Table-Top Electron-Beam Induced Plasma Chemistry

Novel Method of Plasma Chemistry

Application: Recycling of CO_2

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3rd MSE Colloquium, 2013

Final Goal: Processing of CO_2

$$CO_2 \rightarrow CO + O$$

$$\vdots$$

$$CO_2 + X \rightarrow \text{Fuel}$$

Content

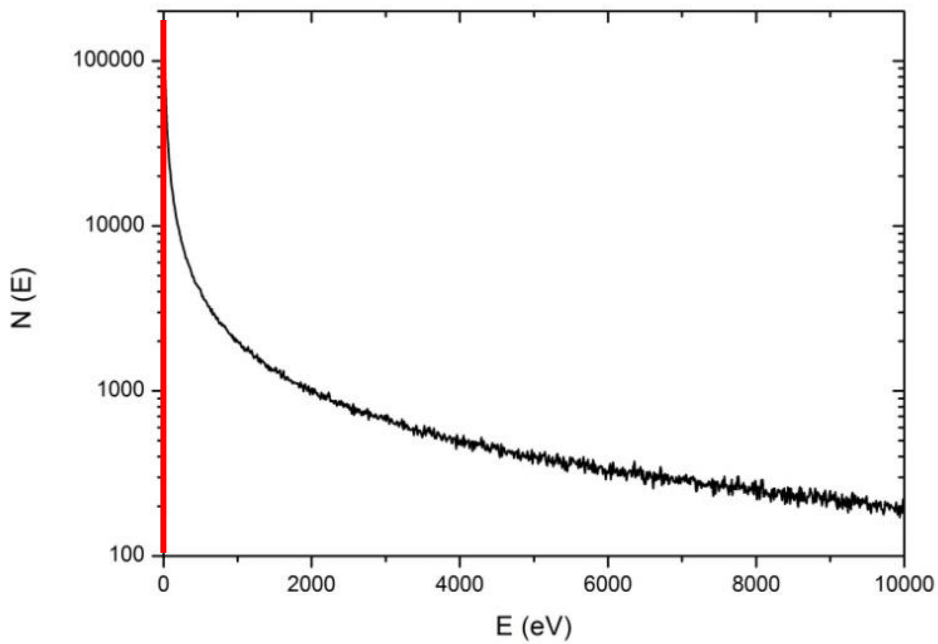
Plasma Induced by a 15 keV Electron Beam

Advantages

- 86 % of electrons above 20 eV
  - able to break chemical bonds
- High power densities in the 15 keV range
  - due to penetration depth (≈ 1 mm)
- No hard x-rays
  - easy shielding
- Compact table-top devices
- Plasma formation under all target conditions
  - no ignition conditions
  - independent from gas composition
  - independent from gas pressure

Plasma Induced by a 15 keV Electron Beam

Electron Energy Distribution Function

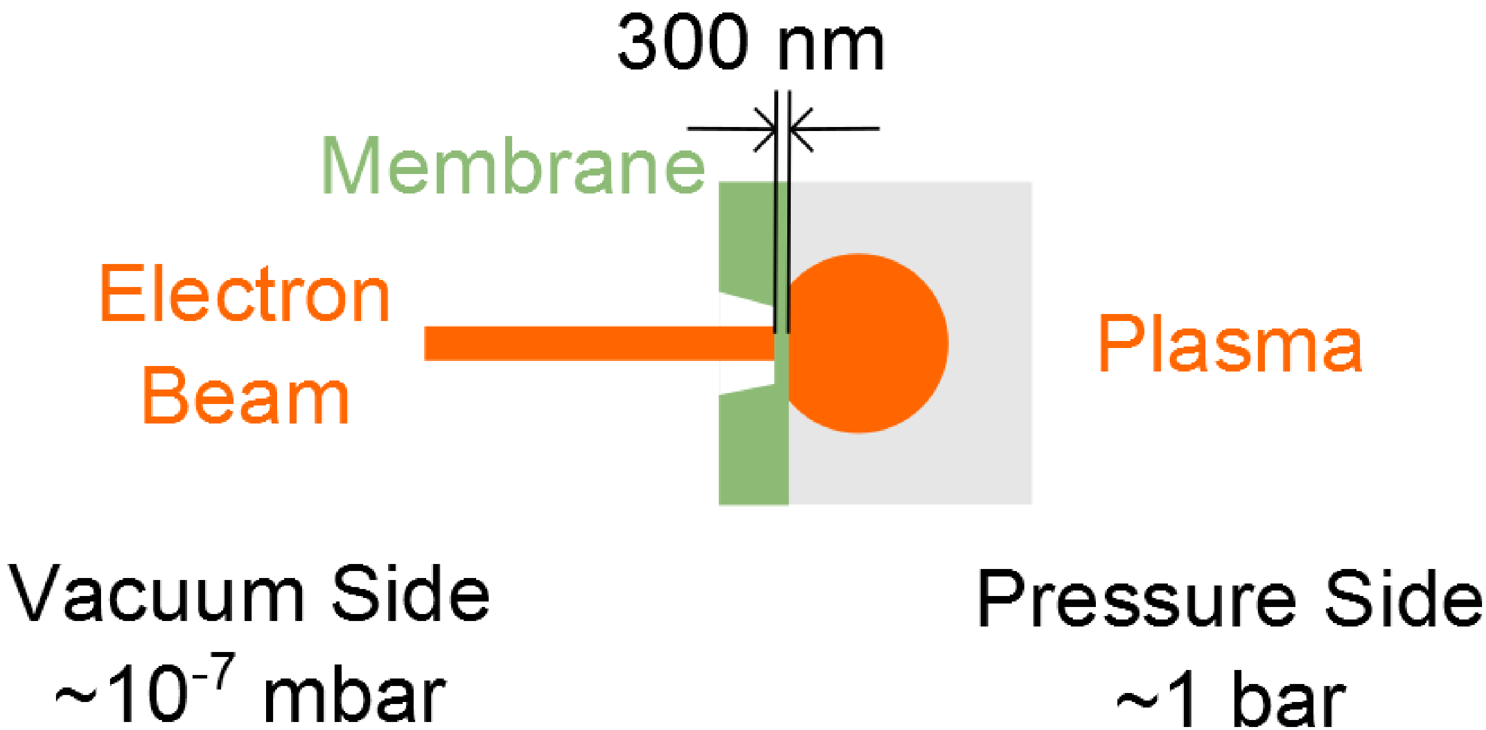


Modeled EEDF of an Electron Beam

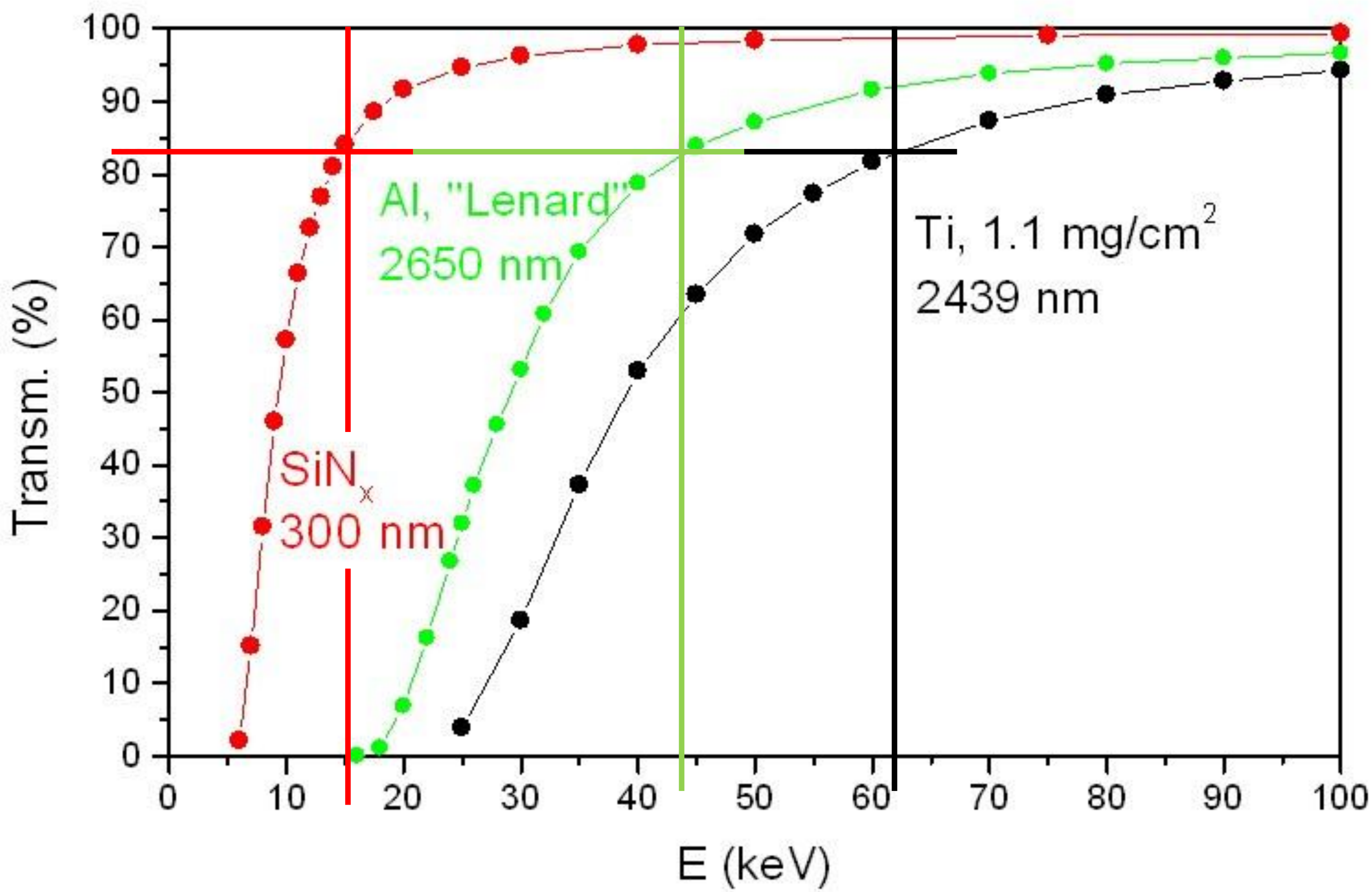
Instead of

- Thermal induced plasma
  - 2300 K => 200 meV
- Discharge plasma
  - Peak below 10 eV
  - needs certain ignition conditions

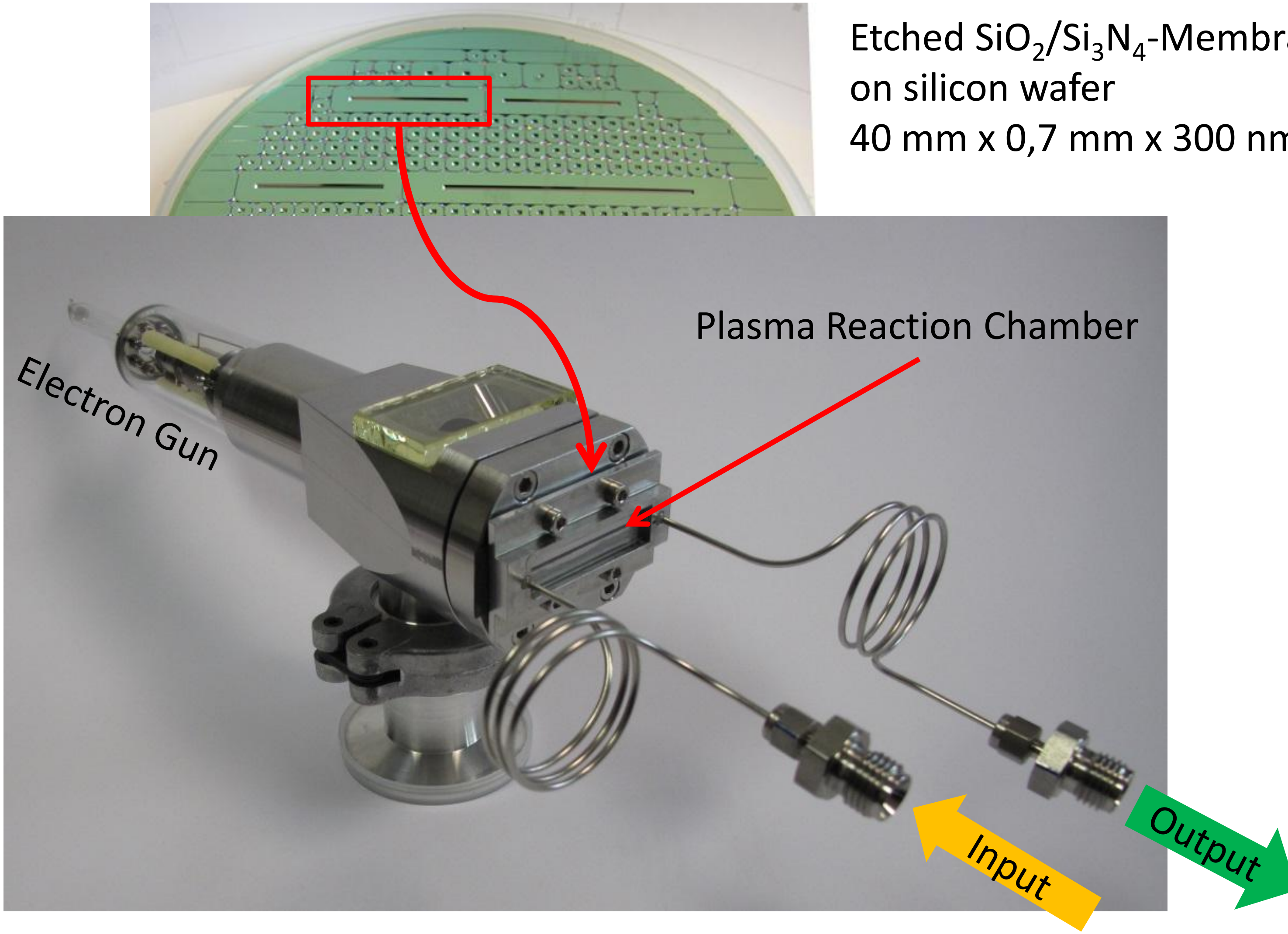
Plasma Chemistry at Atmospheric Pressure



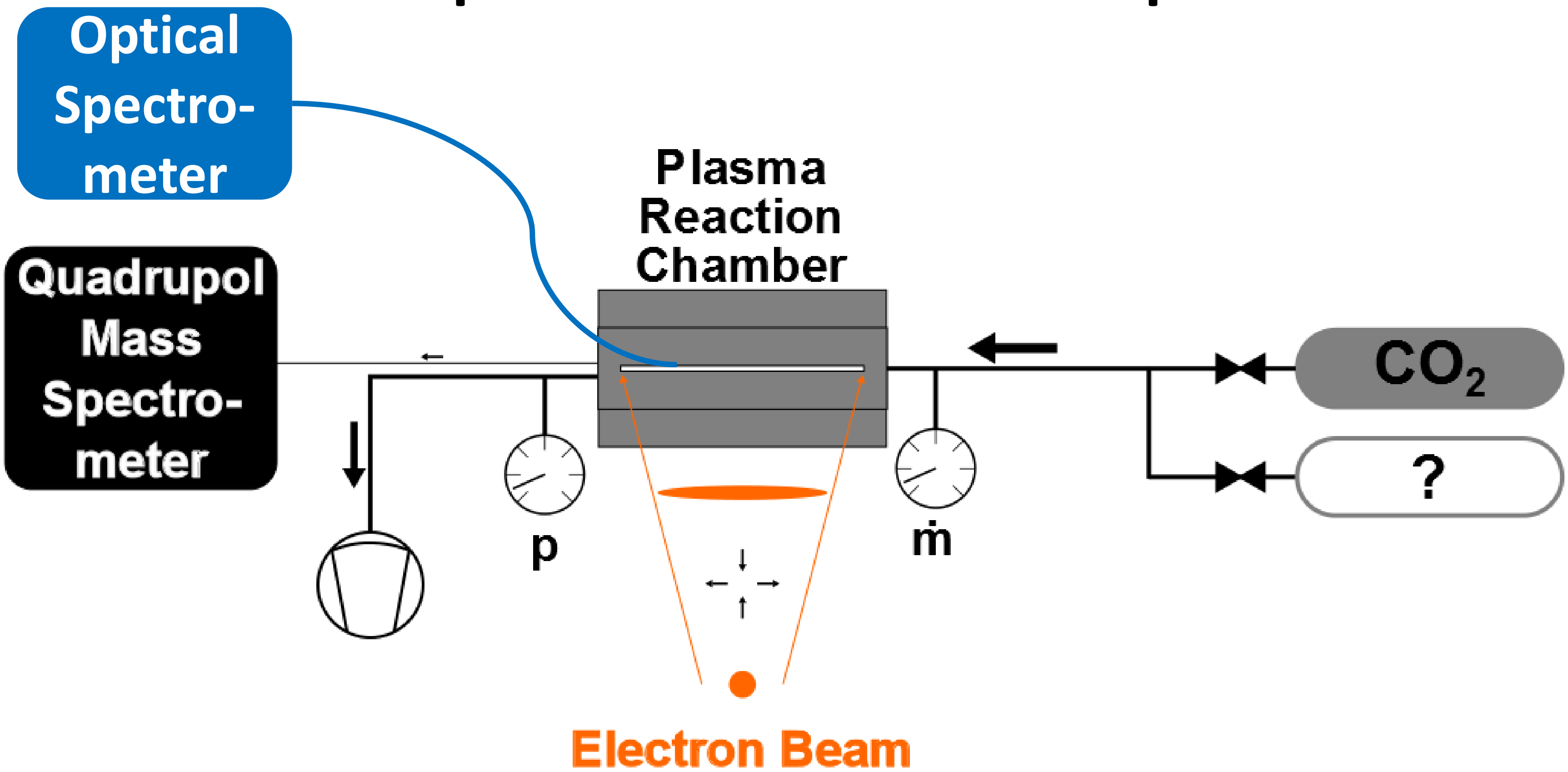
Key Inovation: SiN_x



Etched SiO_2/Si_3N_4-Membrane
on silicon wafer
40 mm x 0,7 mm x 300 nm



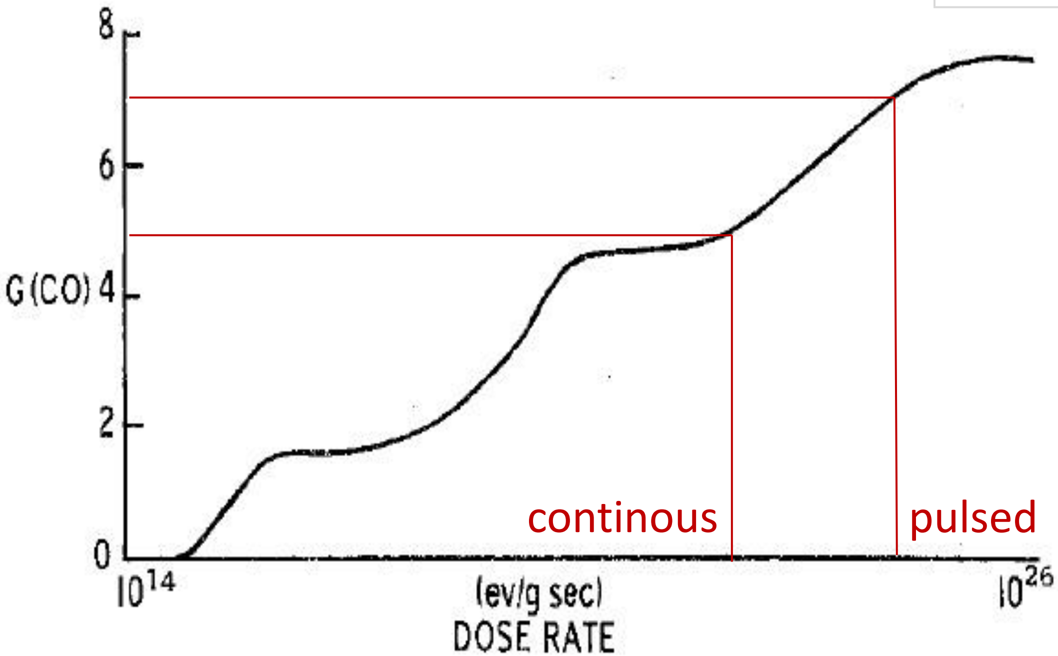
Experimental Setup



Reference Data: Radiolysis

$CO_2 \rightarrow CO + O$

$$G = \frac{Number\ of\ molecules\ produced}{100\,eV\ Energy\ deposited}$$



R. Kummler, C. Leffert, K. Im, R. Piccirelli, L. Kevan, and C. Willis
"A Numerical Model of Carbon Dioxide Radiolysis"
Journal of Physical Chemistry **81**, 2451 (1977)

➔ For efficient experiments:
$\approx 10^{23}$ eV/gs ≈ 16 kW/g

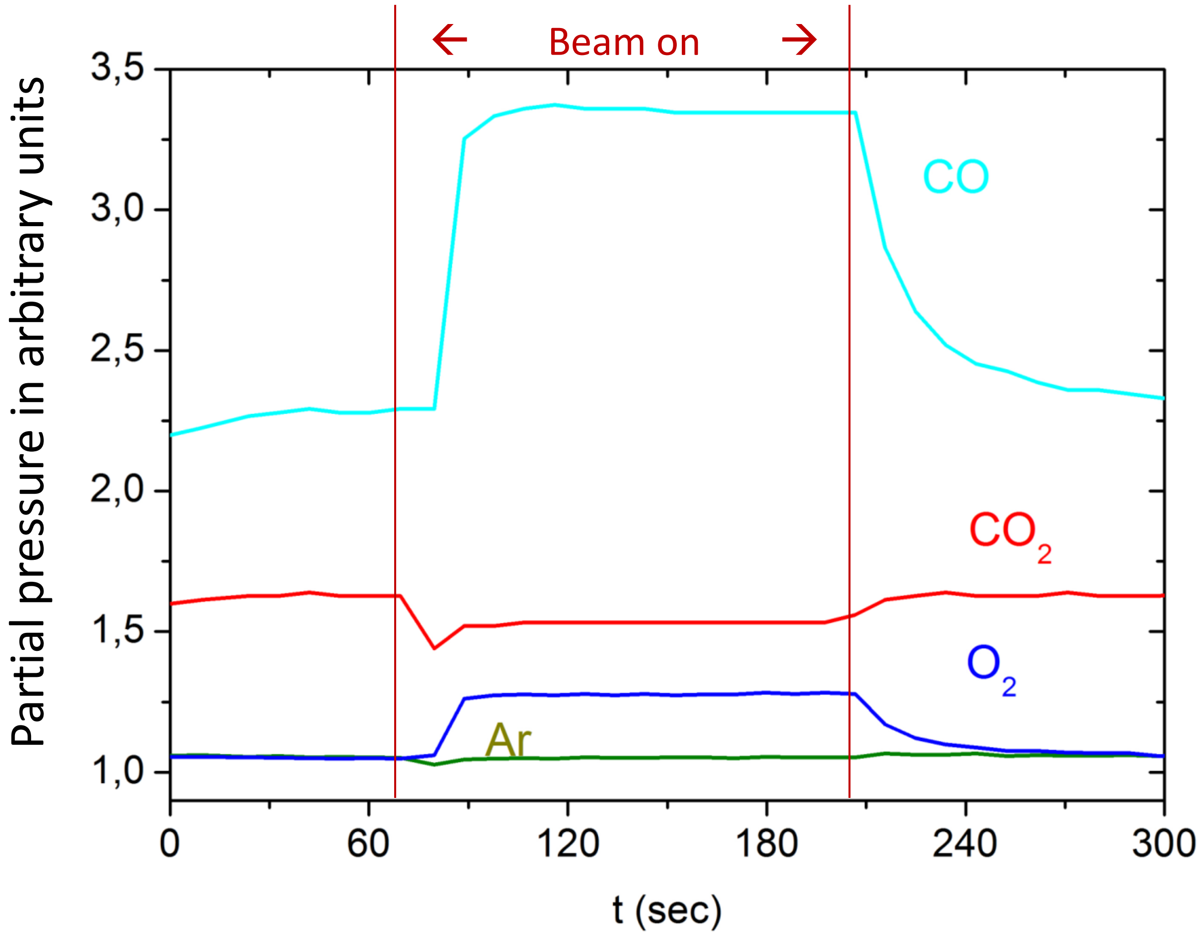
➔ High **power densities** are essential

Our values:

6 kW/g continous

2 MW/g pulsed

Preliminary Results



Summary

- Table-Top Device for Radiolysis
- Desired trend observable
- G-value still too low

Next Steps

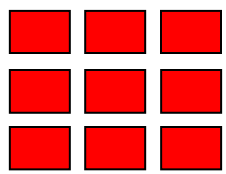
- Optimize process parameters
  - Increasing the flow to avoid back reaction
  - Testing catalytic effects
- Using field emission as electron source

Outlook: The Vision

CO_2 from industrial emissions

Power from renewable energies

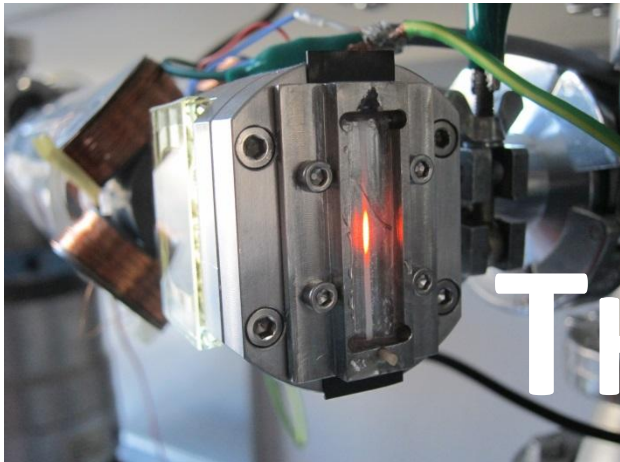
Karl Urban

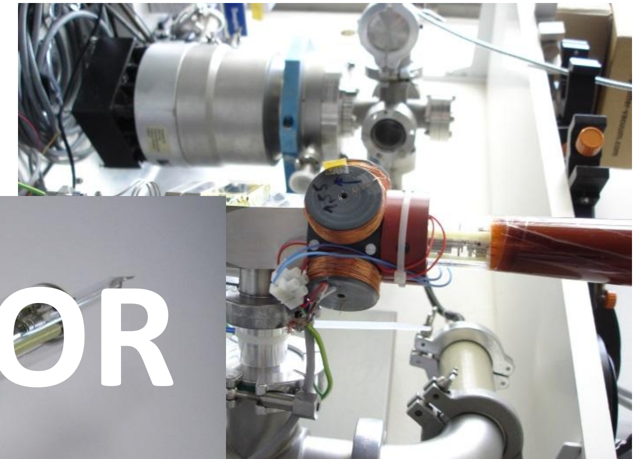


Hydrogen
e.g. from water

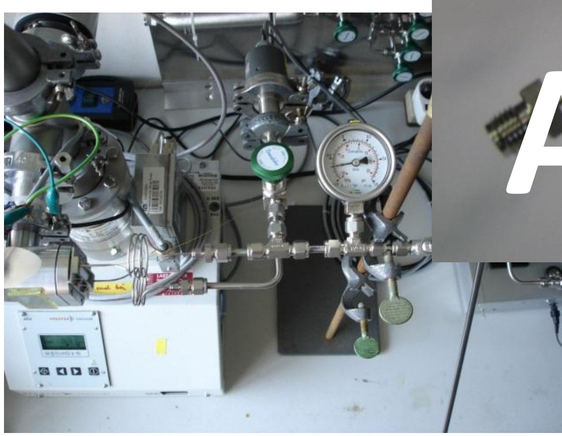
Each module runs under optimum conditions

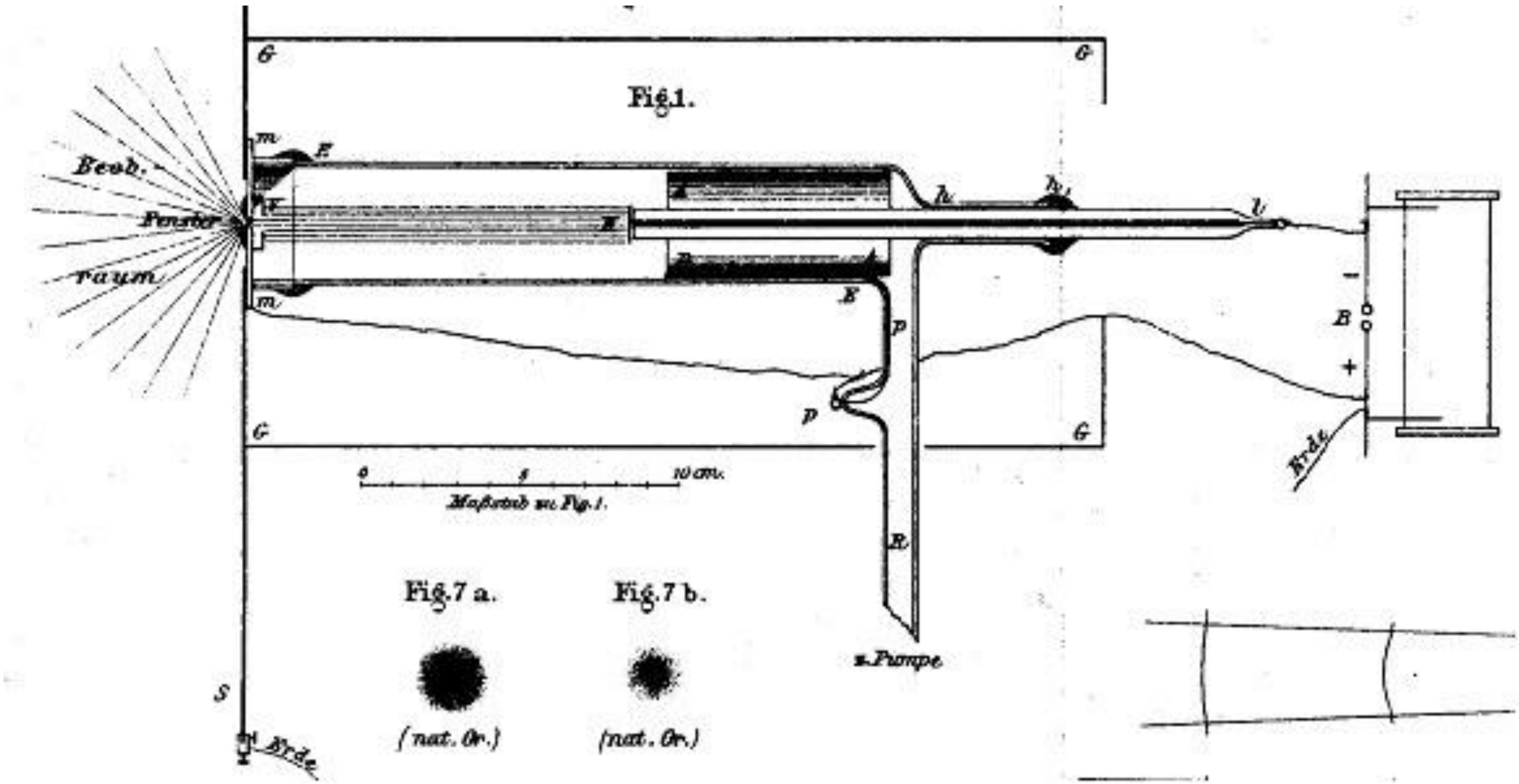
Conversion to **Liquid Fuels** for energy storage



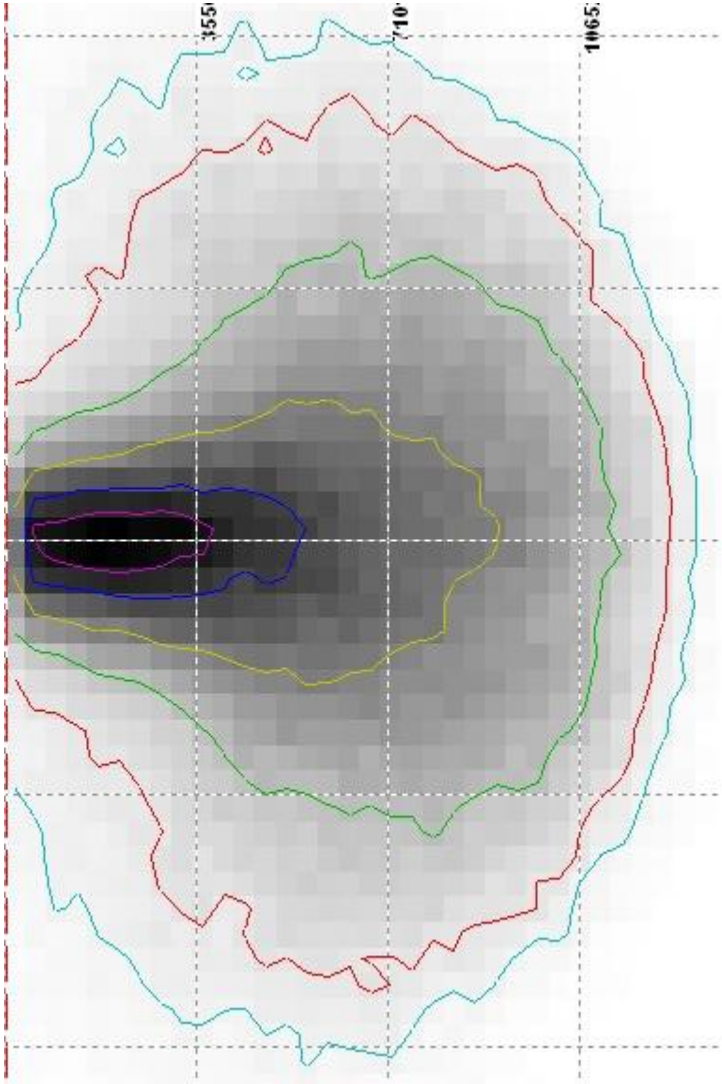


THANKS FOR YOUR ATTENTION!

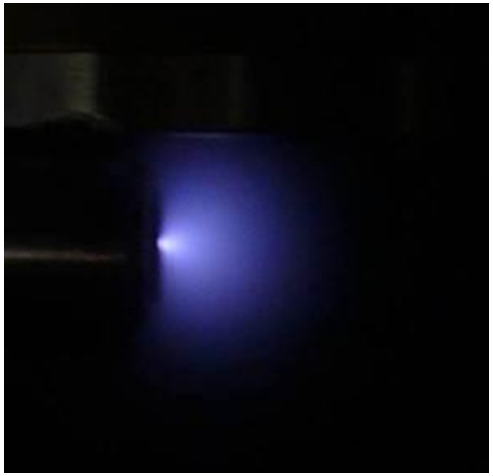


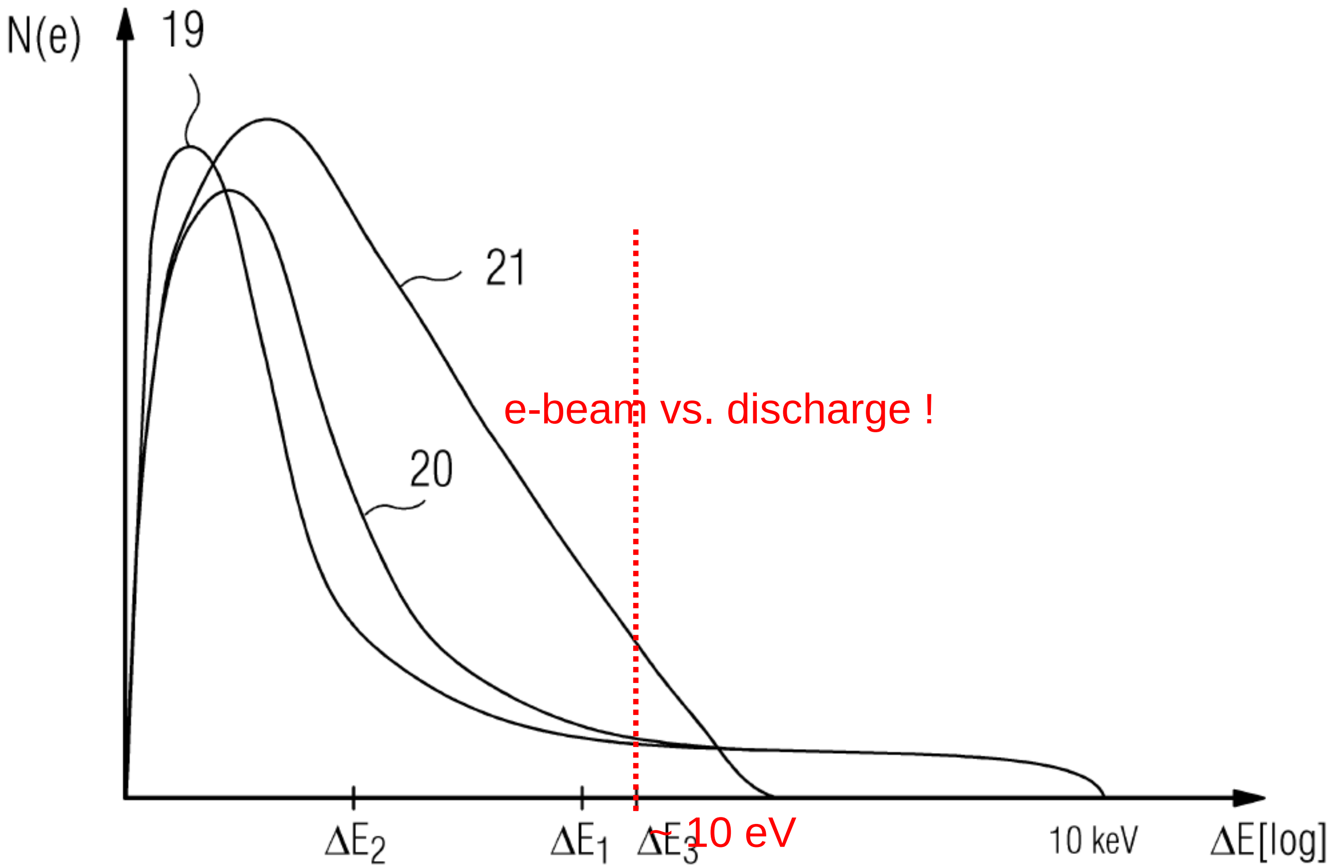


P. Lenard, Ann. d. Phys. u. Chem., Neue Folge **51**, Seite 15 (1894)

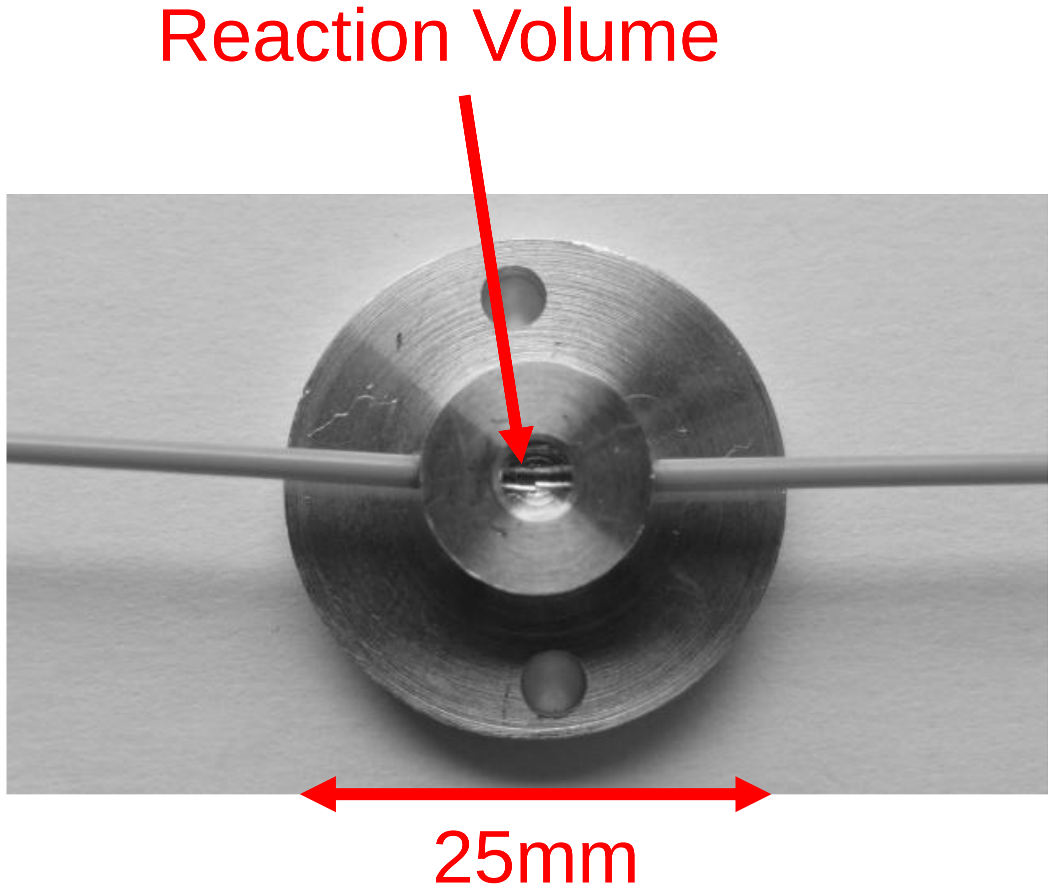


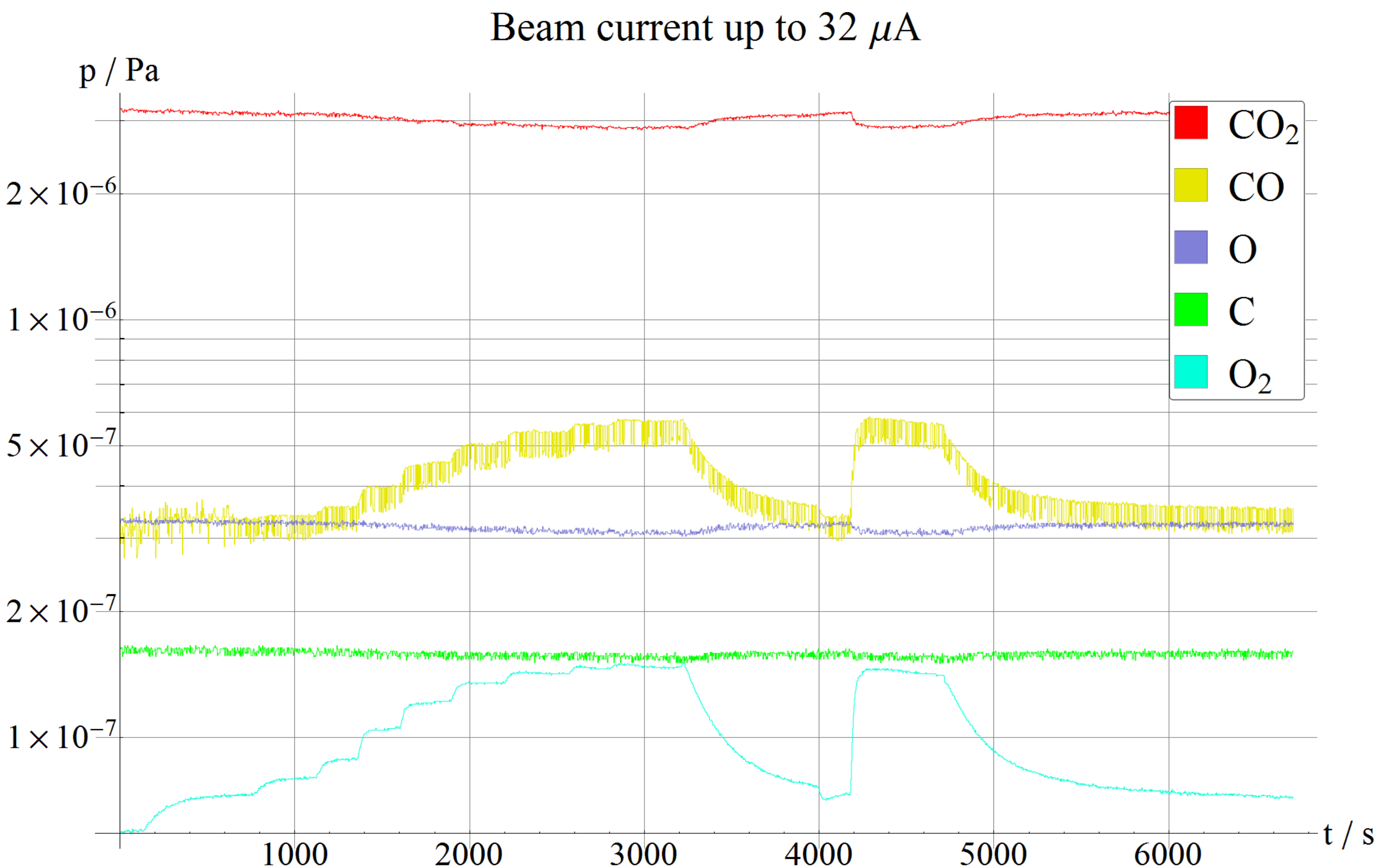
CO_2, 1 bar:
V ~ 1 mm^3
m ~ 2×10^{-6} g



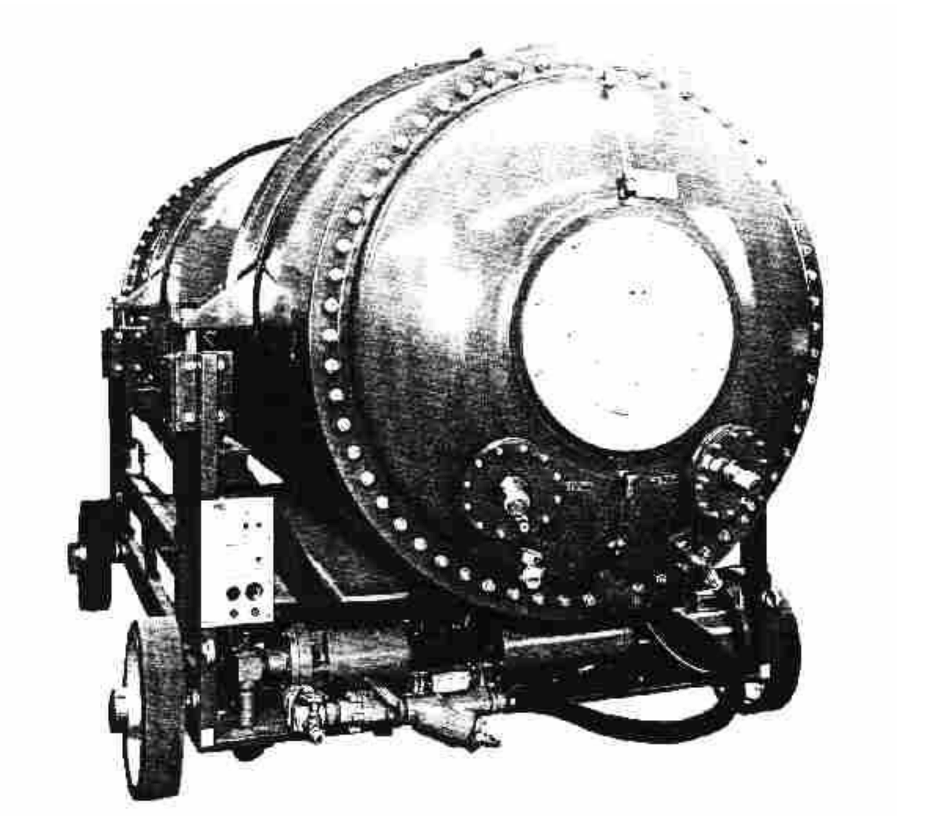


N(e)
19
21
20
e-beam vs. discharge !
ΔE2
ΔE1
ΔE3
~10 eV
10 keV
ΔE[log]


Reaction Volume
25mm



Beam current up to 32 μA
p / Pa
2 × 10^-6
1 × 10^-6
5 × 10^-7
2 × 10^-7
1 × 10^-7
1000
2000
3000
4000
5000
6000
t / s
CO2
CO
O
C
O2



Febetron 706

600 keV, ns pulses

0.69 Mrad delivered / pulse
$= 4.3\times10^{21}$ eV/g results in
$\sim 10^{30}$ eV/gs (ns pulse)

9 ml target volume

250 µm (unspecified material)

1 shot / min

$G_{observed} \sim 8$

R. A. Lee, "Febetron Radiolysis of CO_2 in the Presence of Oxygen and Carbon Monoxide", Radiat. Res. **77**, 233 (1979)