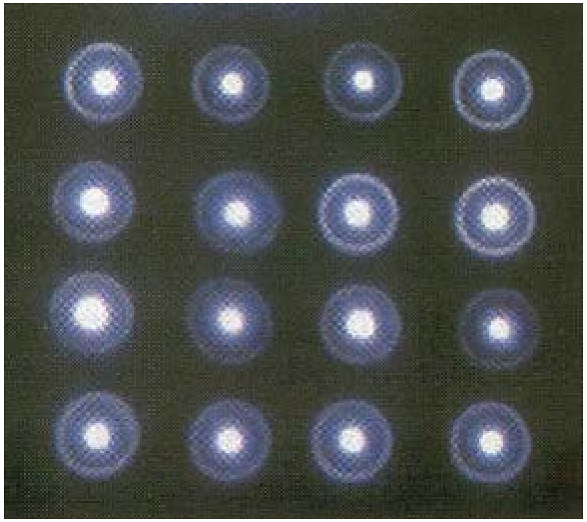
- using arrays of MHCDs
- 3-electrode systems

Plasma densities up to 10^{15} cm^{-3} in air at atmospheric pressure

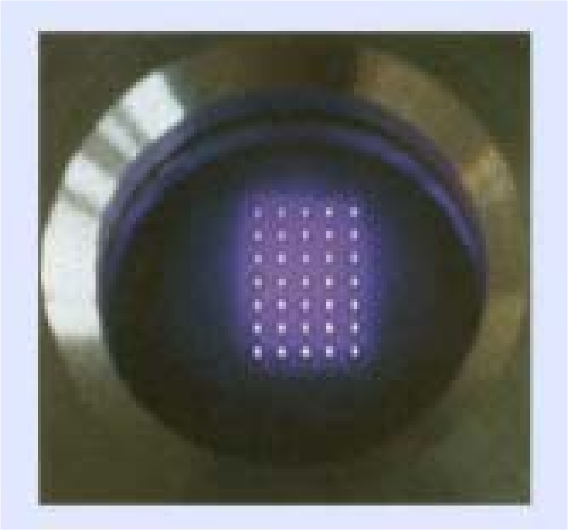


Developed originally by KH Schoenbach et col at Old Dominion Univ in USA

Arrays of MHCDs



K. H. Schoenbach et al. 1998

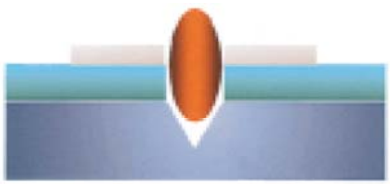


M. C. Penache Ph.D. Thesis, U of Frankfurt 2002

536 JOURNAL OF MICROELECTROMECHANICAL SYSTEMS, VOL. 11, NO. 5, OCTOBER 2002

Development and Characterization of Micromachined Hollow Cathode Plasma Display Devices

Jack Chen, Sung-Jin Park, *Associate Member, IEEE*, Zhifang Fan, J. Gary Eden, *Fellow, IEEE*, and Chang Liu



(schematic – K. Becker)

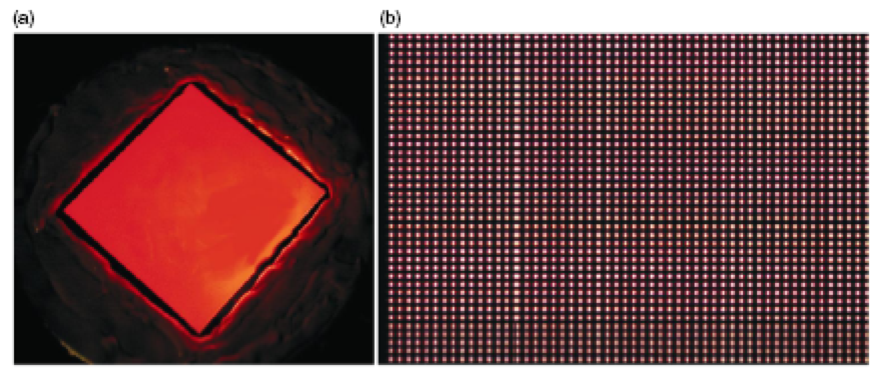


Figure 12. (*a*) Photograph of a 500 × 500 array of pyramidal microplasma devices operating in 700 Torr of Ne and driven by an ac voltage waveform. (*b*) Optical micrograph of a segment of the 500 × 500 array, recorded with a telescope and CCD camera. The device pitch for this array is 100 μm.

Driven in parallel by a 15 kHz, sinusoidal ac voltage waveform.

ANR project: "Microplasré"

CPAT, LPGP, LPTP

Objectives :

Develop an expertise in France in the area of microdischarges

Focus first on the MHCD and MCS geometries :

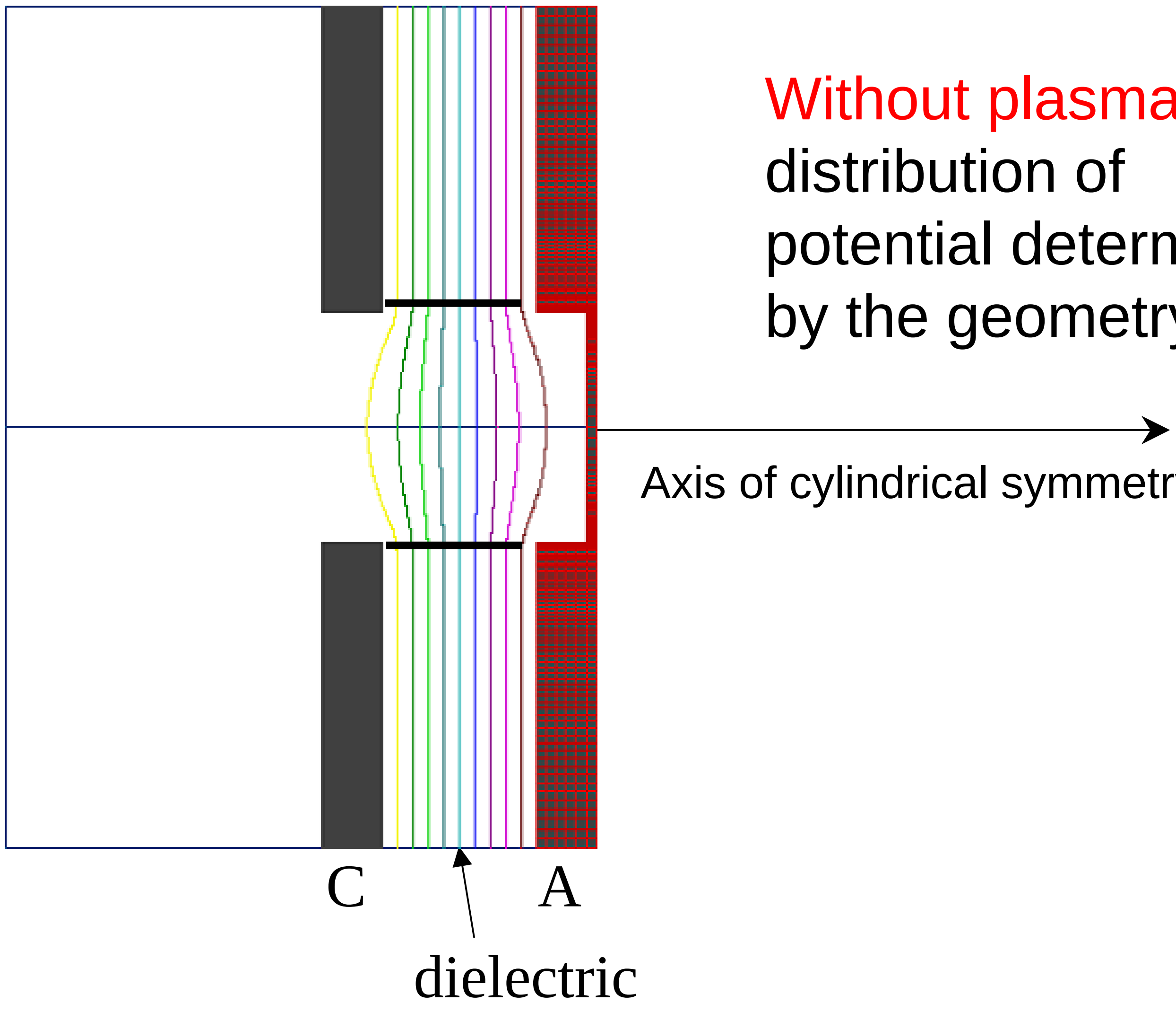
- Understand reasons for the stability and limits of performance
- Characterise the plasma properties in DC and pulsed operation

Explore possibilities of MHCDs as microchemical reactors

Consider other applications in different geometries

In collaboration with LSP, LMT

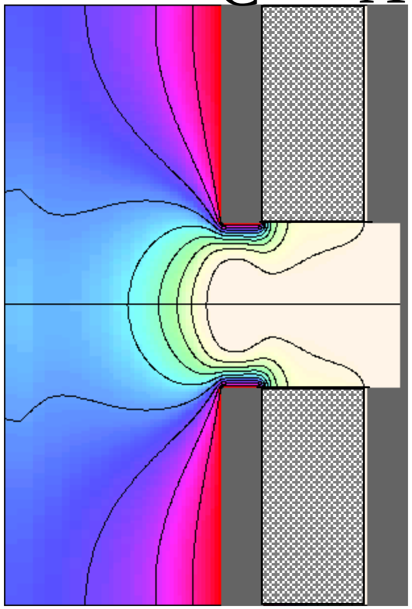
Equipotential contours



Without plasma : distribution of potential determined by the geometry

Equipotential contours

100 torr Xenon

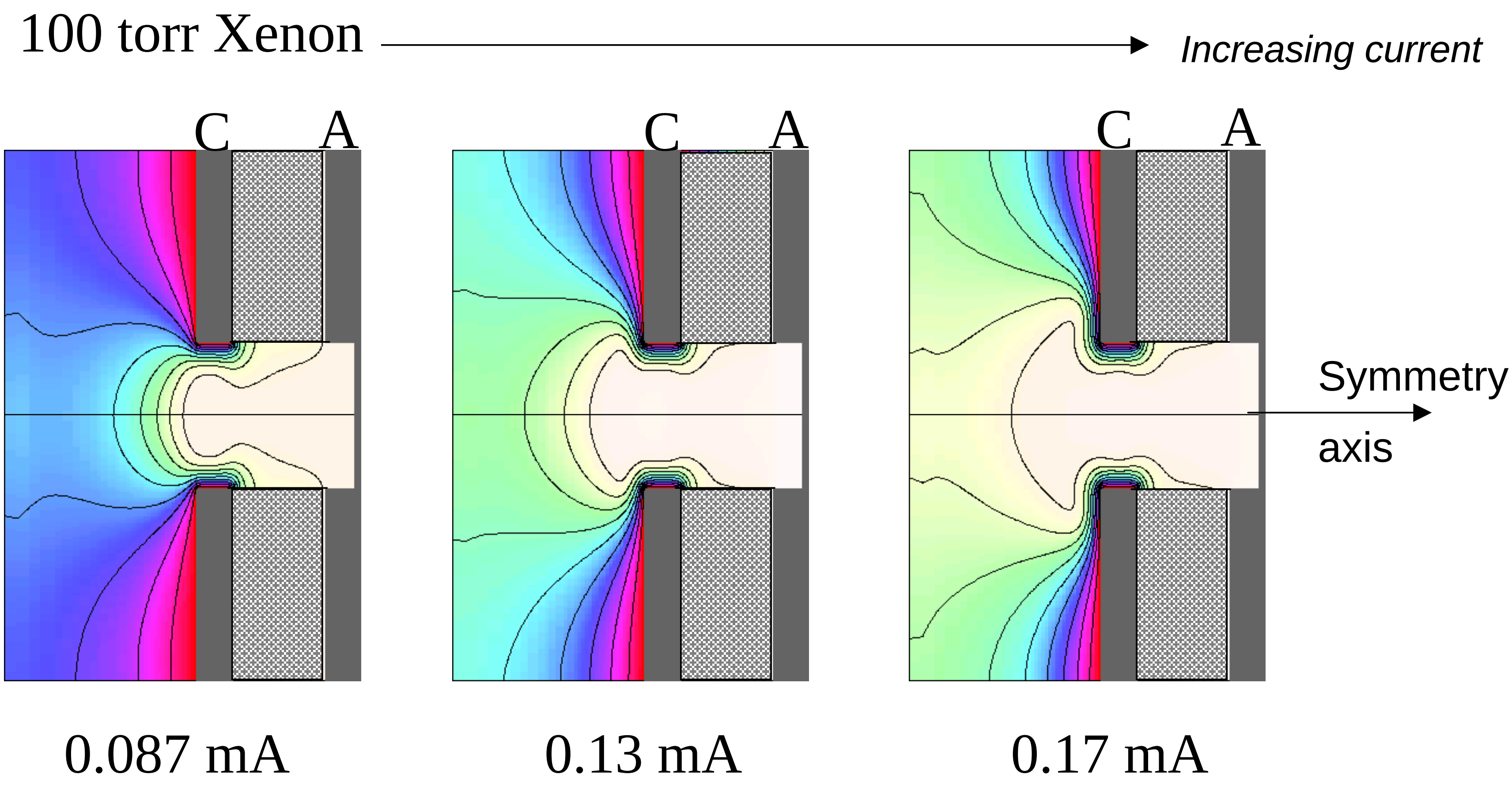


0.087 mA

D = 240 microns
Xmax = 0.1 cm
Anode diameter = 0.1 cm

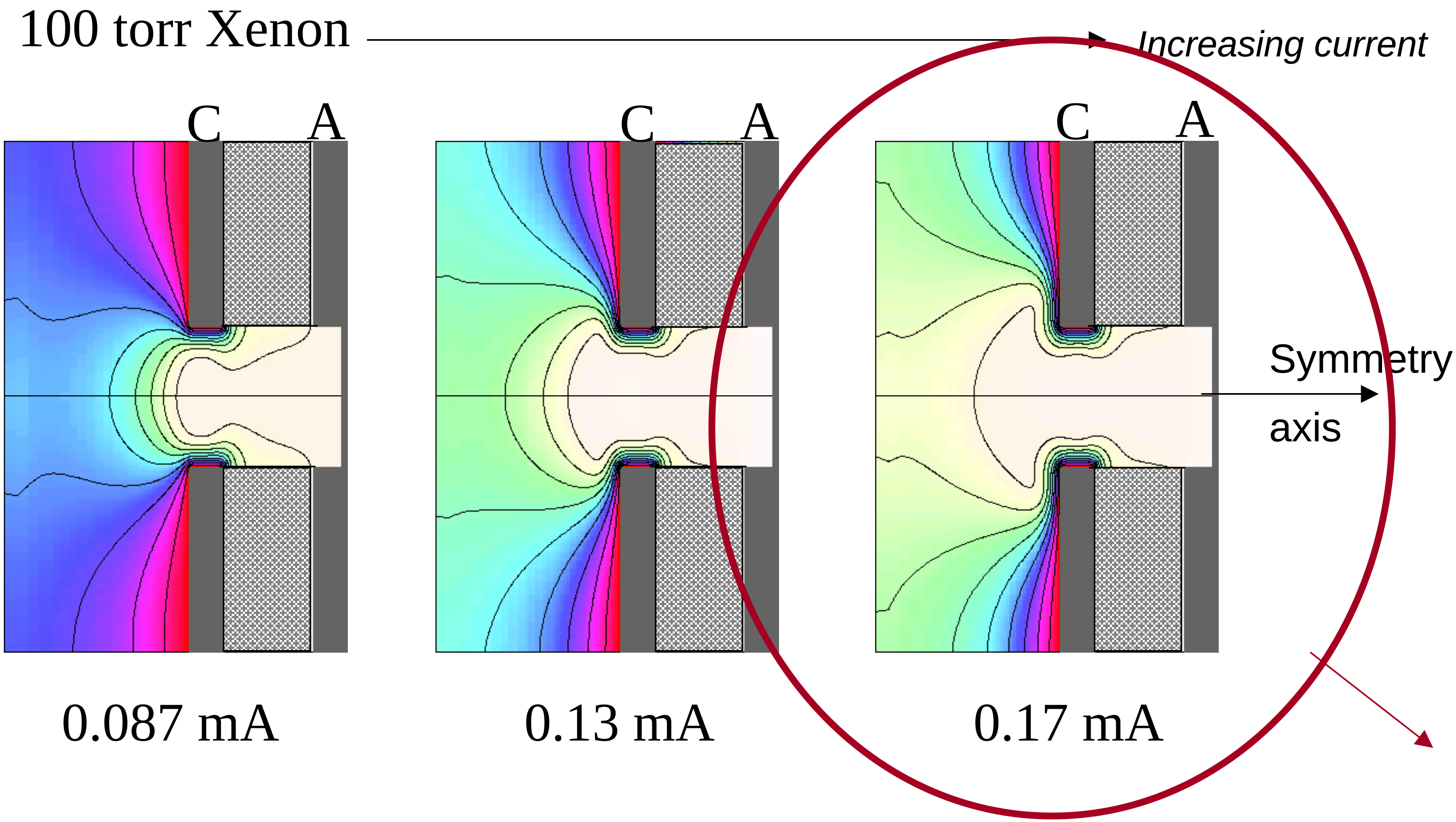
10 contours from 0 to 243 V

Equipotential contours



10 contours from 0 to 243 V

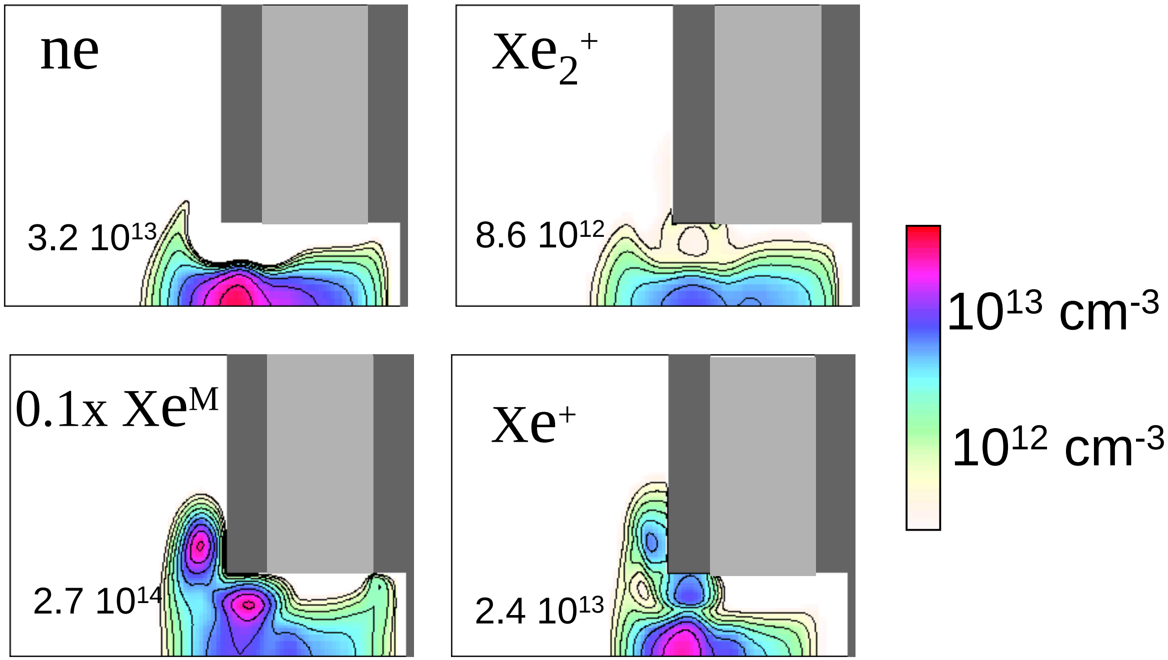
Equipotential contours



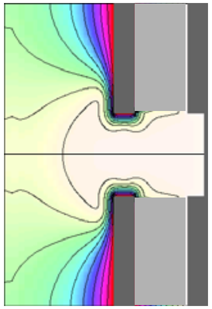
Same scale all curves, 0 – 270 V, 10 contours

Plasma properties at 0.17 mA

Xenon 100 torr



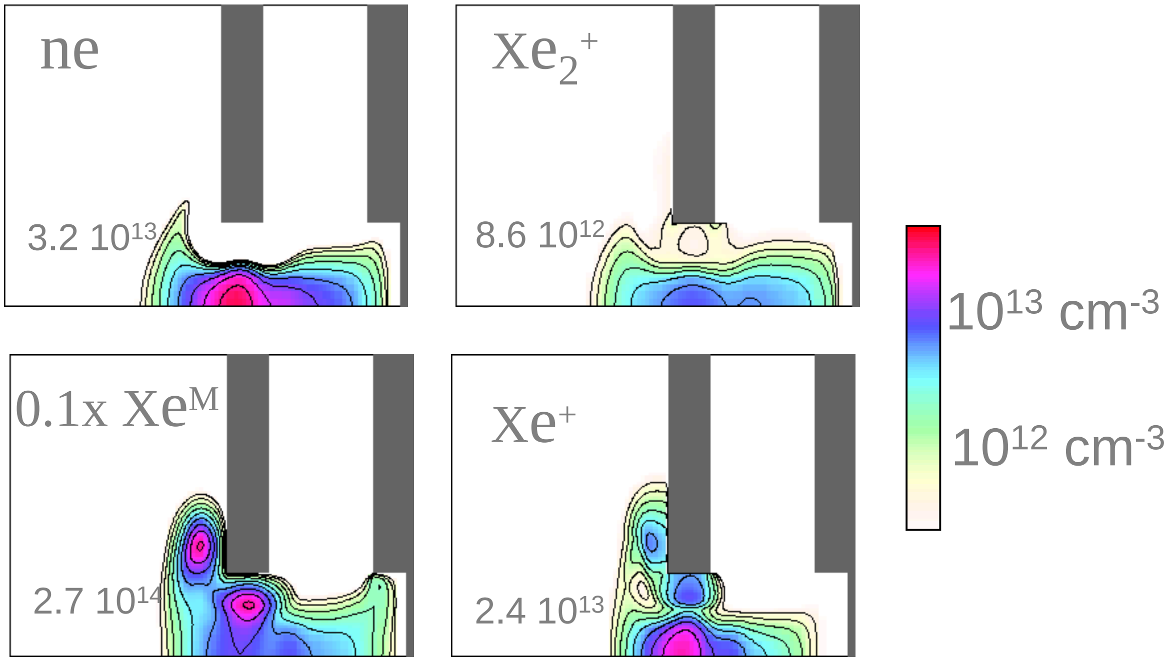
Species number densities
(peak number density cm^{-3})



Equipotential contours

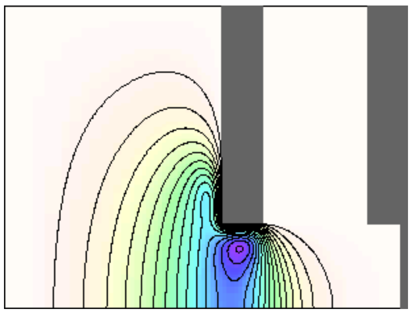
Plasma properties at 0.17 mA

Xenon 100 torr

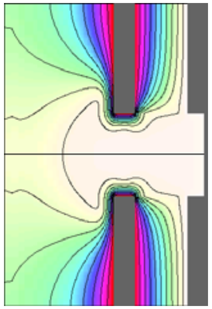


Species number densities
(peak number density cm^{-3})

Gas temperature



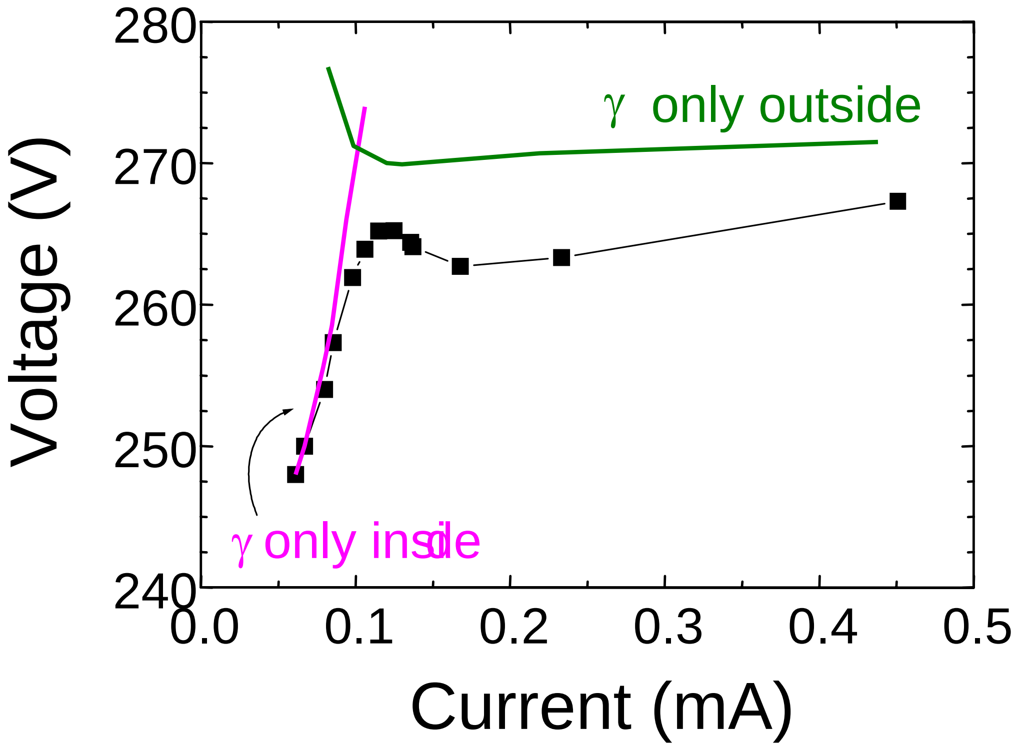
Tg peak = 450K

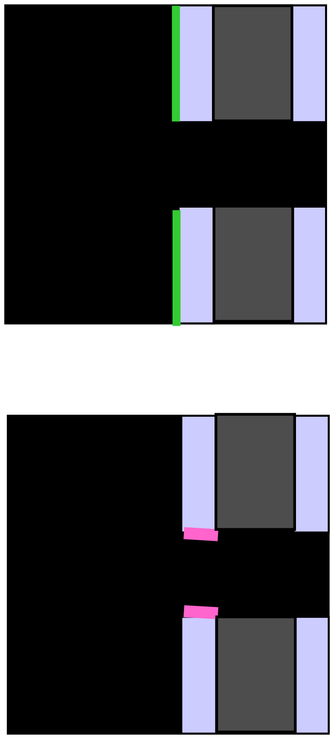


Equipotential contours

Calculated V-I characteristics

Xenon 100 torr



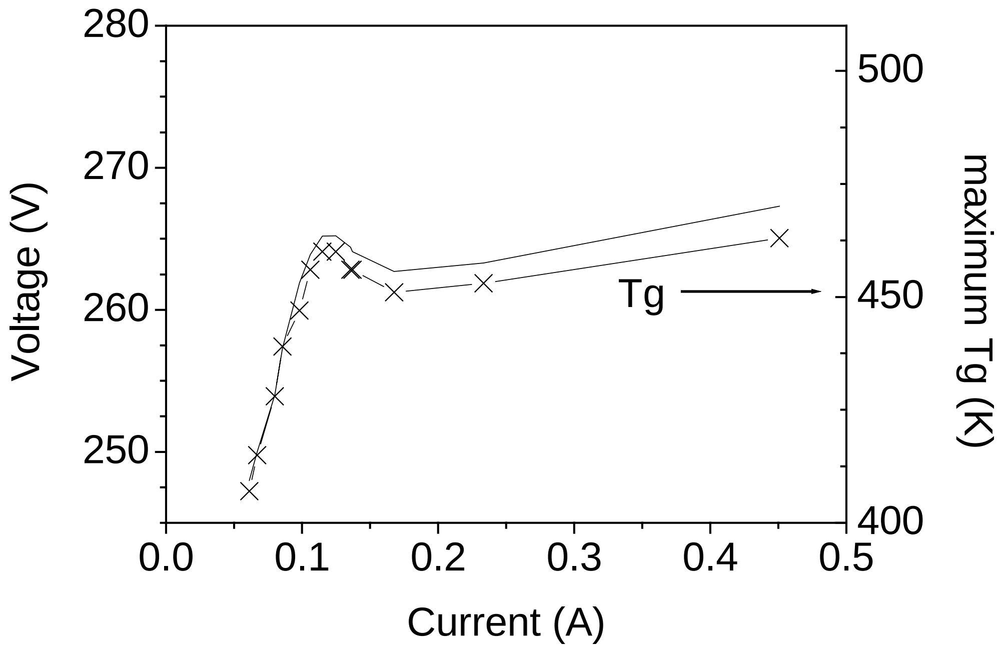


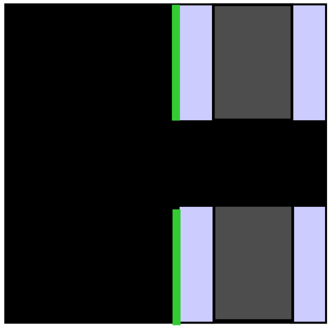
=> Transition from low current "abnormal" glow discharge localized inside the cathode hole to a higher current "normal" glow spreading along the outer cathode surface. The structure is not due to the classical hollow cathode effect.

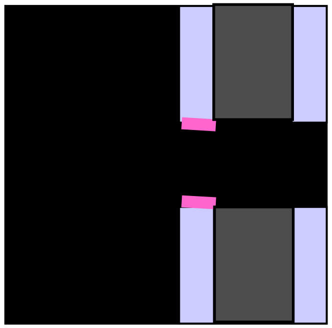
JP Boeuf et al 2005

Calculated V-I characteristics

Xenon 100 torr

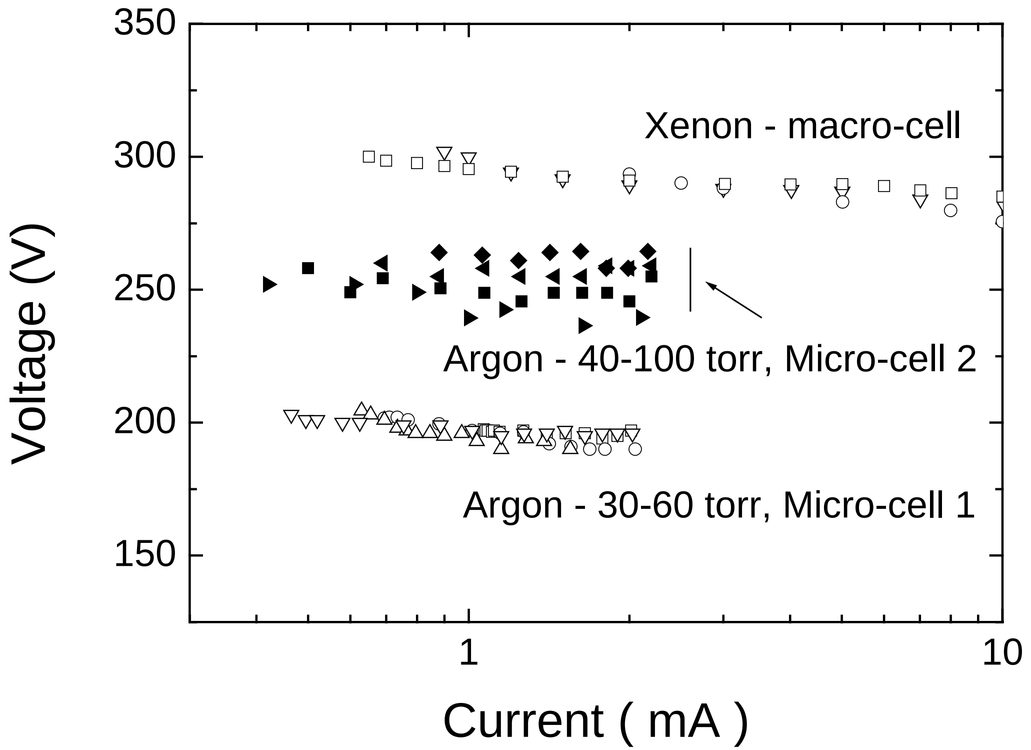






Gas temperature increase with current is limited by the transition to a normal discharge.

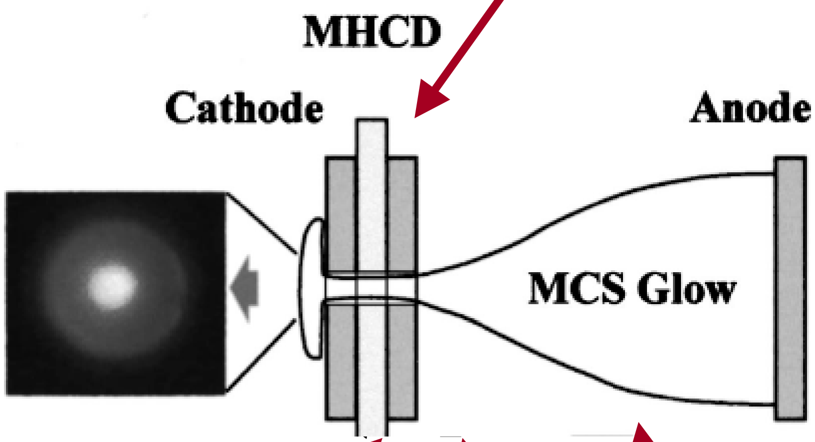
Experimental results :



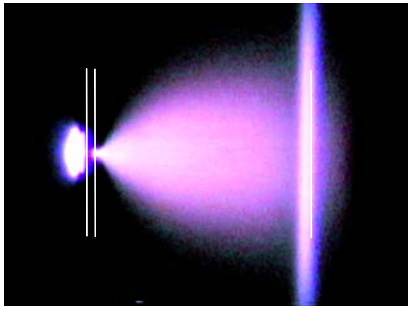
Expts from LPTP, LPGP, CPAT

MHCDs as plasma cathodes

MicroHollow Cathode Discharge (MHCD)



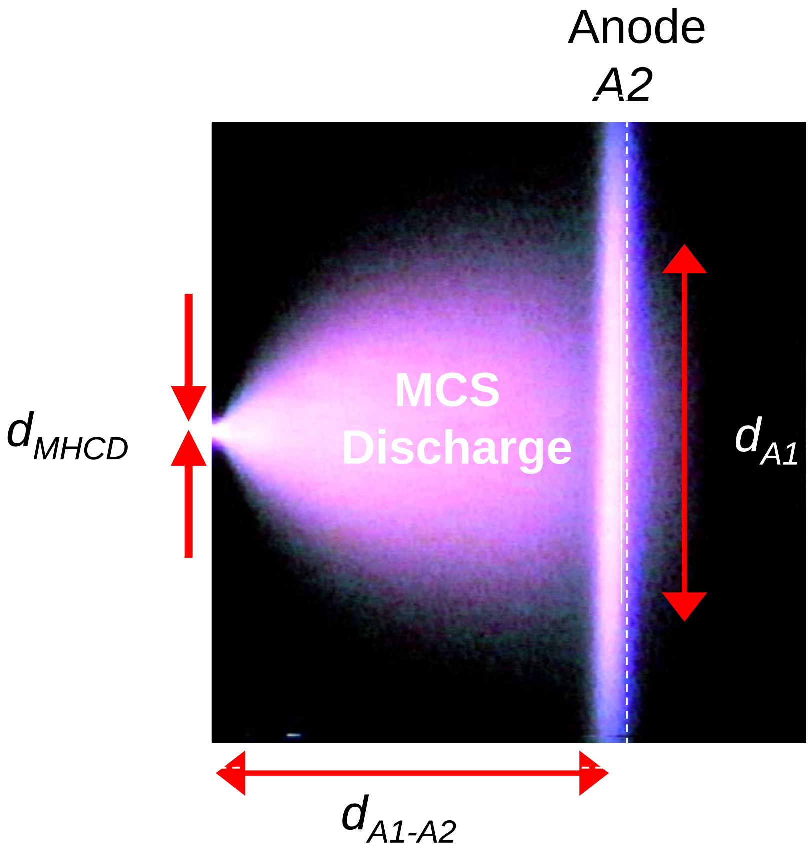
C A



Microcathode Sustained Discharge (MCS)

R.H. Stark and K.H. Schoenbach, JAP **85,** 2075 (1999).

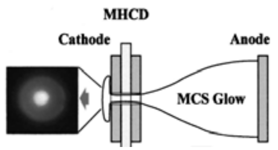
Plasma in the MCS region

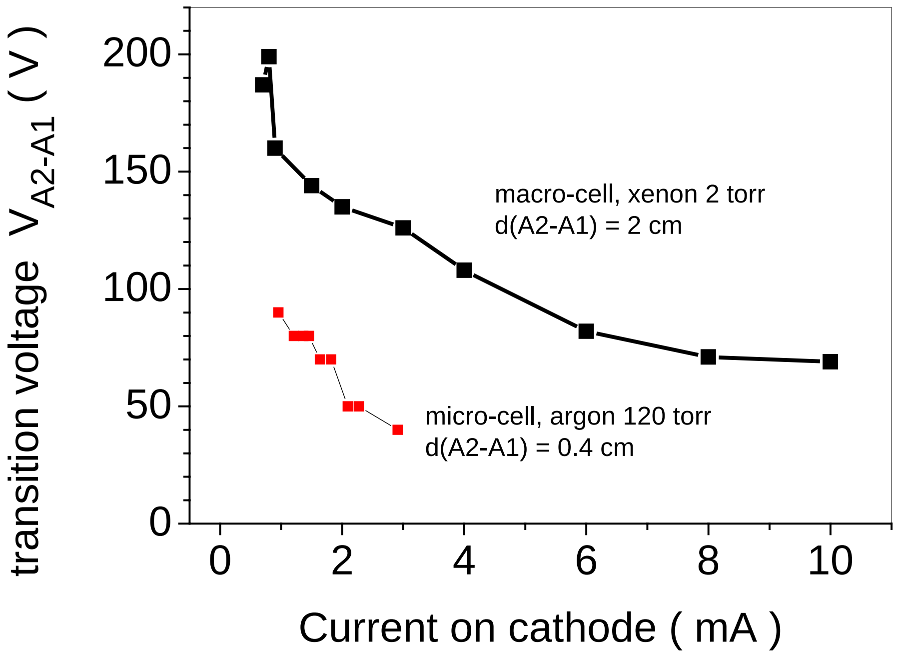


Objective :
Study the characteristics of a steady-state plasma in the MCS region.

Approach :
quasi-neutral model
Electrical diagnostics
Optical diagnostics
Micro and macro cells

Initiation of a MCS Discharge



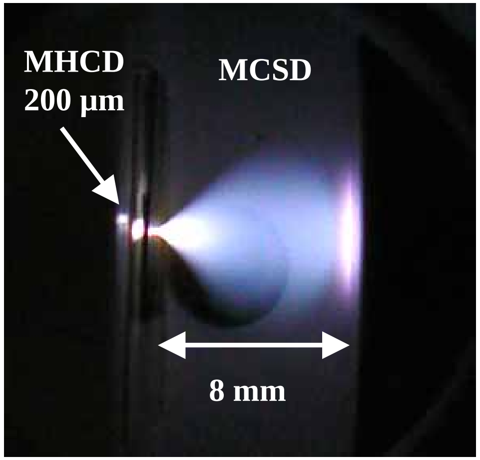


Parameters controlling MCS initiation : V(A2-A1), I(cathode), and P x d

Expts : Aubert (micro) and Callegari (macro)

Visual appearance of MCSD

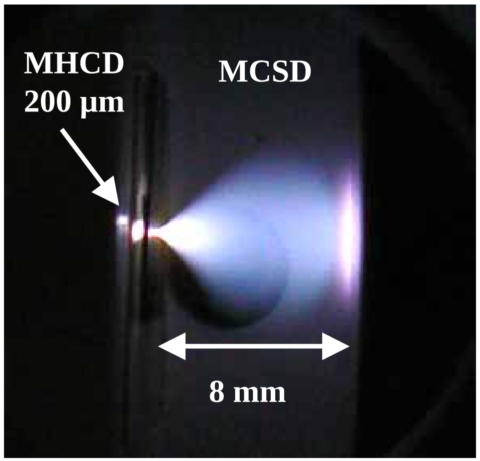
photograph



Photograph of a MCSD operating at 1 mA in 50 torr pure oxygen.

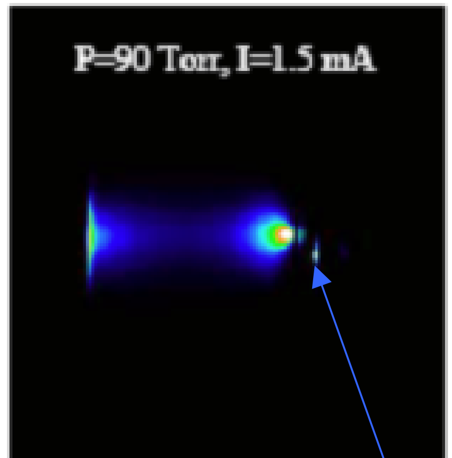
Visual appearance of MCSD

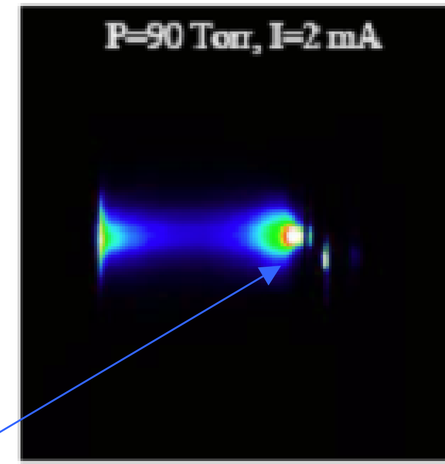
photograph



Photograph of a MCSD operating at 1 mA in 50 torr pure oxygen.

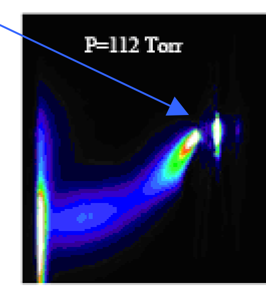
Emission from the MCSD in 90 torr O_2 as a function of current ($I_C = I_{A2}$).





MHCD

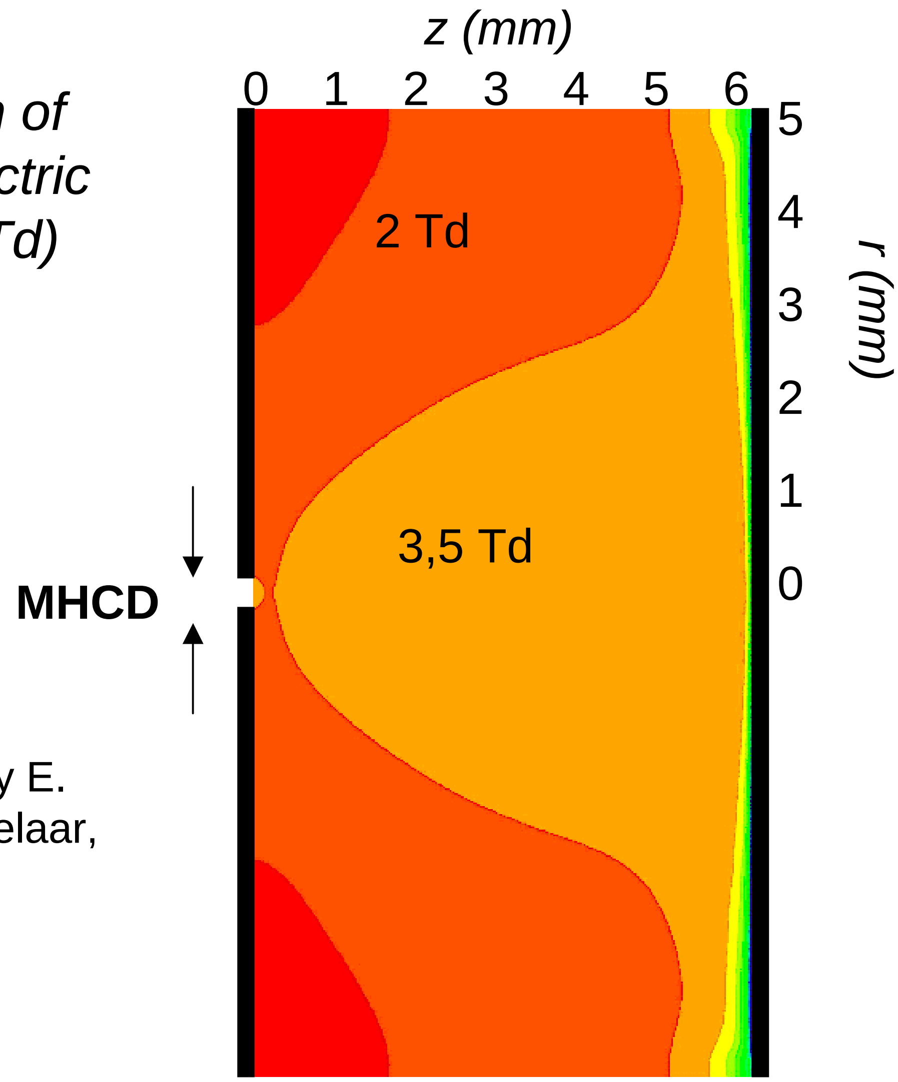
Emission from the MCSD in Ar/O_2 with 5 torr O_2 for different total pressures. $I_C = I_{A2} = 0.5$ mA. The gas flow rate is 78 sccm.



Model Results

Gas: **Ar**

Distribution of reduced electric field ***E/N*** *(Td)*



Model developed by E. Munoz and G. Hagelaar, CPAT

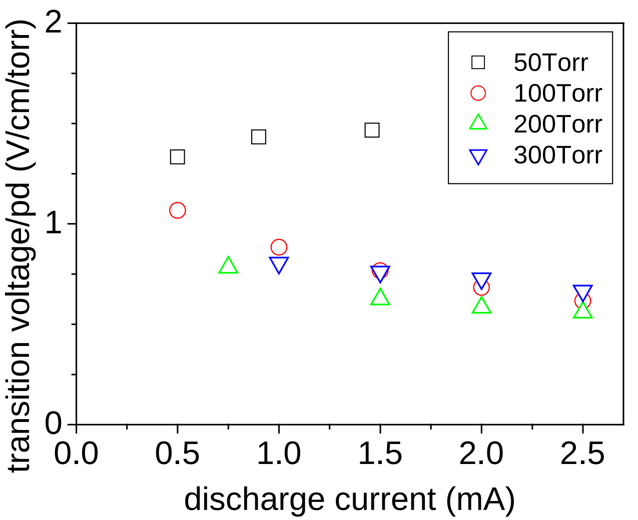
Conditions:

- p = 50 torr
- $d_{A1\text{-}A2}$ = 6 mm
- d_{MHC} = 200 µm
- $d_{A1} = d_{A2}$ = 1cm
- I_{MHCD} = 1 mA

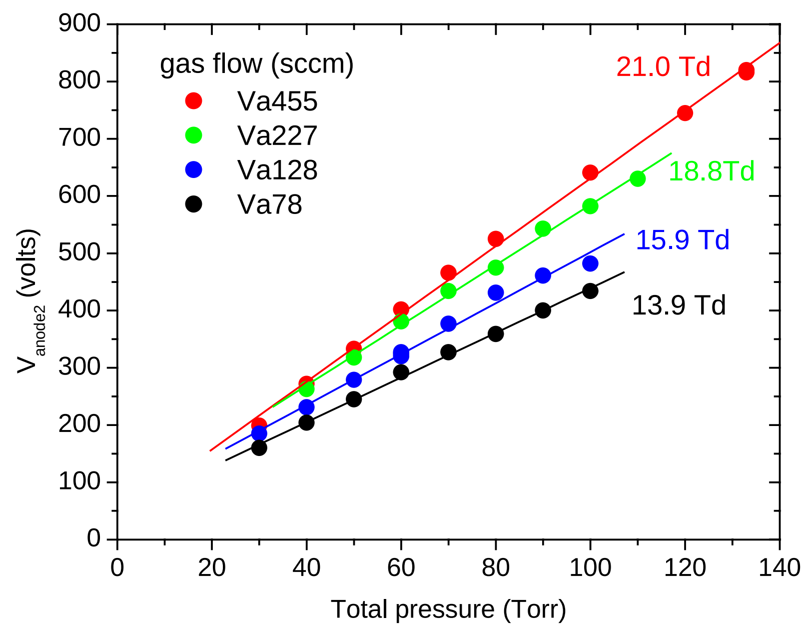
Radial expansion limited by recombination.

E/p in MCSD

Estimated from slope of V vs pd at point where current to A1 = 0.



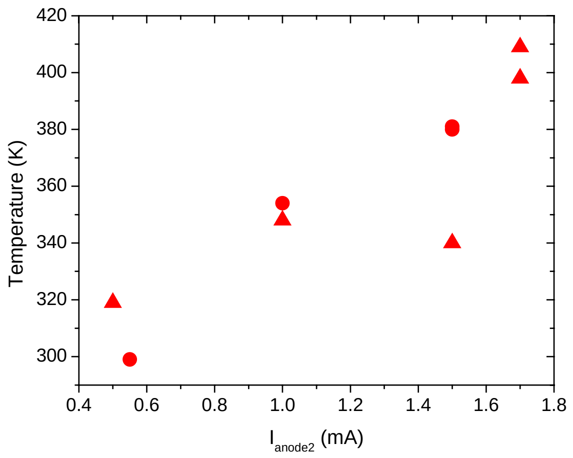
Argon (LPTP)



Ar/O_2 (LPGP)

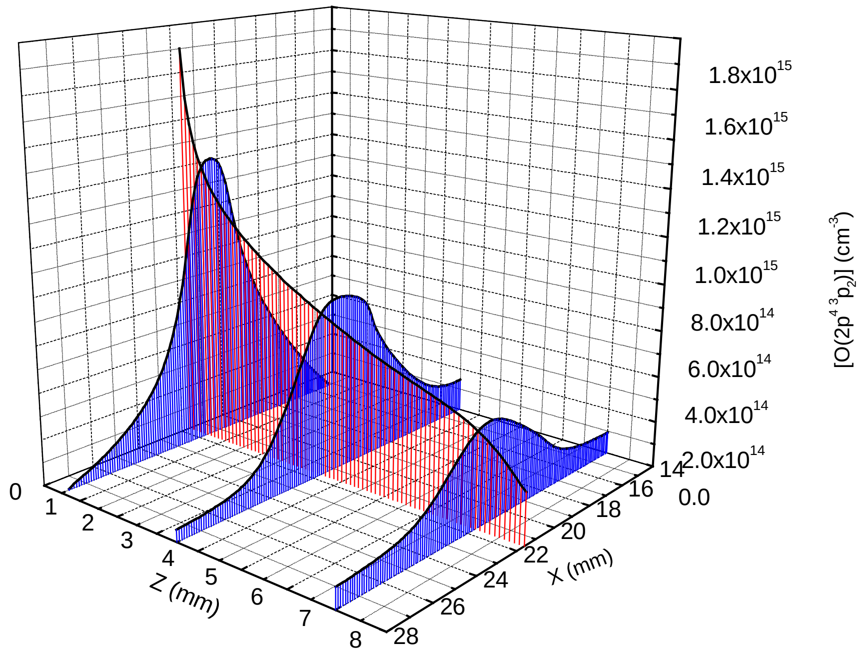
MCSD in O_2 and Ar/O_2 mixtures

Gas temperature



V. Puech, J. F. Lagrange, N. Sadeghi, M. Touzeau, G. Bauville, B. Lacour

[O] number density



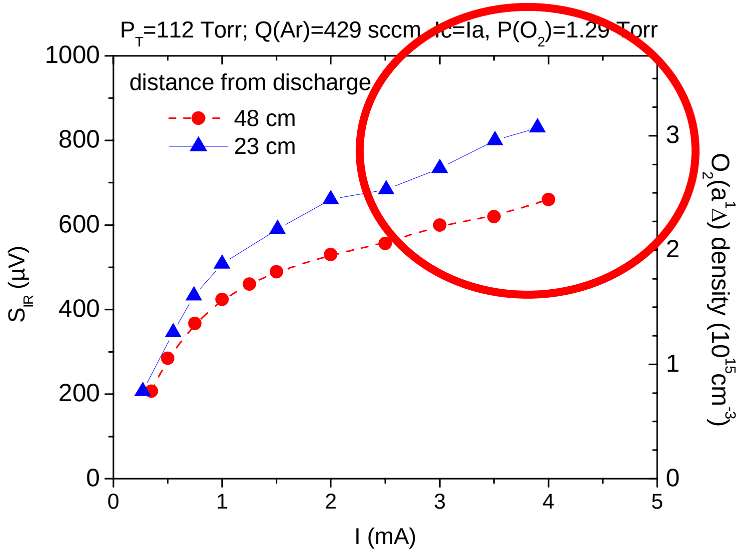
L. Magne, G. Bauville, P. Jeanney, B. Lacour, V. Puech

To be presented at the GEC, 2006

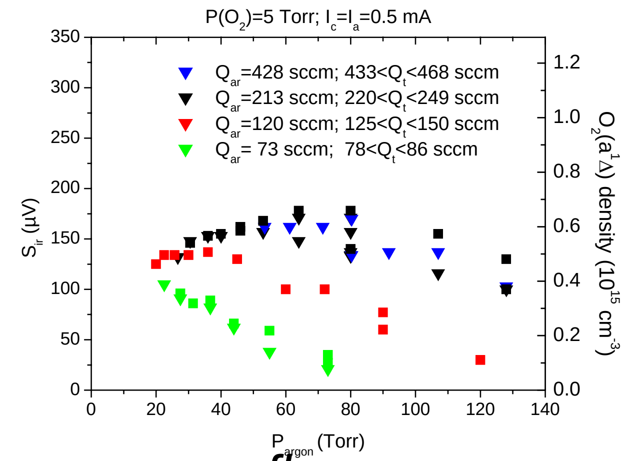
Generation of $O_2(^1\Delta)$ in the MCSD

LPGP, Puech et al

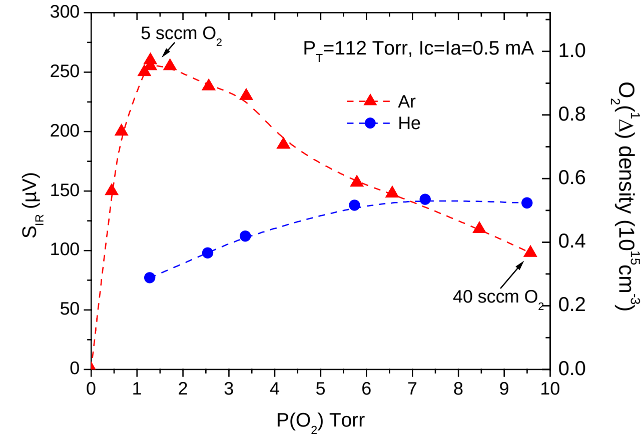
!!



vs discharge current



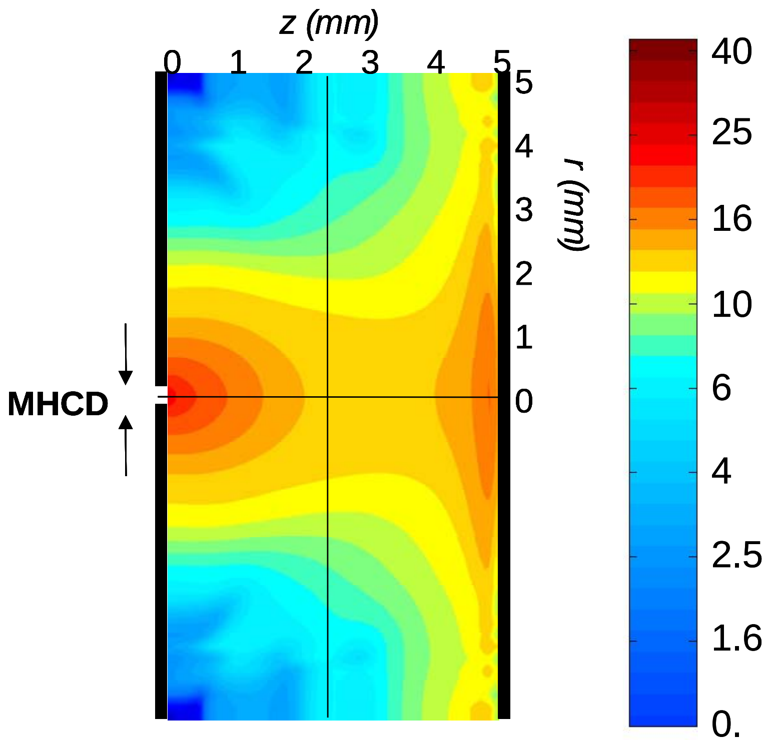
vs gas flow



vs O2 partial pressure and nature of carrier gas

Distribution of
E.N (Td)

Mixture: **10 % O_2 + 90 % Ar**

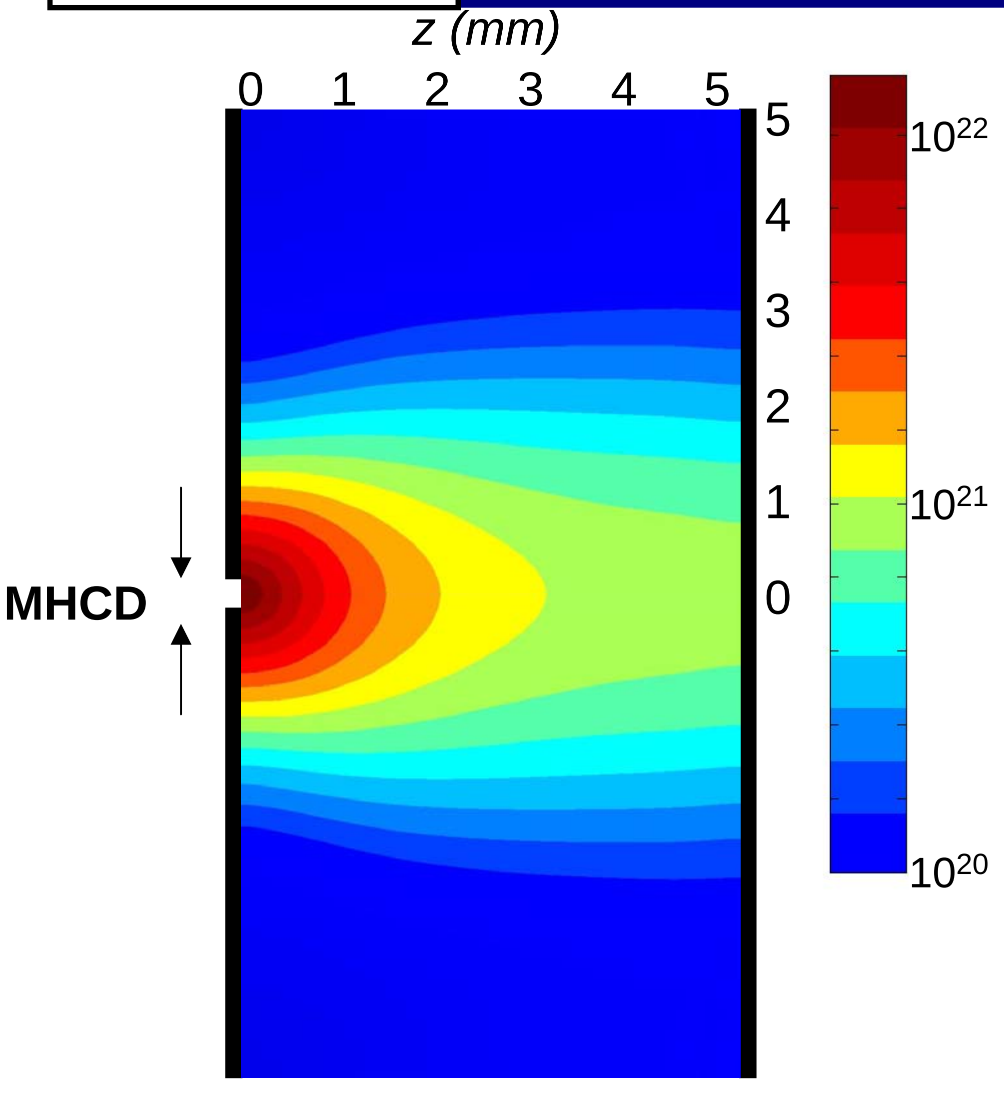


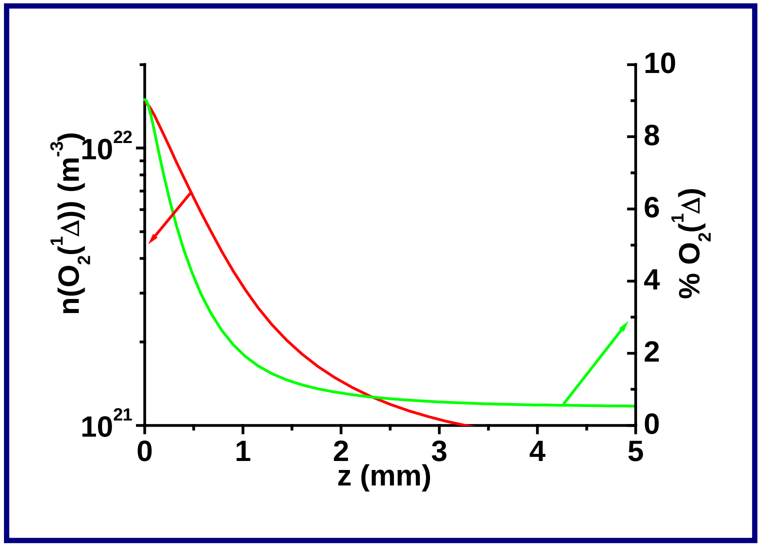
Model :
8 Charged particle species :
e^-, O_2^+, O_4^+, O^-, O_2^-, O_3^-, Ar^+, Ar_2^+
8 Neutral particle species :
O_2, O_2 (1D), O_2 (1S), O_3 , O , $O(^1D)$, Ar, Ar^*

1 mA, 200 microns, 0.5 cm

Distribution of $O_2(^1\Delta)$

Mixture: **10 % O_2 + 90 % Ar**





Comparisons in progress with expts of Puech et col.

Conclusions

✓Stable, high pressure, non-thermal plasmas can be generated and maintained in small (100s of micron-sized) geometries.

✓The stability is due to the spreading of the discharge along the back surface of the cathode.

✓ In a 3-electrode configuration, the MHCD acts as a plasma cathode for the MCS ➔ STABILITY

✓ MCS region is similar to a positive column plasma with a constant and low reduced electric field axially uniform: E/N ~3.5 Td in Ar, ~10 - 20 Td in Ar/O2 => possibilities for interesting plasma chemistry

✓Other applications…..