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MICROCAVITY PLASMA SCIENCE AND RECENT APPLICATIONS: BOUND-FREE COUPLING, TRANSISTO AND ILLUMINATION

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ECE Illinois

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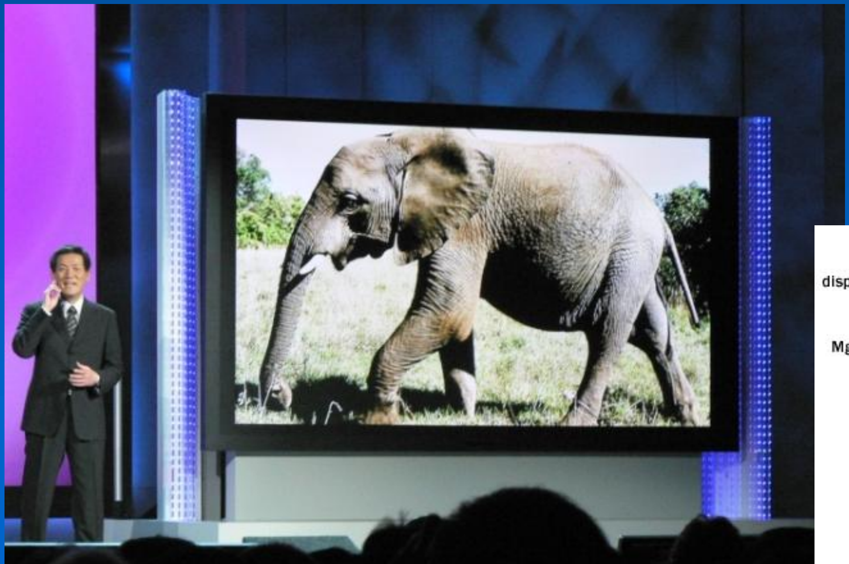
Gas Laser

Ozone generator

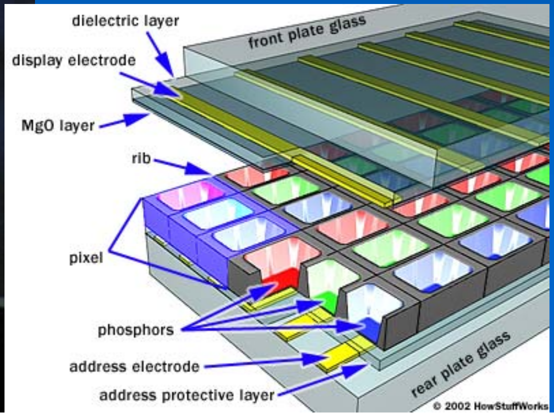
High Intensity
Plasma Arc Lamp

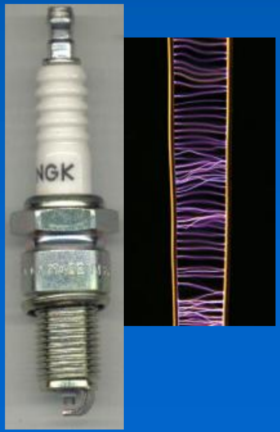
Plasma Surface Treatment

Fluorescent Lamp



Plasma Display (150 inch Panasonic)





Spark Gap

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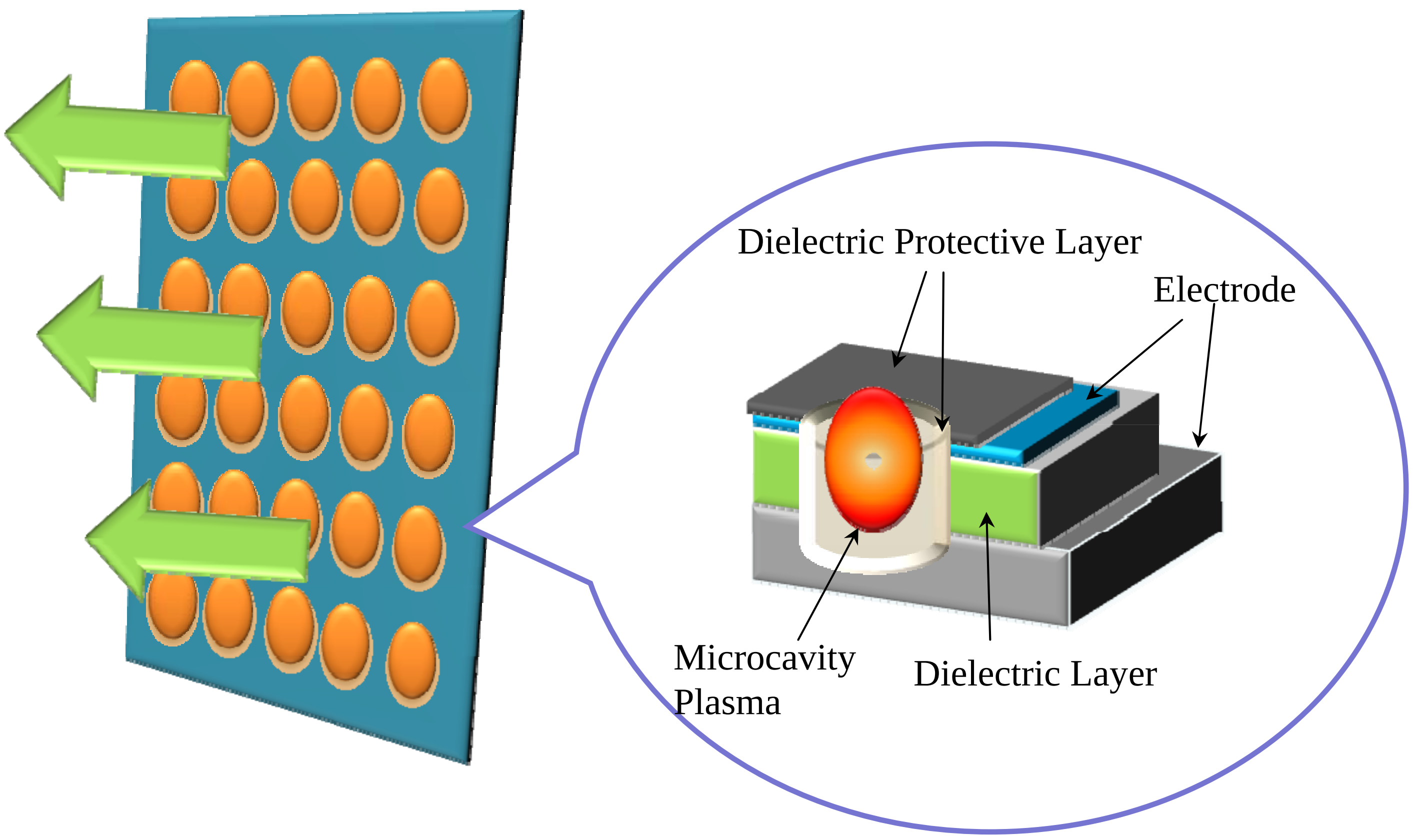
MICROCAVITY PLASMAS:

LOW TEMPERATURE, NONEQUILIBRIUM PLASMA CONFINED TO MESOSCOPIC CAVITIES



KEY CHARACTERISTICS

- Glow discharges confined to mesoscopic dimensions (< 10 ~ 100 μm)
- Microcavity volumes: nanoliters → picoliters
- A variety of atomic and molecular emitters are available (VUV ~ IR)
- Can be operated continuously at gas pressures beyond one atmosphere at power loadings exceeding 100 kW/cm^3
- Ability to interface plasma in gas or vapor phase with $e\text{-}h^+$ plasma in a semiconductor
- Precise control of microcavity geometry

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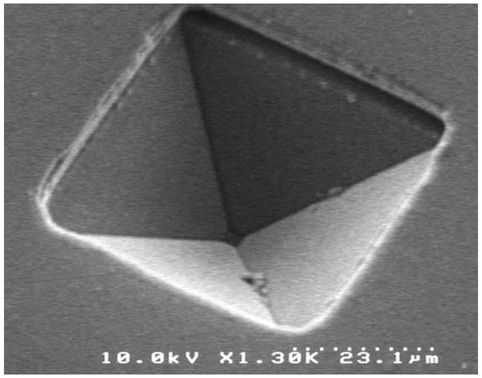
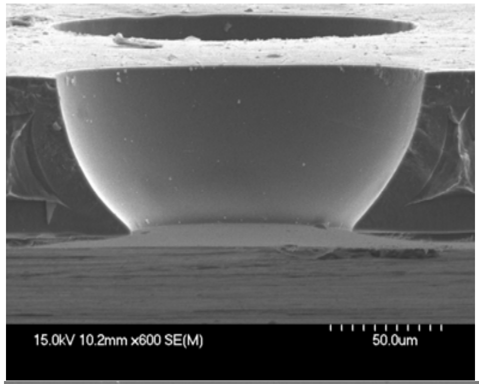
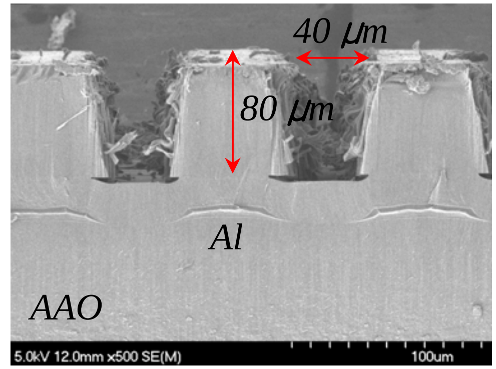
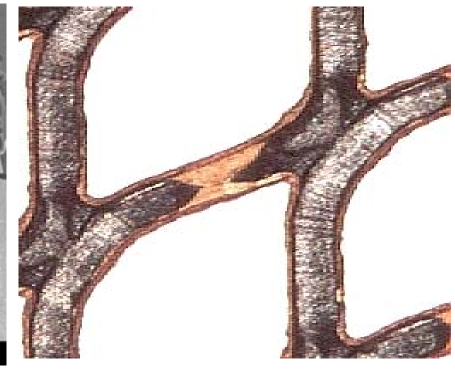
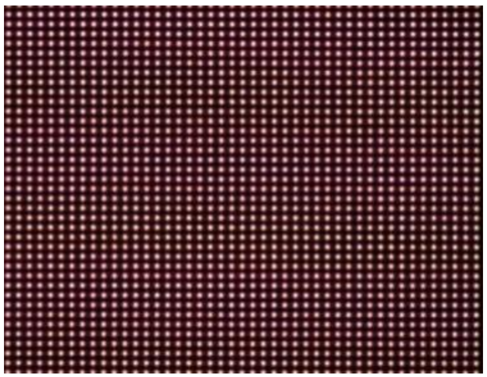
Microplasma Arrays at Illinois

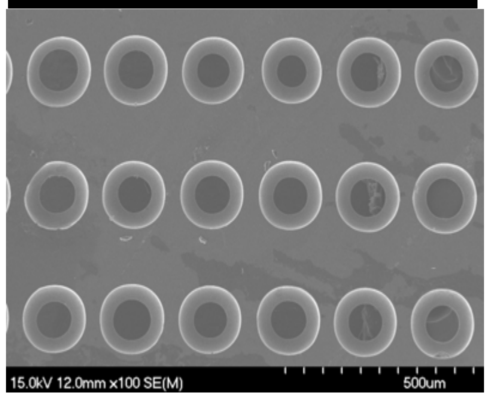


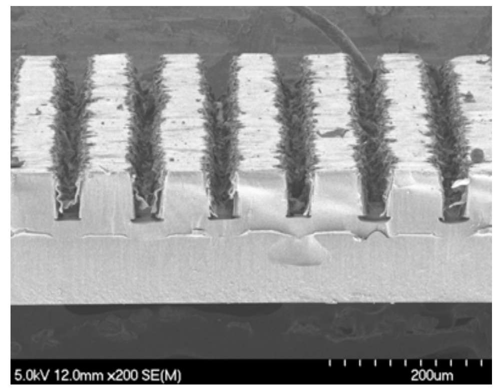


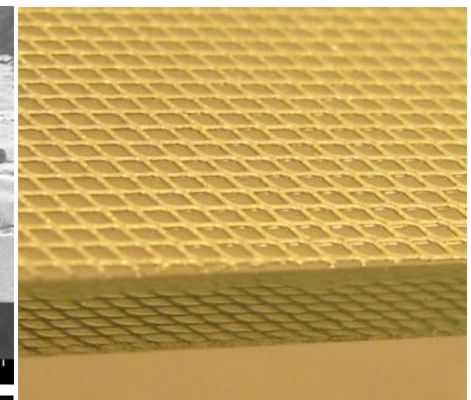


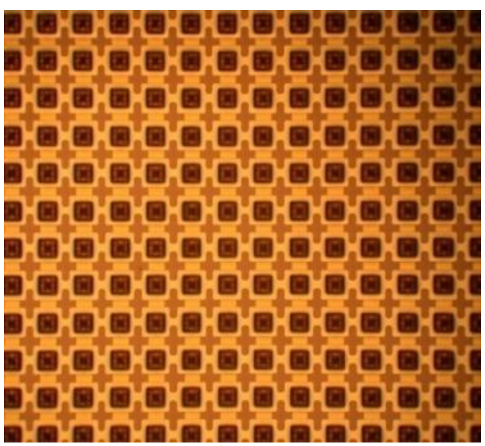


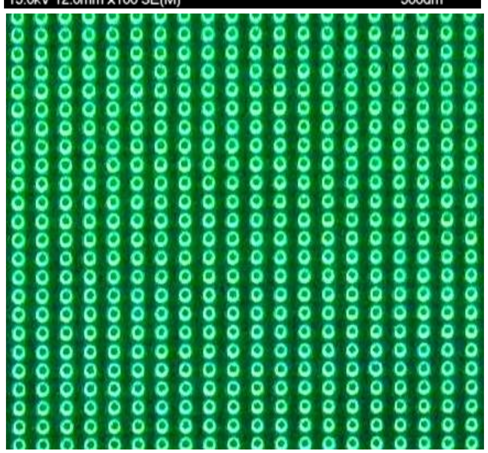


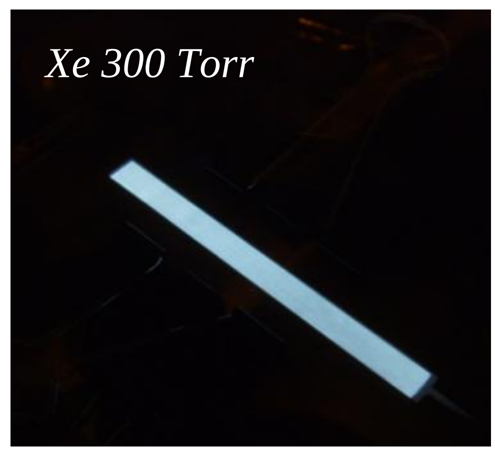


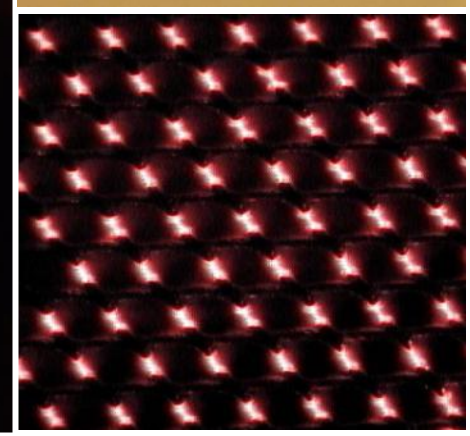




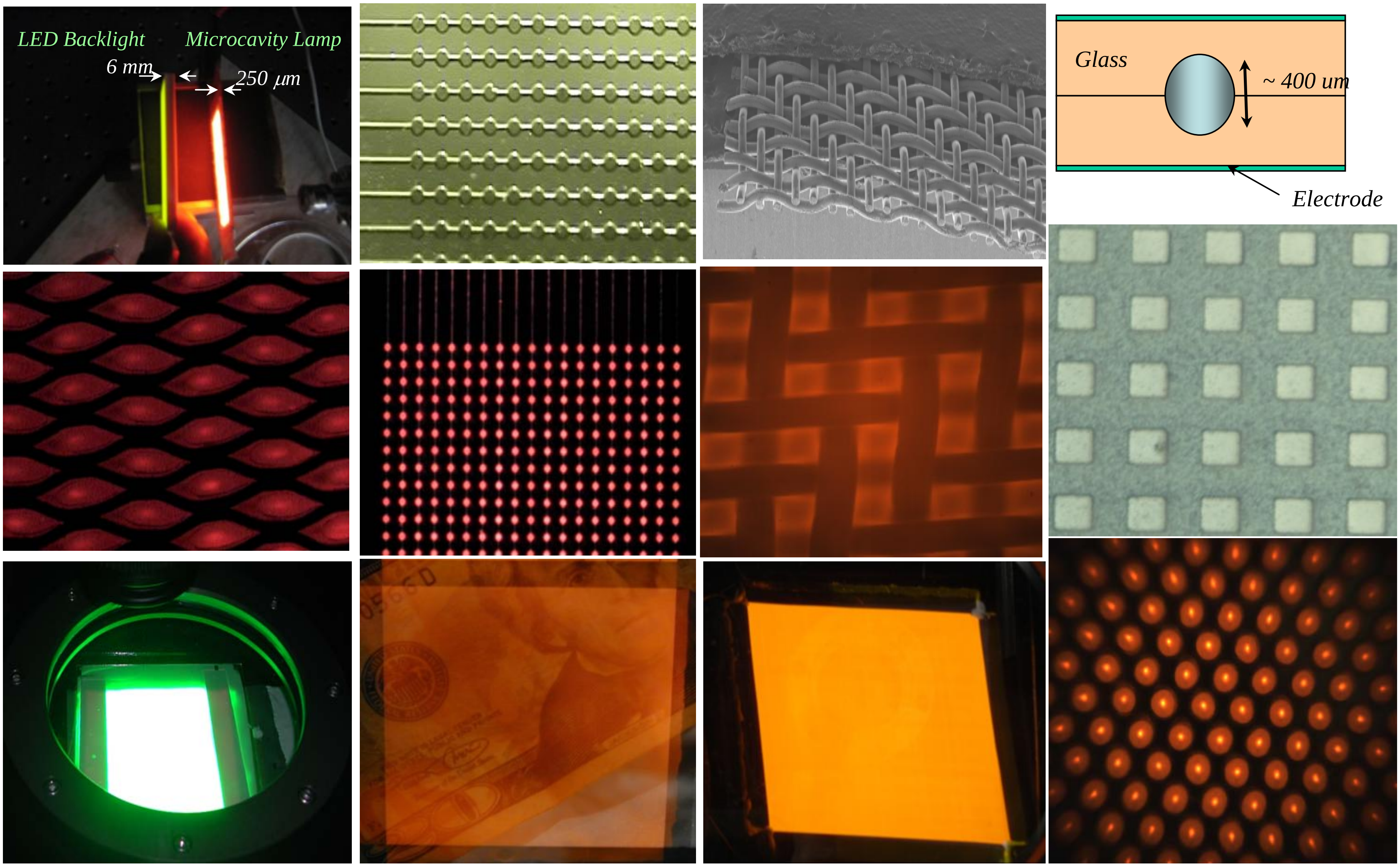




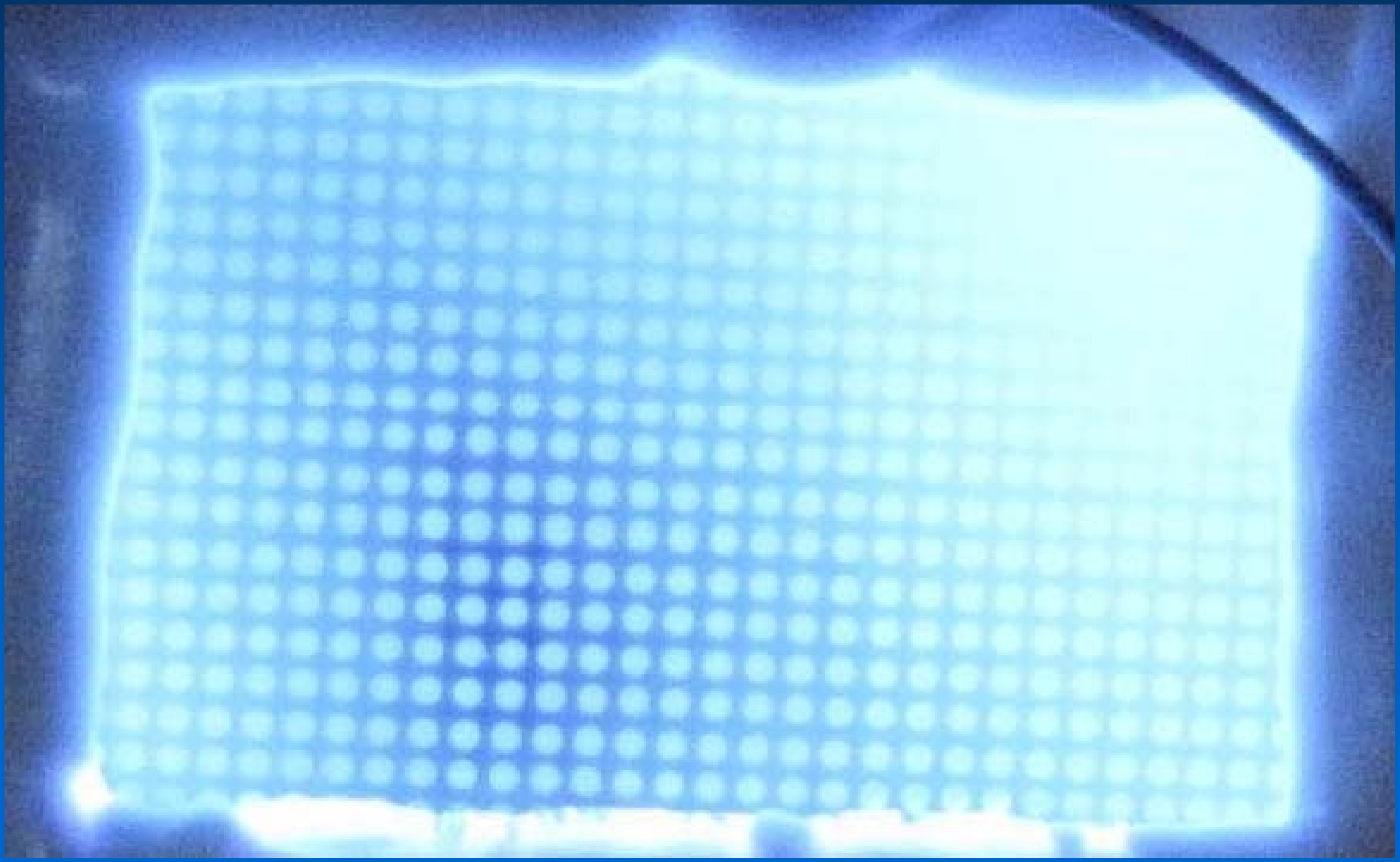




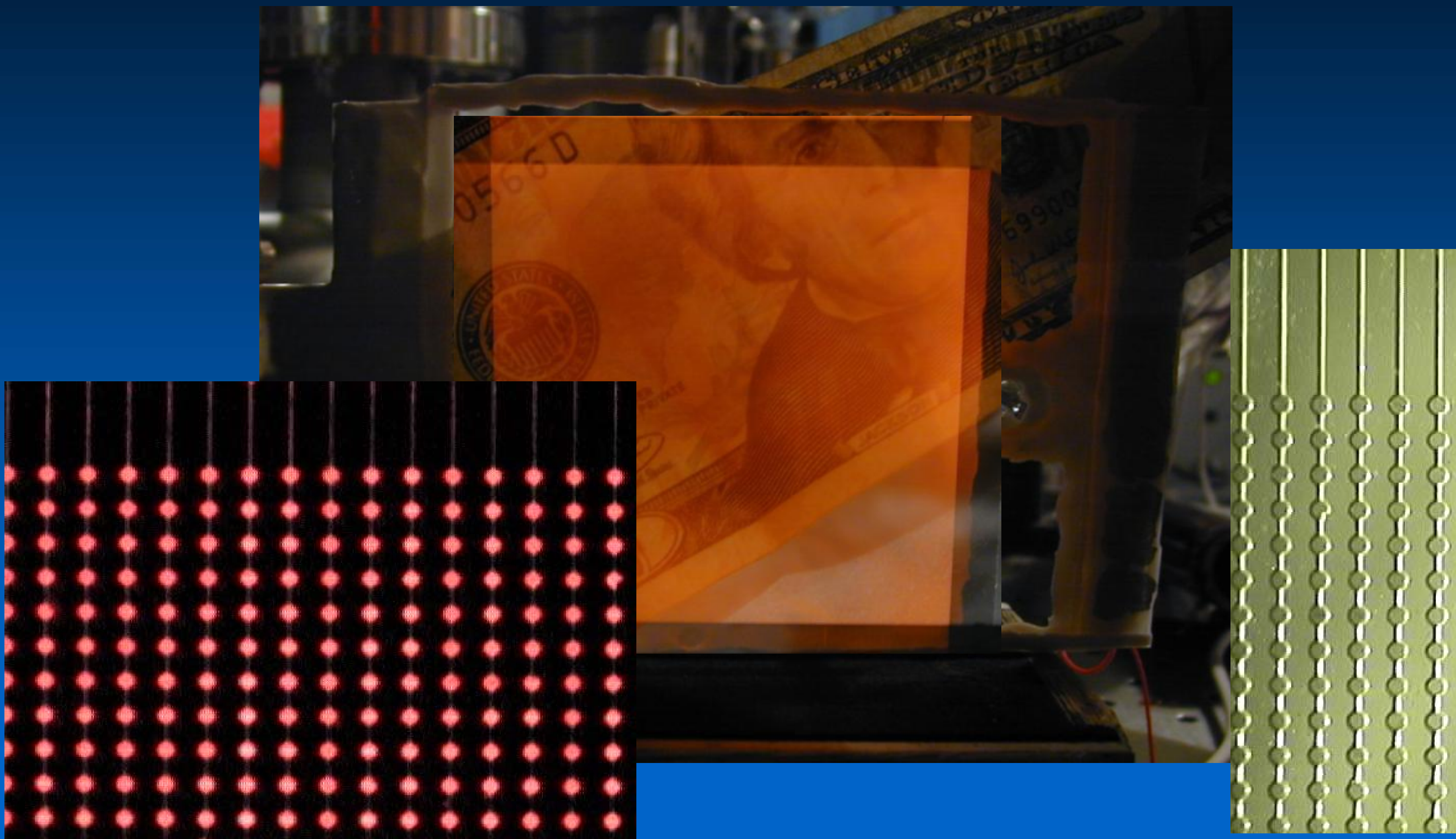
Microplasma Arrays at Illinois



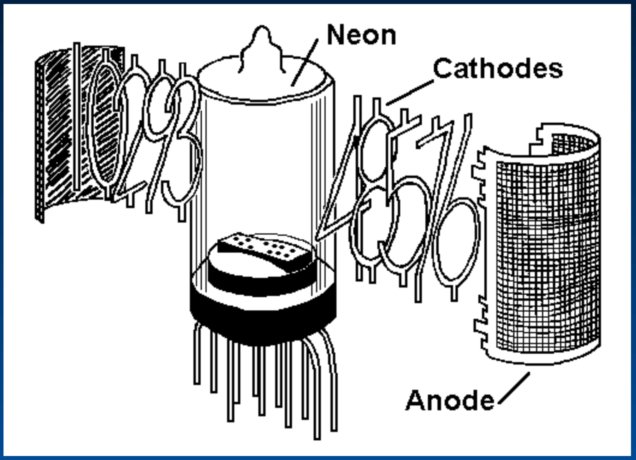
OPERATION OF MICROCAVITY PLASMA DEVICES IN ATMOSPHERIC AIR

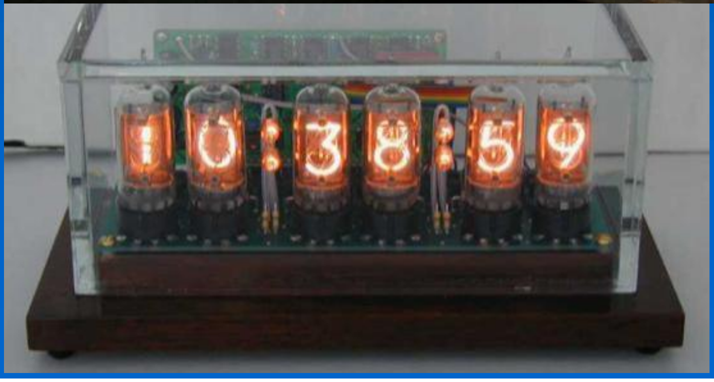


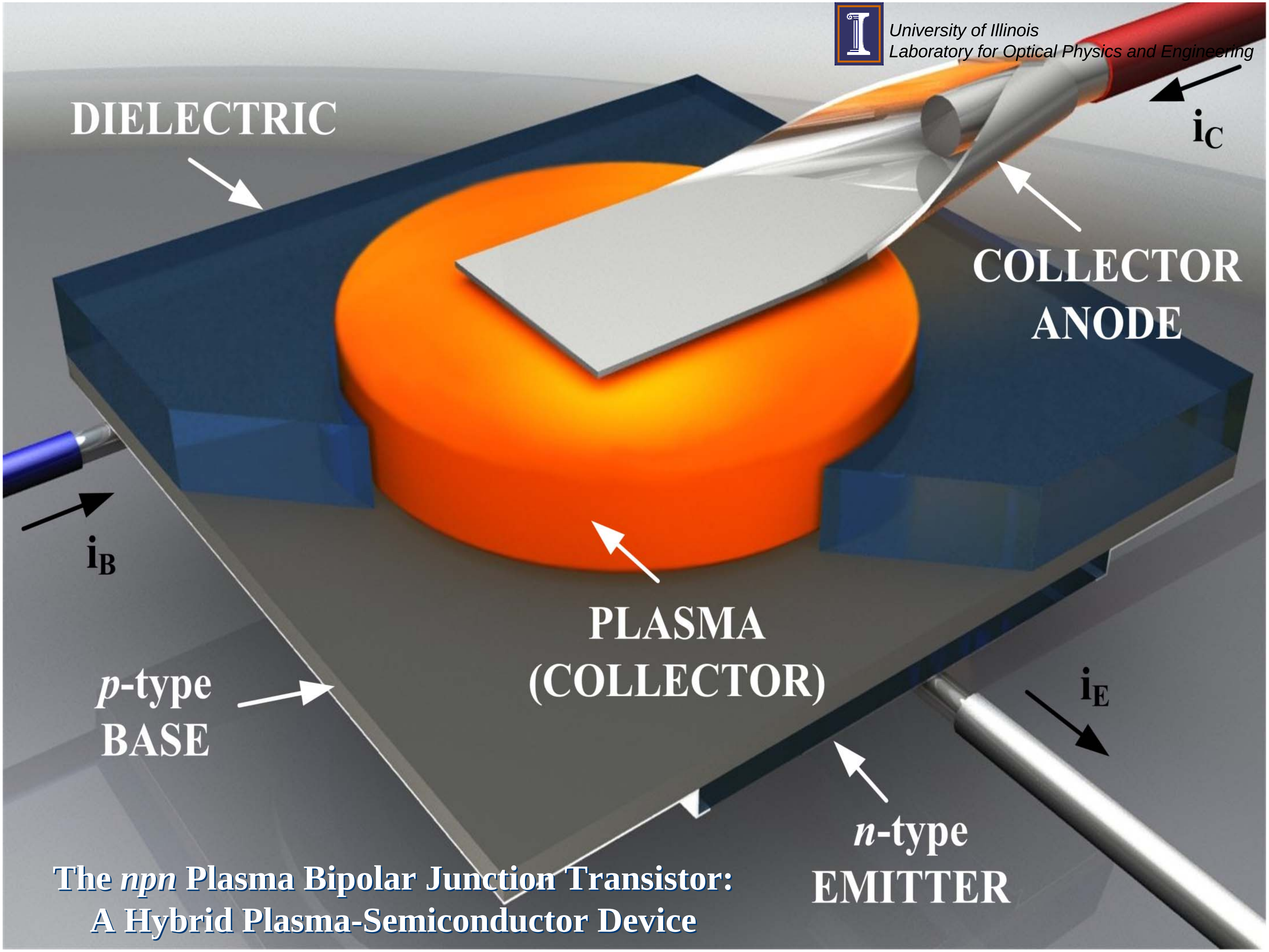
FULLY TRANSPARENT 250 × 250 MICROCAVITY ARRAY



PLASMA ELECTRONICS/PHOTONICS: NIXIE TUBES



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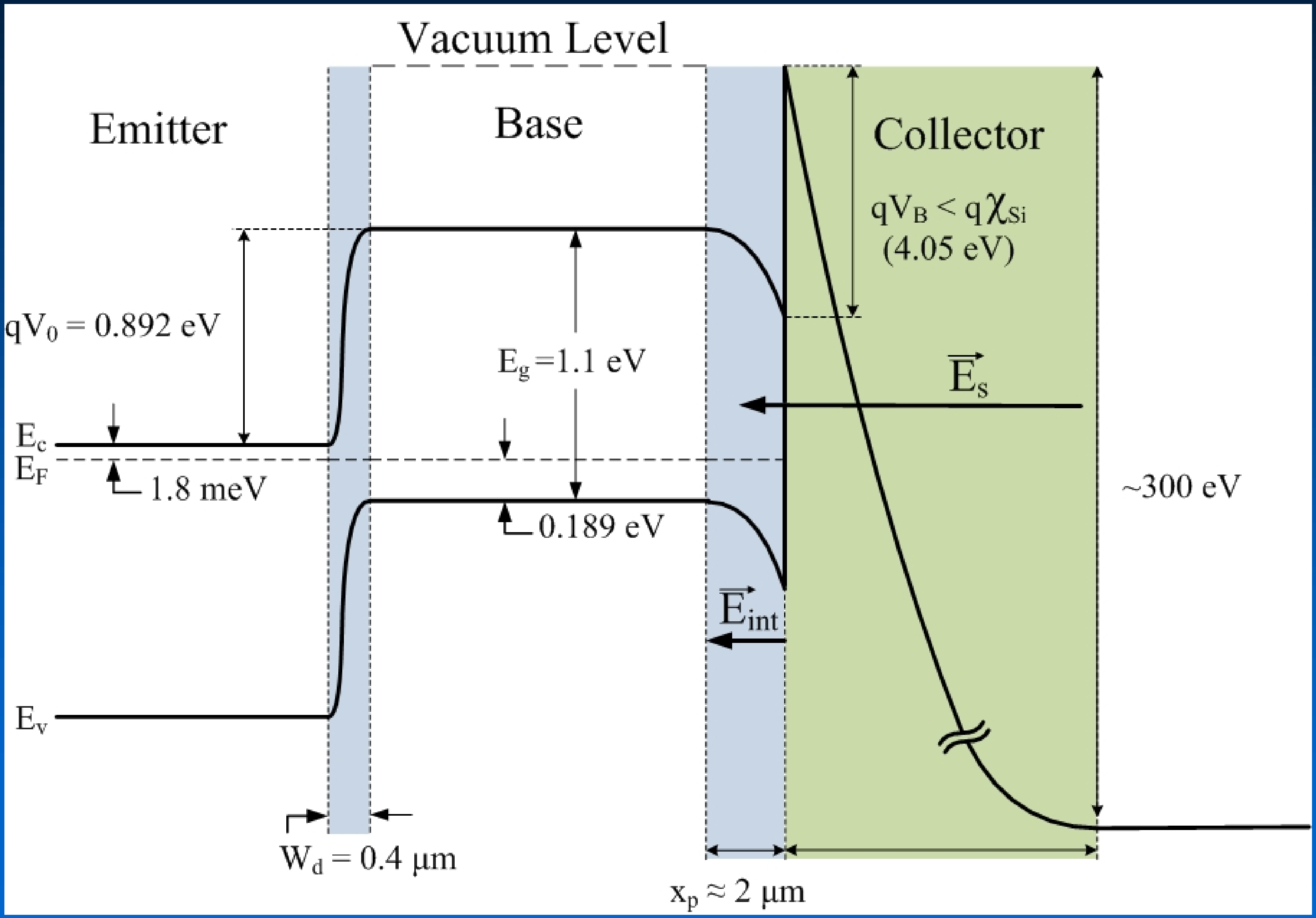
DIELECTRIC
COLLECTOR
ANODE
i_C
i_B
PLASMA
(COLLECTOR)
p-type
BASE
i_E
n-type
EMITTER
The *npn* Plasma Bipolar Junction Transistor:
A Hybrid Plasma-Semiconductor Device


Vacuum Level
Emitter
Base
Collector
$qV_B < q\chi_{Si}$
(4.05 eV)
$qV_0 = 0.892$ eV
$E_g = 1.1$ eV
$\vec{E}_s$
E_c
E_F
1.8 meV
~300 eV
0.189 eV
$\vec{E}_{int}$
E_v
$W_d = 0.4$ μm
$x_p \approx 2$ μm

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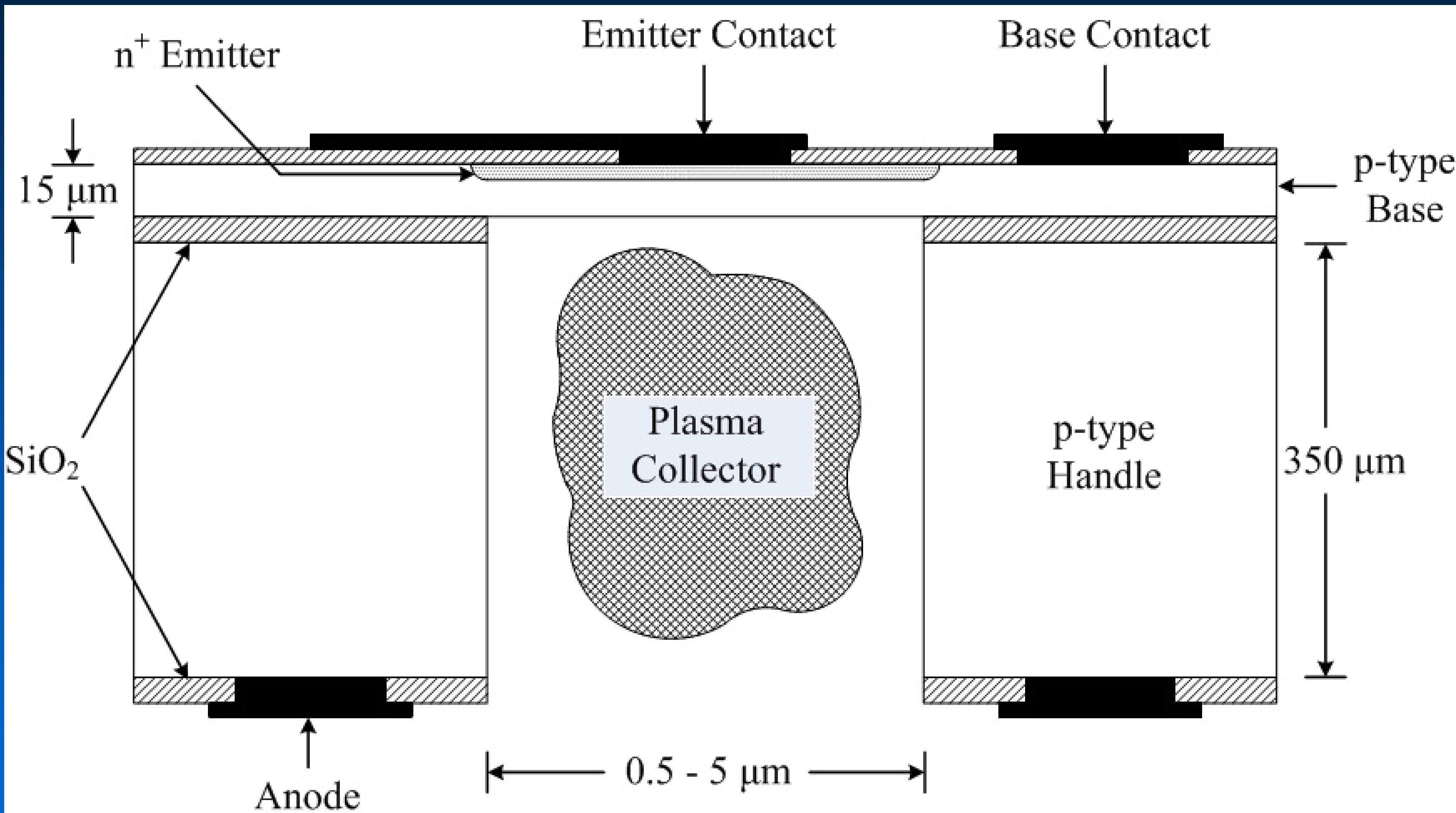
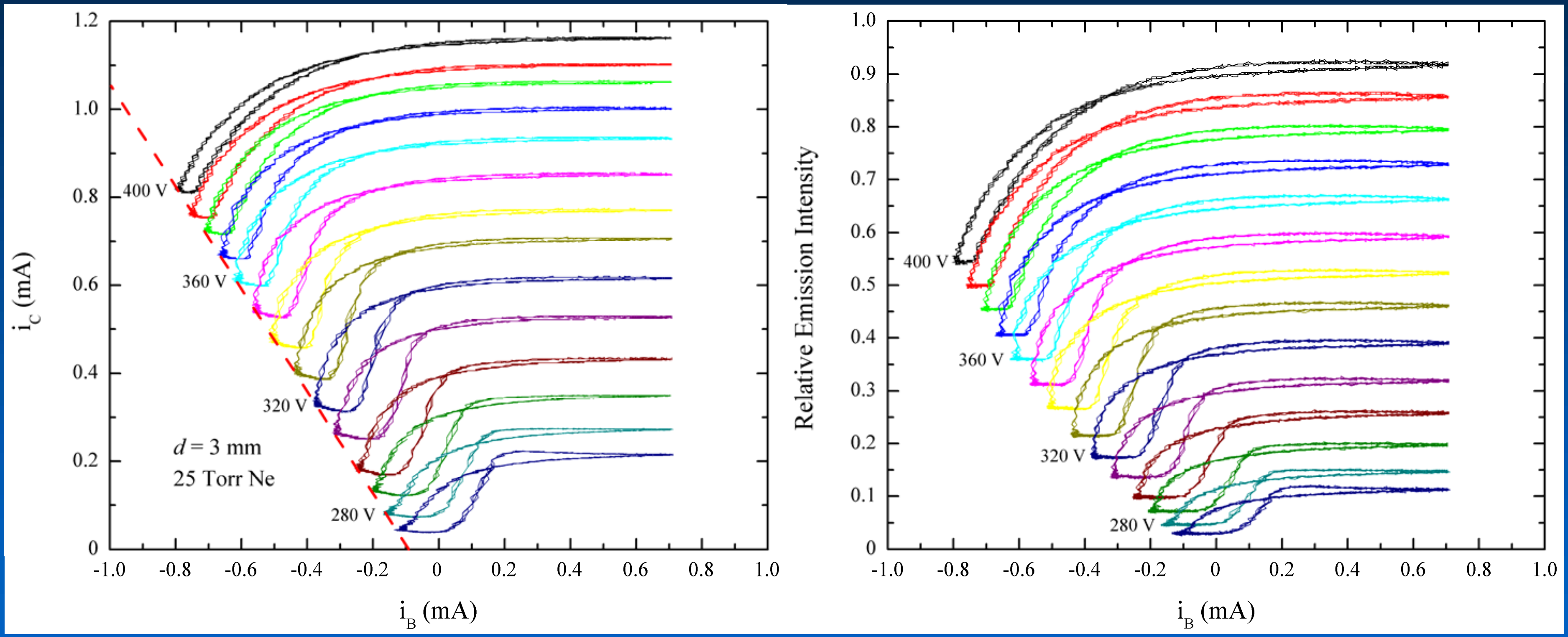
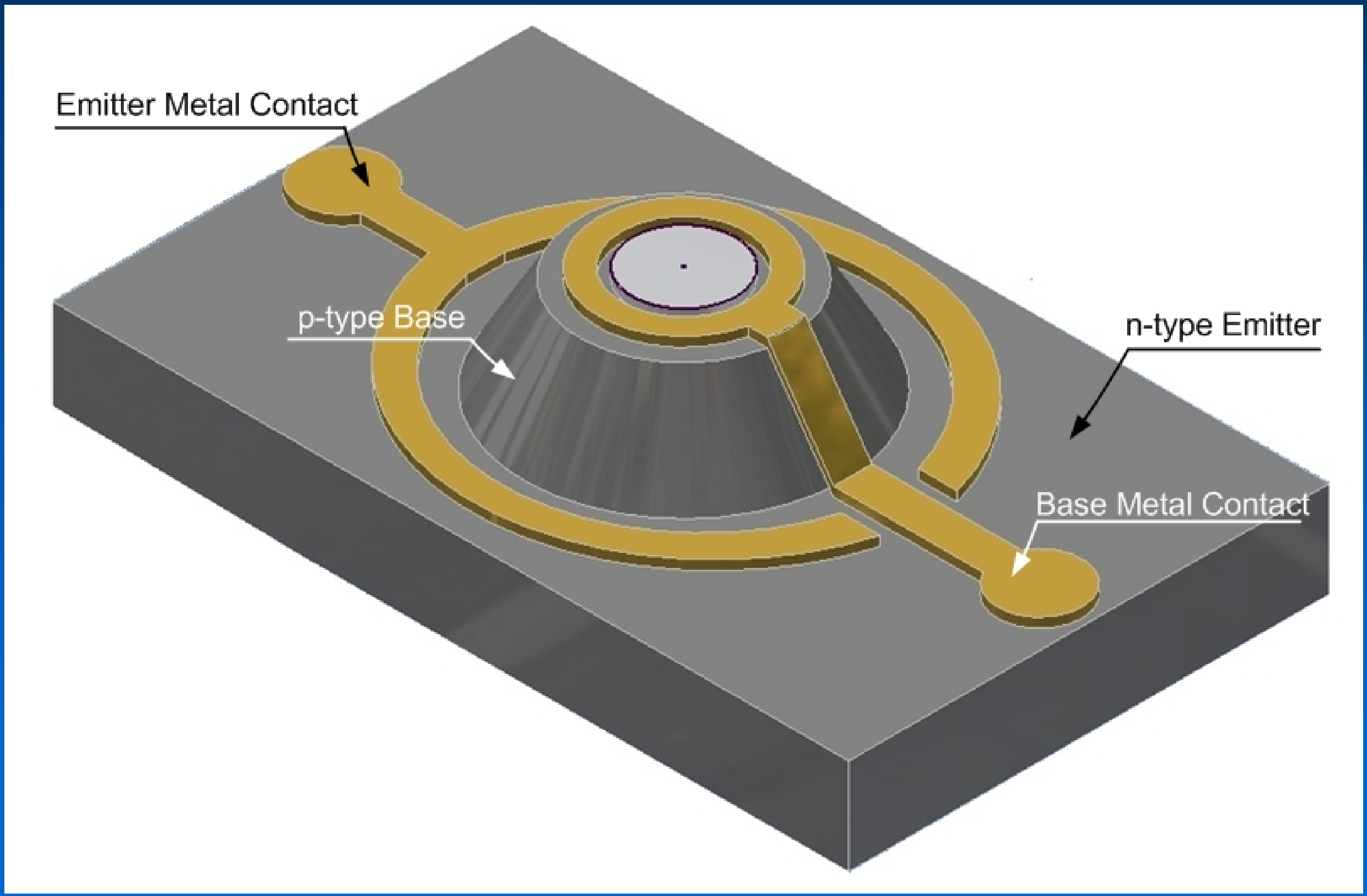


BASE-COLLECTOR CHARACTERISTICS

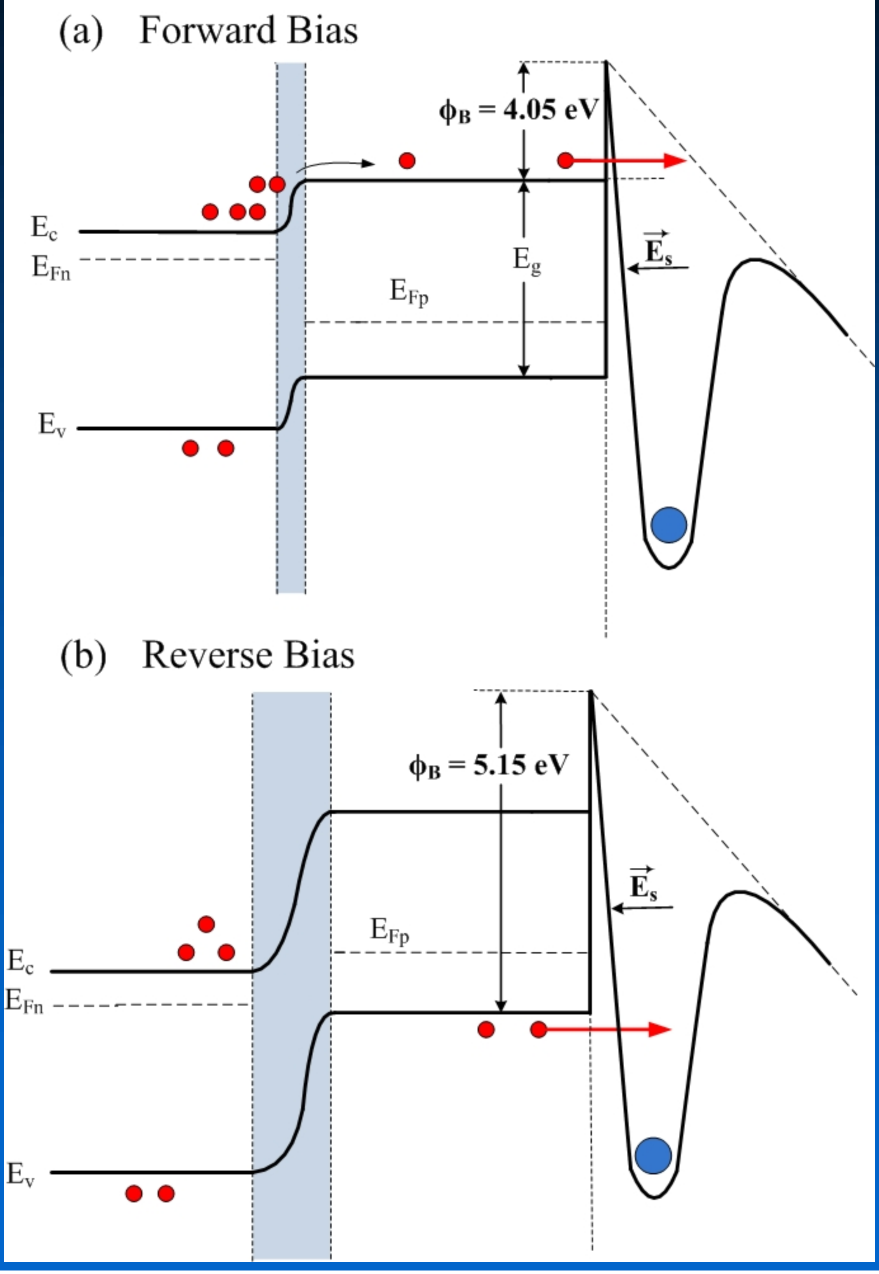


25 Torr Ne

MESA DEVICE STRUCTURE

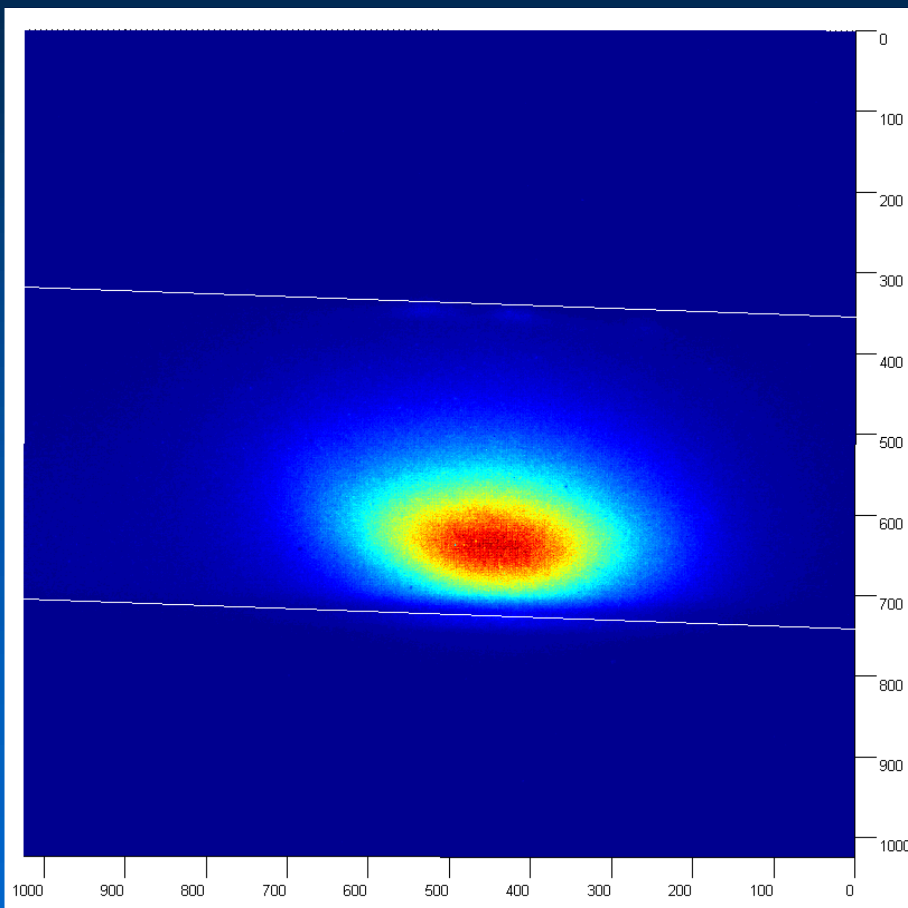


ENERGY BAND DIAGRAM

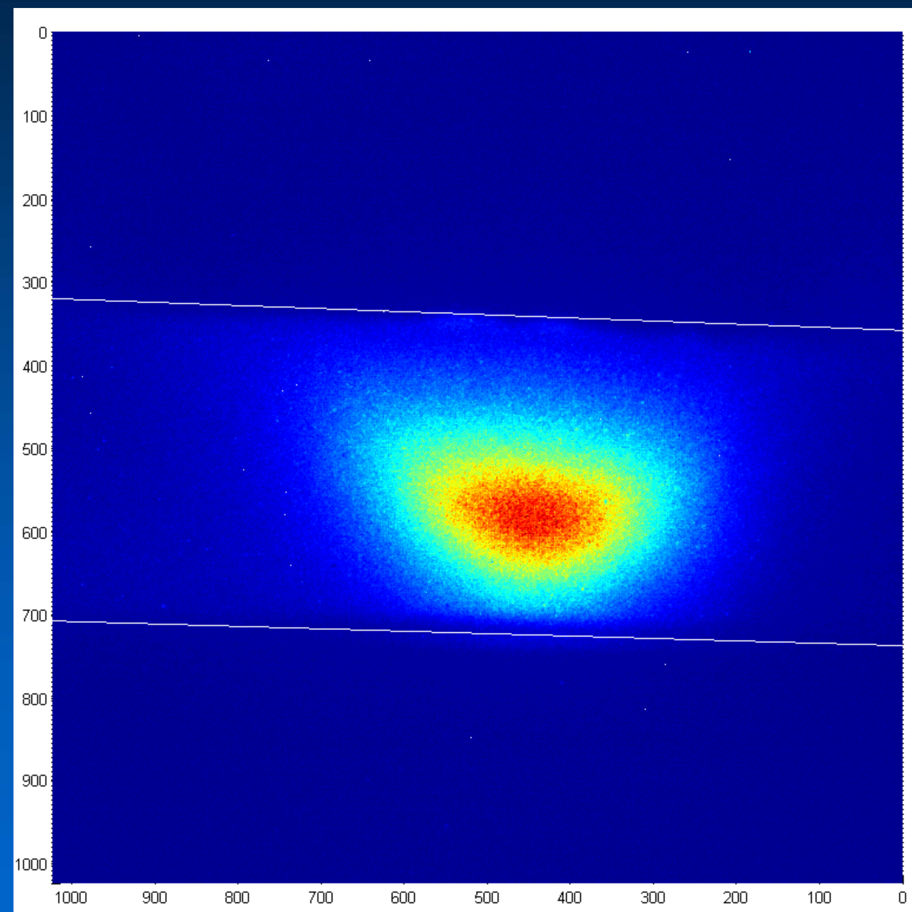


- Control of the Effective Secondary Electron Emission Coefficient

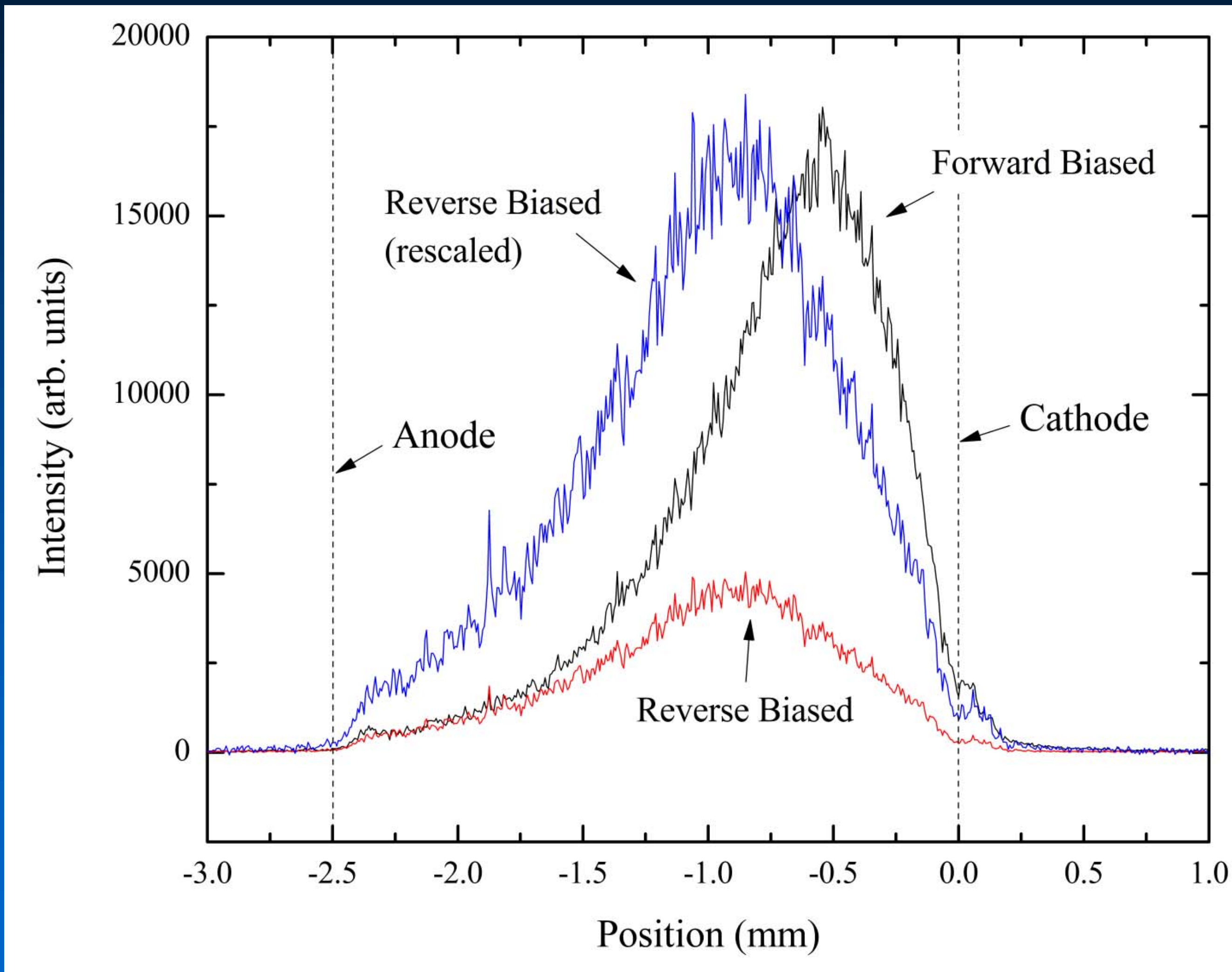
IMAGE OF COLLECTOR PLASMA

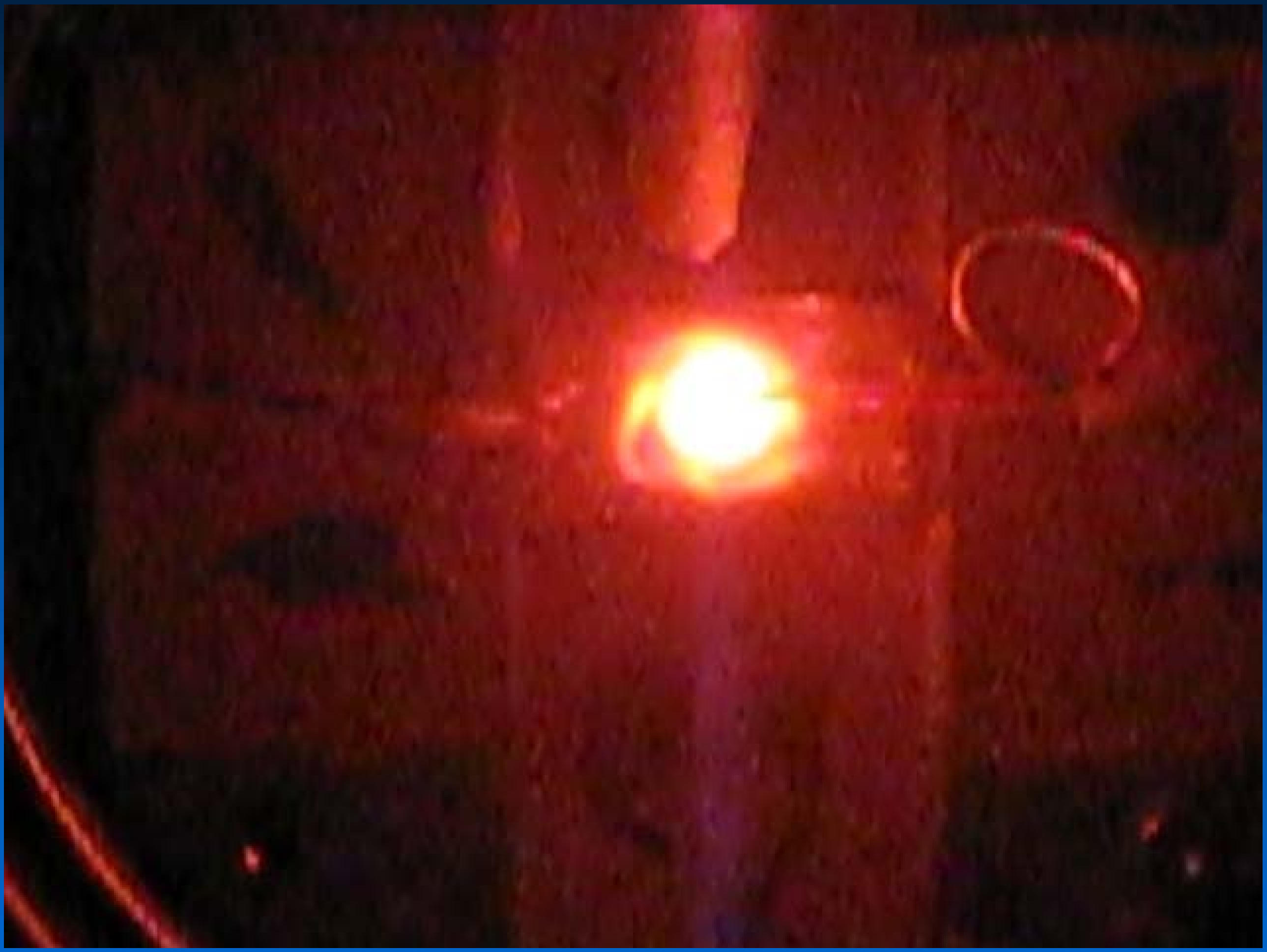


Forward Bias

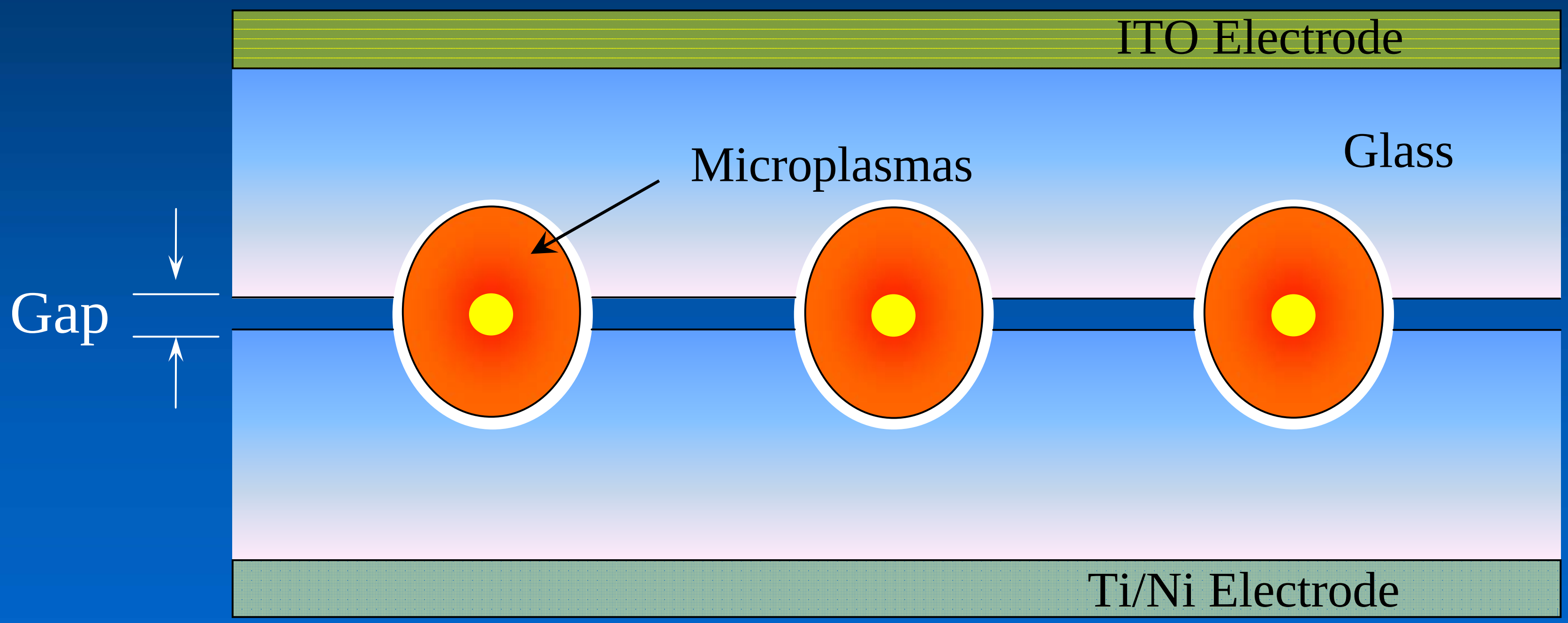


Reverse Bias


Reverse Biased
(rescaled)
Forward Biased
Anode
Cathode
Reverse Biased
Intensity (arb. units)
Position (mm)
20000
15000
10000
5000
0
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0



FREE-TO-BOUND PLASMA COUPLING



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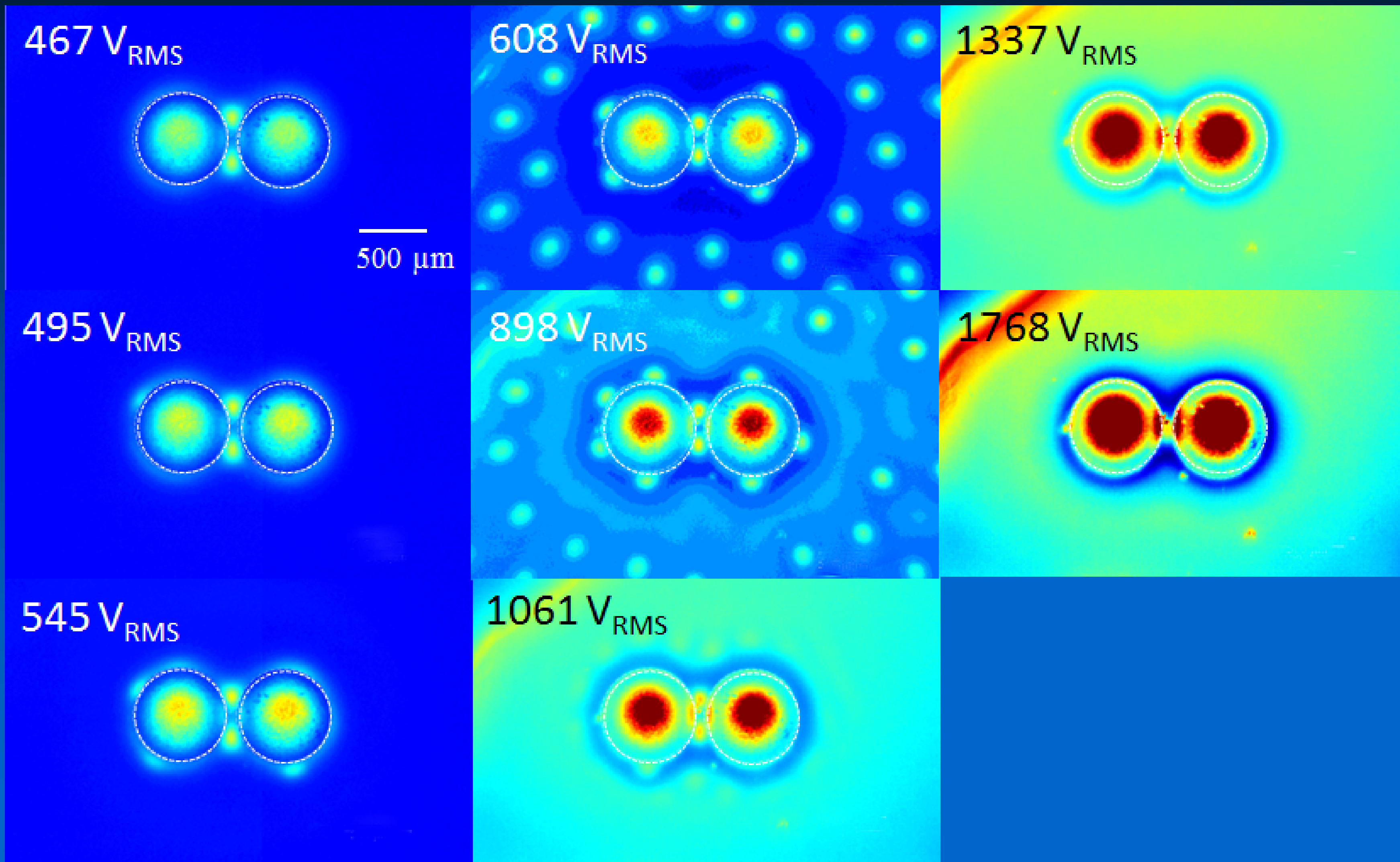
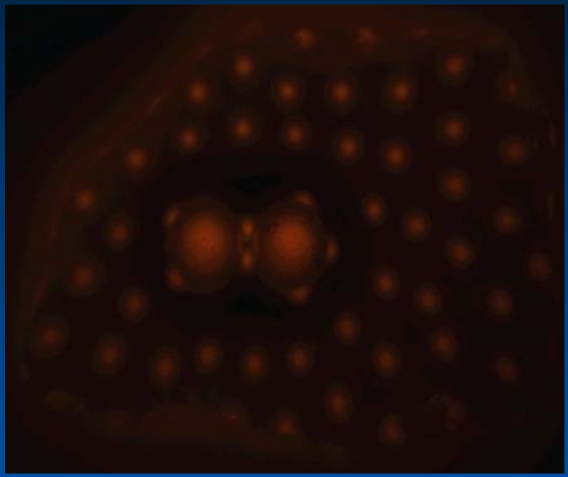
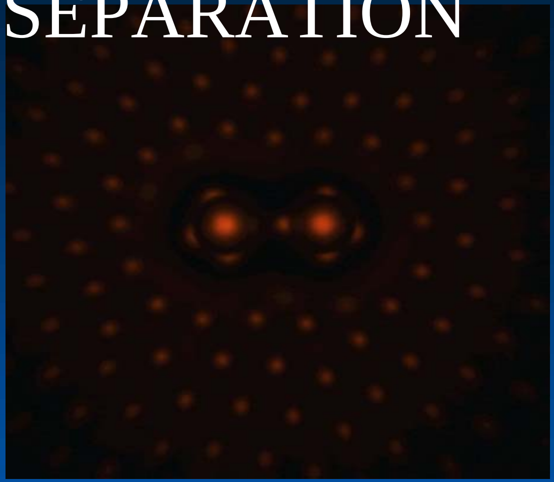


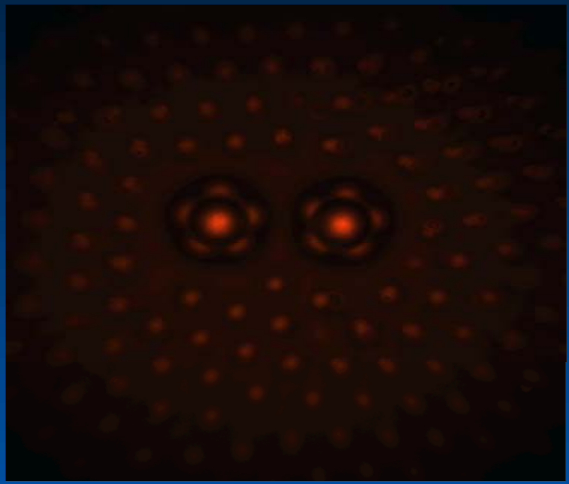
VARIATION OF BOUND PLASMA SEPARATION



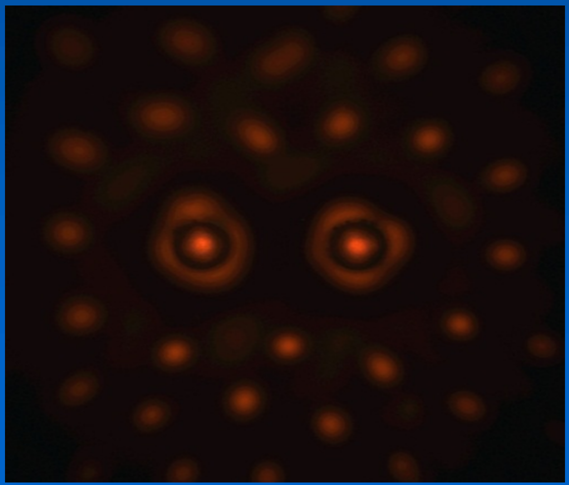
80 μm



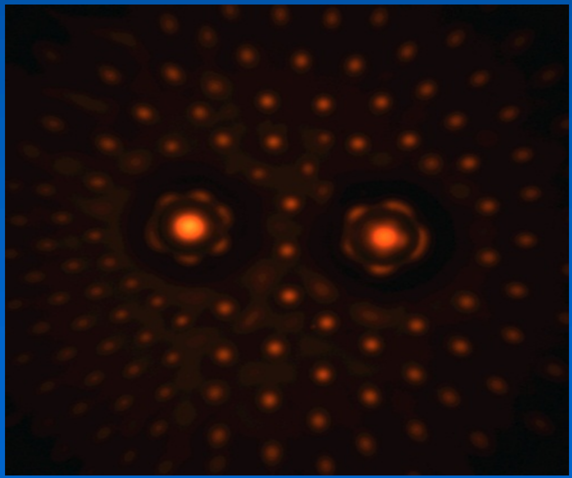
400 μm



800μm

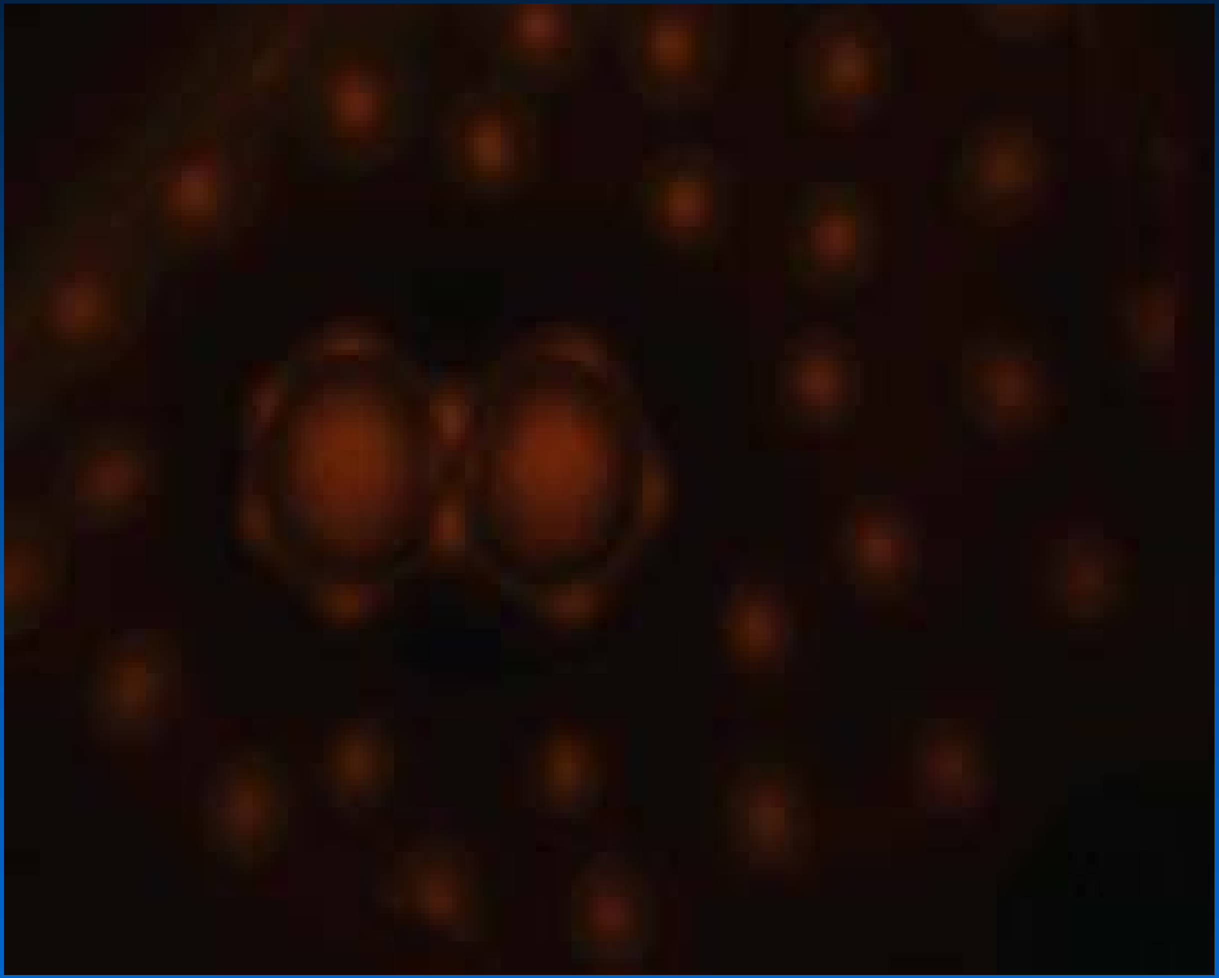


1.2 mm



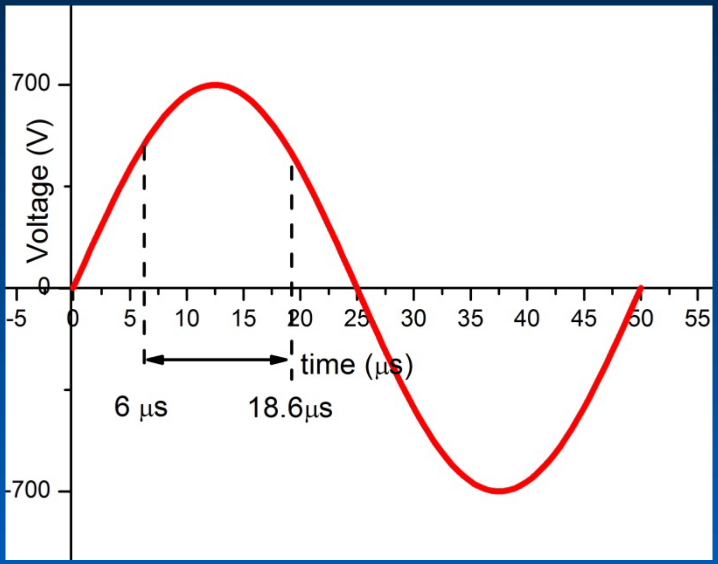
1.6 mm

d = 80 μm



P = 760 Torr Ne

TEMPORAL RESPONSE



Exposure time: 200 ns
Time frame: 6 μs ~ 18.6 μs

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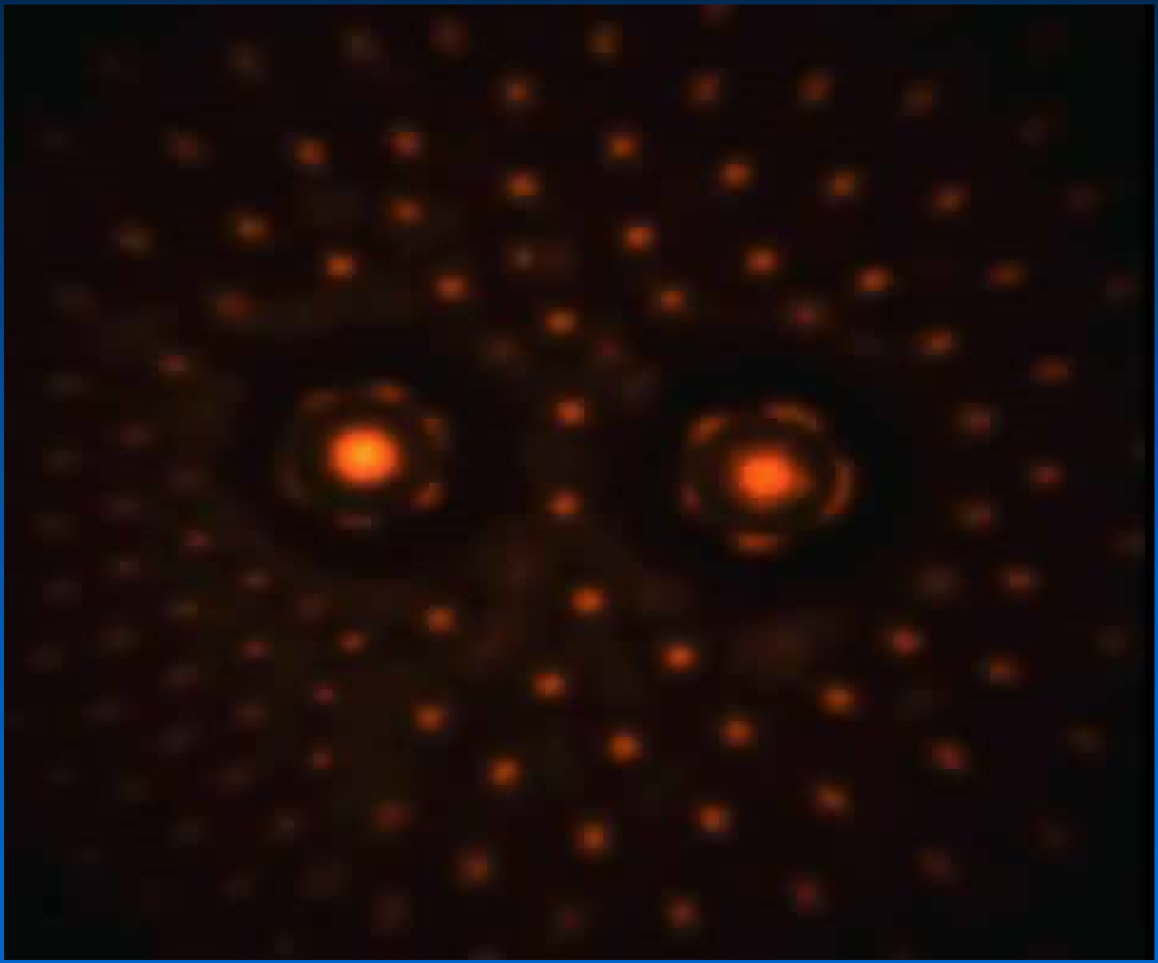
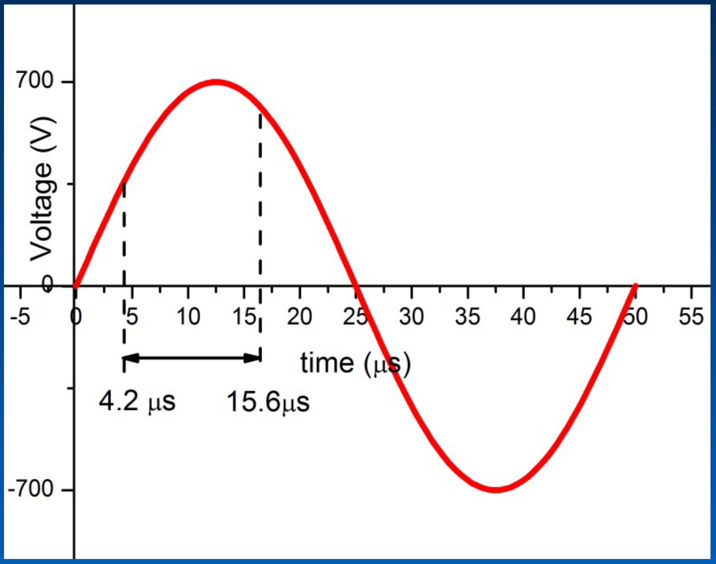
d = 1.6 mm



P_{Ne} = 760 Torr

TEMPORAL HISTORY



Exposure time: 200 ns
Time frame: 4.2 μs ~ 15.6 μs

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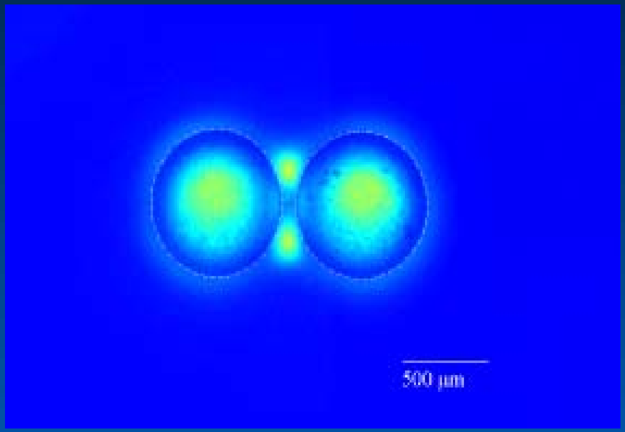
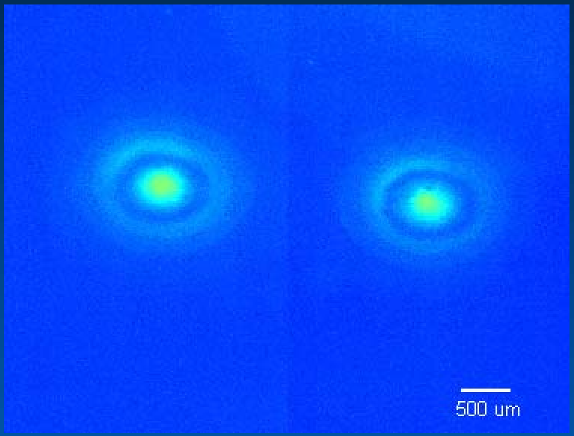
FALSE COLOR (TIME INTEGRATED)

80 μm device

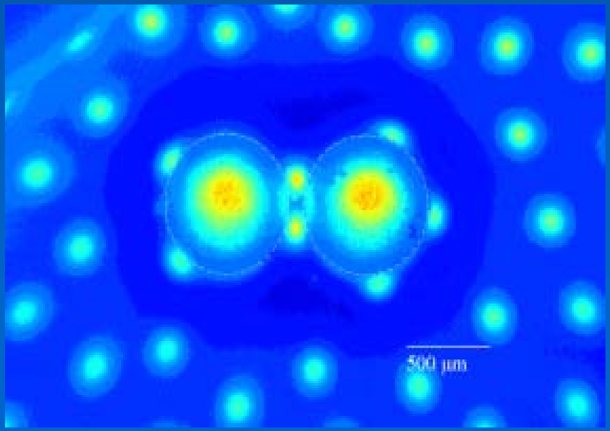
1.6 mm device



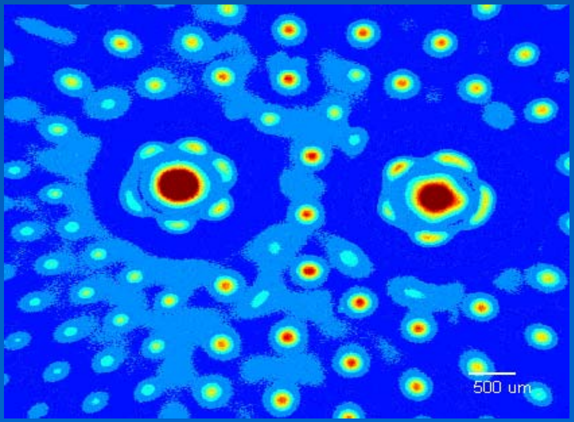
467 V_{RMS}



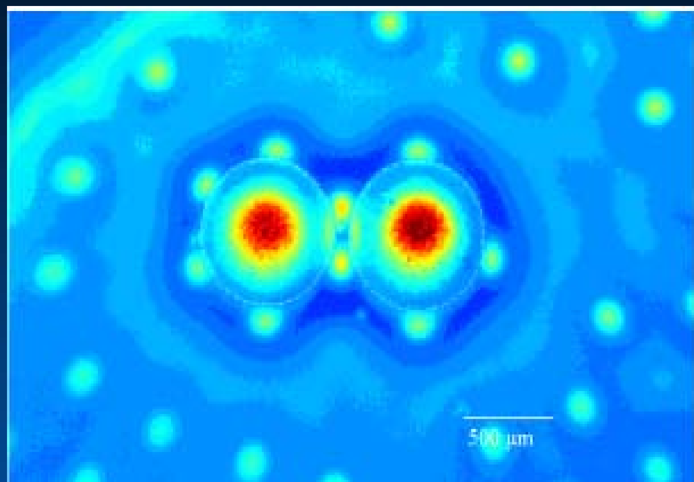
346 V_{RMS}



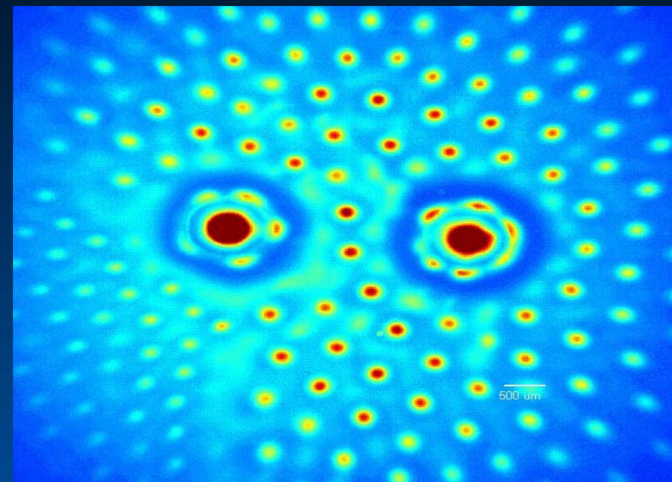
608 V_{RMS}



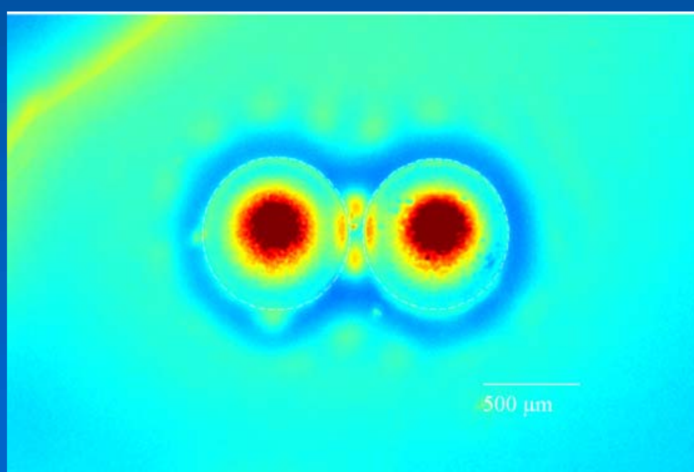
494 V_{RMS}



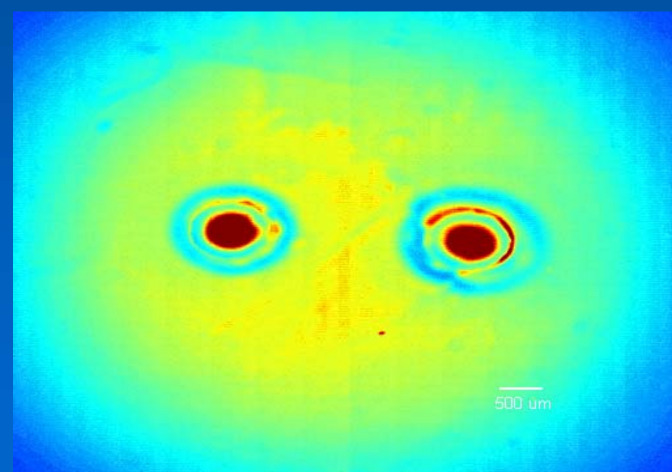
898 V_{RMS}



636 V_{RMS}

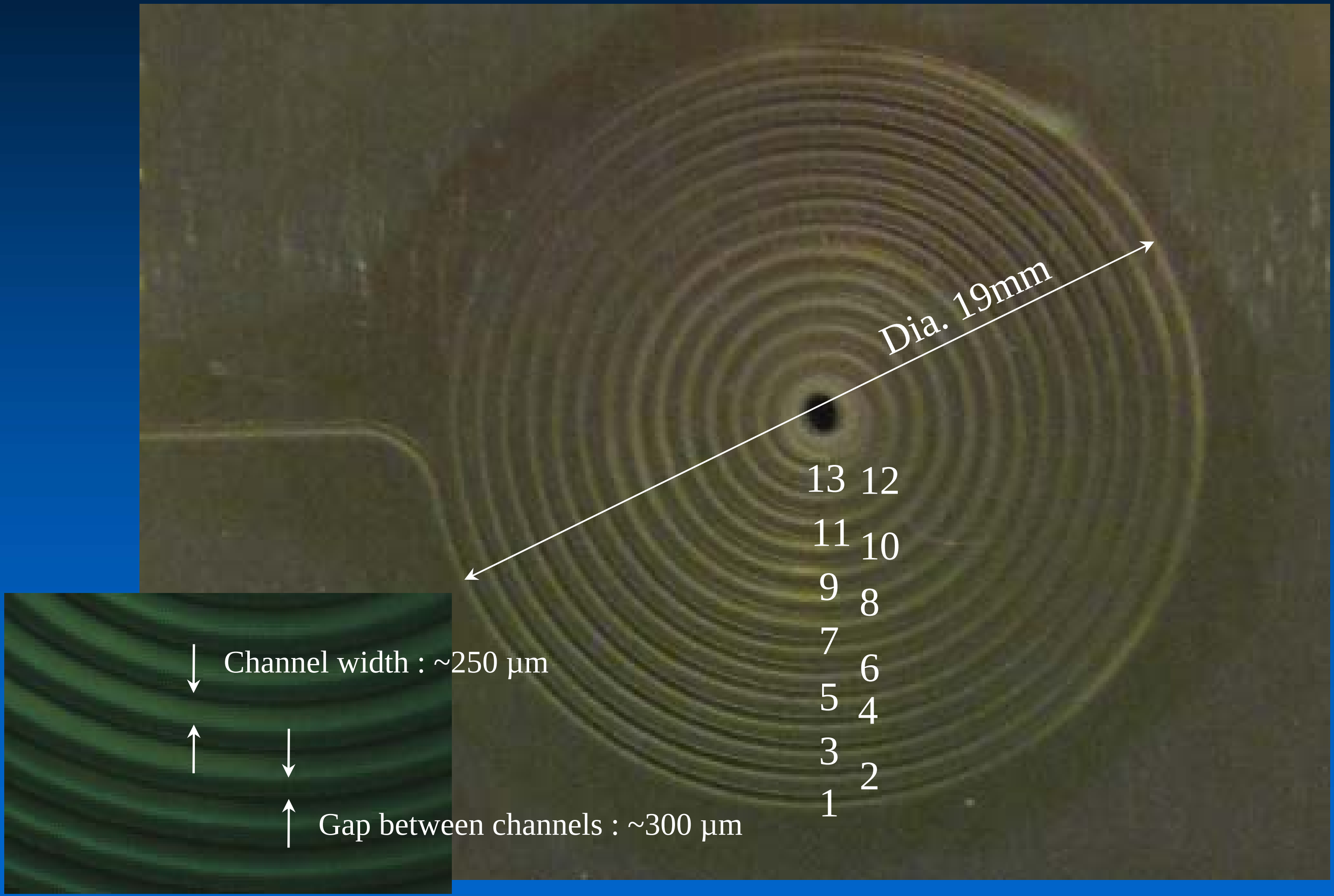


1061 V_{RMS}

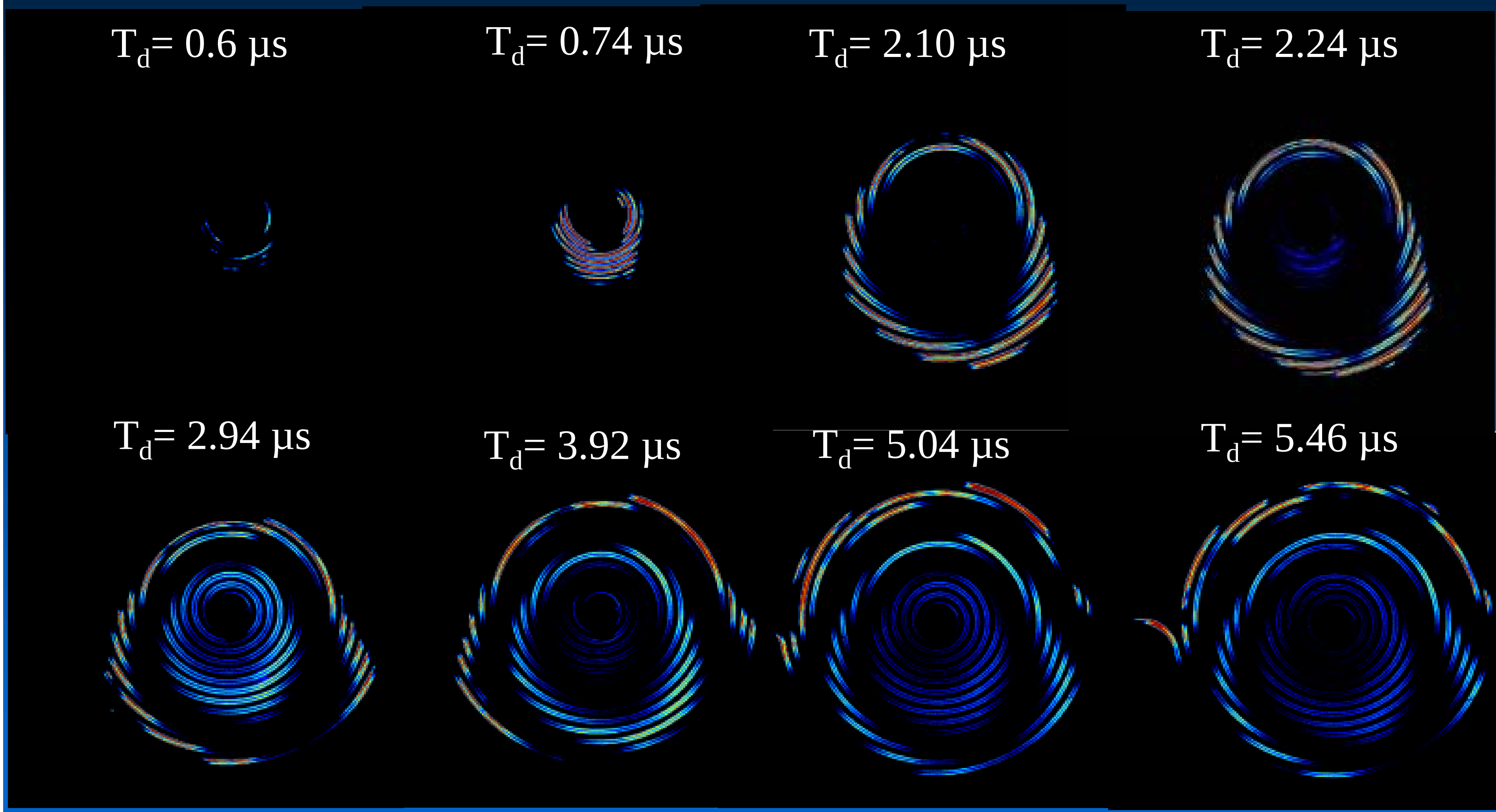


1060 V_{RMS}

SINGLE MICROCHANNEL SPIRAL STRUCTURE



PLASMA PROPAGATION



760 Torr Ar

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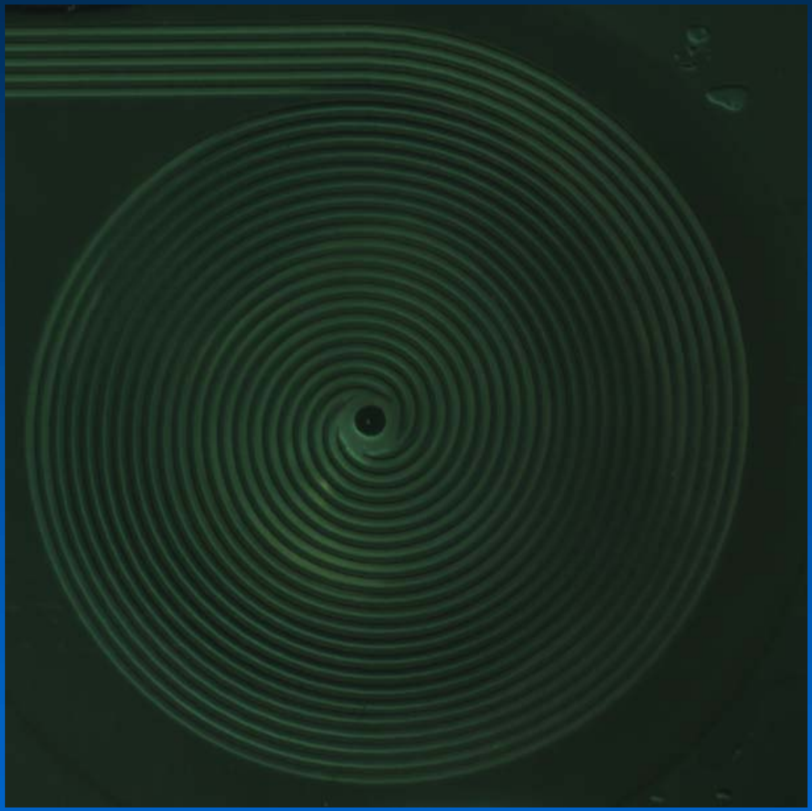
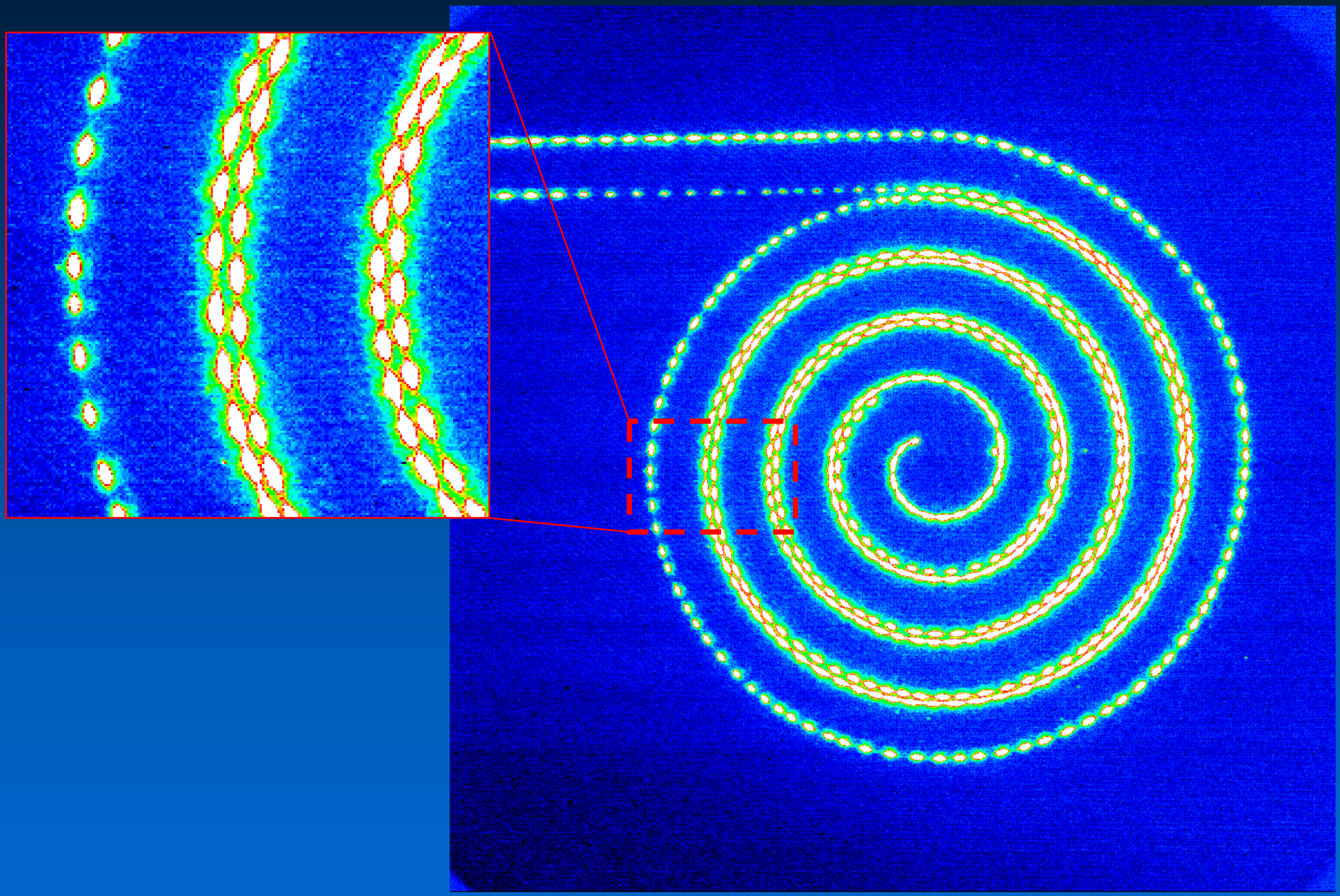
5 CHANNELS SPIRAL DEVICE

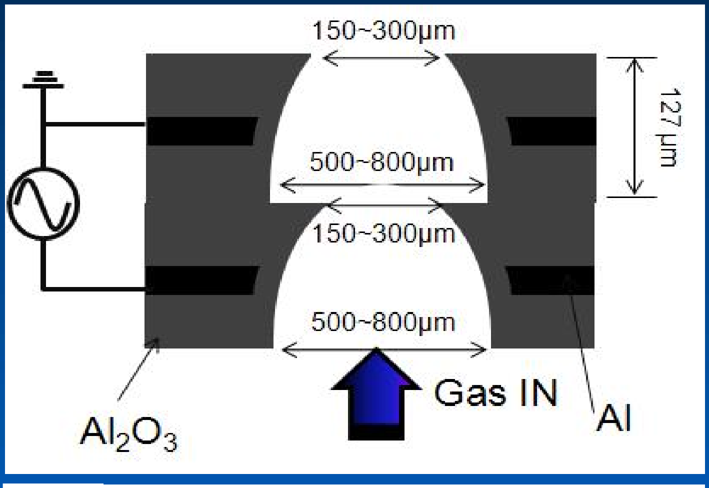


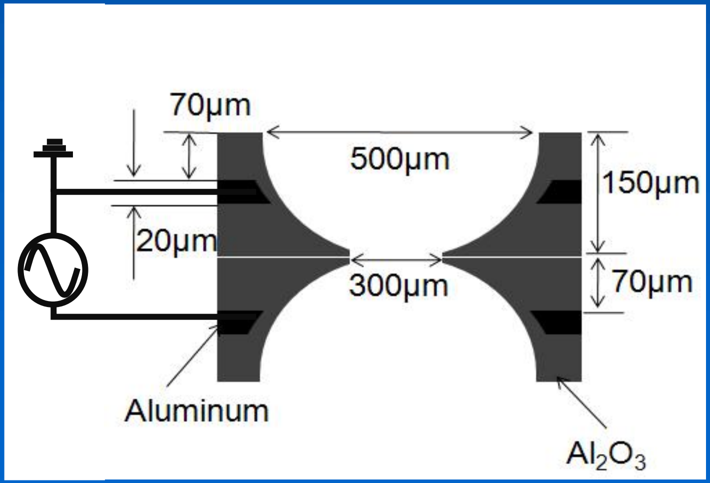
Ne 600 Torr

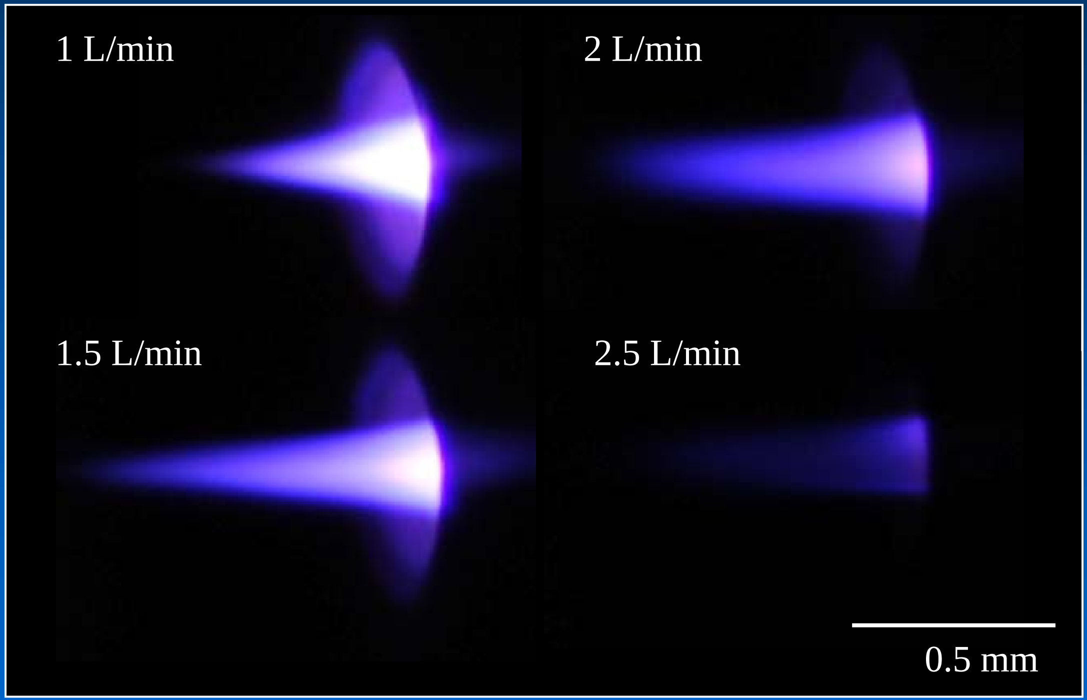


Exposure time: 50 ns

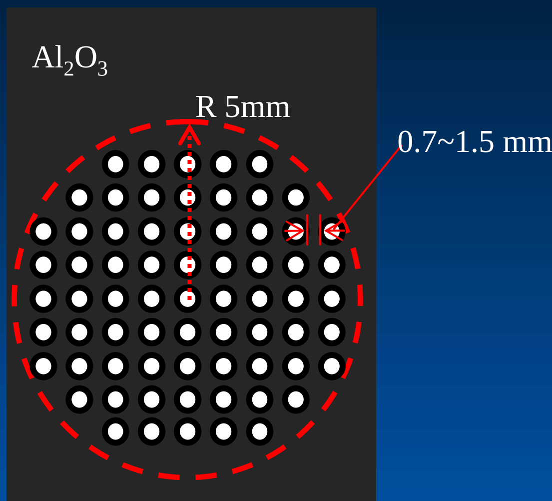
Al/Al_2O_3 MICROCAVITY PLASMA JET DEVICE



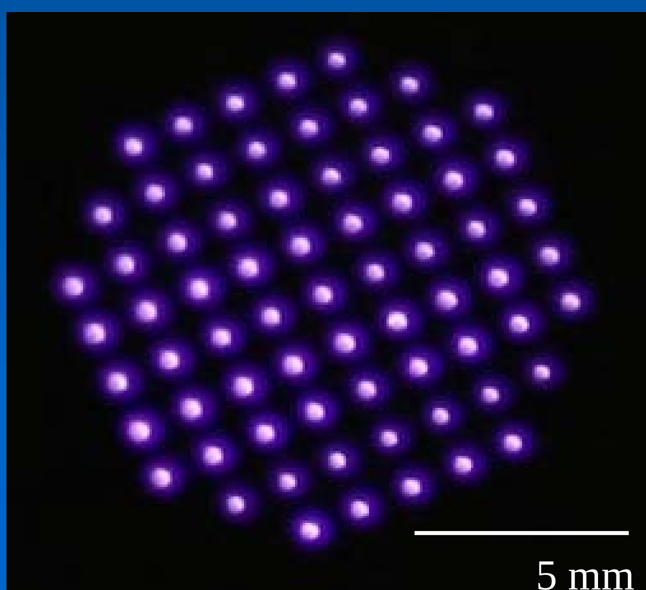


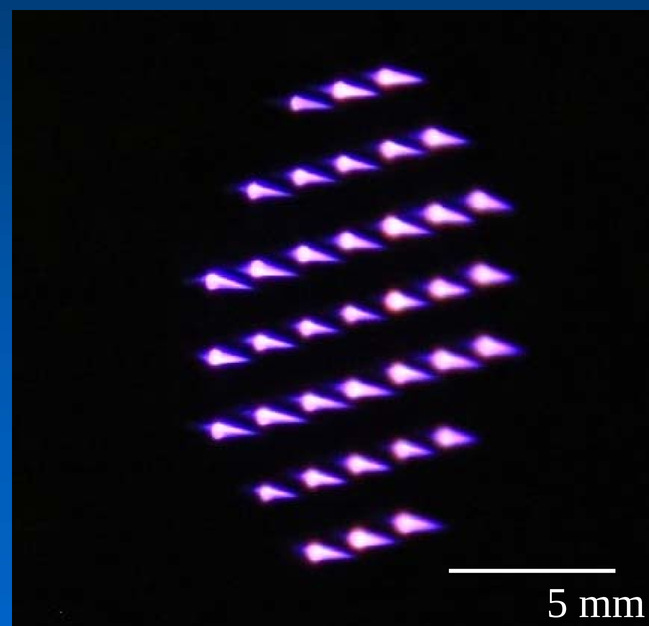


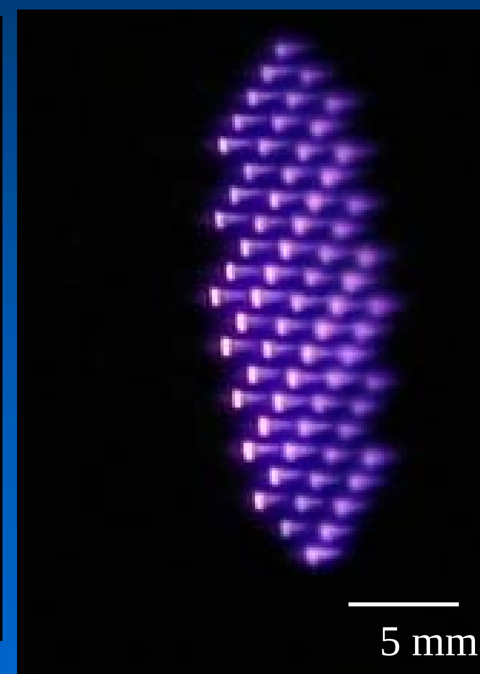
Al/Al_2O_3 MICROCAVITY JET ARRAY: PARALLEL OPERATION



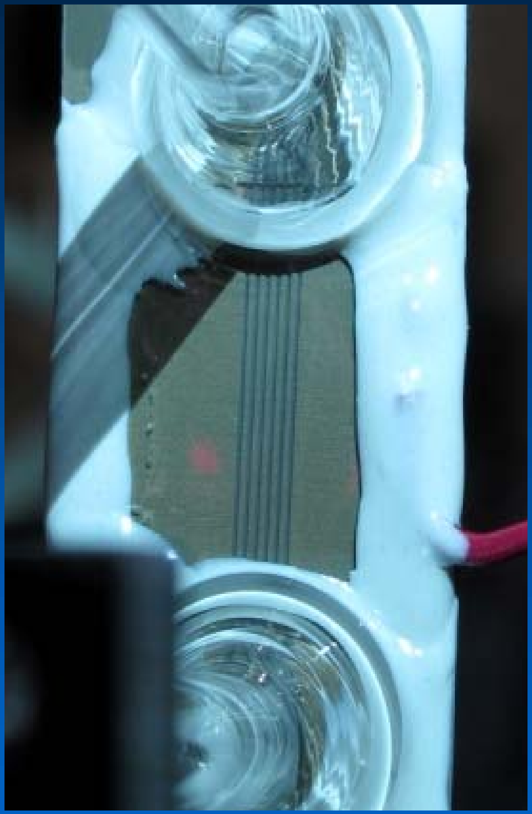
Up to150 cavities



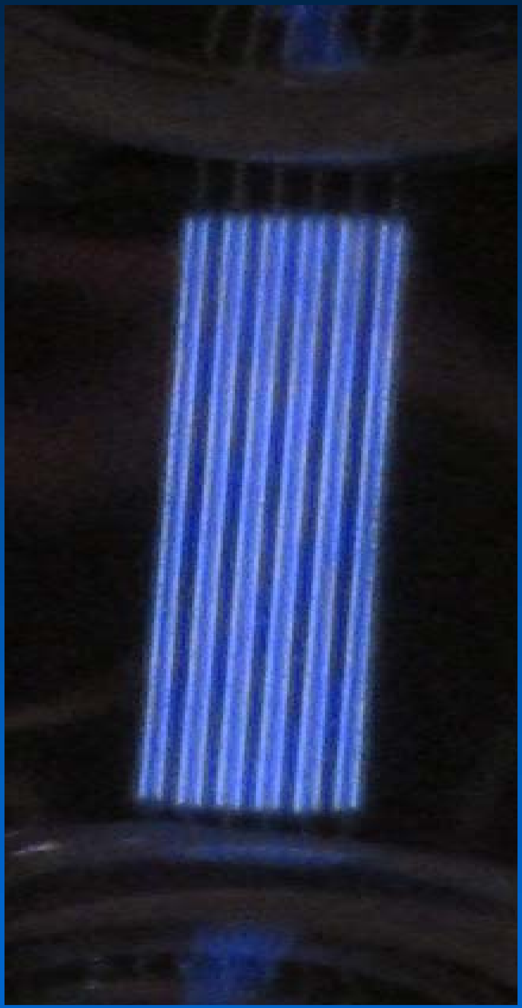


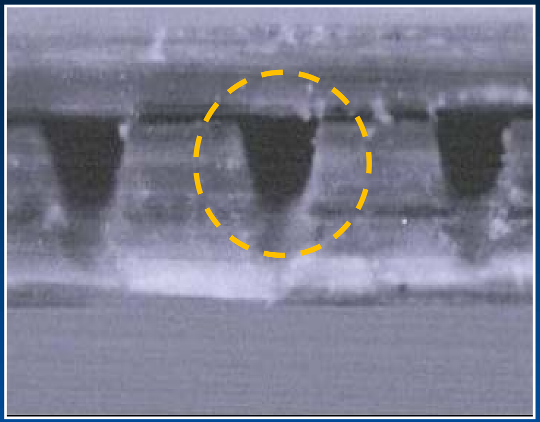


MICROPLASMA GENERATION OF OZONE



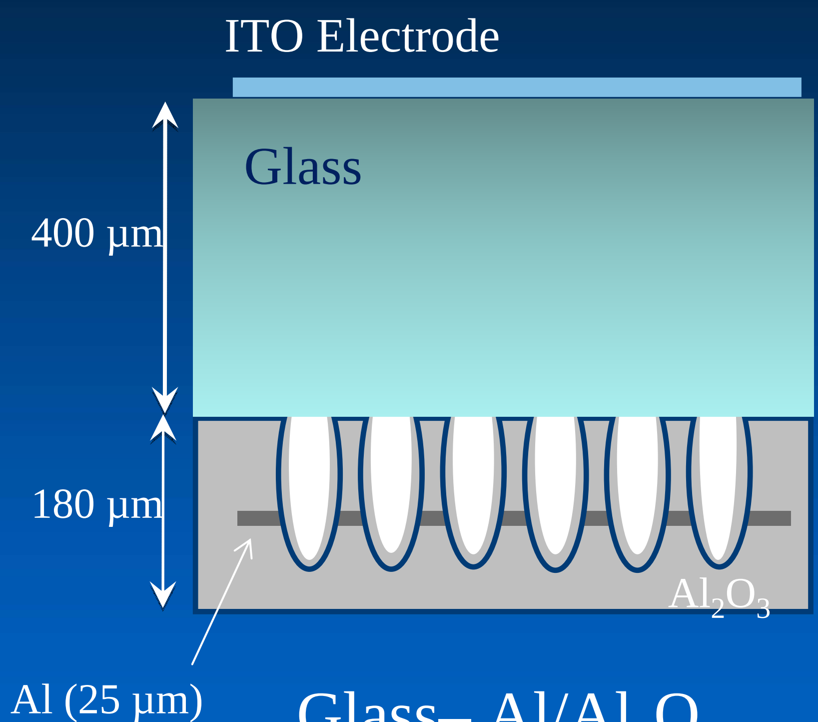
Channel Array Image



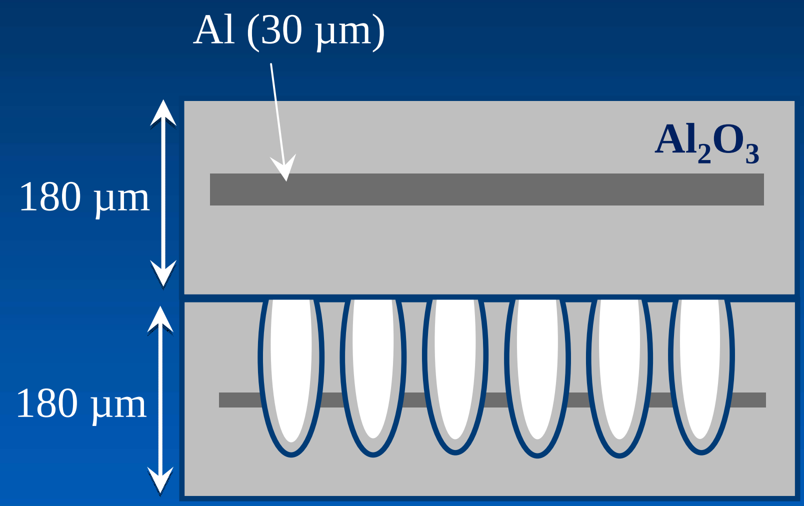


End On Image

OZONE GENERATION IN TWO DIFFERENT DEVICE CONFIGURATIONS: 6 CHANNEL ARRAY



Glass– Al/Al_2O_3
Electrode Geometry

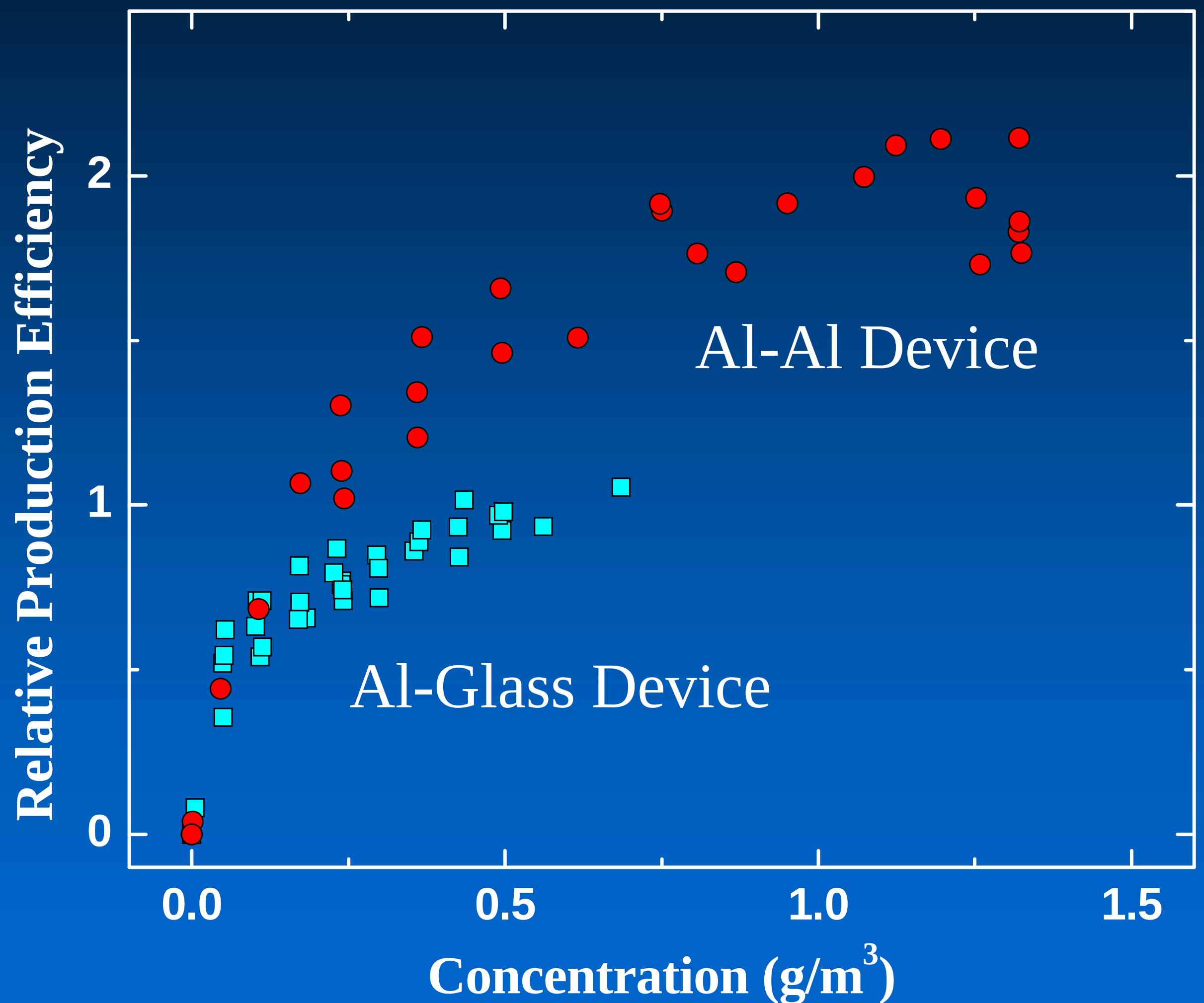


Al/Al_2O_3
Electrode Geometry

Microchannel Width: 220 µm, Depth: 130 µm
Channel Length : 22 mm

University of Illinois
Laboratory for Optical Physics and Engineering

OZONE PRODUCTION EFFICIENCY



Doubled concentration and production efficiency in Al/Al_2O_3 electrode

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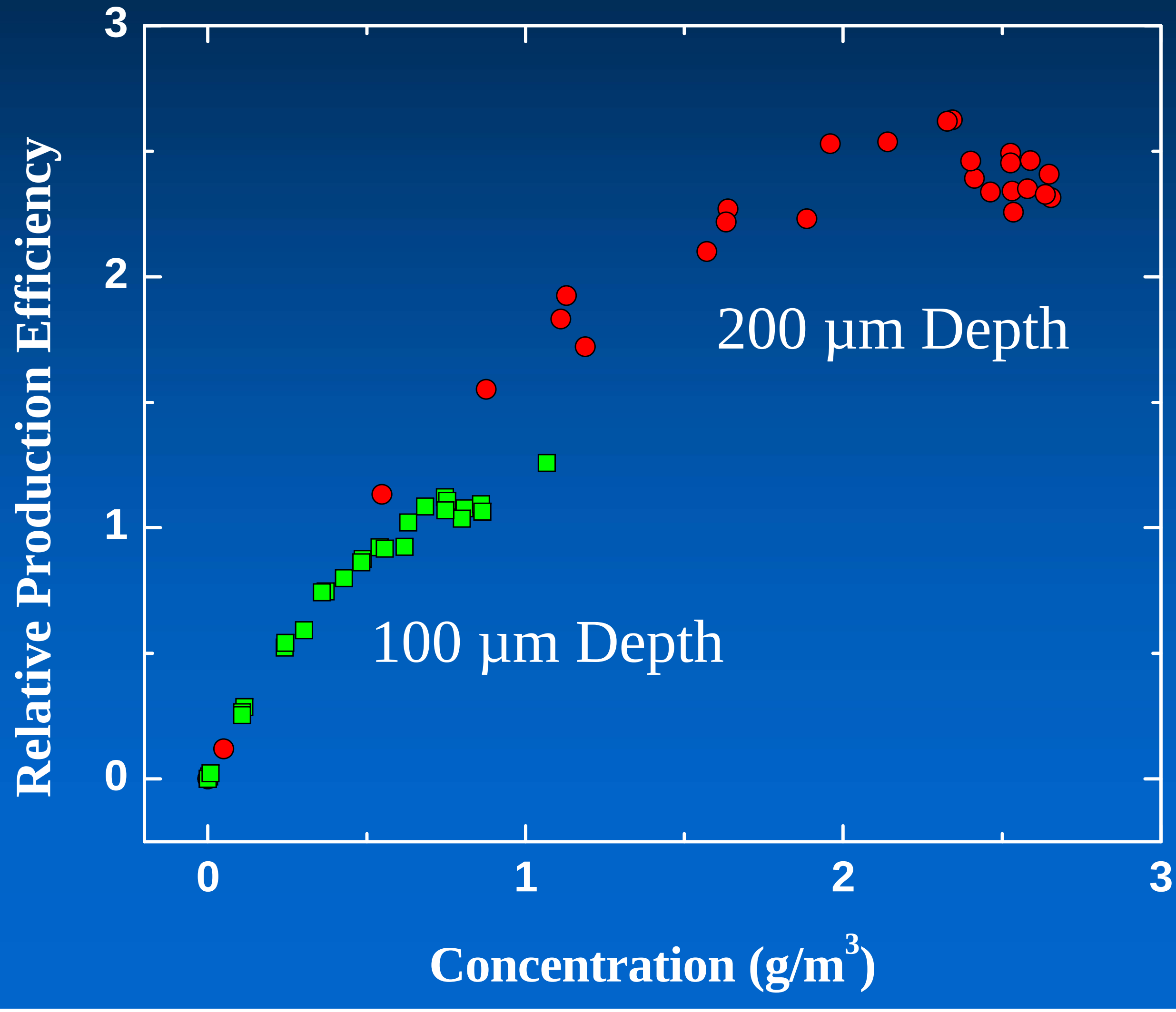
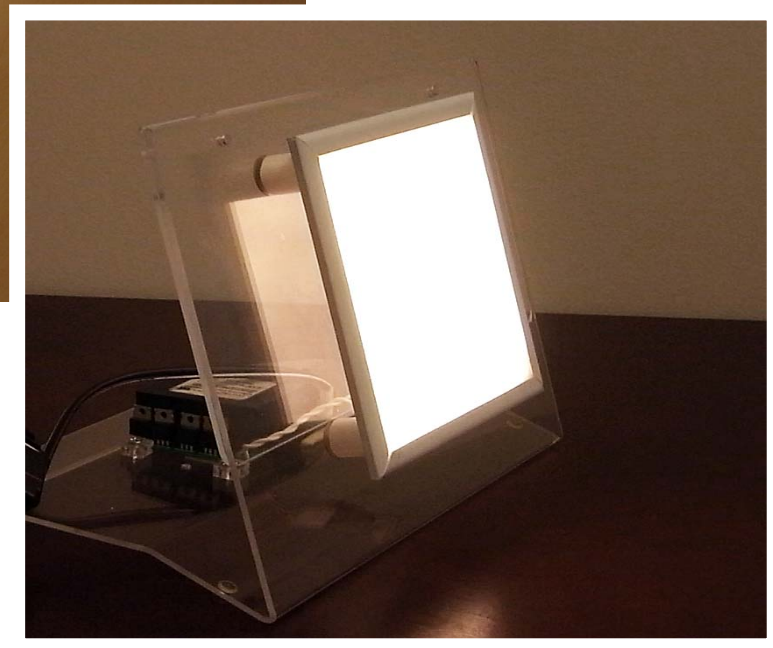
VARIATION IN CHANNEL DEPTH : 6 Channel Al-Al Device



EDEN PARK
ILLUMINATION

THE EVOLUTION OF LIGHT

FLAT MICROPLASMA LAMP: Phoenix 6” × 6” (~ 225 cm^2)



- Spatial Uniformity: ± 5 %
- Luminance : >12,000 cd/m^2
- Efficacy: > 25 lm/W
- CRI: > 80
- Fully Dimmable

EDEN PARK ILLUMINATION

LIGHTING TECHNOLOGY COMPETITION

Light Emitting Diode

LED

- Heat Sensitive => Heat Management
- "Dots" Forced into Planar Form
- Requires Robust Hardware
- Performance Tied to Cost (binning)
- Difficulty maintaining uniformity and intensity over time
- Requires waveguide technology limiting size and color spectrum
- Good color mixing is difficult to achieve in edge-lit structures

Organic Light Emitting Diode

OLED

- Short Lifetime
- High Manufacturing Cost => High Market Price
- Scale Limitation
- Low Light Output
- Efficacy Tied to Light Output

Microplasma

- High Light Output Natural Planar Source
- Cost / TCO Advantage
- Lightweight => Easy to Install
- Scalable => Design Flexibility
- Environmentally Friendly

	LED	OLED	Microplasma
Efficacy (lm/W)	54*	25-30**	25-35
Lifetime (hrs)	50,000	2000-14,000	50,000
$ per lm/W	**$2.00********	**$10.0** ($300 @ 30 lm/W)	**$1.00****** ($25 @ 25lm/W)
$ per klm	~ $100	$ 6000 - $25000	$ 42 ($25 @ 600 lm)
$ per m^2	$ 800 - 900	$17, 000 – 75,000	$ 200 – 250 (expected)

* lm/W based on initial lumens in average luminaire (per DOE CALiPER Summary Report, October 2010)

** OLED WORKS LLC, April 2011

**** at present – January 2011 - $ per lm/W will further decrease with improved efficacy because cost base stays (relatively) the same*

***** $ per lm/W calculated using multiple LED units as necessary to create equivalent 6" uniform distribution planar light emission*

CONCLUSIONS

- Hybrid plasma/semiconductor devices provide the potential for manipulating microscopic processes at the plasma-solid interface
- Control of secondary electron emission coefficient
- Nonequilibrium plasmas can be modulated and extinguished with $\lesssim$ 1 V across base-emitter junction
- Bound-free plasma interactions have been observed and can be controlled (plasma gates and traps)
- Plasma chemical generation of ozone efficiency approaches best industrial values
- Flat plasma lamps outperform OLEDs in cost and performance