Development and Application of Brand-new Atmospheric Plasma Sources

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Plasma is the fourth state of matter

0°C 100°C a few 1000°C

ice water water vapor ionized gas

Solid Liquid Gas Plasma

Plasma consists of ions, electrons, excited/nonexcited atoms/molecules and radicals.

Plasma has some different characteristics from normal gases.

Reactivity

Has chemical reactivity

Emissivity

Can emit light (～FIR～IR～visible～UV～EUV～)

Electric conductivity

Has electric conductivity and the degree is controllable

High temperature

Has very high temperature (over 10,000 K)

Plasmas around us

Natural :

- Lightning bolt
- Solar wind
- Aurora

Artificial :

- Fluorescent tube
- Neon sign
- Plasma display
- Xenon discharge light

Characteristics of plasma

Reactivity

Can generate dense high reactive species (radicals, ions, electrons,,).

→ Semiconductor processing (CVD, etching)

→ New material processing (CNT, DLC)

Emissivity

Can emit light (～FIR～IR～visible～UV～EUV～)

The wavelength is depend on the gas species and the temperature

→ PDP, Light source, Laser, Elemental analysis

Electric conductivity

Has electric conductivity and the degree is controllable
(depend on the temperature)

→ Plasma switch

High temperature

Has very high temperature (over 10,000 K) (Combustion : below 3,000 K)
In the nuclear fusion plasma it is higher than 10,000,000 K.

→ Decomposition of industrial wastes

→ Cutting of high melting point material, Nuclear fusion

Generation method of plasmas

In industrial use, plasma generation method is chosen according to demand of plasma pressure, temperature, purity, kind of gas,,,

◆ Discharge frequency

DC ～ HF (kHz) ～ RF (MHz) ～ Microwave (GHz) or HV pulse

◆ Discharge type

Electrode, Barrier, Colona, Inductive,,

◆ Pressure

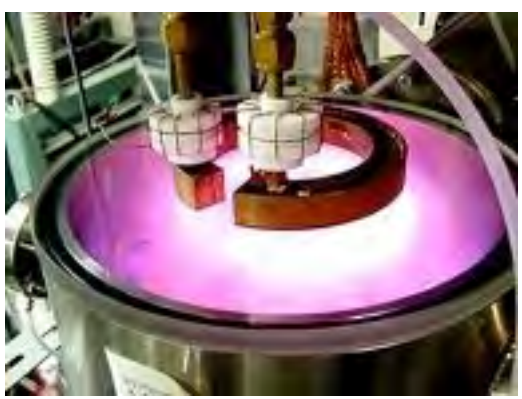
Vacuum ～ Low ～ **Atmospheric** ～ High pressure

It's very special !

Why atmospheric plasma is so special ?

Merits

(1) Eliminate vacuum chamber, pumping system → Low cost
(2) Eliminate pumping → Continuous processing
(3) High density plasma → High speed processing
(4) Applicable for large targets → Car, Airplane
(5) Applicable for heat-sensitive targets → Skin, Cells, Plants



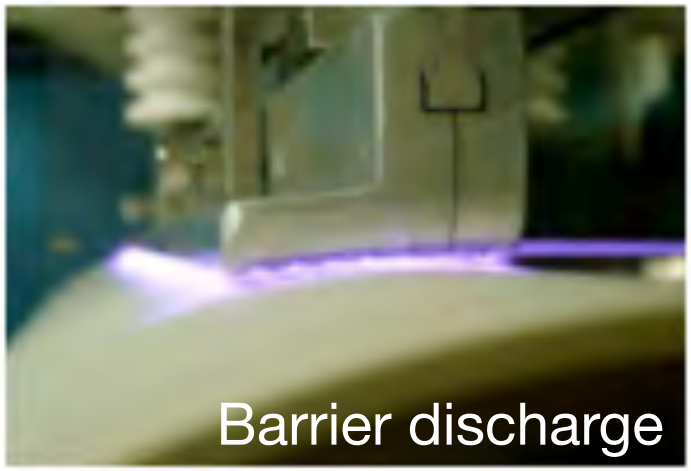
Low pressure

Atmospheric

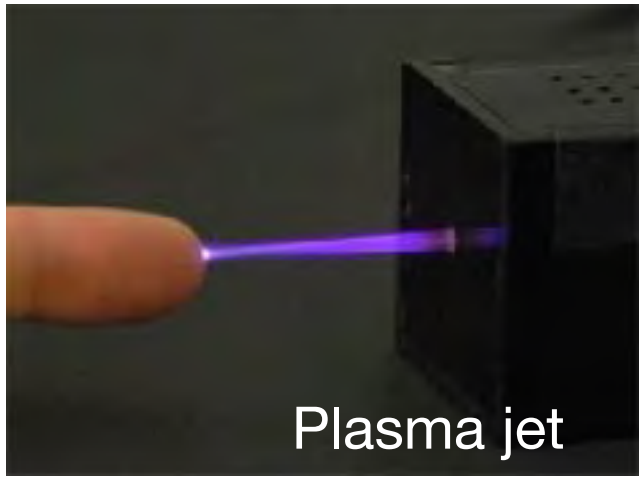
→ Suitable for biological/medical applications

Atmospheric low temperature plasmas

Atmospheric plasma research has been widely spread because Low Temperature Plasma could be generated.


Barrier discharge

Corona discharge


Plasma jet

Applications：

Improvement of

- ✓ Adhesion
- ✓ Paintability

Sterilization

Merit:

- ✓ Low temperature (room temp ～ 200°C)

Problems:

- ✓ Limitation of target size/material
- ✓ Limitation of plasma gas
- ✓ Temperature is not controllable

Our atmospheric DAMAGE-FREE plasma sources

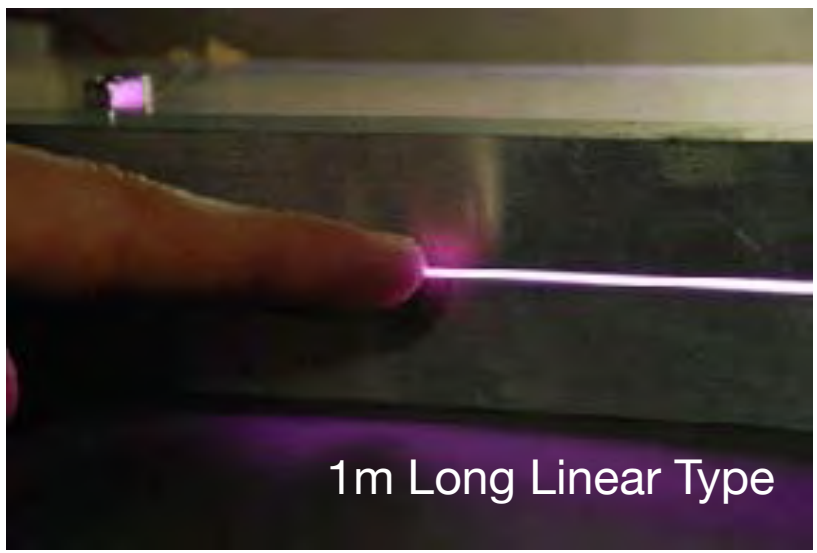
✓ Low temperature

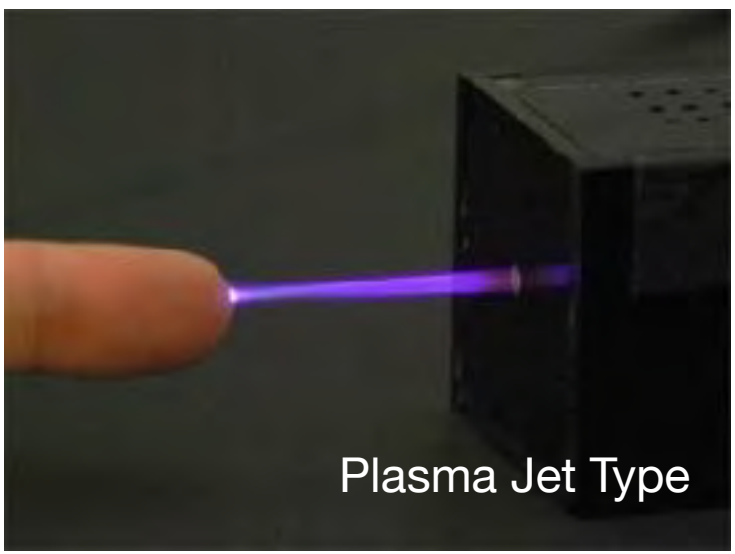
✓ No electric shock

Damage-free plasma

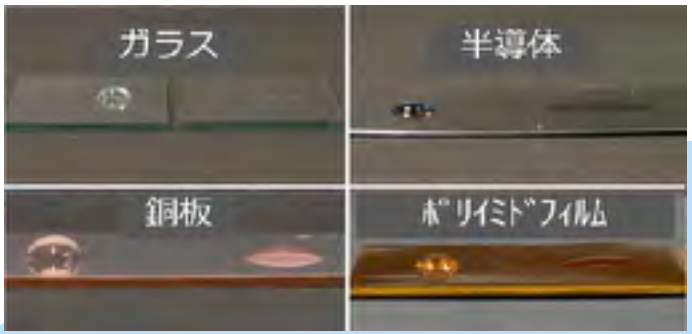
It's touchable !

Applicable for living body/
metal/plastic/paper/textile.





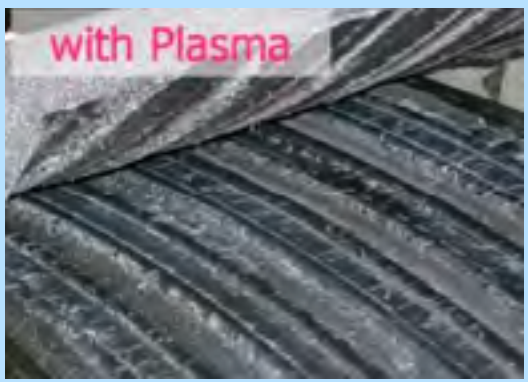
Applications of atmospheric low temperature plasma



Surface modification

Agriculture

Disinfection



High strength bonding

Atmospheric Low Temperature Plasma

Gas decomposition

Hemostasis

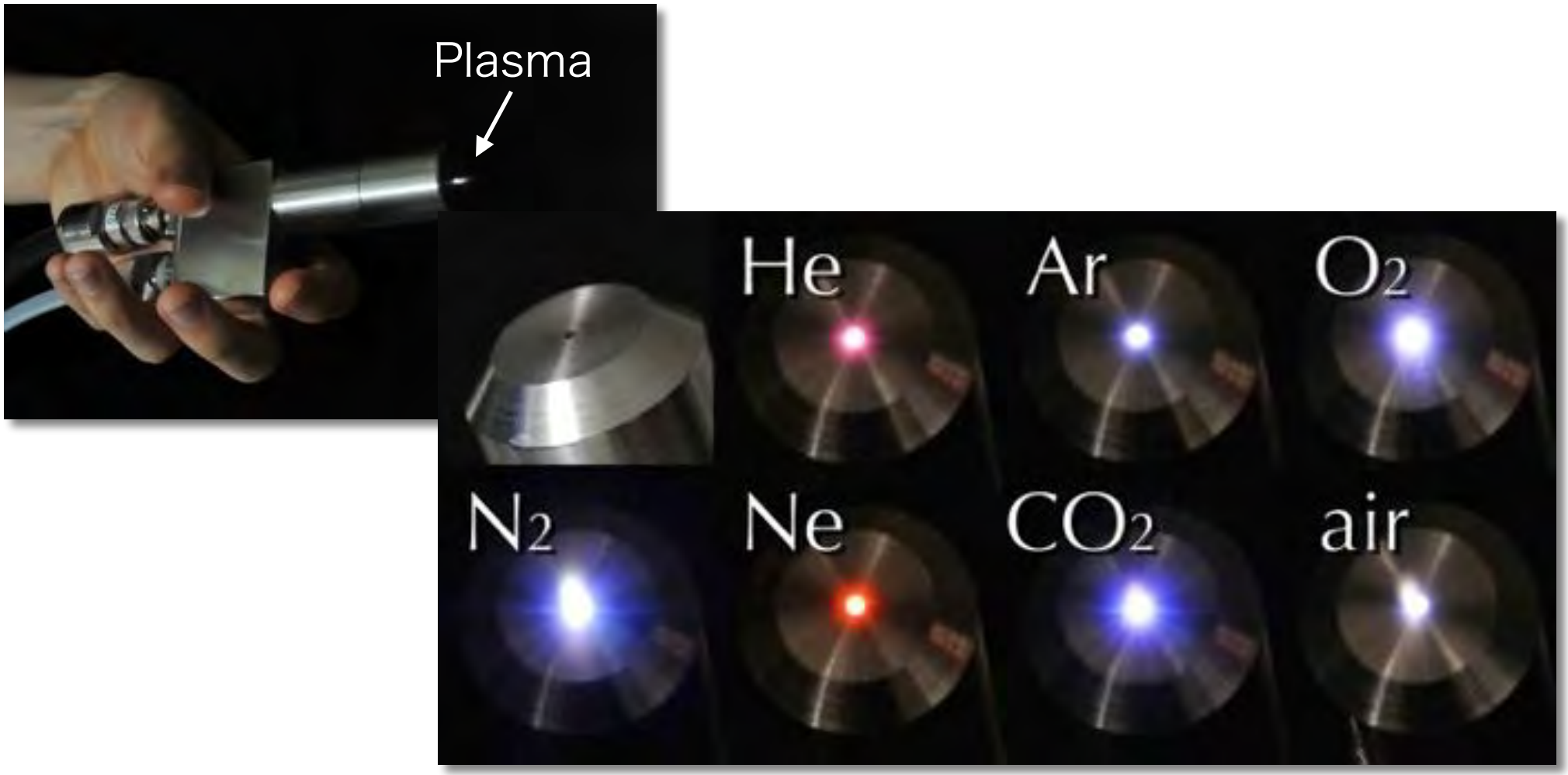
High sensitive analysis

Two problems of common low temperature plasma sources

1. Limitation of plasma gas

2. Temperature is not controllable

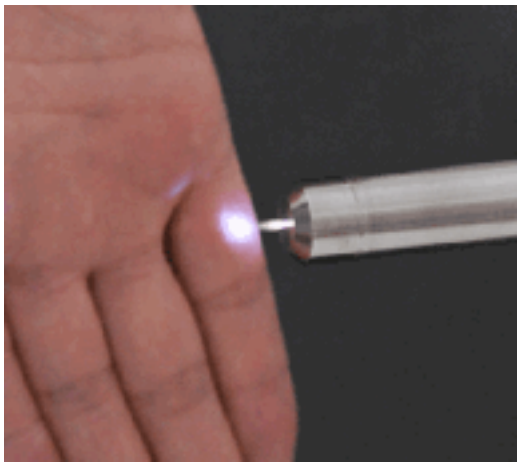
Atmospheric MULTI-GAS plasma jet



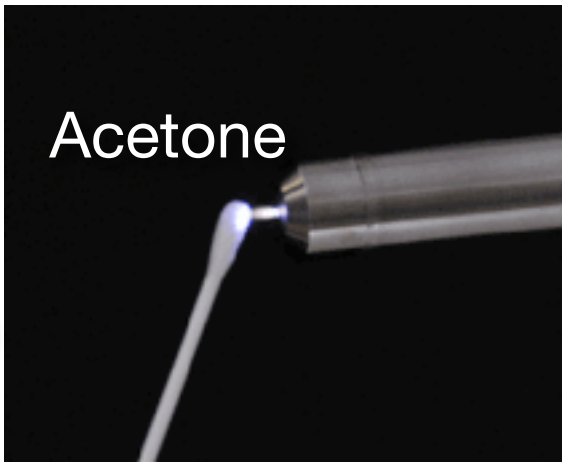
Each gas produces a plasma with different characteristics.

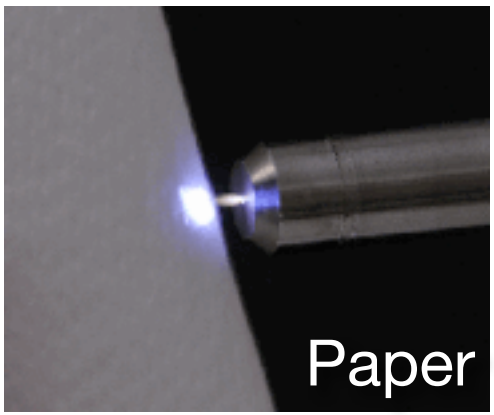
Appropriate gas composition must be selected for each application.

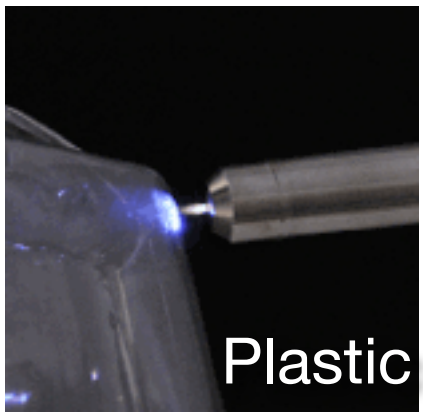
Irradiation of damage-free multi-gas plasma jet

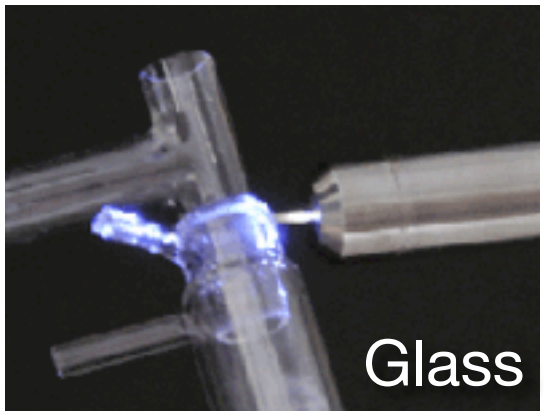


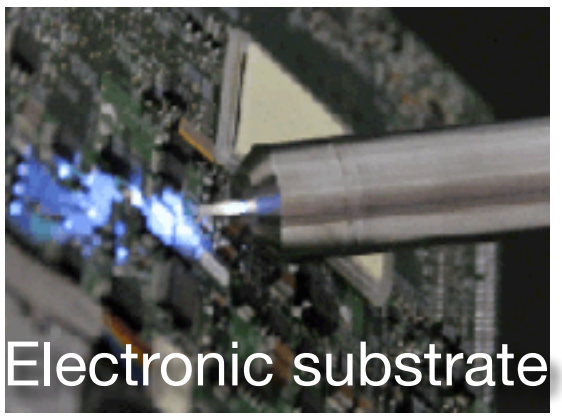
- ✓ You can touch the plasma (left)
- ✓ Not ignite acetone (right)

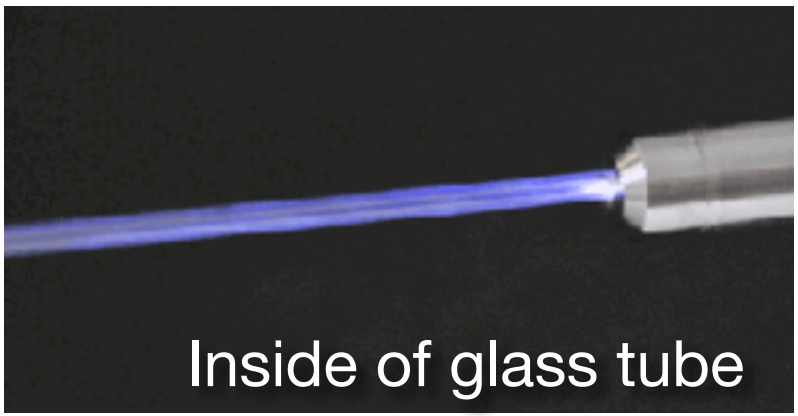






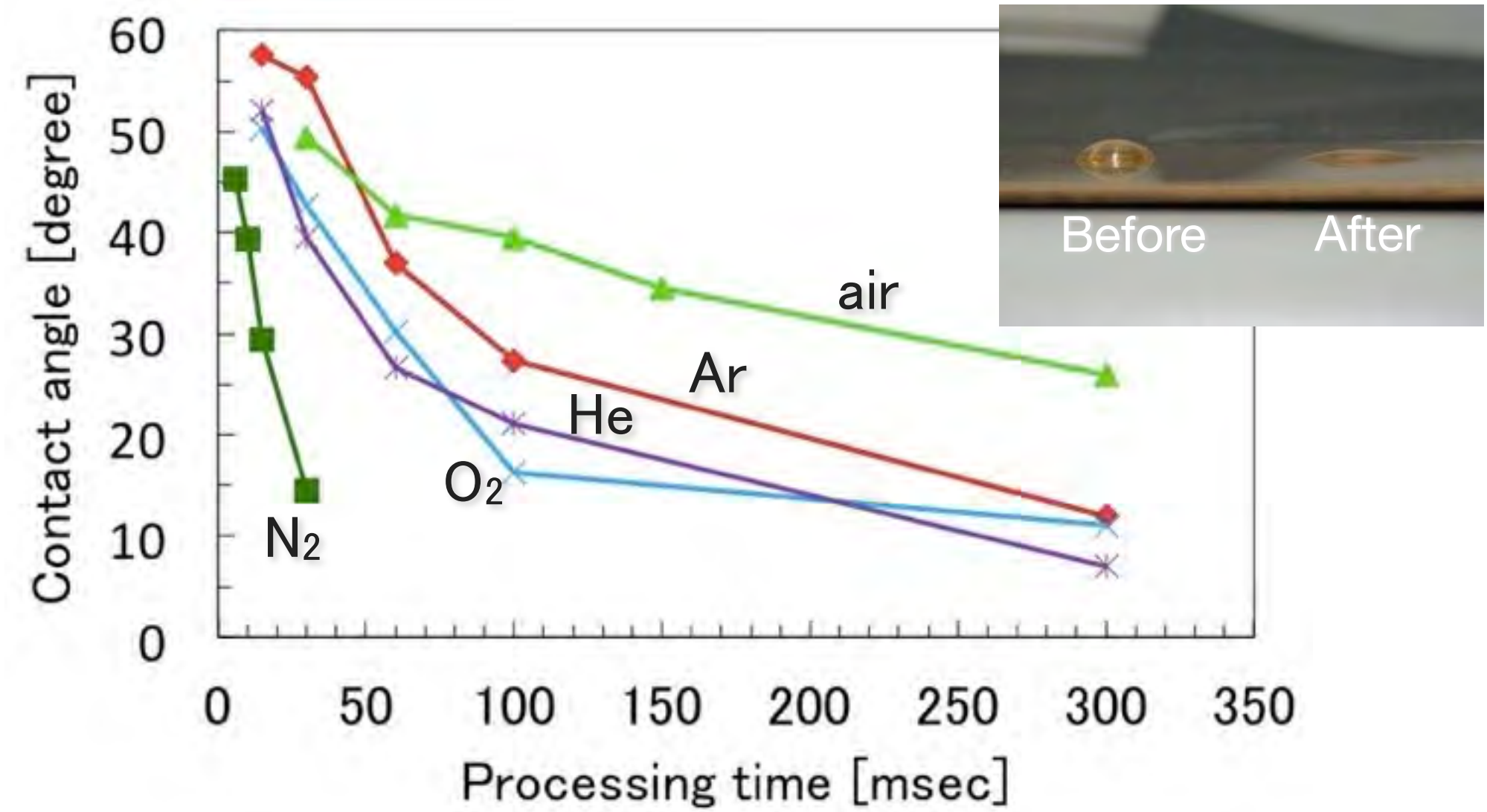






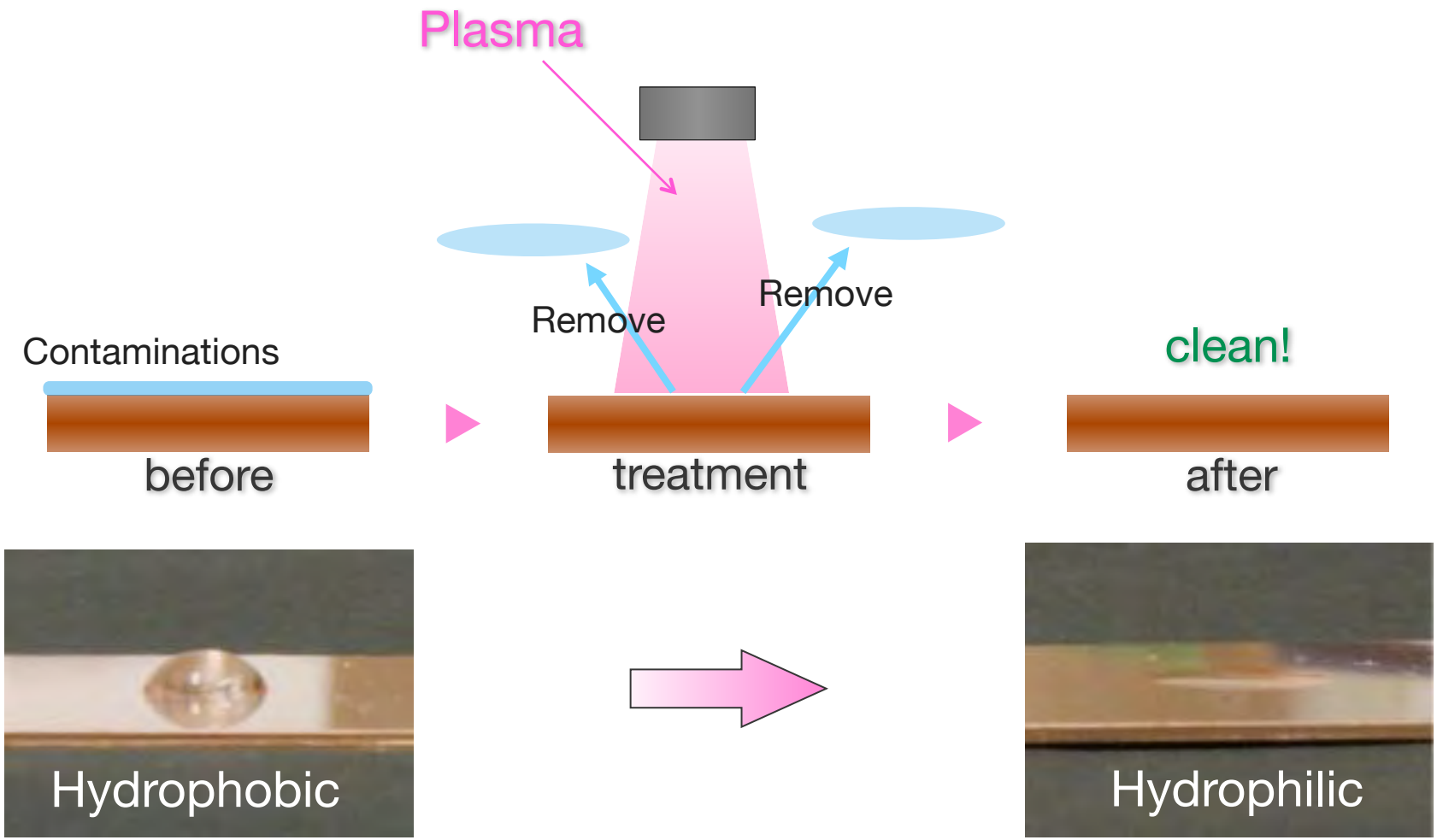
Hydrophilization of polyimide film

3L/min, 15W, 15kHz



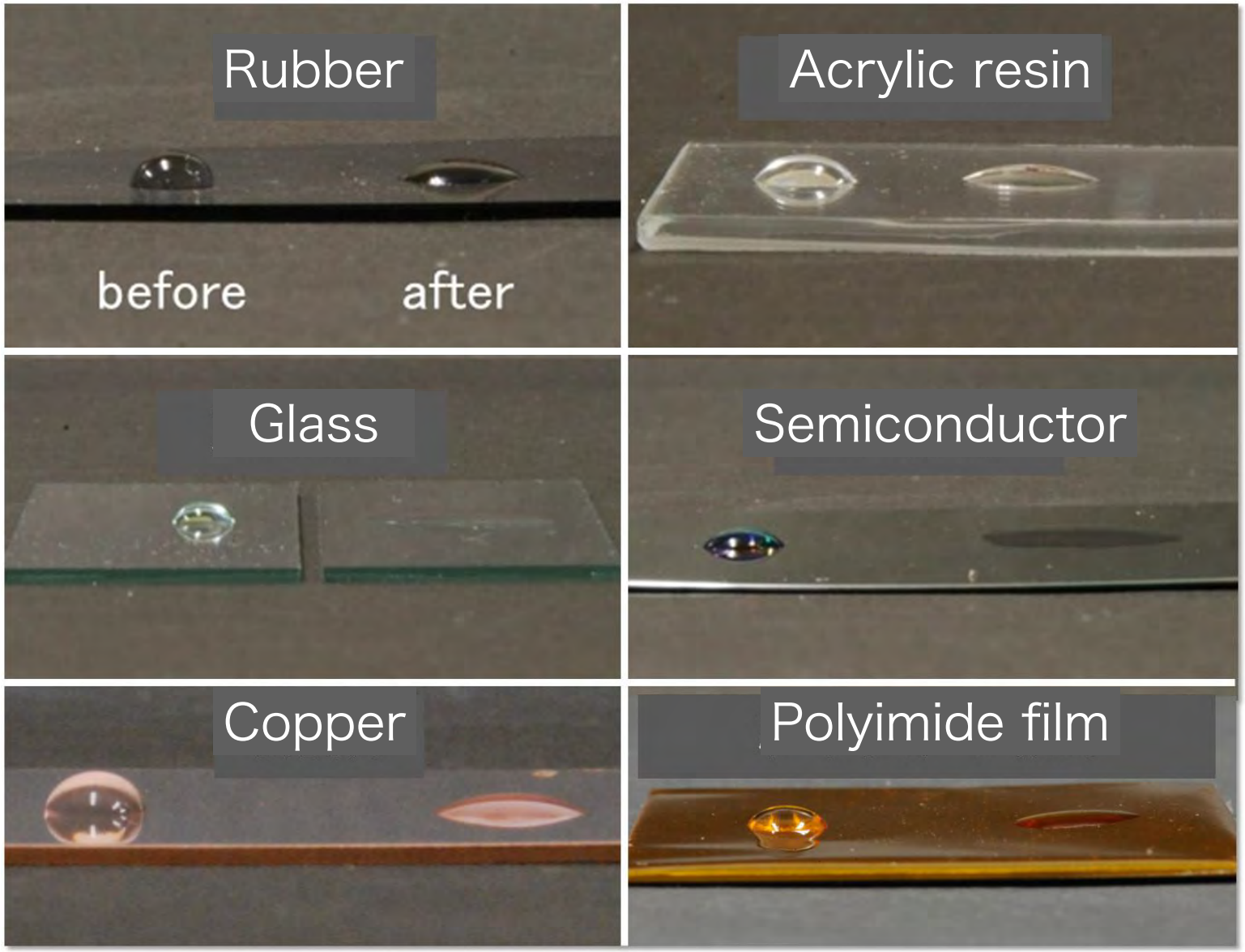
- ✓ Material surface is easily hydrophilized by plasma irradiation.
- ✓ Treatment speed is depend on the plasma gas species.

Principle of hydrophilization ≒ Surface cleaning



Organic contaminations on the surface are removed by radicals.
Then, the metal surface is cleaned up and hydrophilized.

Can hydrophilize almost all materials



Can hydrophilize almost all materials

Gauze (Cotton100%)

Knit (Cotton100%)

Rayon

Weather (Poly65%, Cotton35%)

Shading curtain

Work clothes (Poly65%, Cotton35%)

Can hydrophilize almost all materials

Cardboard

Woods

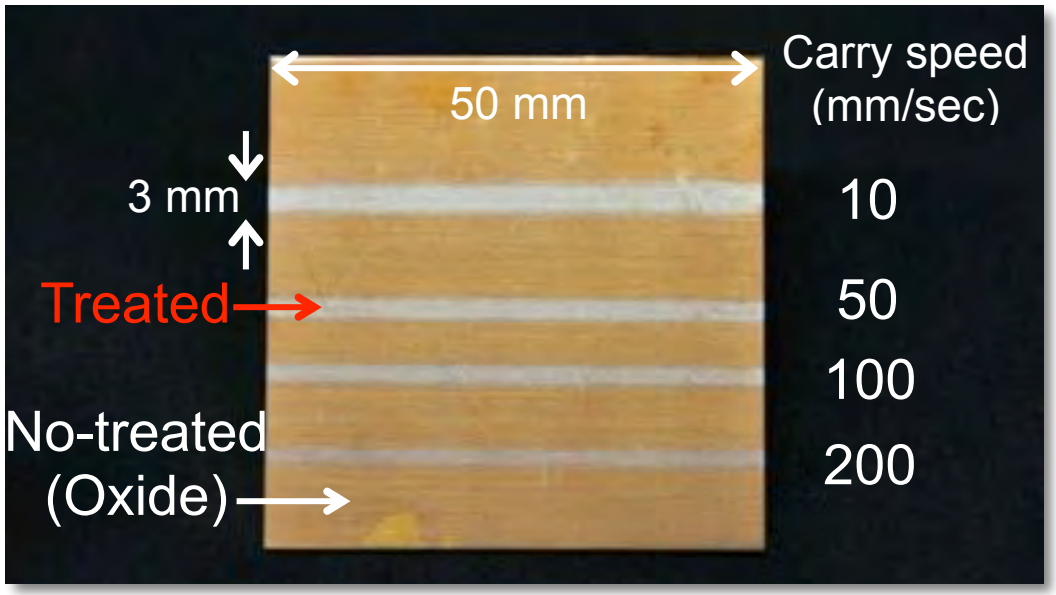
Natural rubber

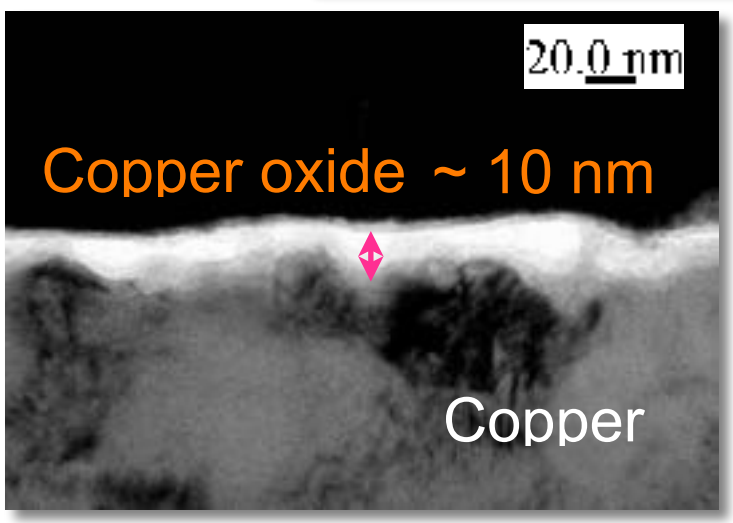
Bamboo

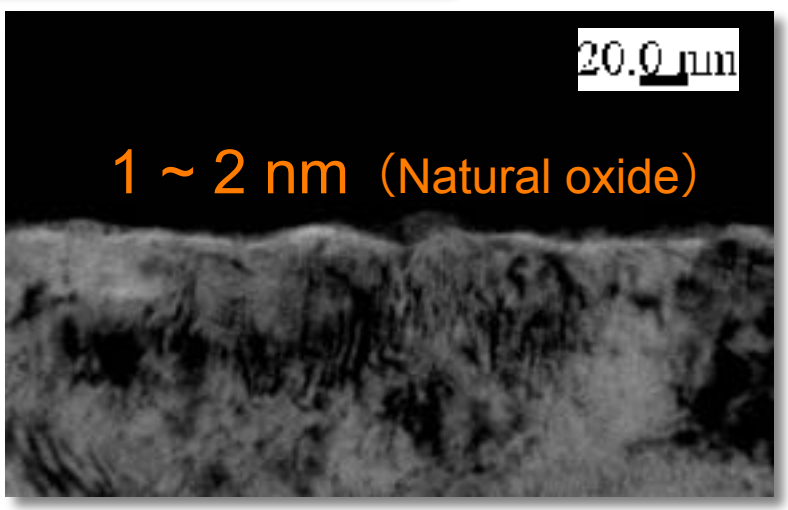
Drawing paper

Floor tile

High speed removal of copper oxide







- ✓ Max carry speed: 700 mm/sec
- ✓ Removal speed: 93 μm/sec

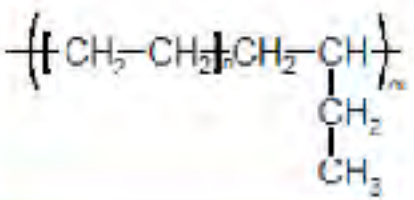
Atmospheric LINEAR type plasma source

Adhesion improvement of HDPE/epoxy resin

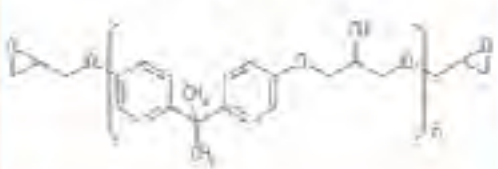
HIDEN to HIDEN adhesion test

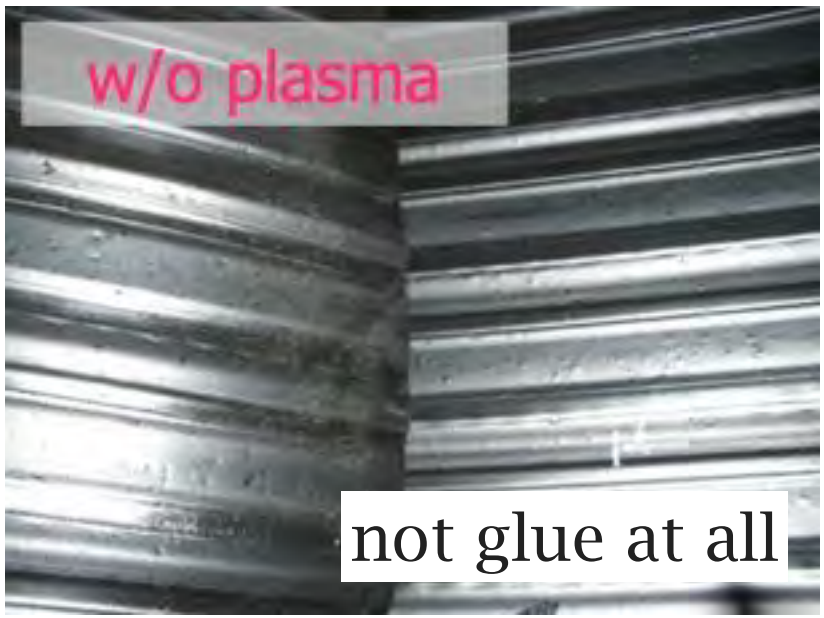
- ✓ Target samples are treated under atmospheric pressure
- ✓ Apply epoxy resin adhesive and cure perform compress test

High Density PolyEthylene

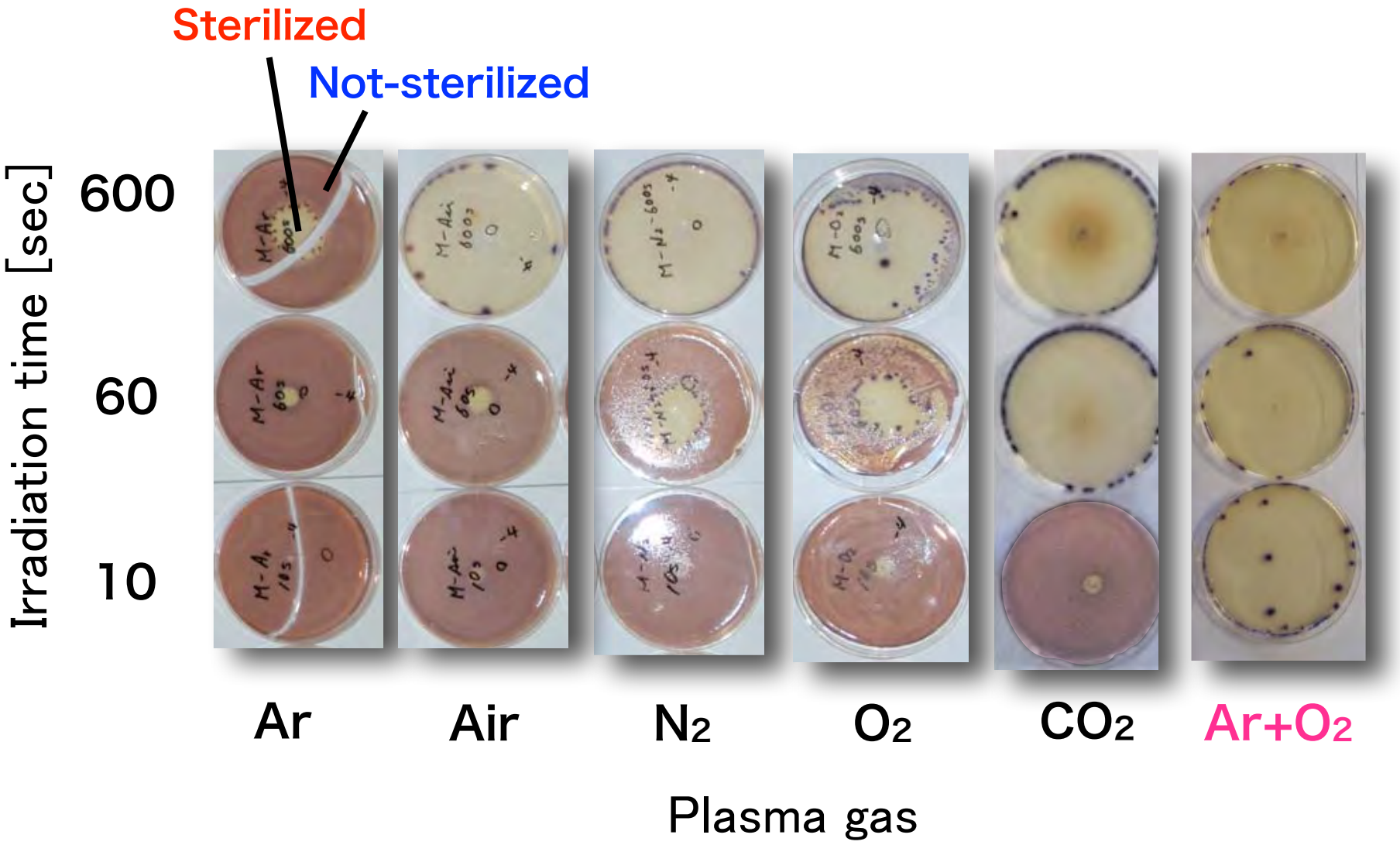


Epoxy (adhesive)





Sterilization of *E.coli*



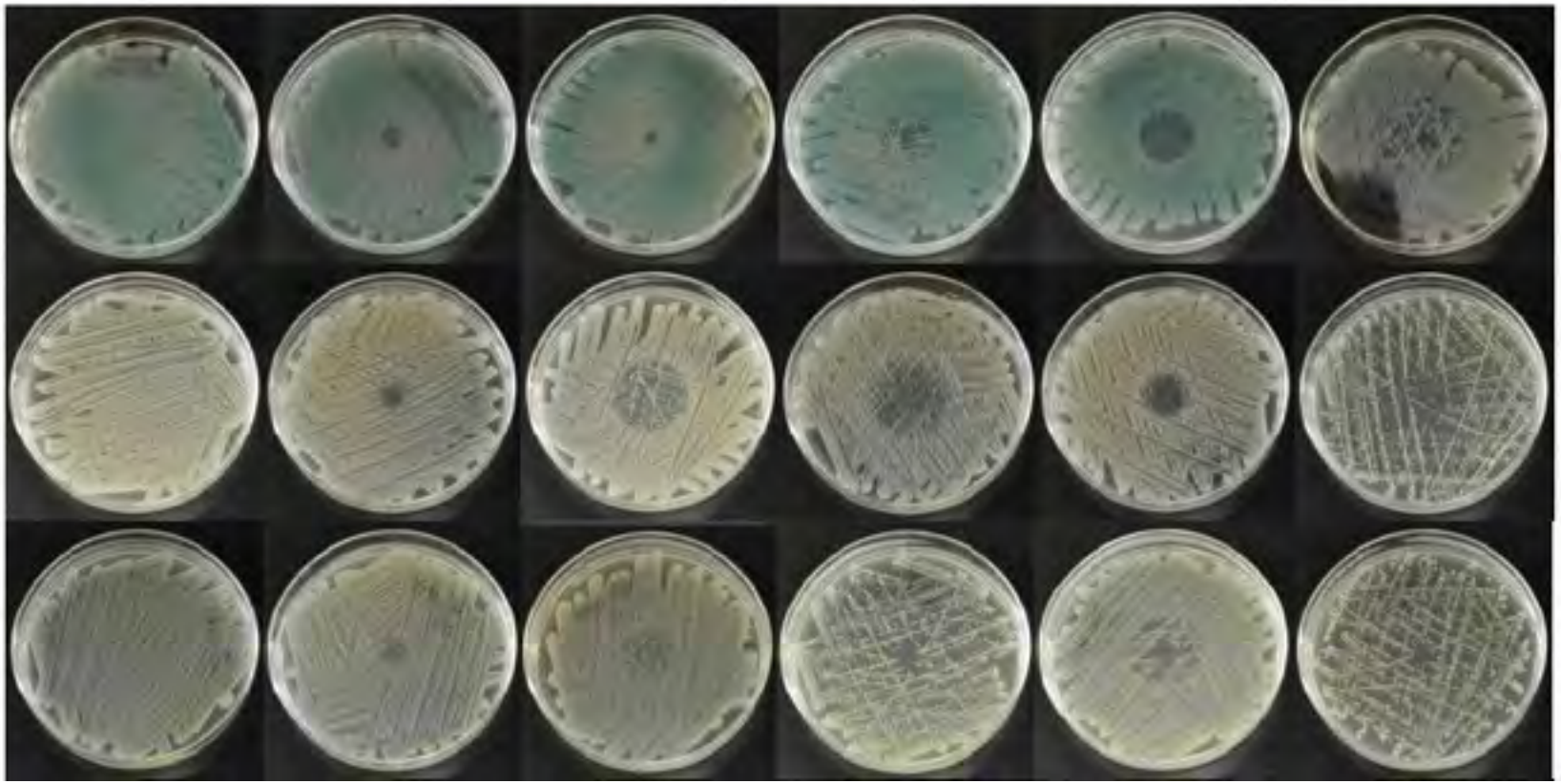
✓ Sterilization speed deeply depends on the plasma gas.

Bactericidal effect against various bacteria

緑膿菌
P. aeruginosa
グラム陰性好気性桿菌

黄色ブドウ球菌
S. aureus
グラム陽性通性嫌気性球菌

大腸菌
E.coli
グラム陰性通性嫌気性桿菌



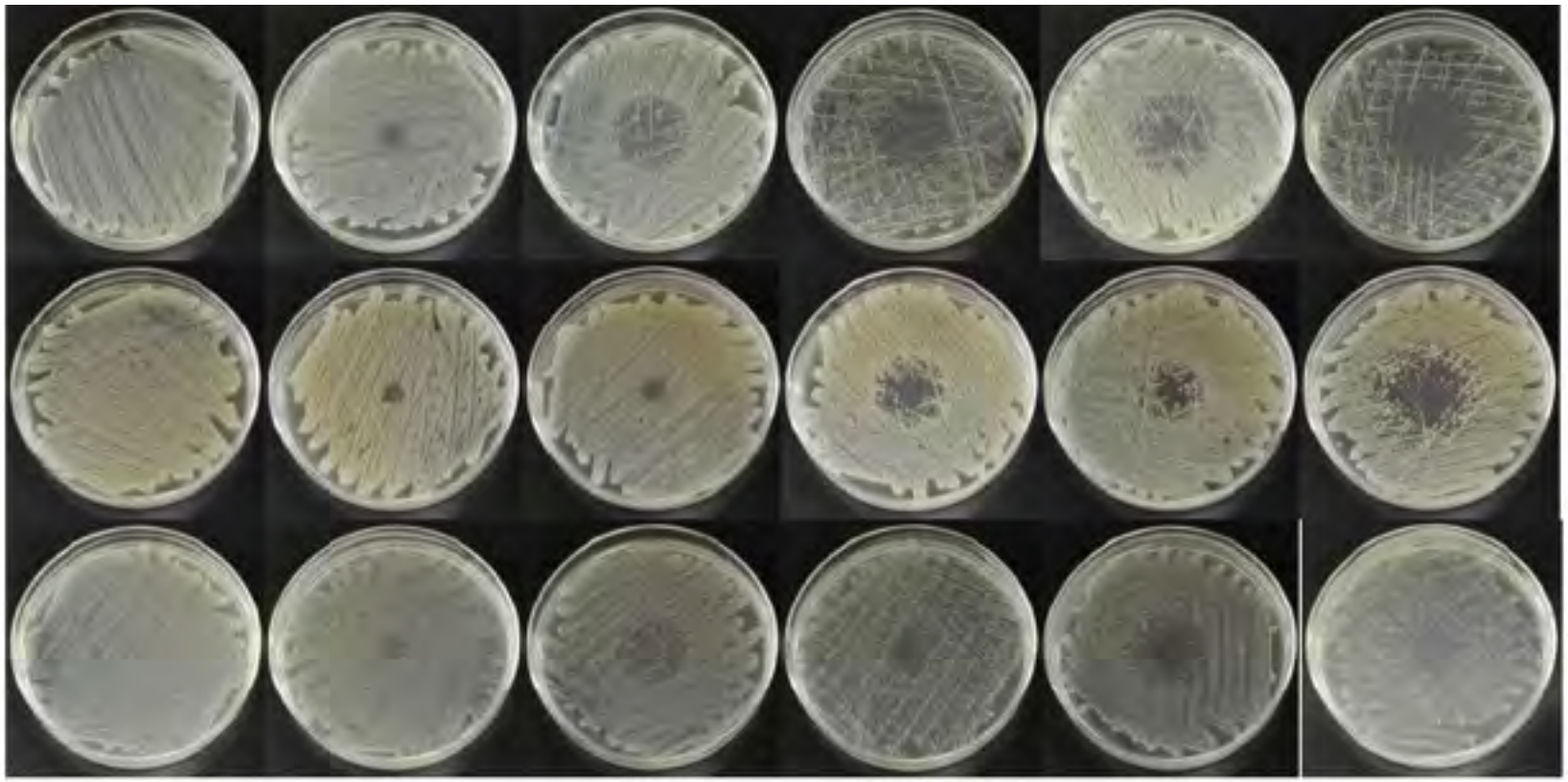
Untreated Ar N_2 CO_2 air O_2

Bactericidal effect against various bacteria

腸球菌
E. faecalis
グラム陽性通性嫌気性連鎖球菌

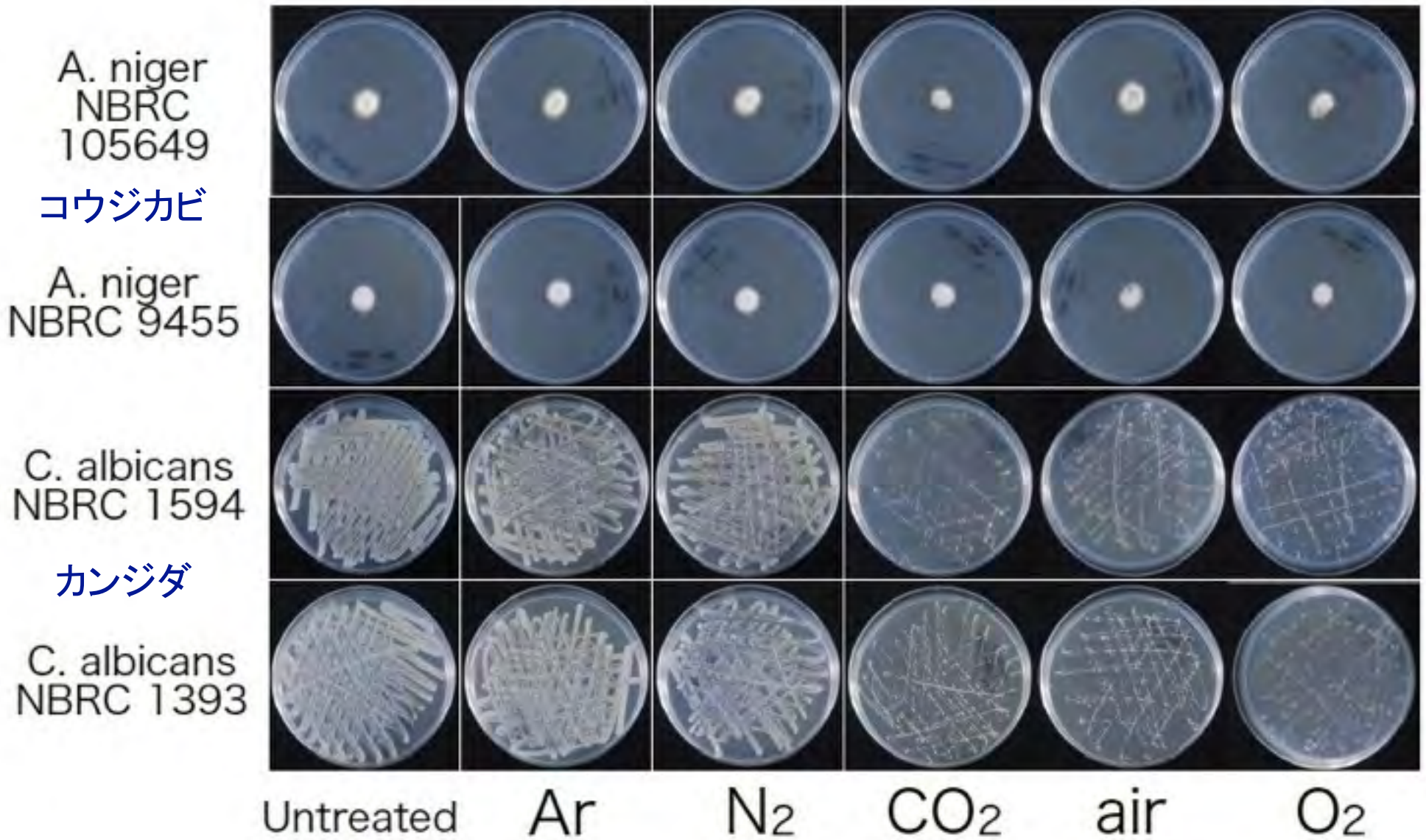
肺炎桿菌
K. pneumoniae
グラム陰性通性嫌気性桿菌

表皮ブドウ球菌
S. epidermidis
グラム陽性通性嫌気性球菌

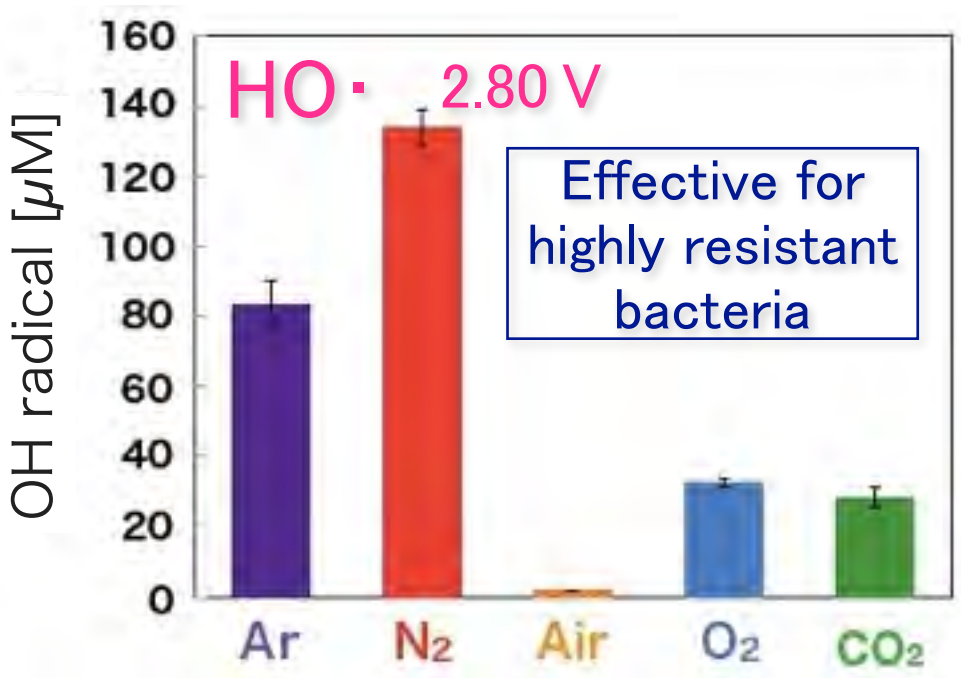


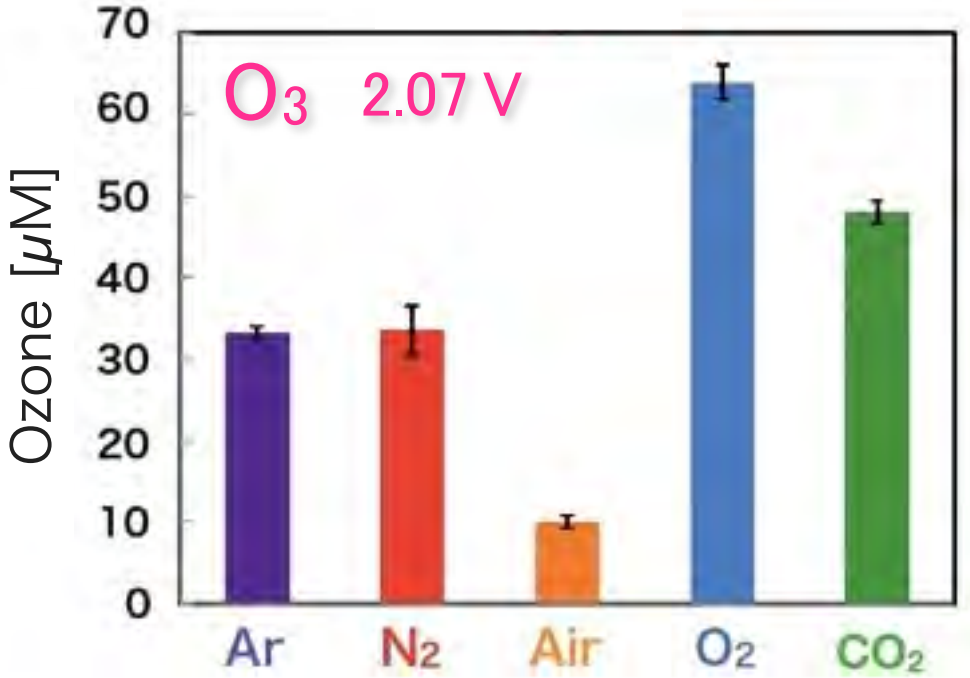
Untreated Ar N_2 CO_2 air O_2

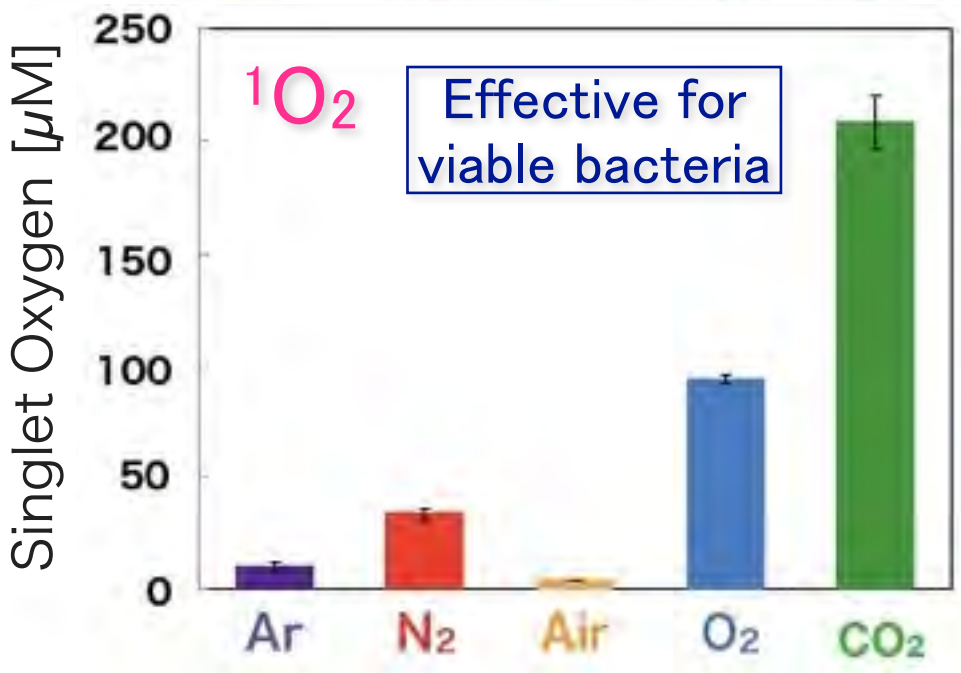
Bactericidal effect against various fungi

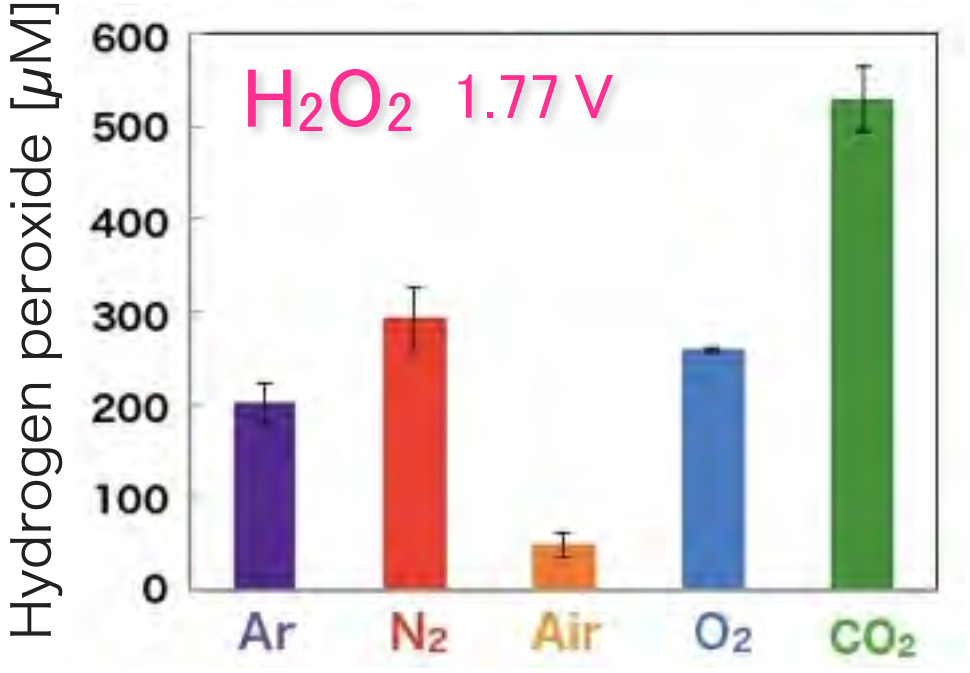


Reactive species in plasma irradiated water





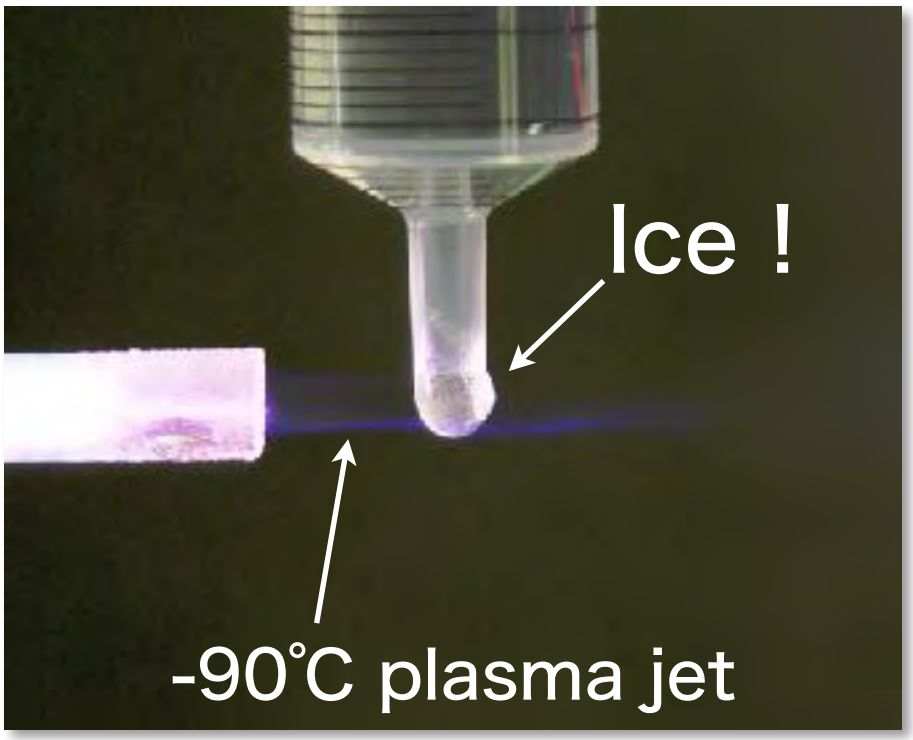


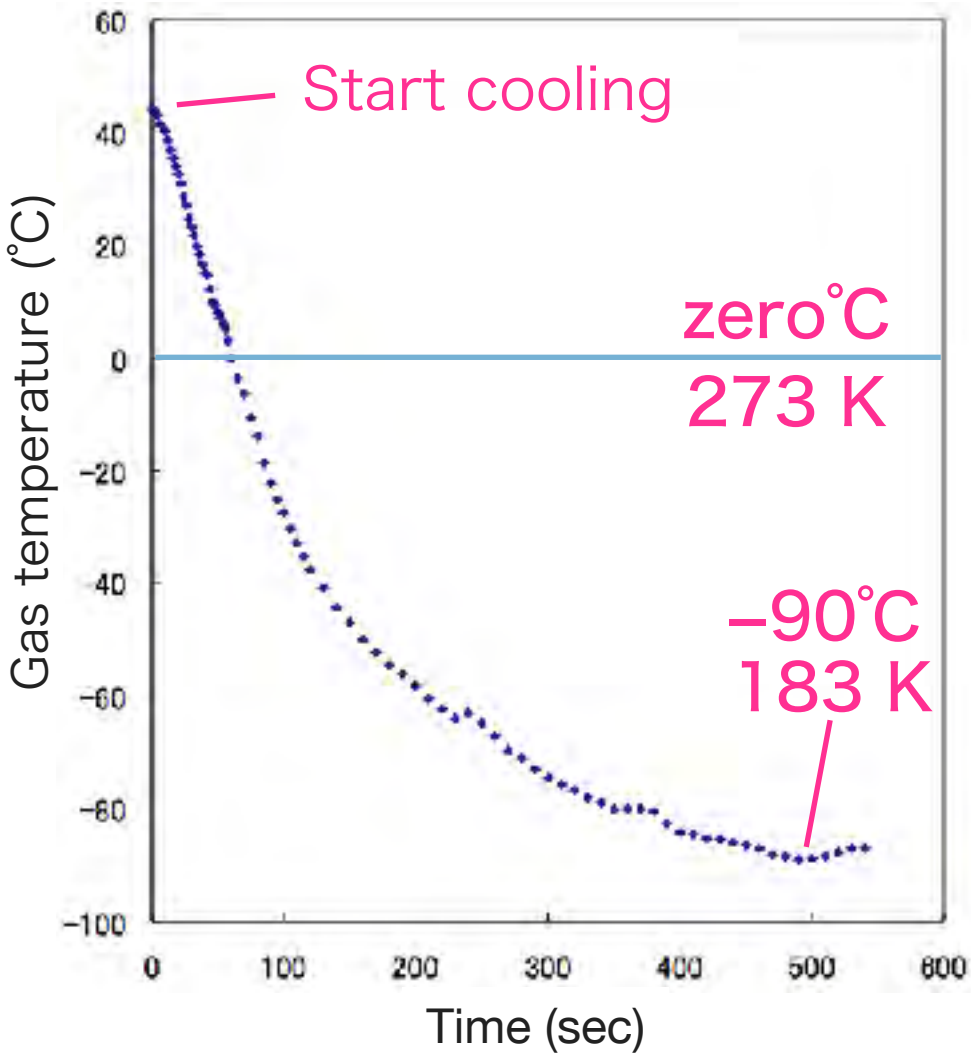


Temperature-controllable helium plasma

PAT Japan, USA, China

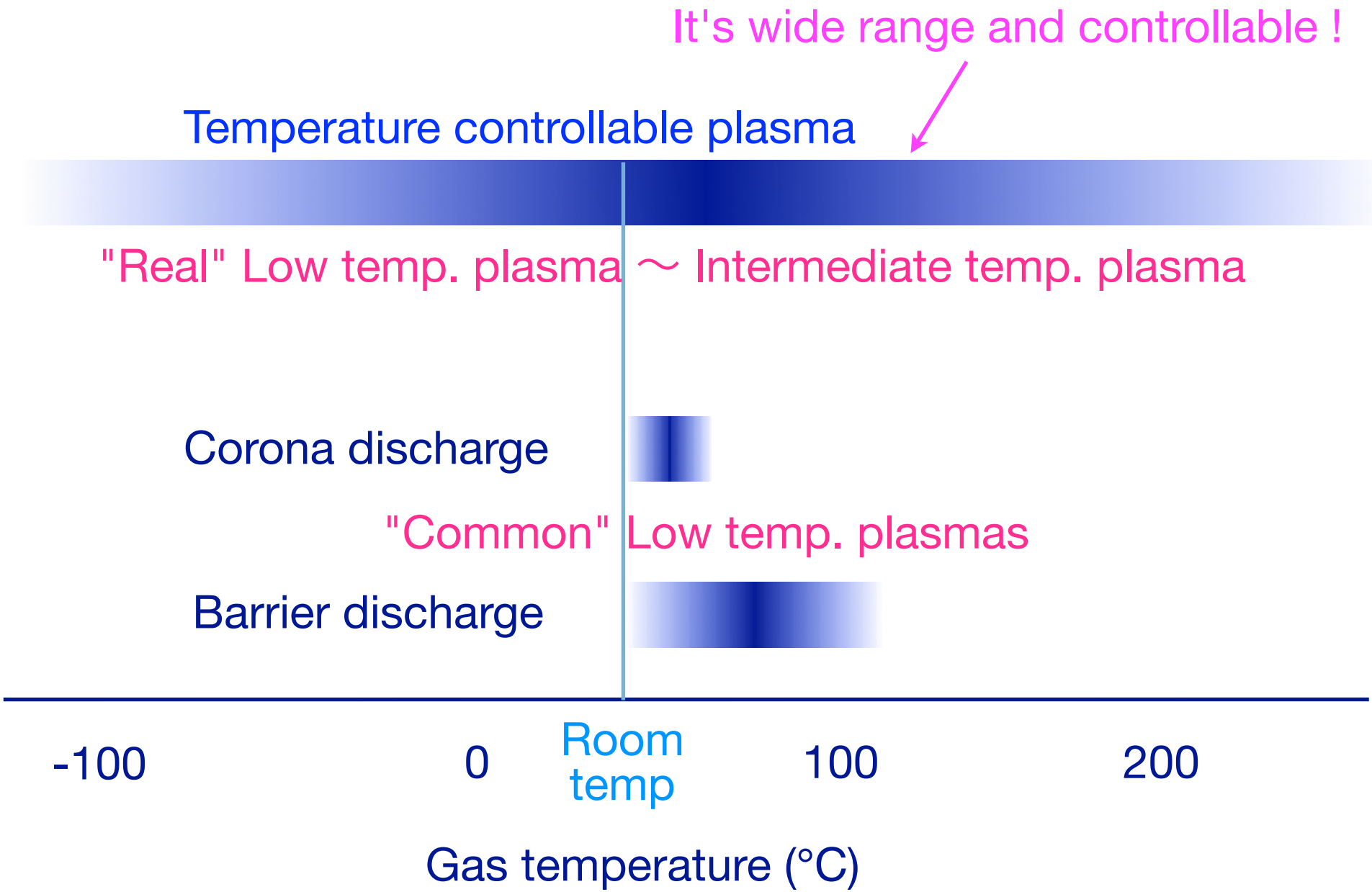
water freeze in 10 seconds



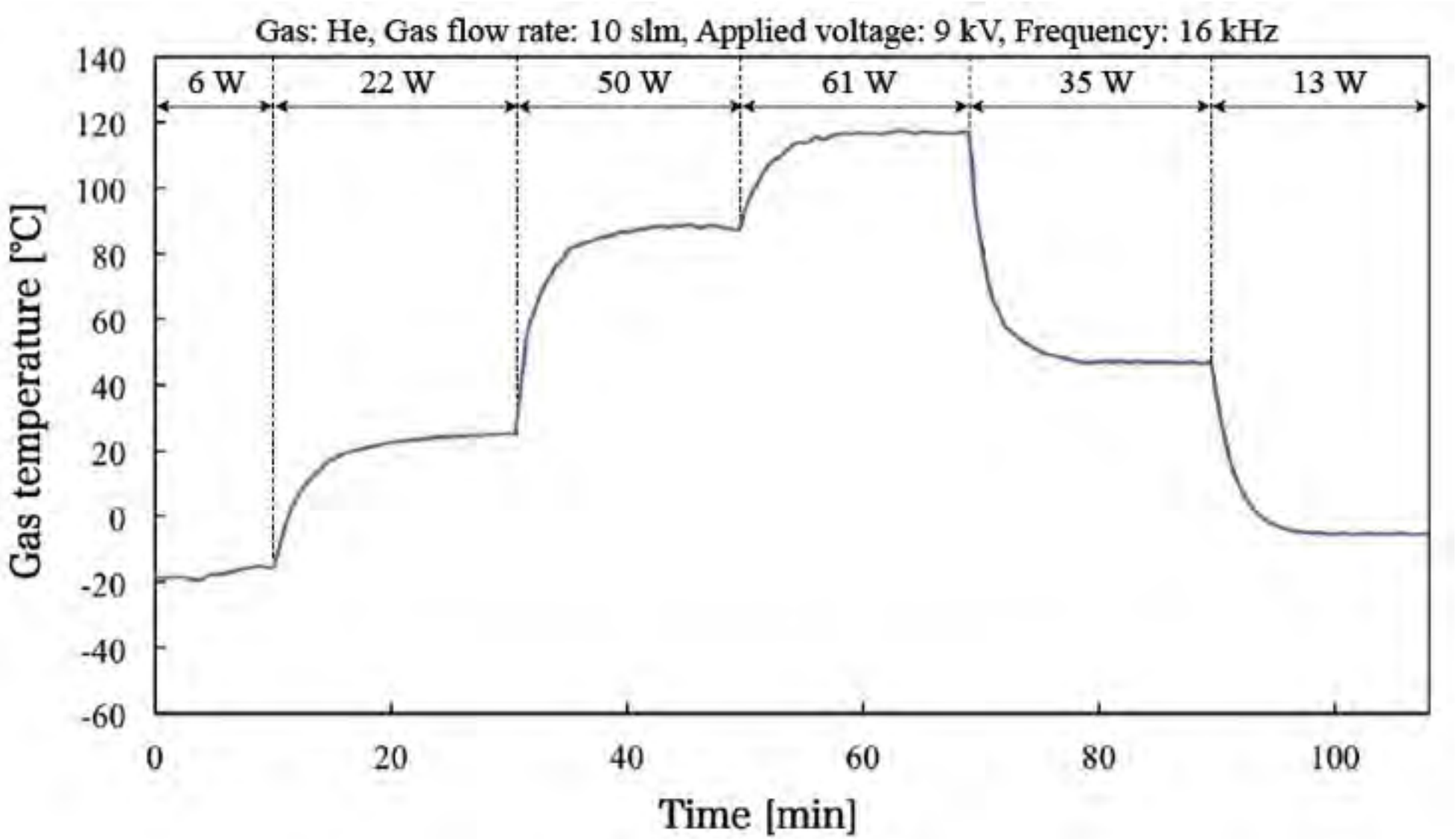


High power plasma can safely irradiated to heat-sensitive materials such as living body.

Comparison of low temperature plasmas

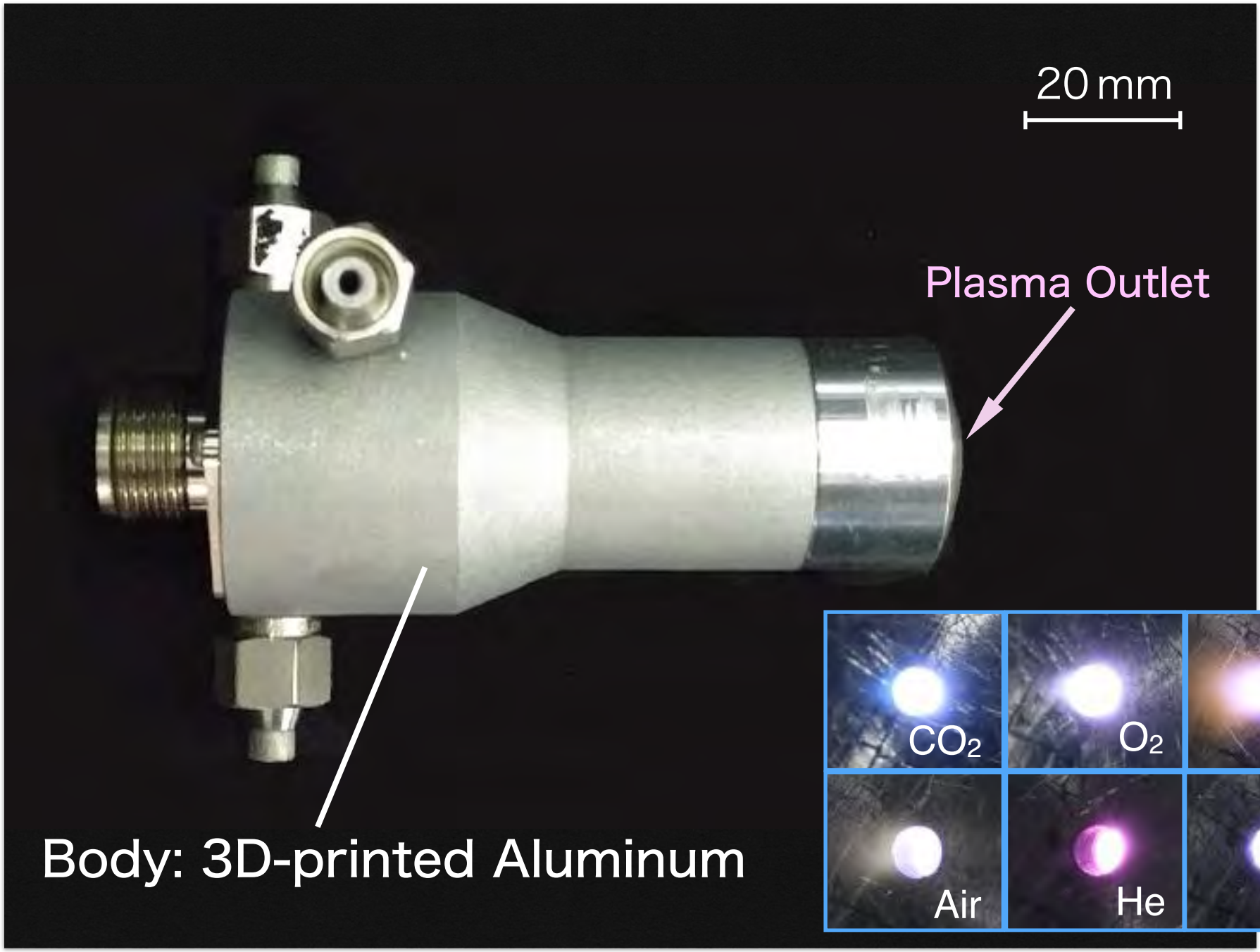


Control of the plasma gas temperature Helium, 1L/min, 15W, 15kHz



- Controllable from below 0 °C to high temperature

3D-Printed multi-gas temperature-controllable plasma jet



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東工大ニュース

・ 東工大ニュース
カテゴリ別
教育
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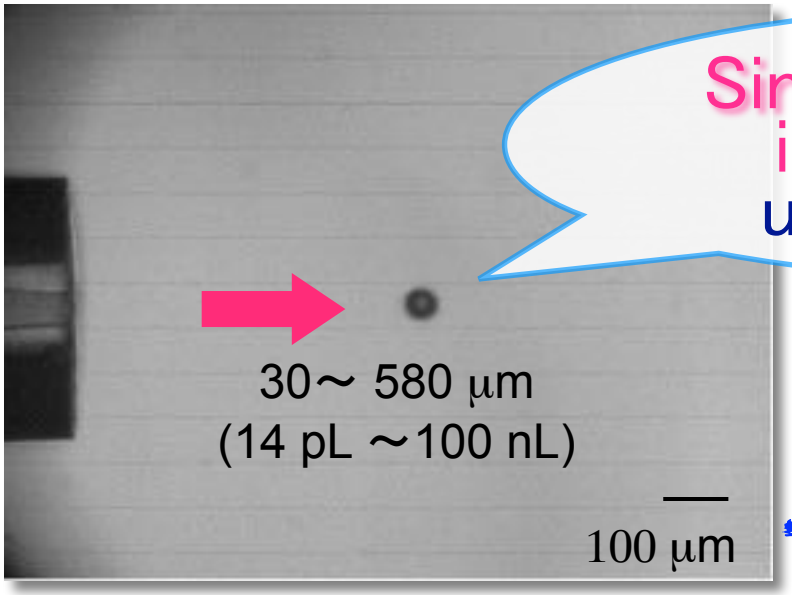
社会連携
国際交流
受賞・表彰
学生の活躍
開催報告
来訪者
メディア
大学からのお知らせ
プレスリリース

3°Cから108°Cまで温度を制御できる大気圧プラズマ装置を開発

Elemental analysis in single cell

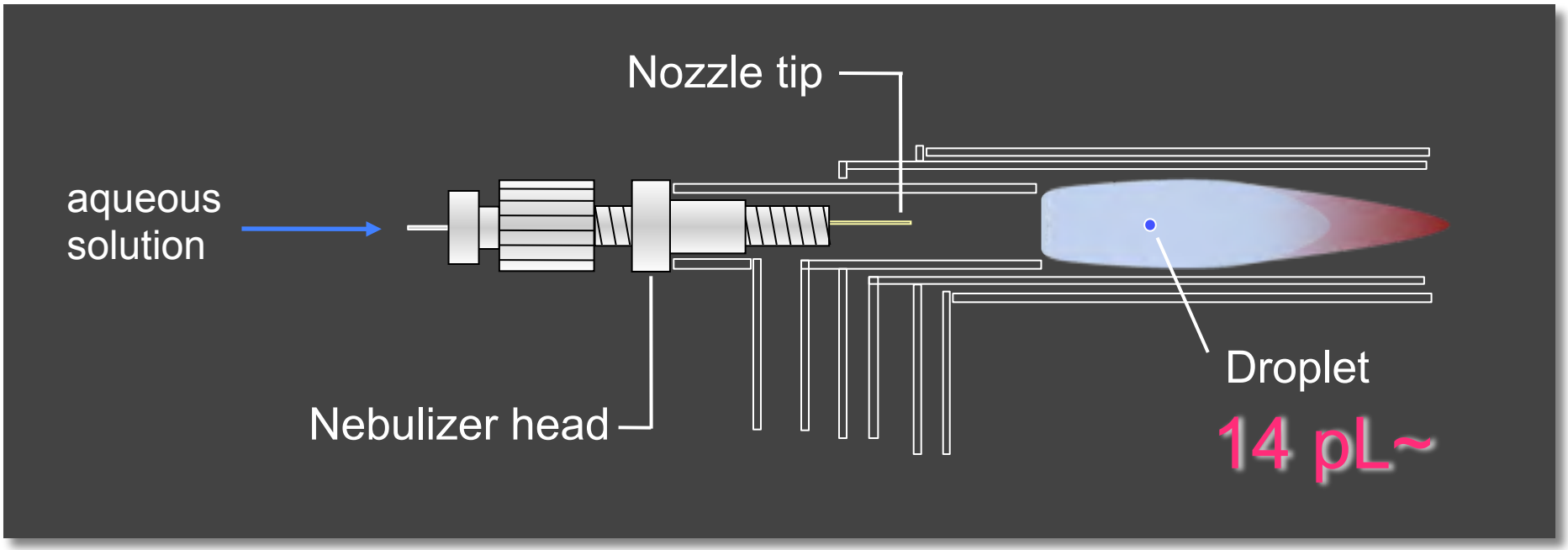
Droplet nebulizer for single cell analysis

PAT Japan etc.



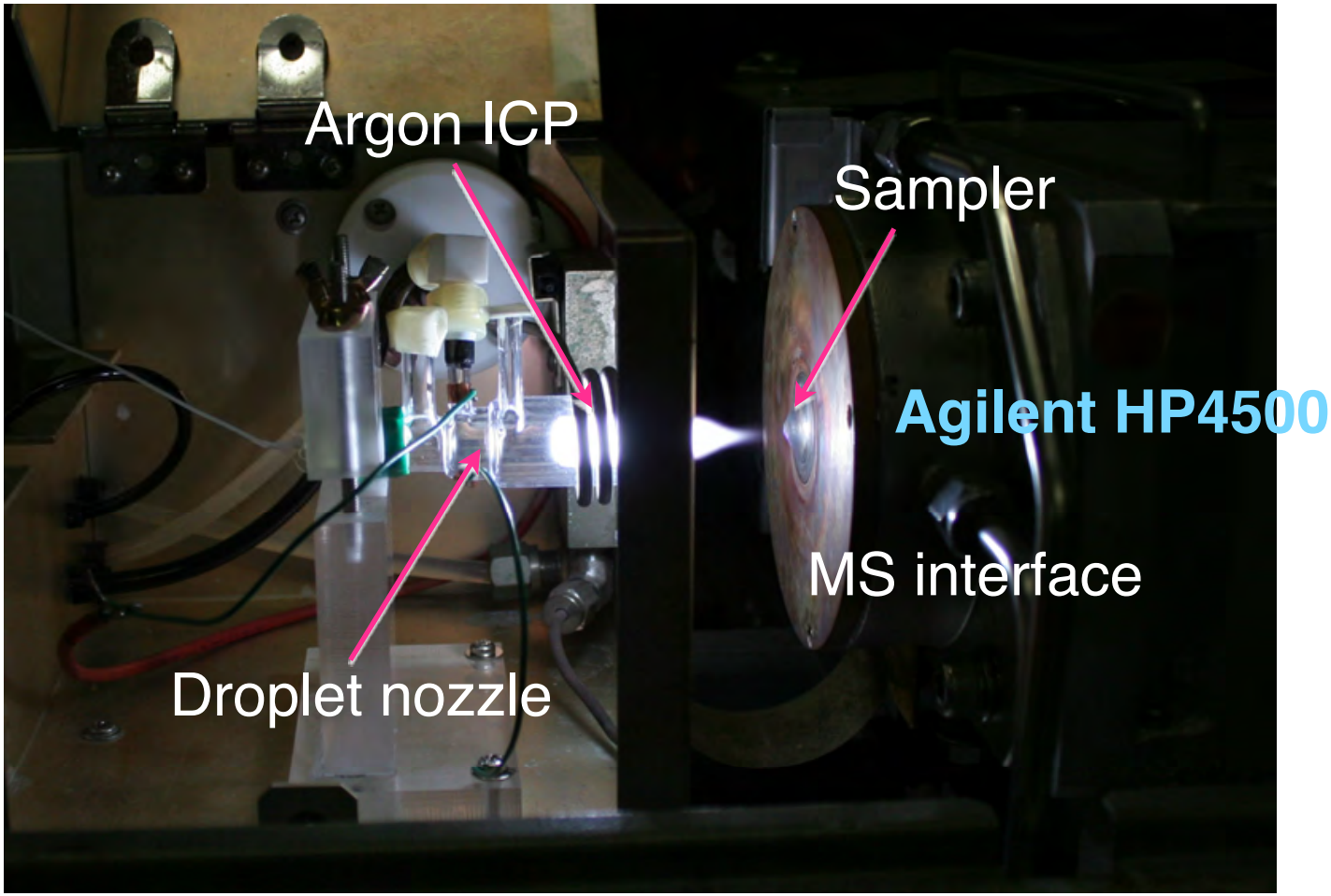
Single cell is included
in a single droplet
using microscope.

Individual analysis of single cell/particle

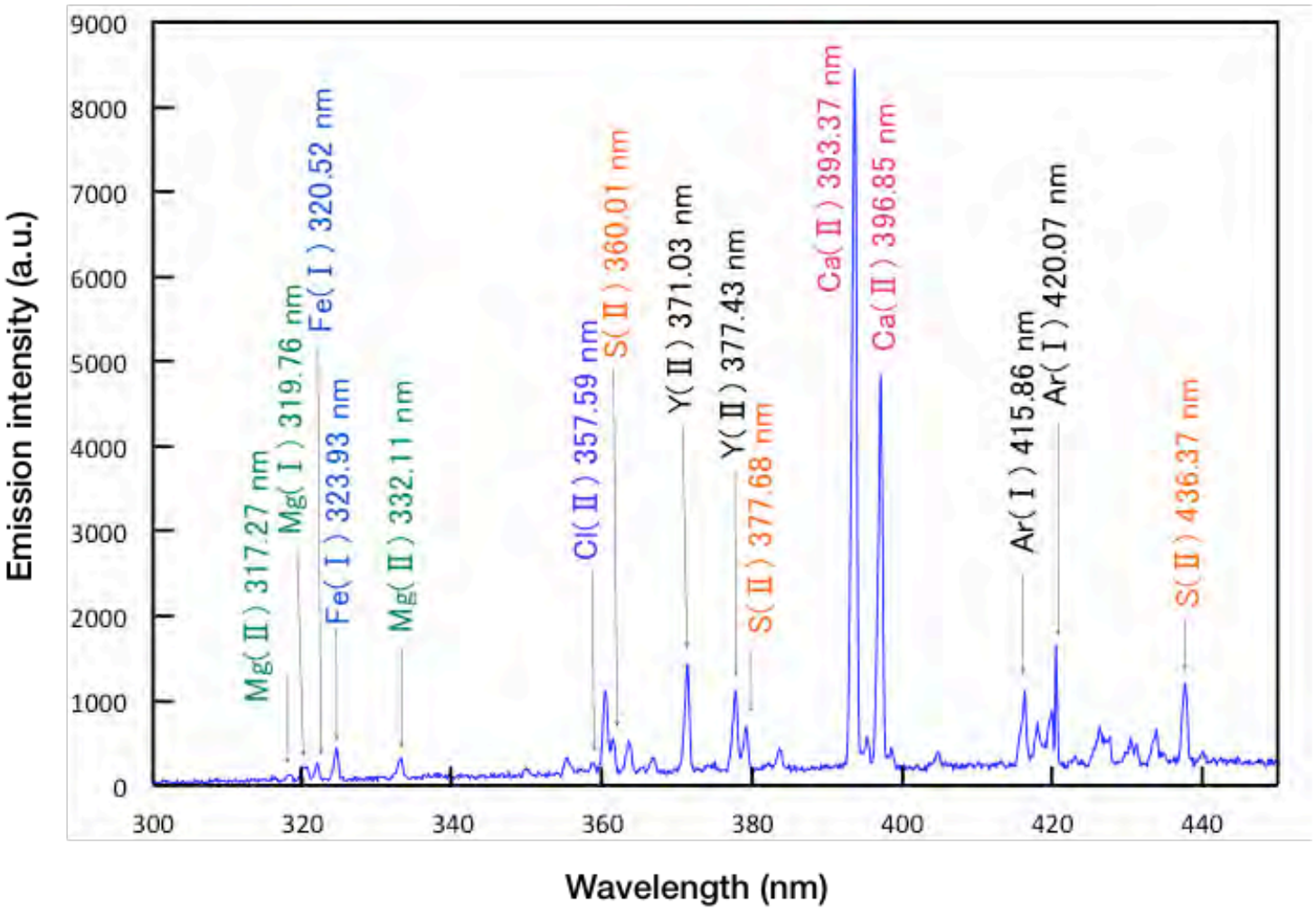


Droplet-DIN-ICPMS

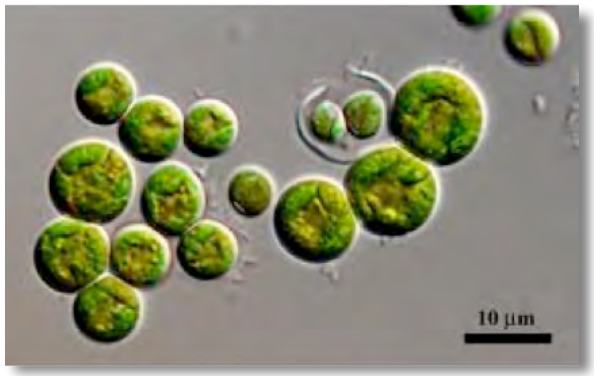
We applied the Droplet-DIN to ICP-Mass Spectrometer.



Element anaysis of single unicelluar algae



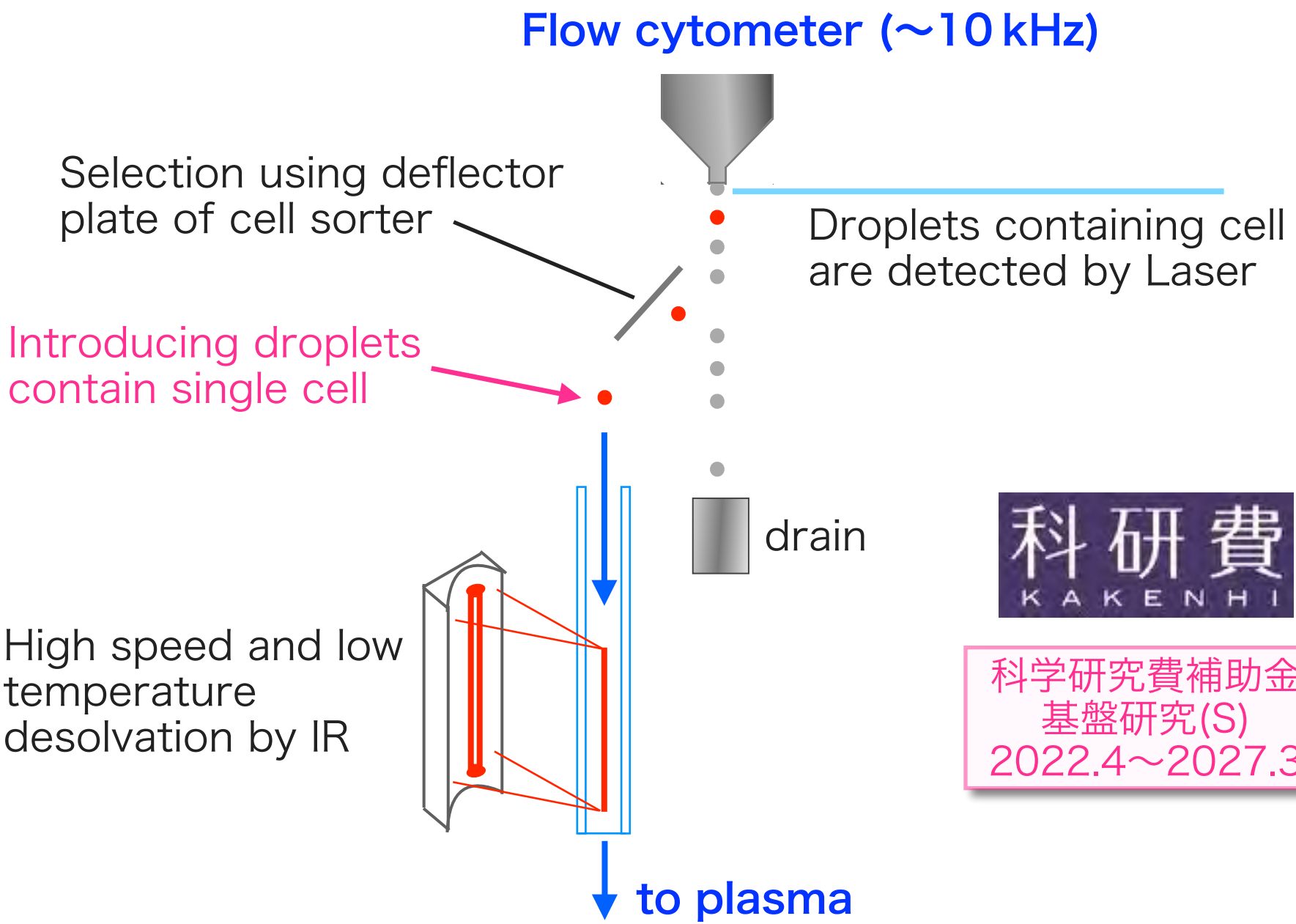
Pseudococcomyxa simplex



Element	Absolute amount（fg）
Fe	360
Mg	92
S	63
Ca	26
Zn	0.91
Mn	0.73

Fe, Mg, Ca contained in a single cell were observed by AES.

Direct connection to flow cytometer "**Metal Cytometer**"



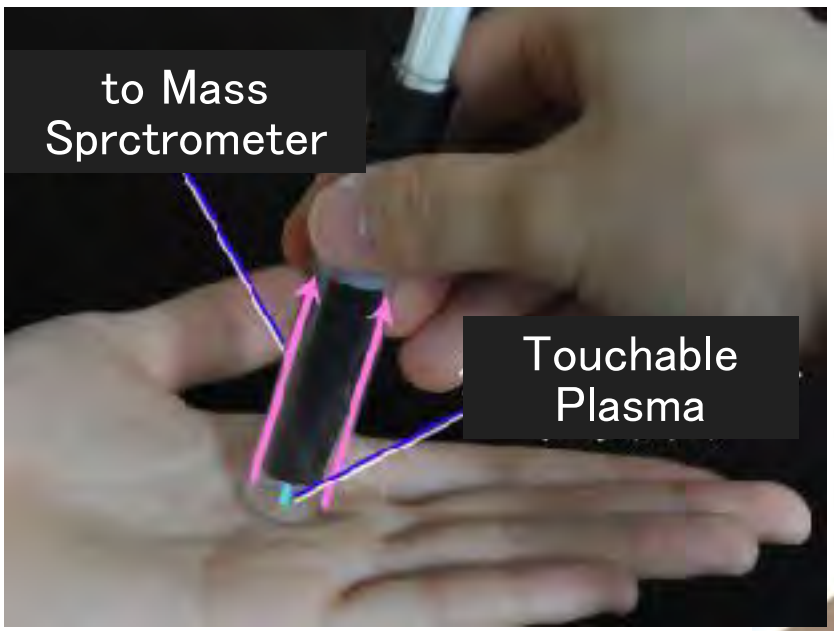
科研費
KAKENHI

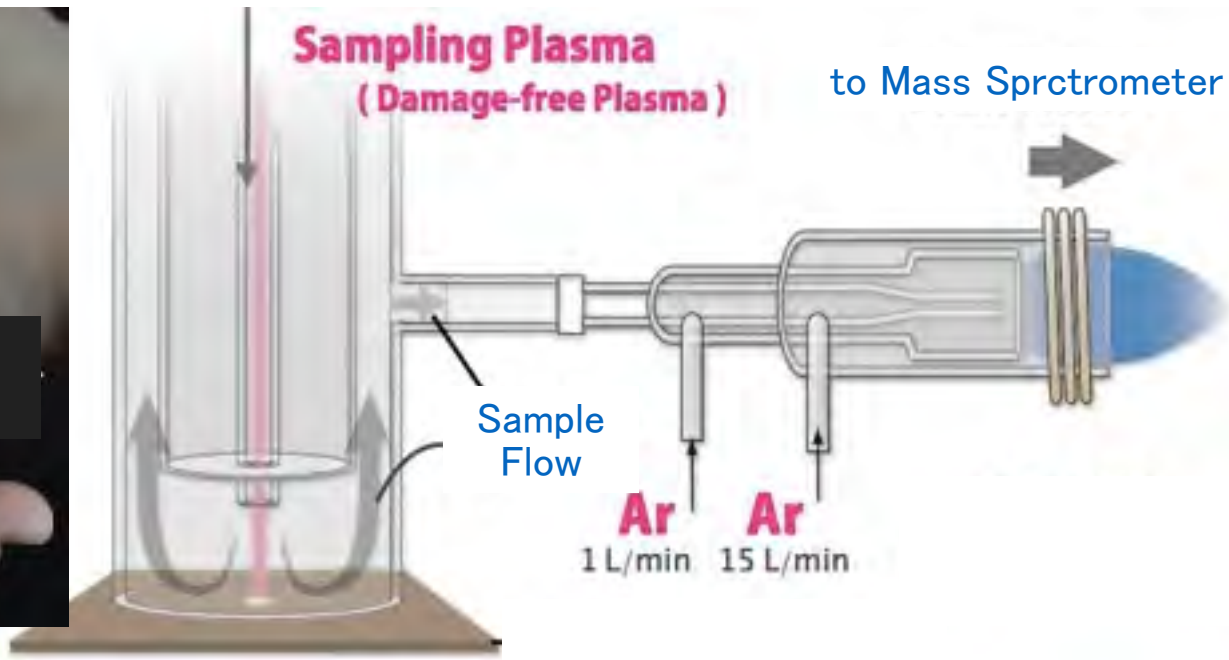
科学研究費補助金
基盤研究(S)
2022.4～2027.3

Measurement of adhesion material on heat sensitive surfaces

Atmospheric Plasma Soft Ablation; APSA

PAT Japan etc.



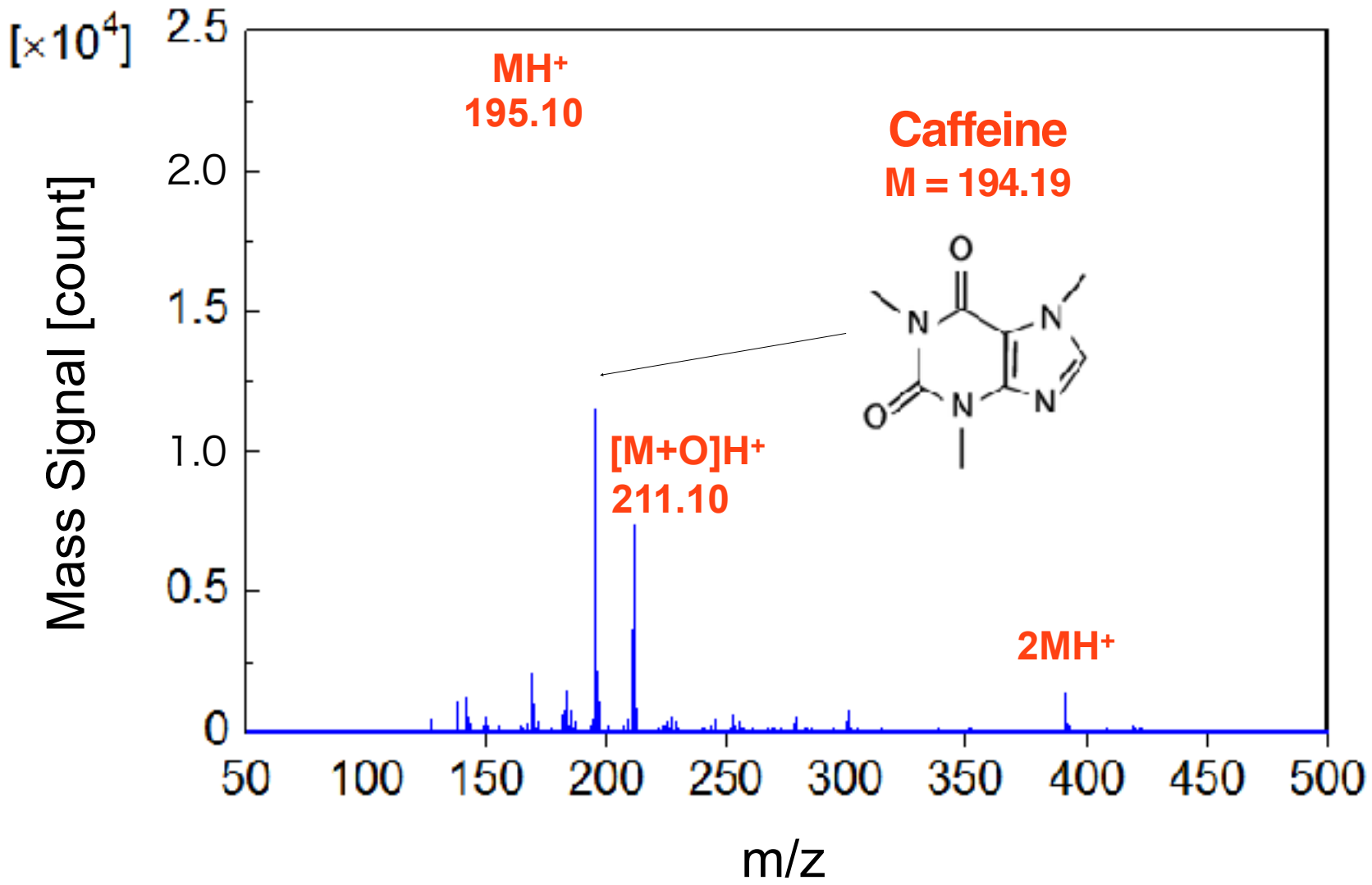


- Sampling surface adhesion materials without damaging to the surface
- Applicable to various mass spectrometers

✓ Disease diagnostics by sweat
✓ Security at airport
✓ Quality inspection of foods/drugs
✓ Measurement of cosmetics/sebum

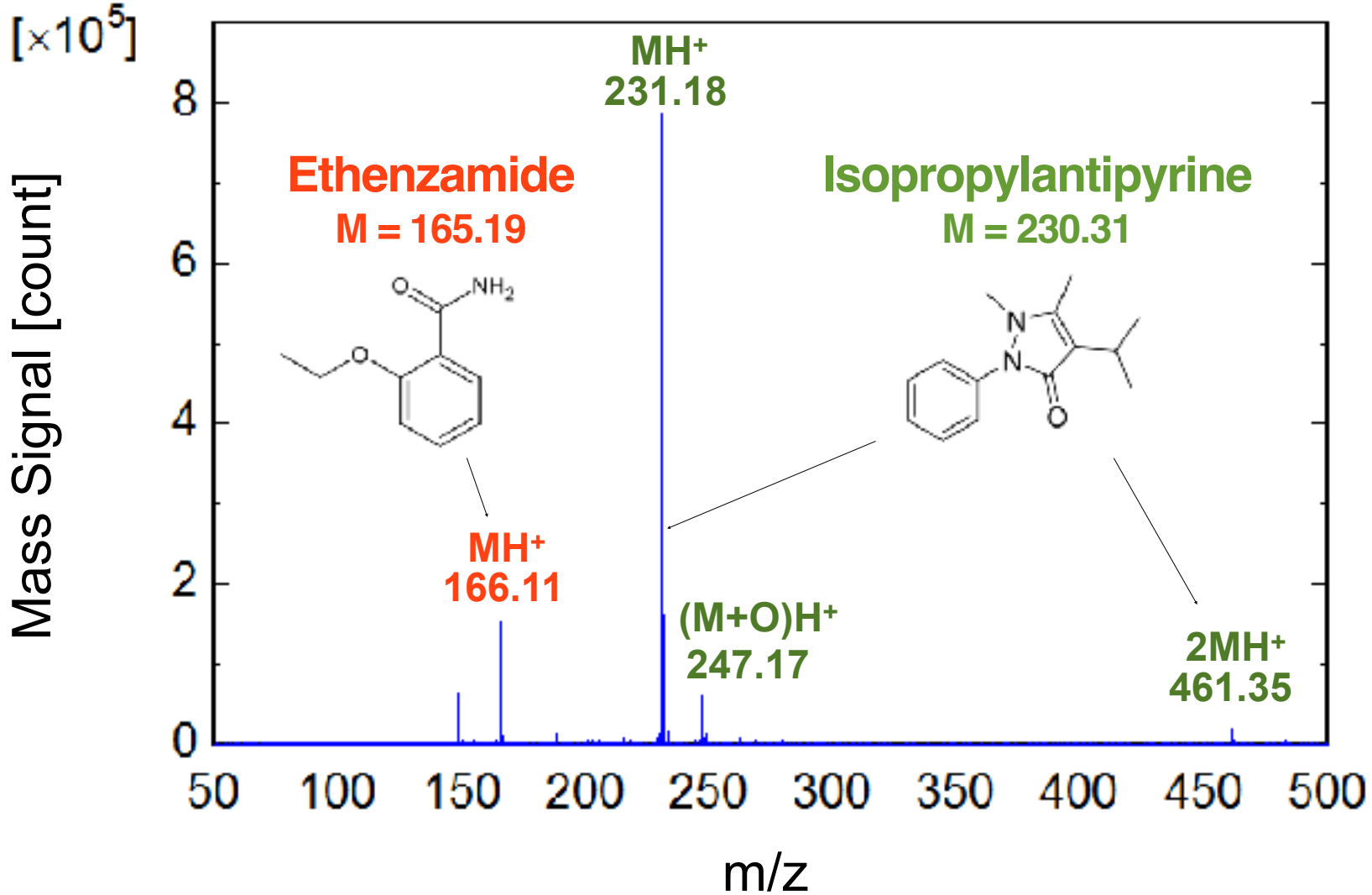
Estaron Mocha®

Boiling point: 178°C Gas temp: 55°C



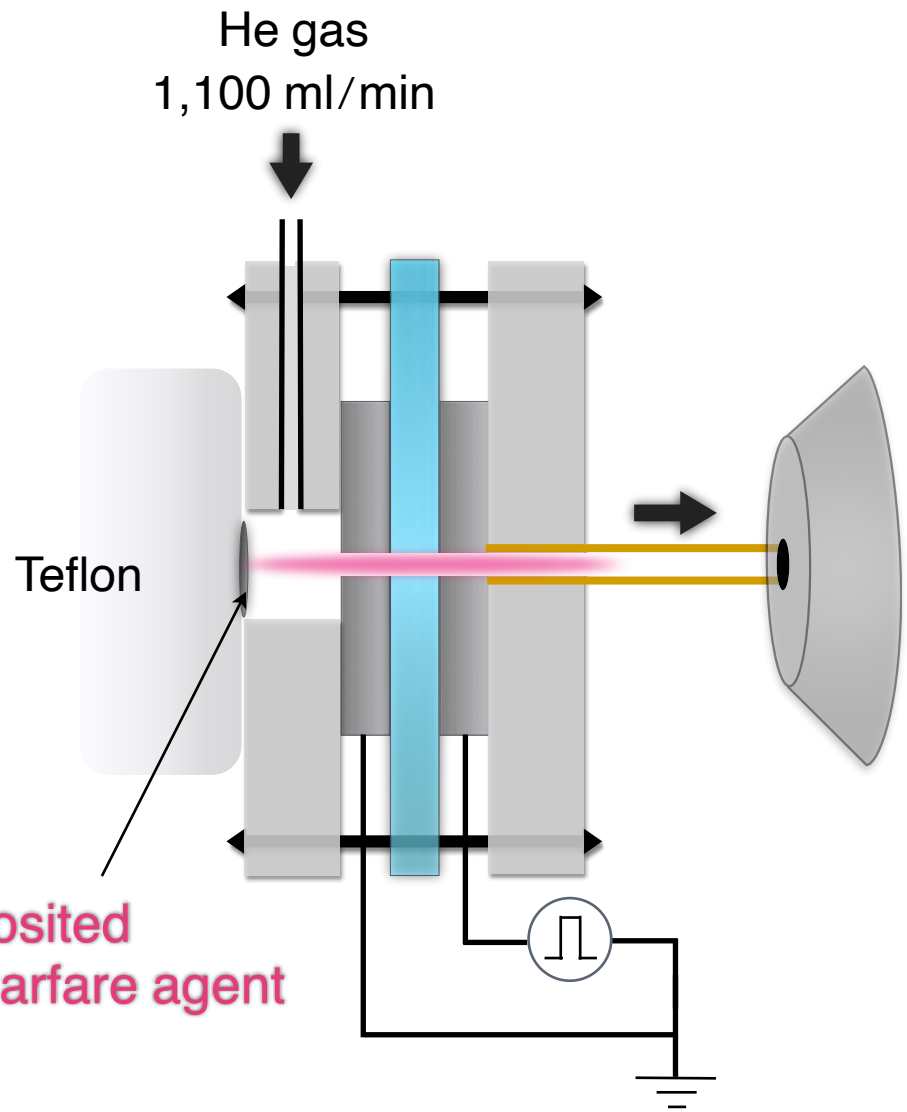
Saridon®

isopropylantipyrine	**150 mg**	B.P. : 319℃
Ethenzamide	**250 mg**	B.P. : 302℃



Detection of chemical weapons

National Research Institute of Police Science

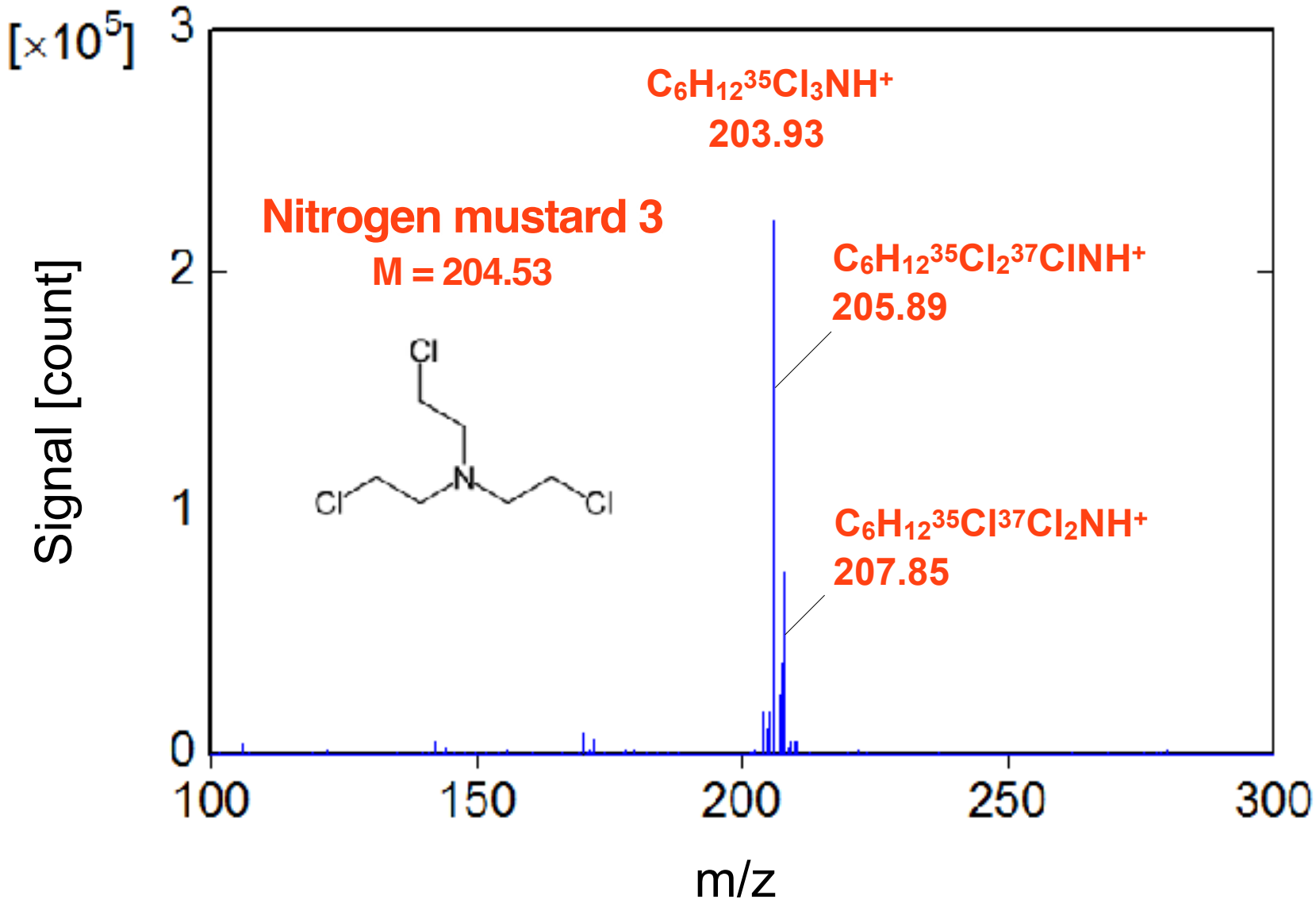


Ion trap
mass spectrometer

(Agilent technologies, 1100 Series LC/MSD trap)

NH3 (Blister agent)

1000 ppm in 5 μL Hexane Boiling point：143°C



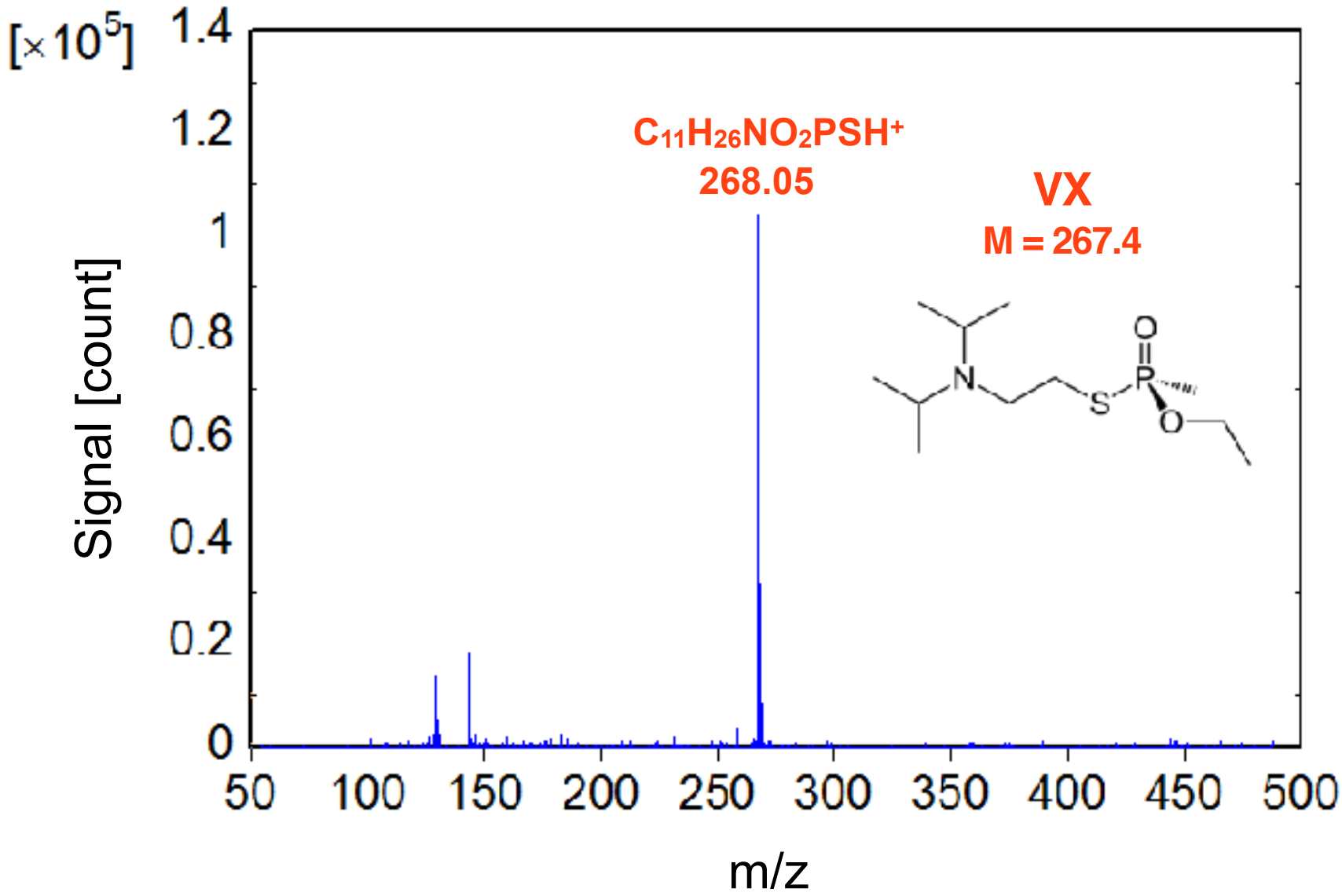
VX (Nerve gas)

1000 ppm in 5 μL Hexane

Boiling point：298°C

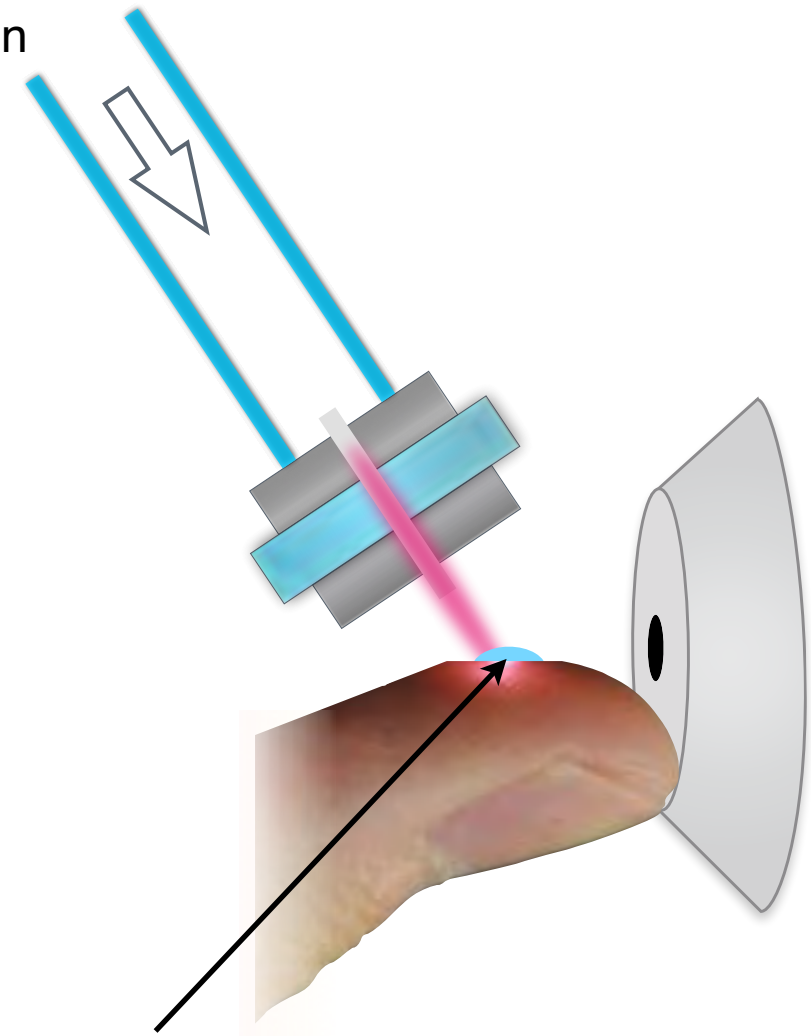
VX is the most danger in nerve gas.

Median lethal dose：0.1 g・min/m^3



Isopropylantipyrine on a finger

He gas
200 ml/min



Discharge capacitor：**12 μF**
Discharge voltage：**380 V**
Dischrge frequency：**20 Hz**

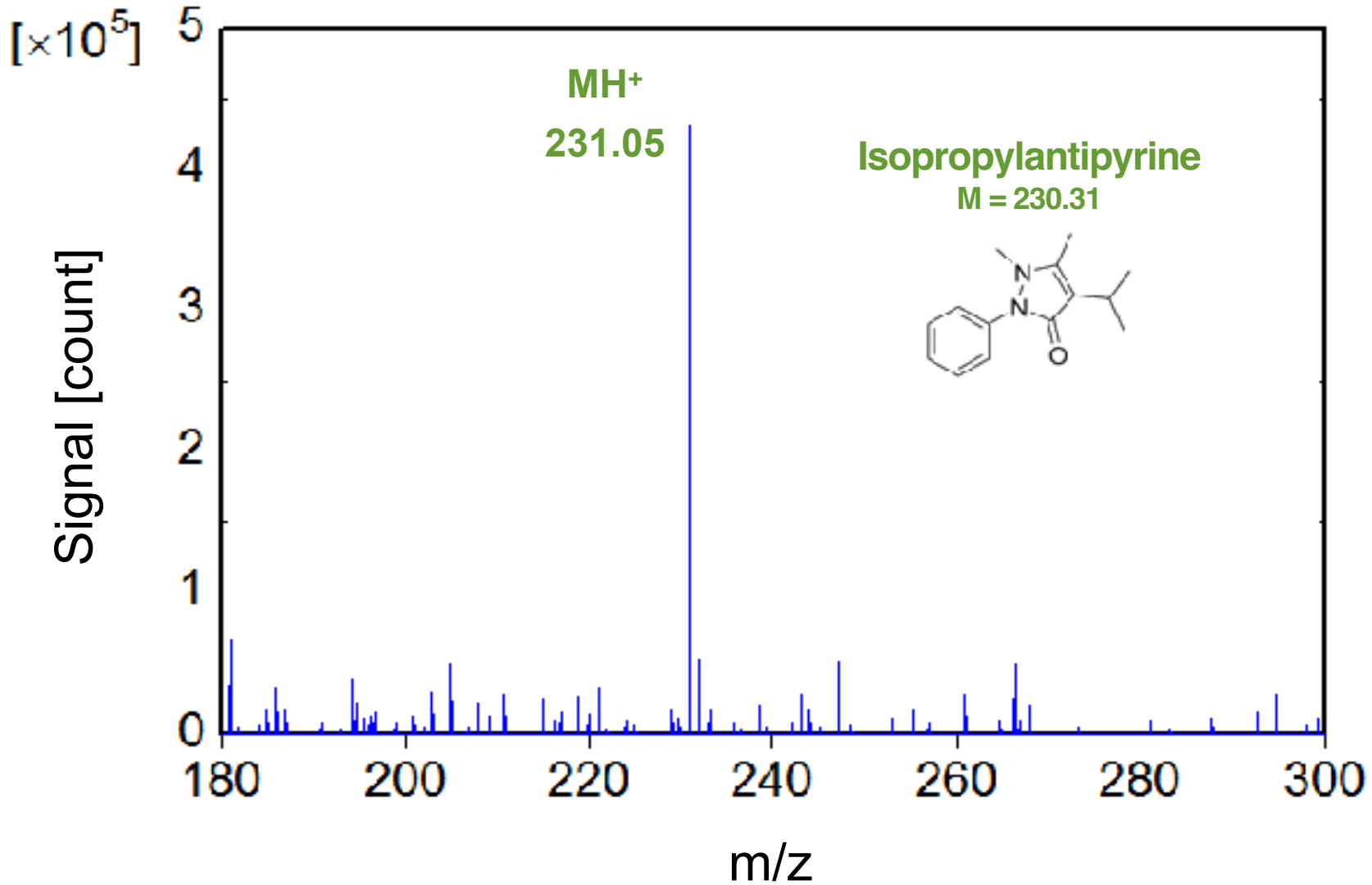
Ion trap
mass spectrometer

(Agilent technologies, 1100 Series LC/MSD trap)

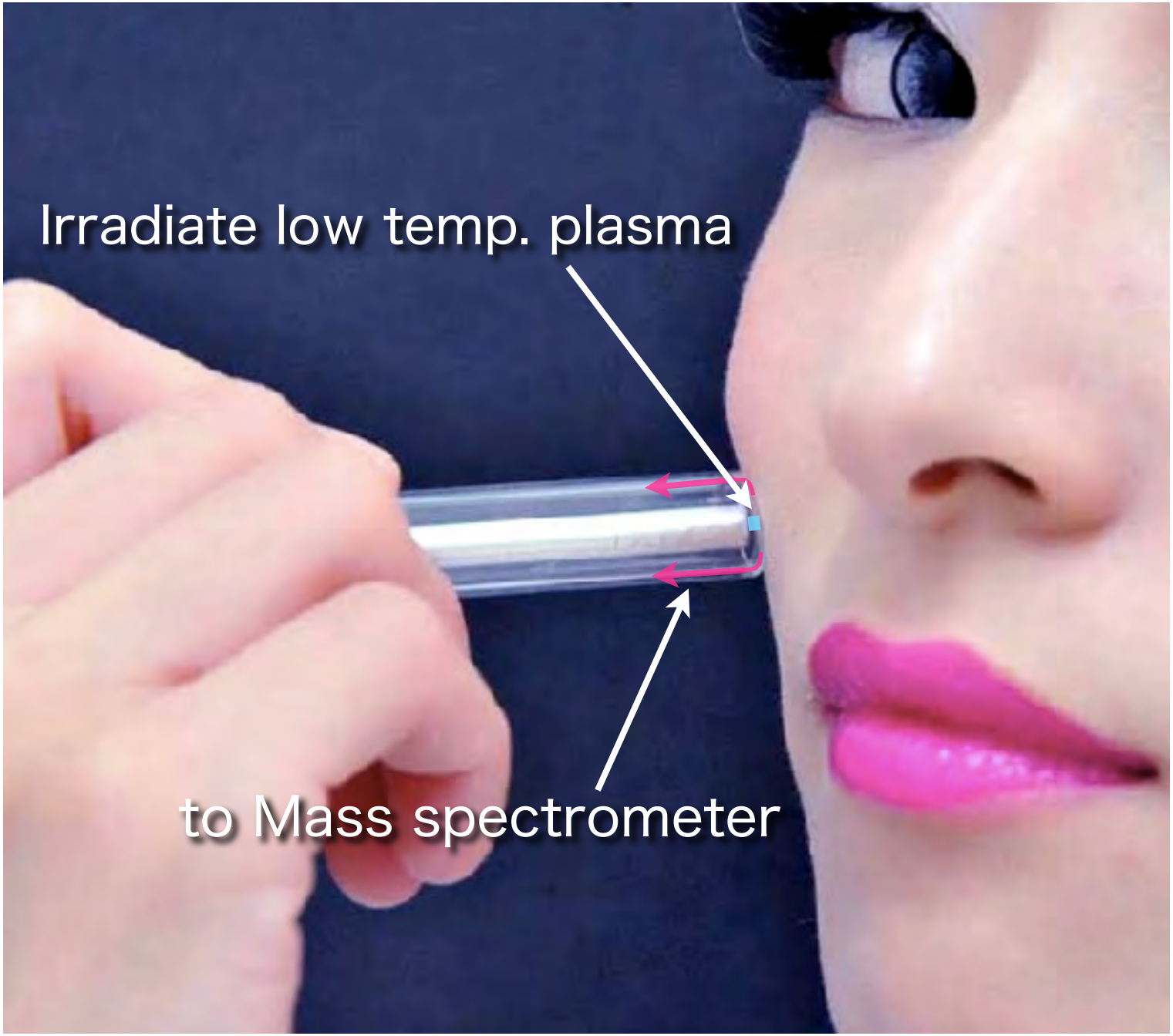
Isopropylantipyrine 50 ppm
in 10μL methanol

= 0.540 μg

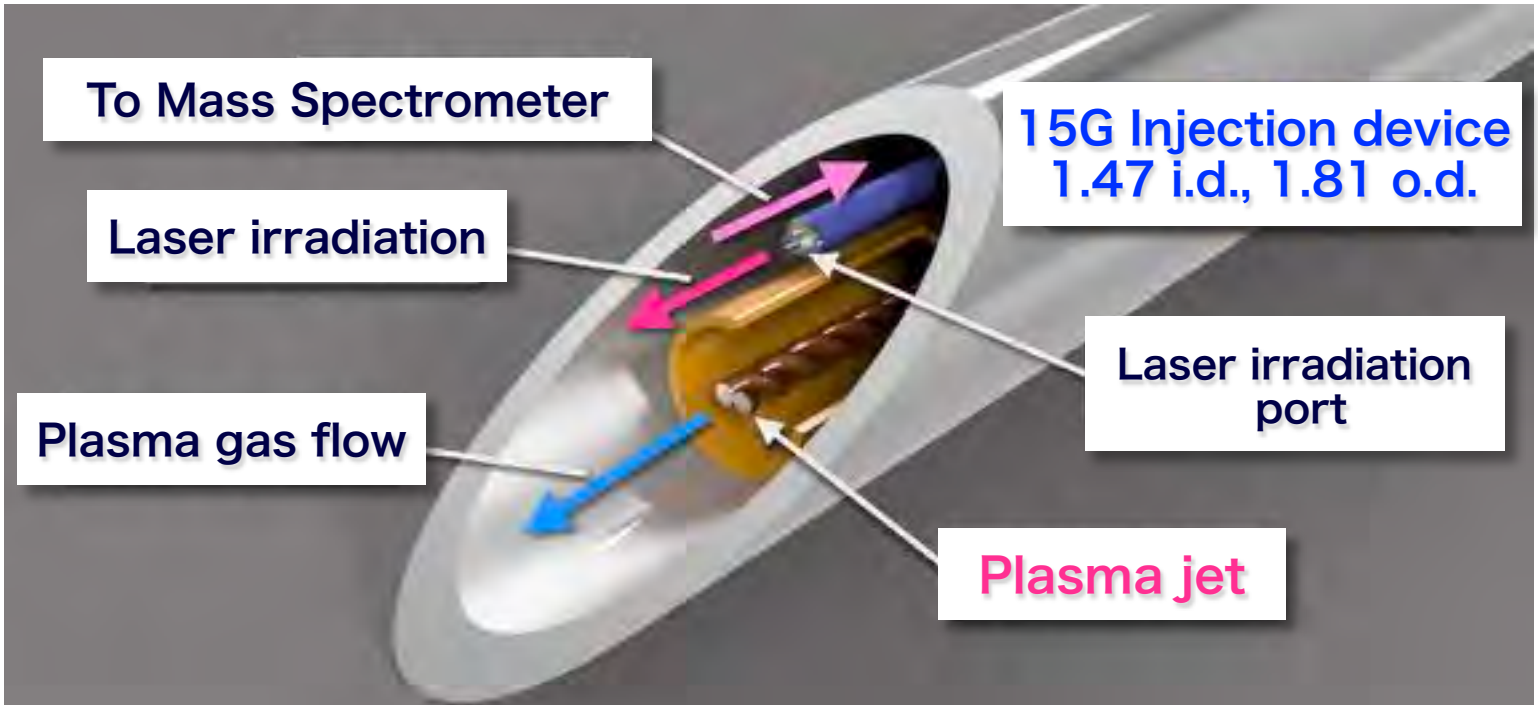
Measurement of isopropylantipyrine on a finger



We are applying it for human skin/cosmetics



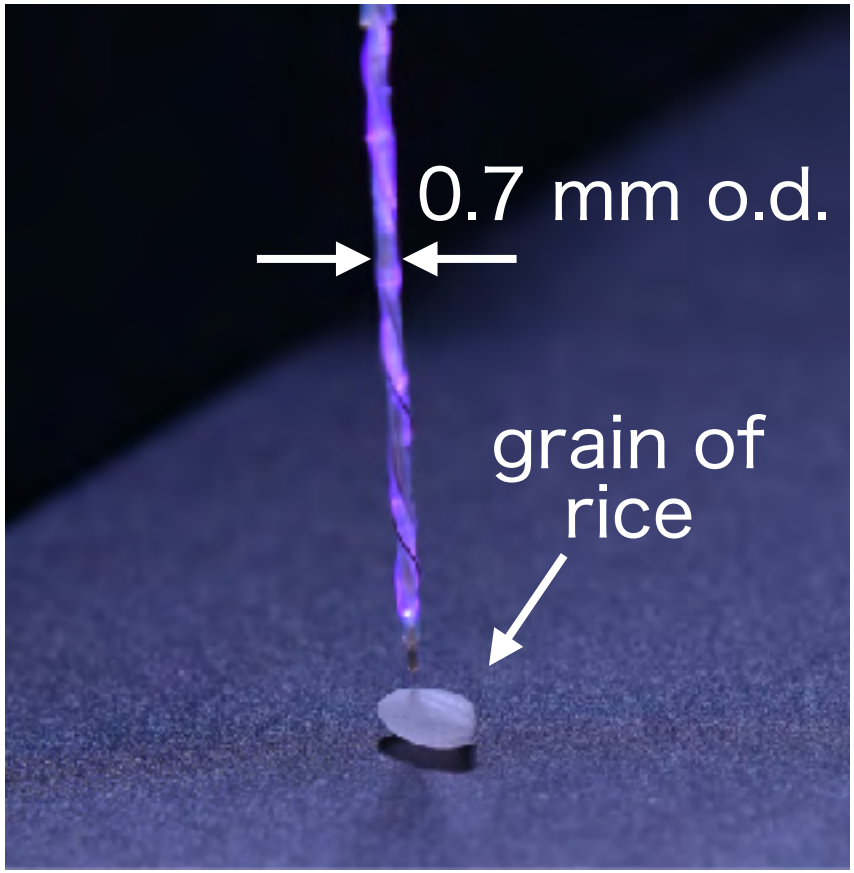
Plasma Injection Probe



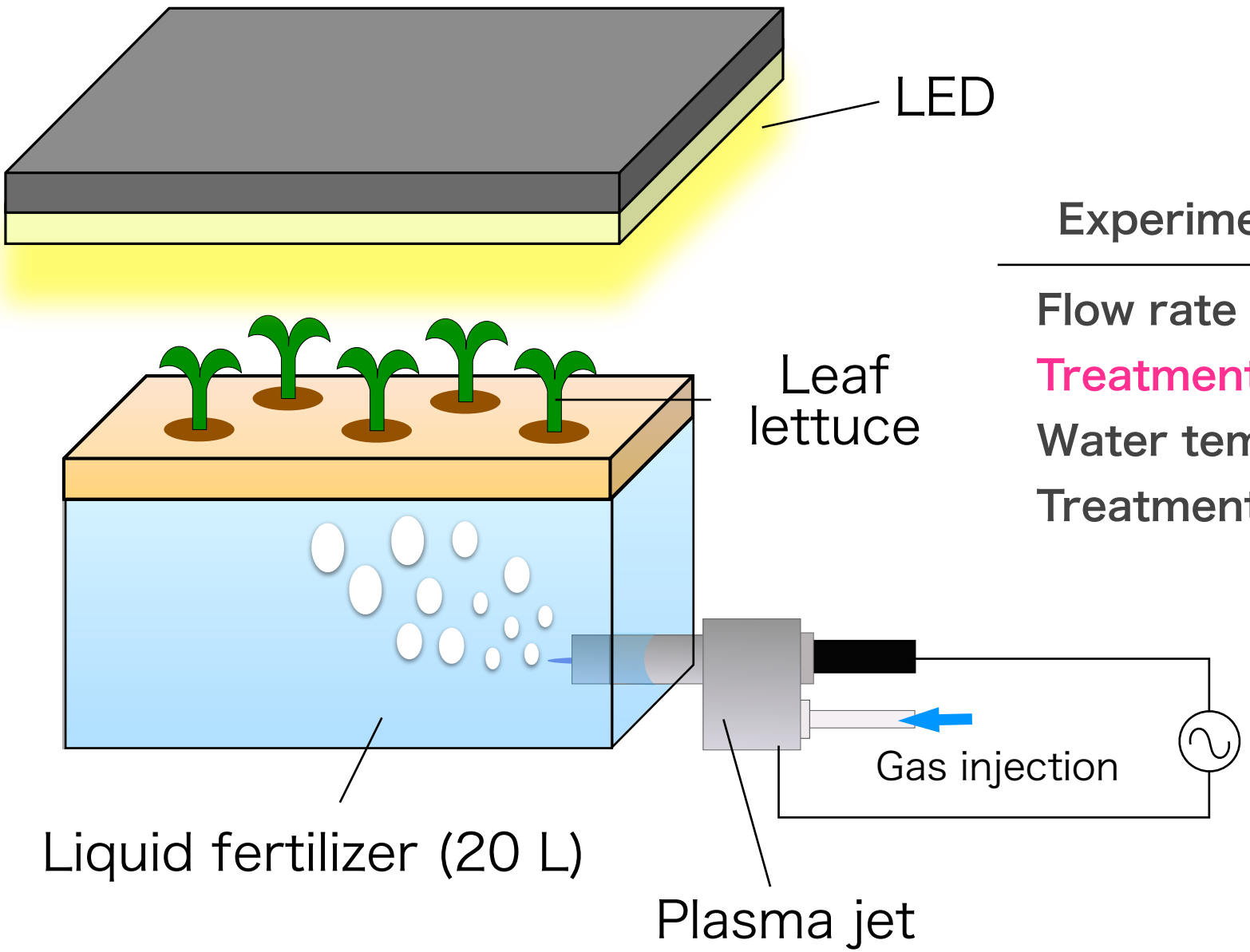
科研費
KAKENHI
科学研究費補助金
挑戦的研究(萌芽)
2022.6～2024.3

- Plasma and laser are placed in a thick needle and inserted into the body.
- Analyze drugs at specific locations in vivo with high spatial resolution.
- Measure the time variation of the drug by leaving it inside the body.

Analysis of drugs in bio-simulated samples



Agriculture (Hydroponic) by plasma bubble-up water



Experimental conditions

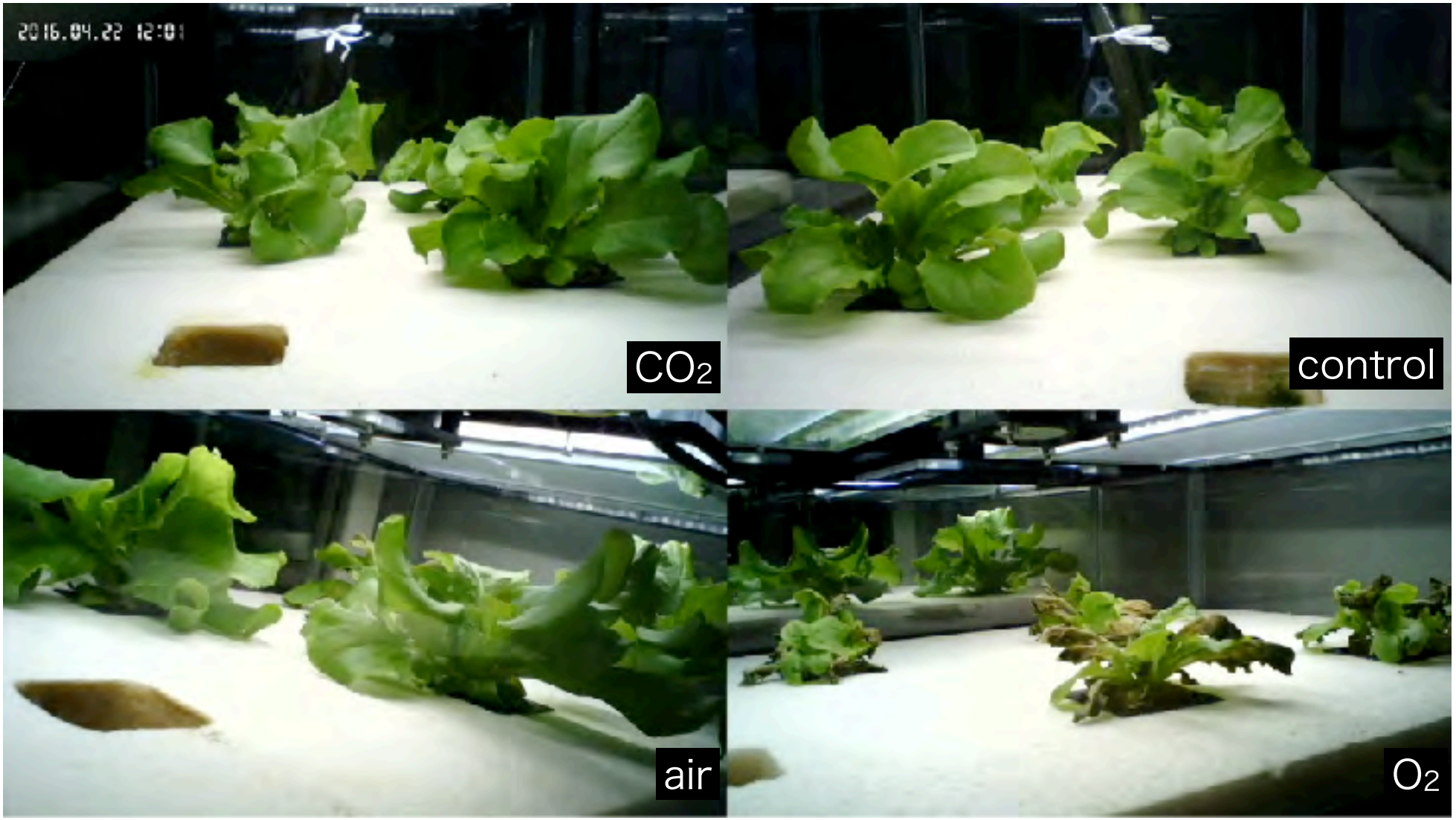
Flow rate : 5 L/min

Treatment : 2 min/day

Water temperature : 25 ℃

Treatment term : 3 weeks

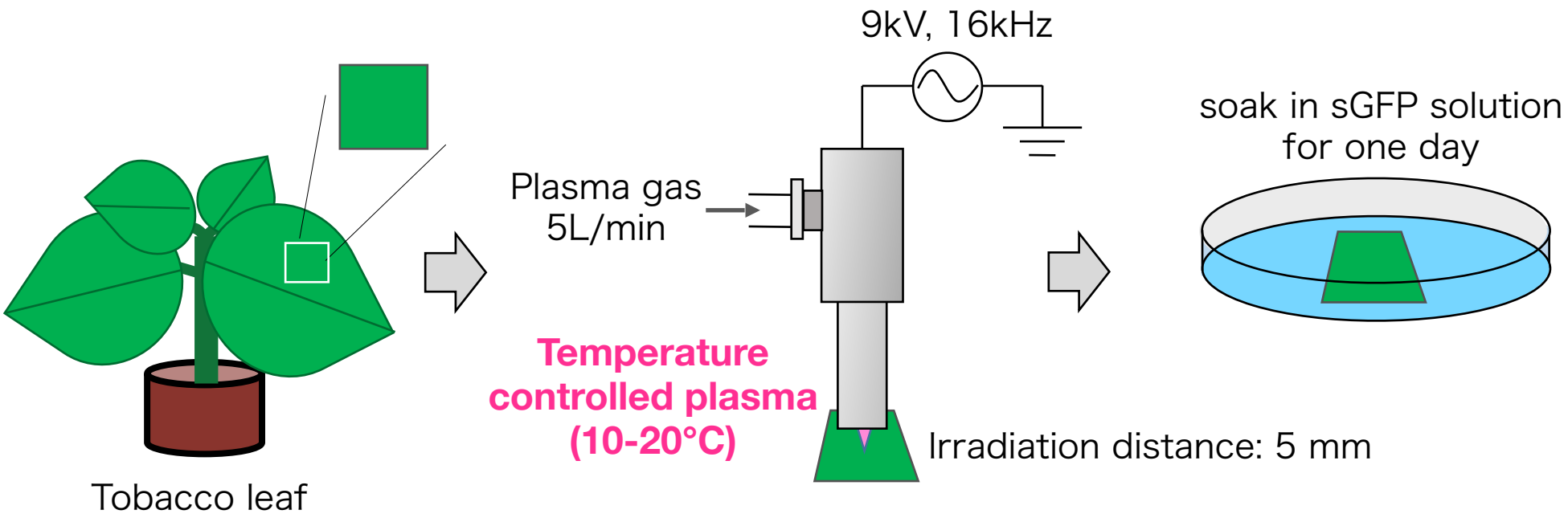
Agriculture (Hydroponic) by plasma bubble-up water

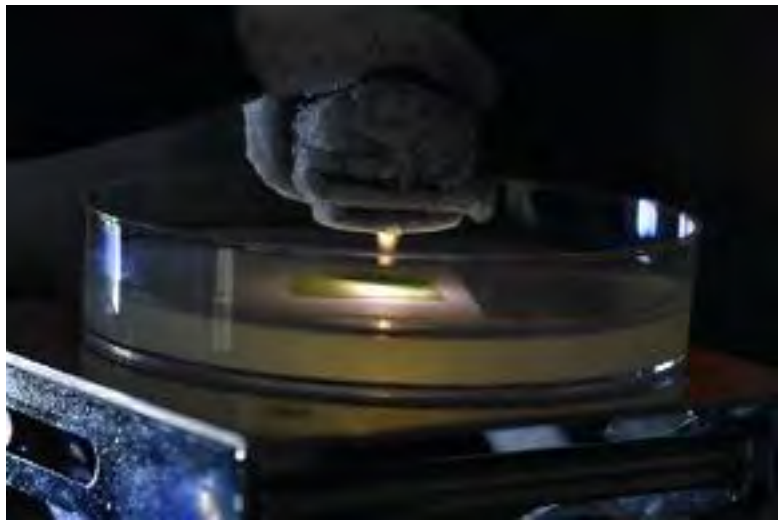


Lettuce harvested after 4 weeks

control Air CO_2

Procedure for introducing protein into plant cells

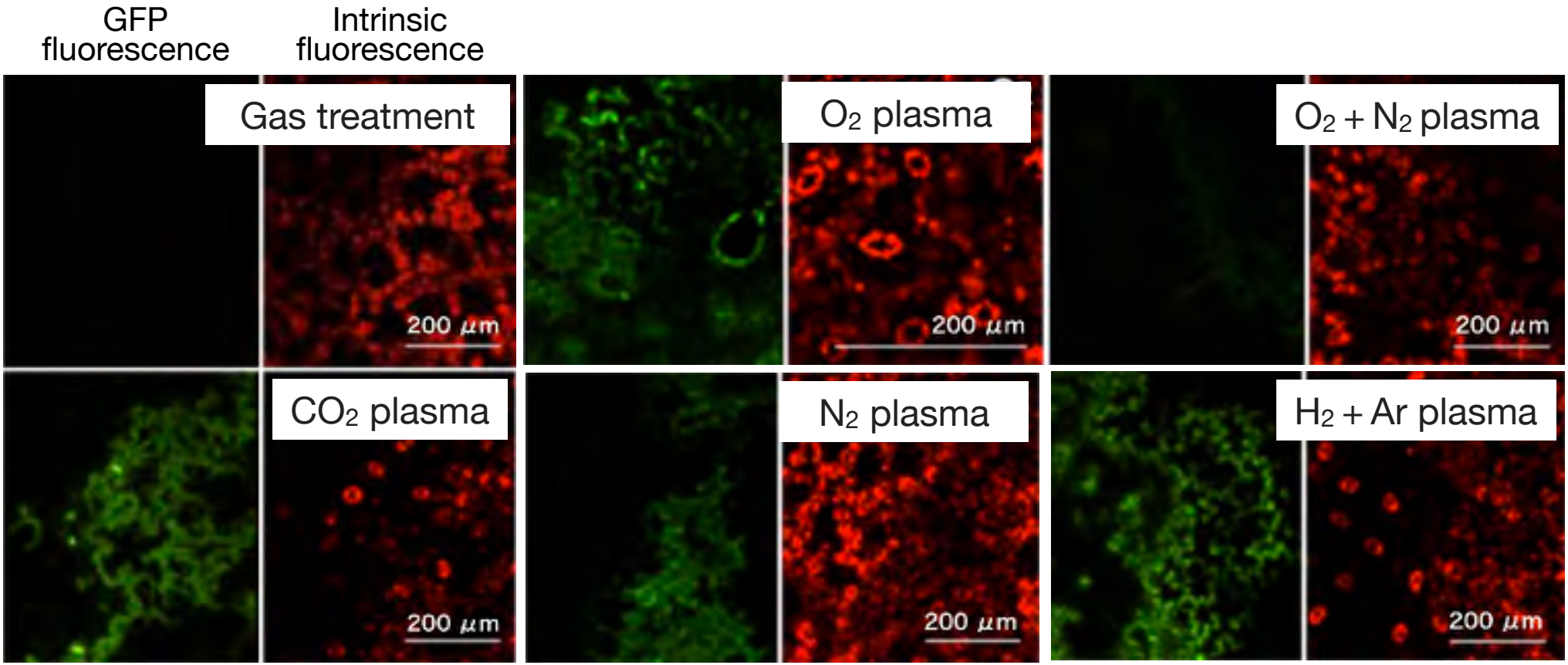




sGFP: green fluorescent protein

Molecular weight: 75,000

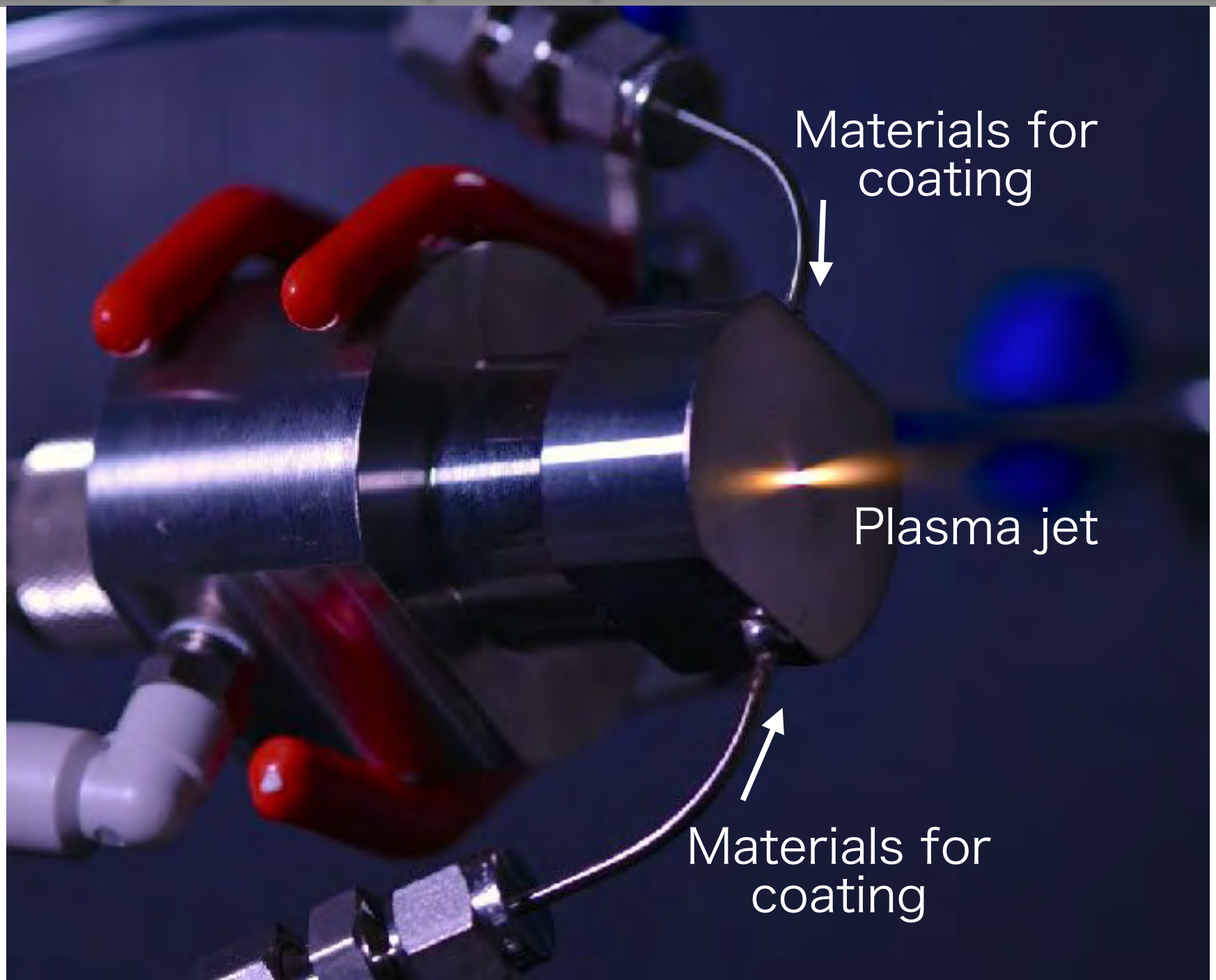
Observation of fluorescence with confocal microscope



Y. Yanagawa, A. Okino, I. Mitsuhara *et al*., Direct protein introduction into plant cells using a multi-gas plasma jet, PLOS ONE, 2, 12, e0171942 (2017).

Currently we are conducting genome editing experiments using CRISPR-Cas9.

Plasma jet for atmospheric pressure CVD

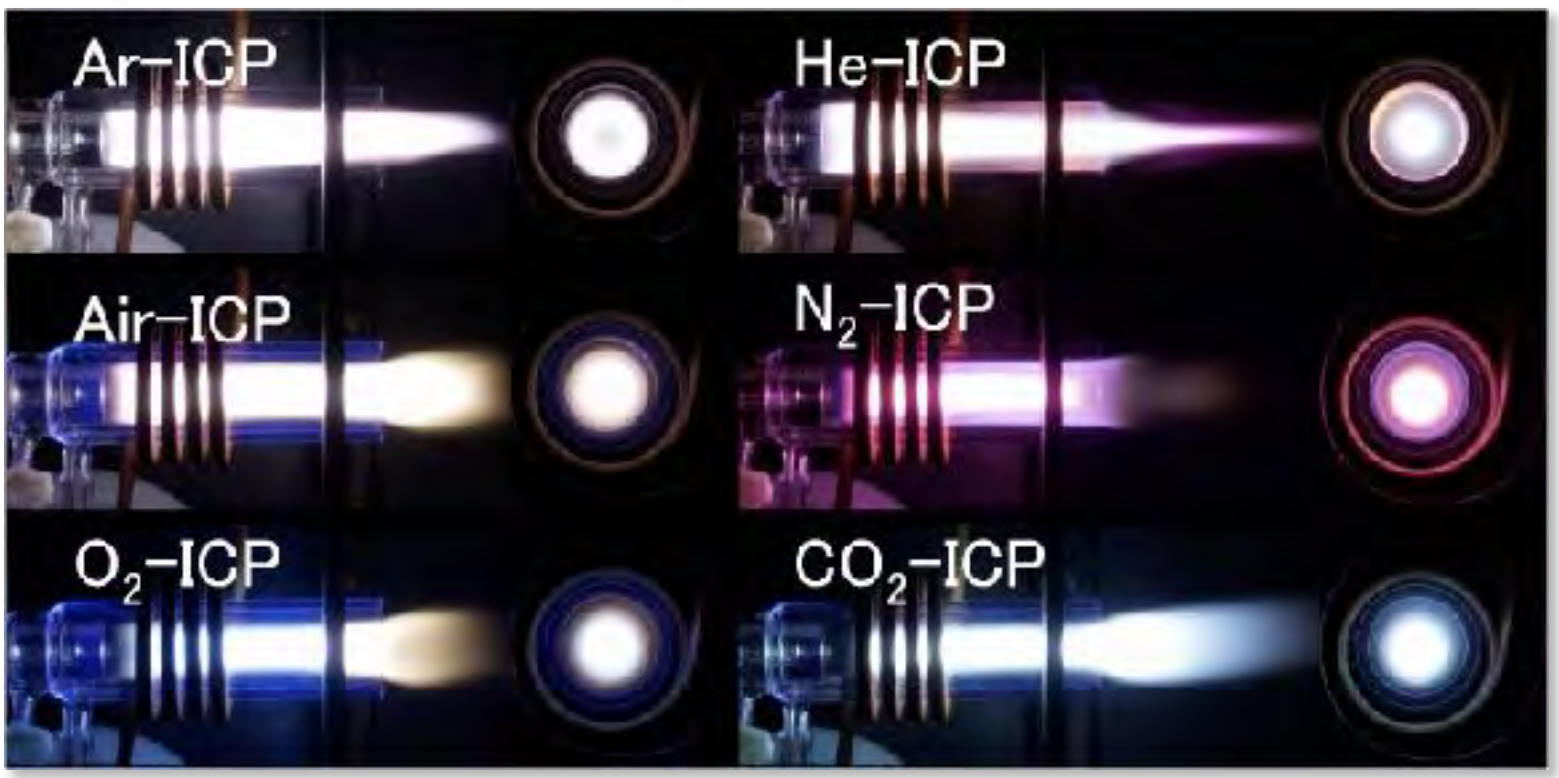


Atmospheric multi-gas thermal plasma

✓ Can generate not only Ar but He, N_2, O_2, CO_2, N_2O, air and their mixture gas plasma in atmospheric pressure.

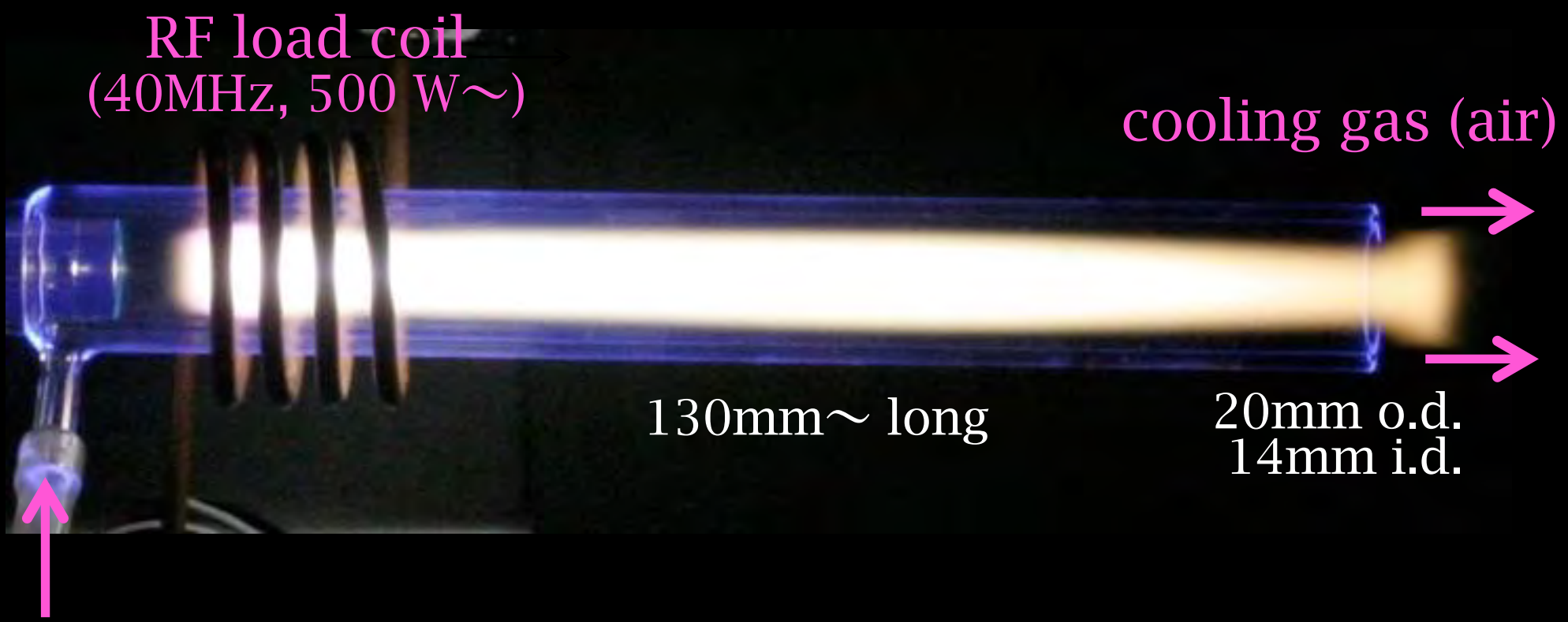
✓ High purity thermal plasma because it's electrode-less source.

- High gas temp：3,000 to 8,000 K
- High electron temp：～ 10,000 K
- High electron number density：～10^{15}cm^{-3}



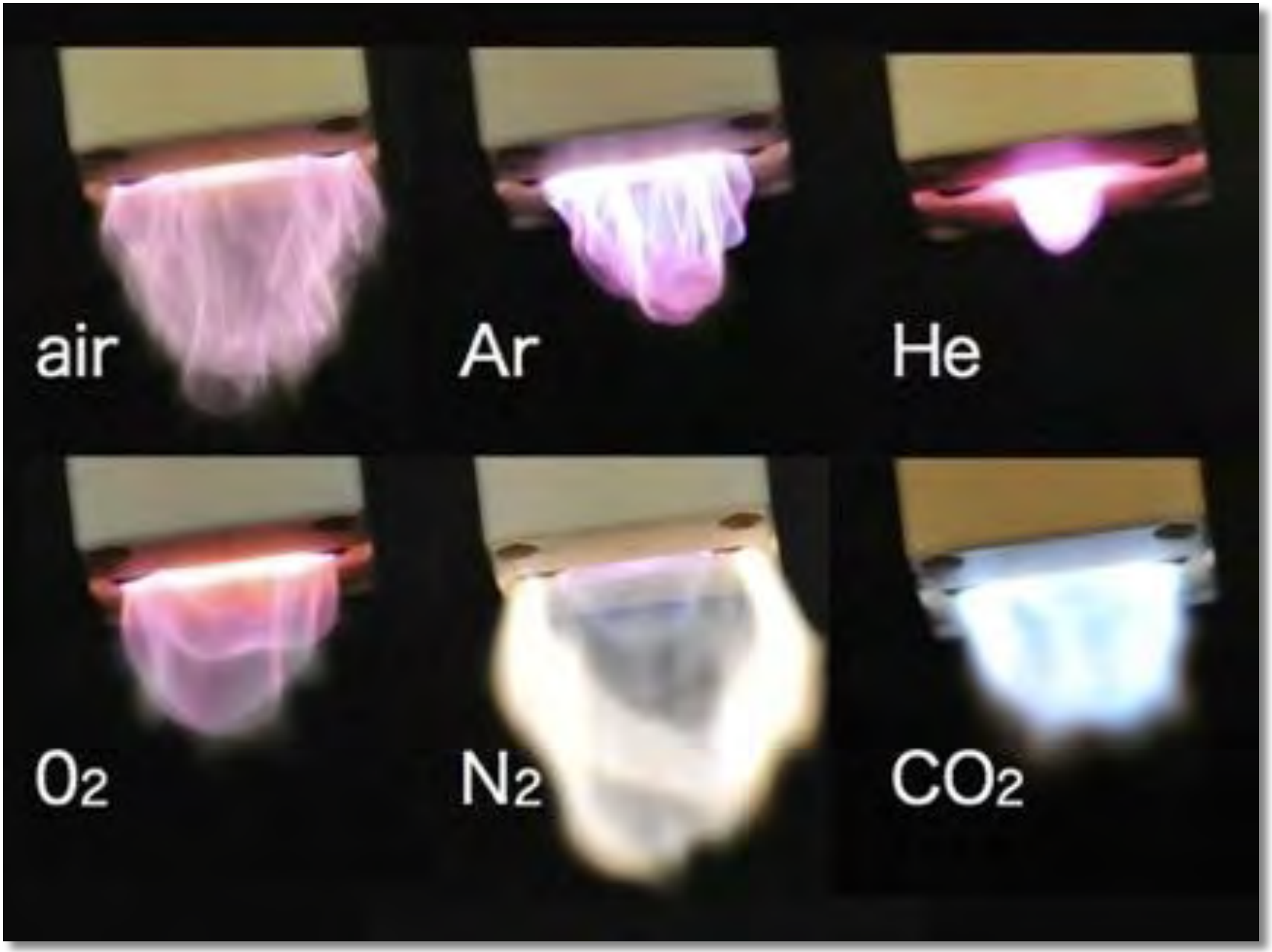
Only one device in the world!

Anethentic gas atmospheric thermal plasma
(Decomposition of Global Warming gas)

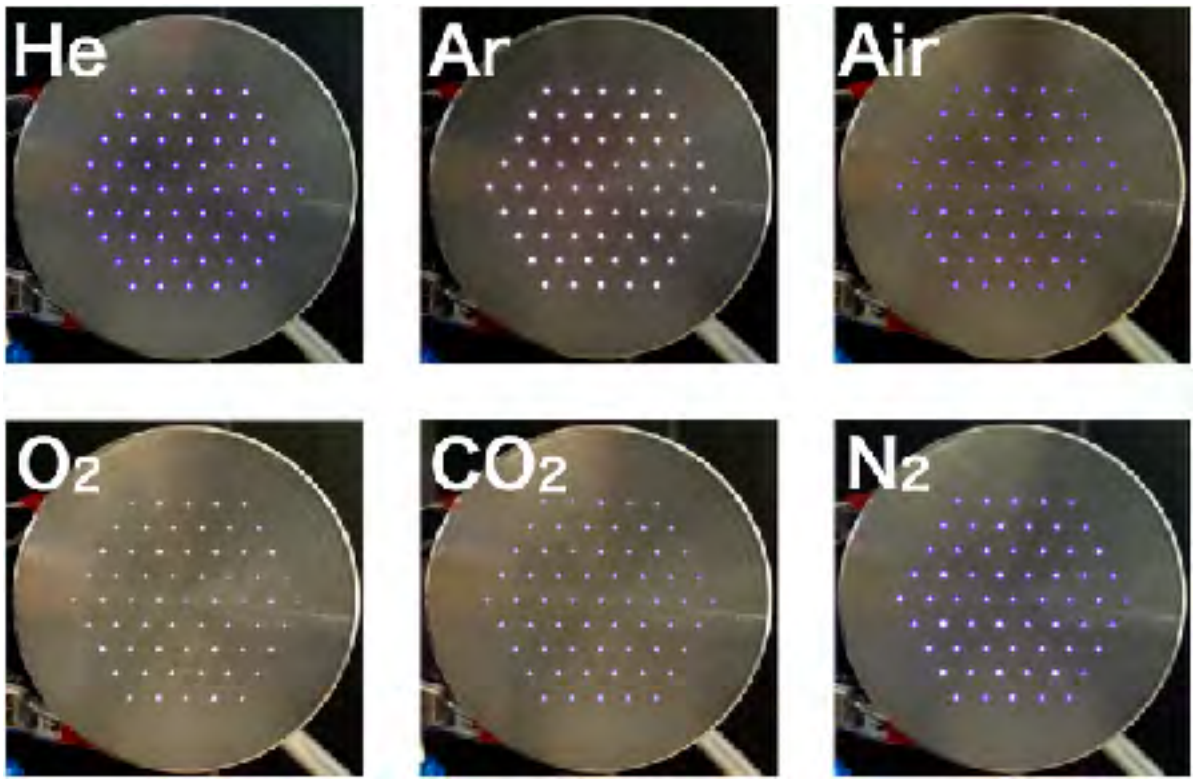


N_2O 4L/min + O_2 2L/min + buffered air 4 L/min
(for patient-safe exhaust)

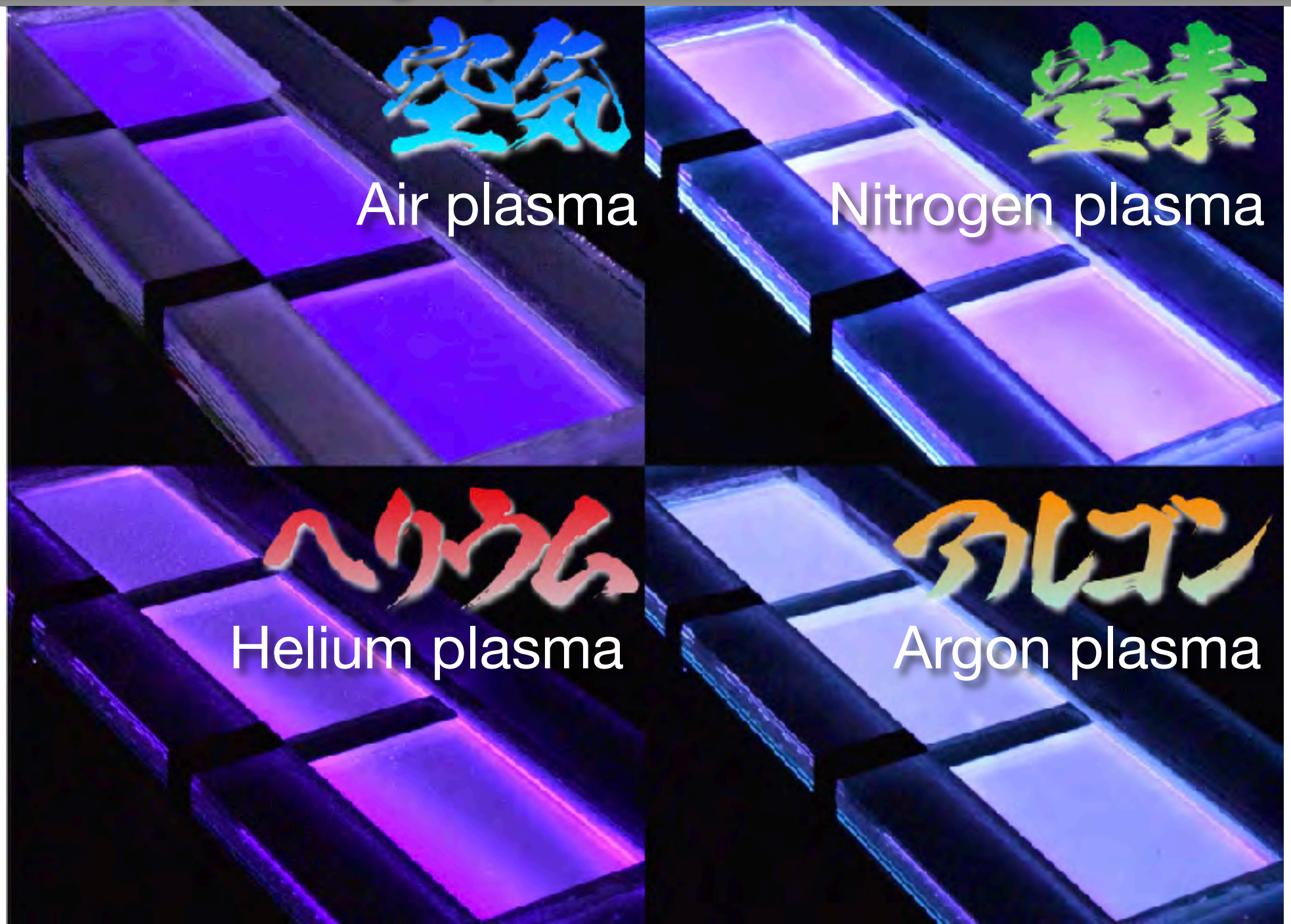
Atmospheric multi-gas gliding arc plasma



Shower head type multi-gas plasma for surface treatment



Sheet-type multi-gas plasma



High power pulsed multi-gas micro plasma

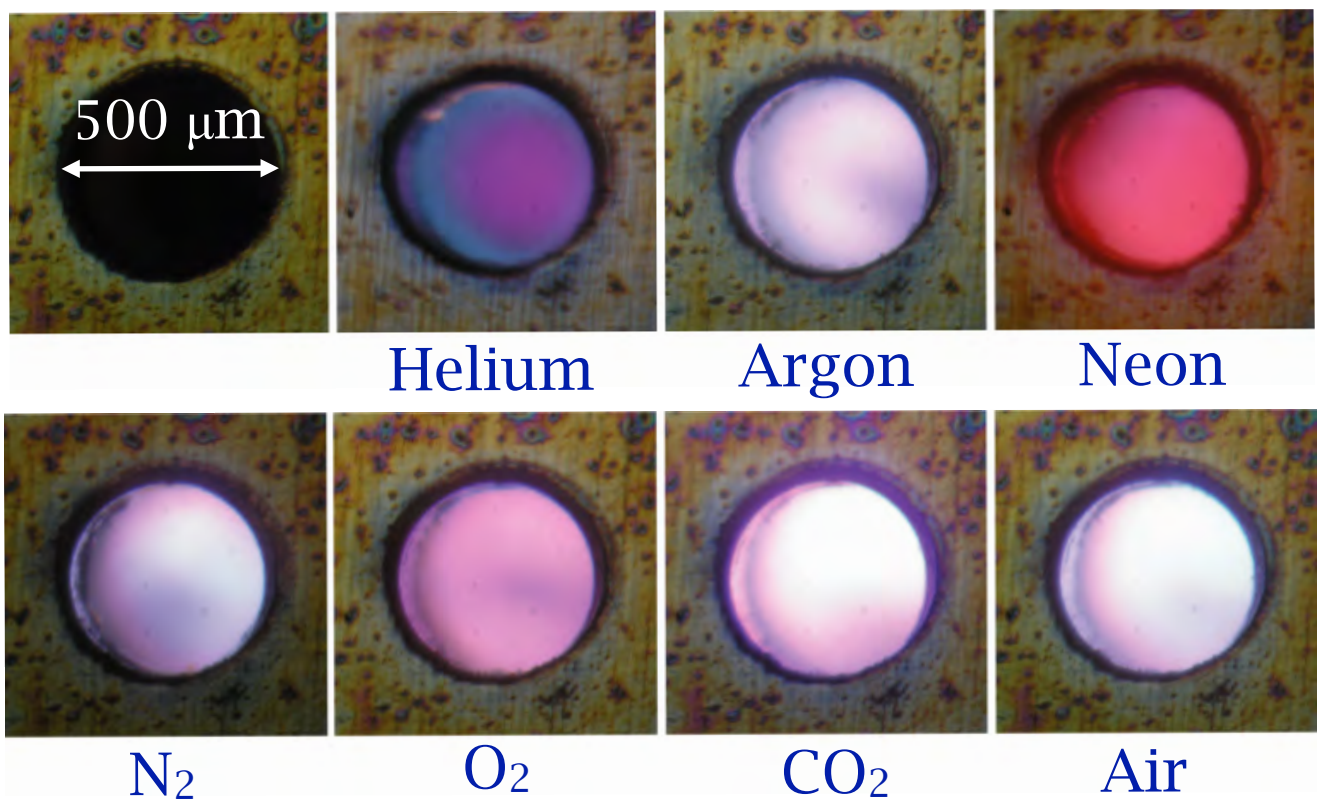
PAT.P

- ✓ Multi-gas plasma generation is possible
- ✓ High power drive up to 100 kW by pulsed operation
- ✓ Battery drive is possible ⇒ Mobile analysis/treatment
- ✓ Scale up is easy by two/three dimensional set up

High gas temp : 1,000 to 5,000 K

High electron temp : ～ 30,000 K

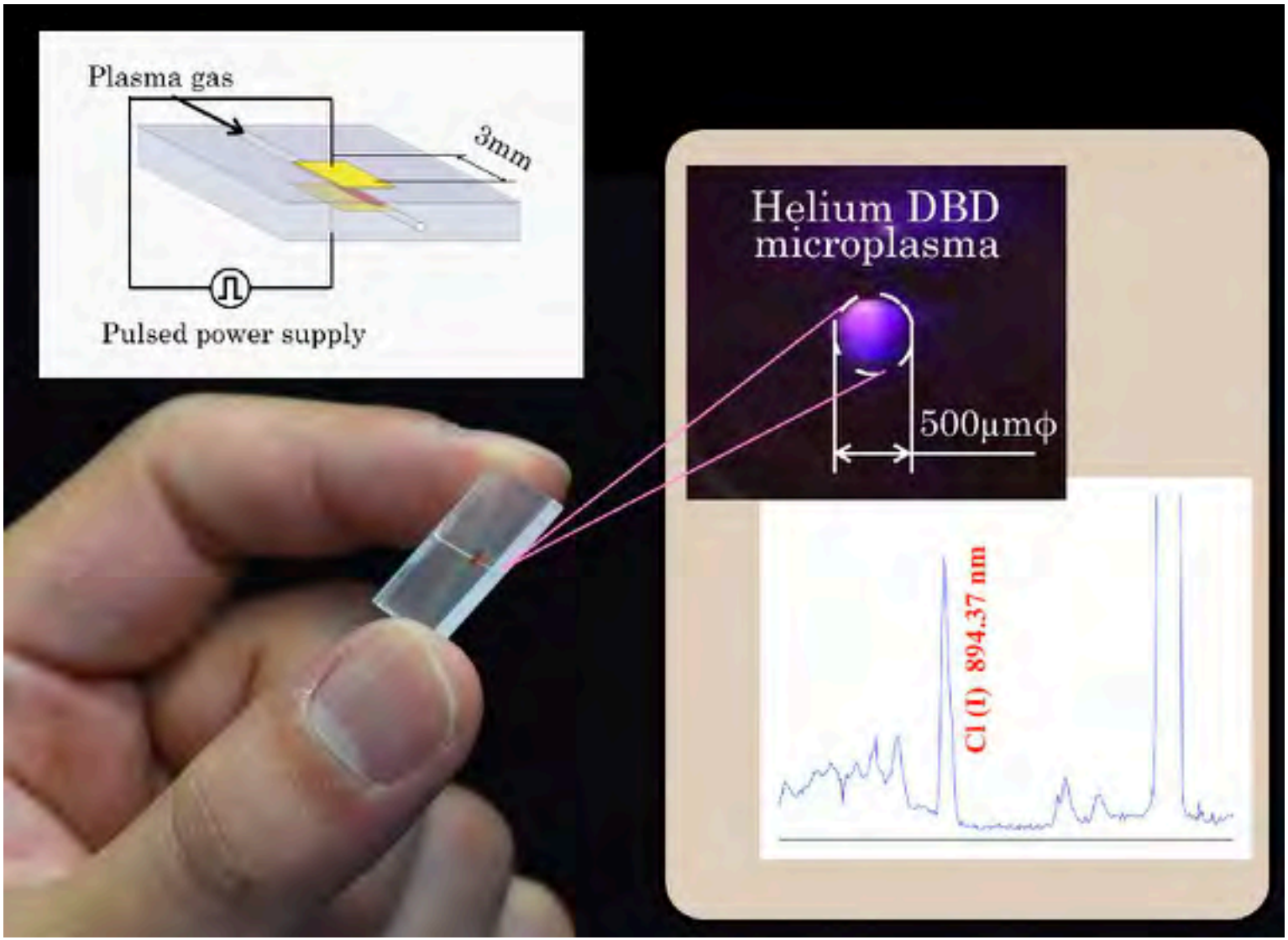
High Electron number density : ～10^{15}cm^{-3}



On chip plasma source using MEMS technique

Ken Kakegawa, Ryoto Harigane, Mari Aida, Hidekazu Miyahara, Shoji Maruo and Akitoshi Okino, Development of High-density Microplasma Emission Source for Micro Total Analysis System, Anal. Sci., 33, 505-510 (2017).

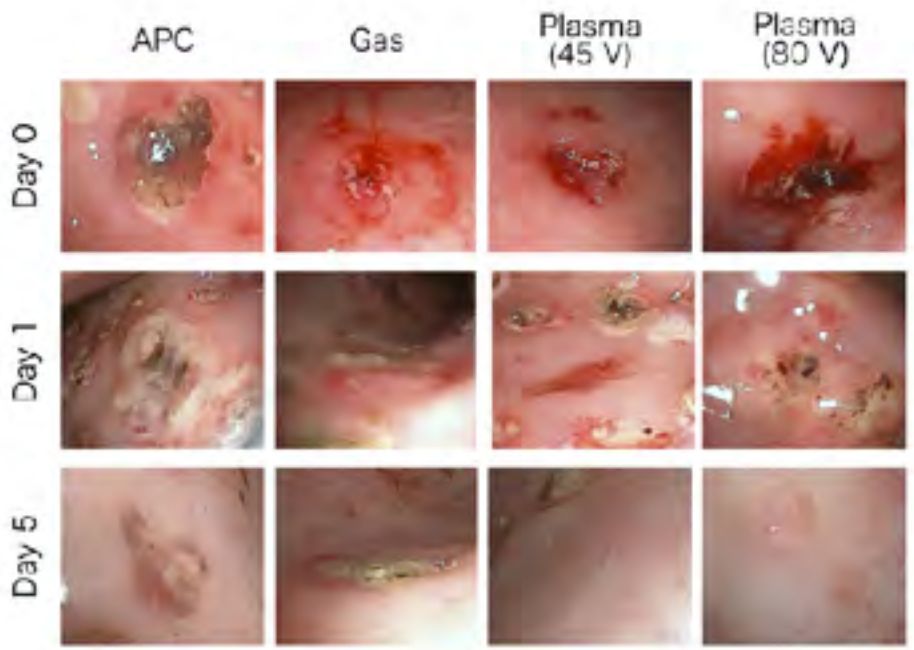
Best-Paper Award for Analytical Sciences2017



Hemostasis by low temperature plasma

神戸大学 承認番号：IVT15-05

Endoscopic hemostasis

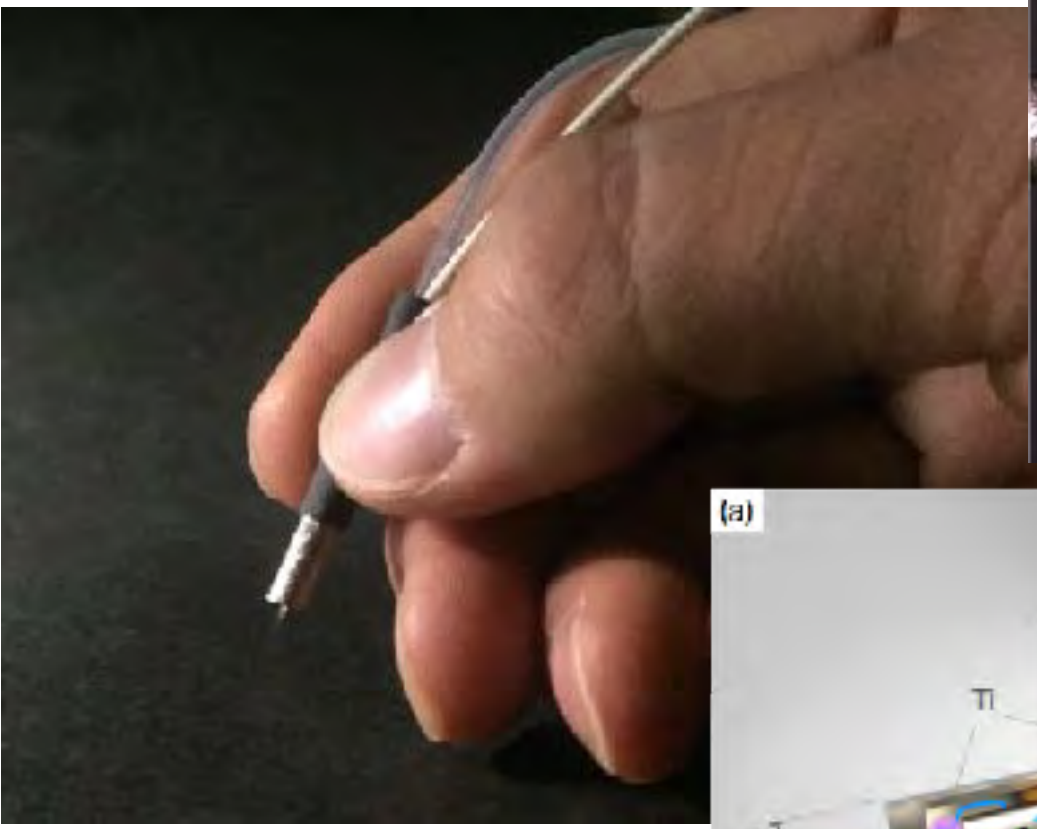


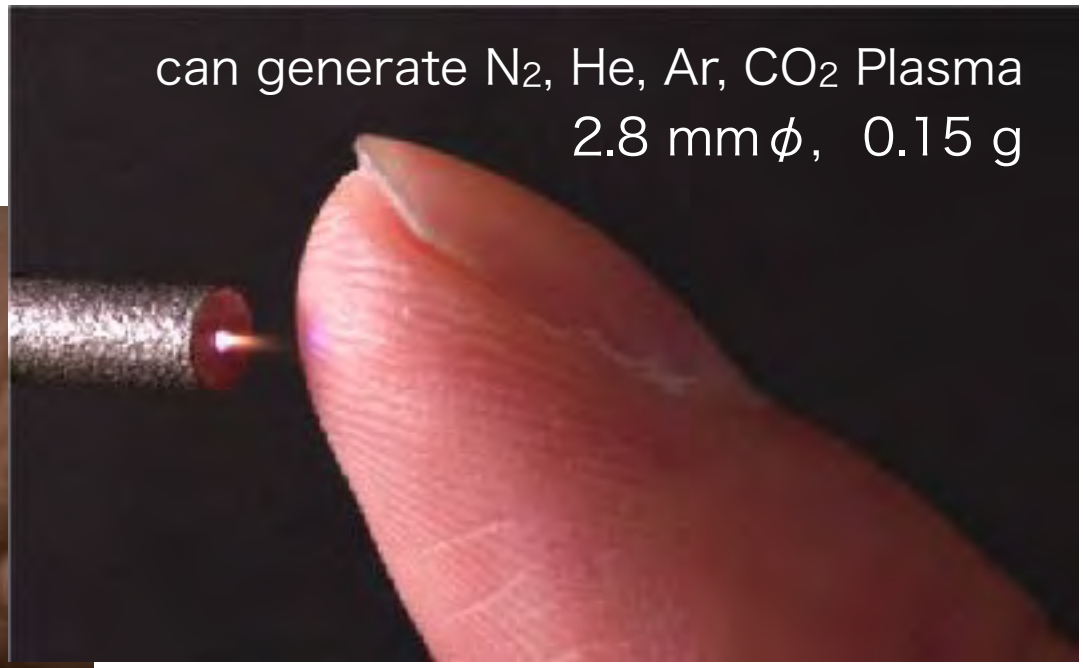
- Ulceration did not occur in low temperature plasma hemostasis

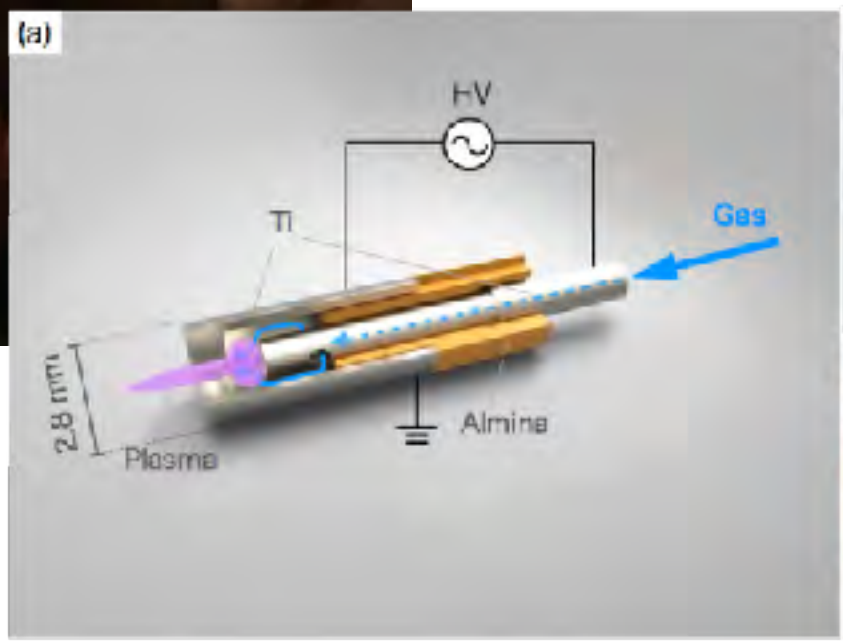
Yudai Nomura, Toshihiro Takamatsu, Hiroaki Kawano, Hidekazu Miyahara, Akitoshi Okino and Takeshi Azuma, Investigation of Blood Coagulation Effect of Non-thermal Multi-gas Plasma Jet on in vitro and in vivo, Journal of Surgical Research (2017).

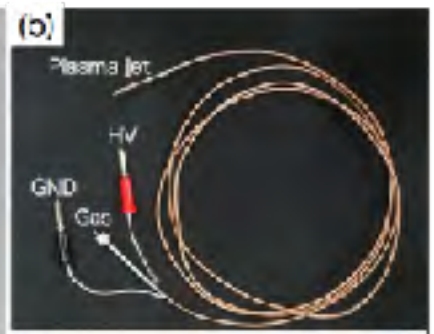
3D printed small plasma jet for endoscopic treatment

Toshihhiro Takamatsu, Hiroaki Kawano, Hidekazu Miyahara, Takeshi Azuma and Akitoshi Okino, Atmospheric nonequilibrium mini-plasma jet created by a 3D printer, AIP Advances, 5, 077184 (2015).



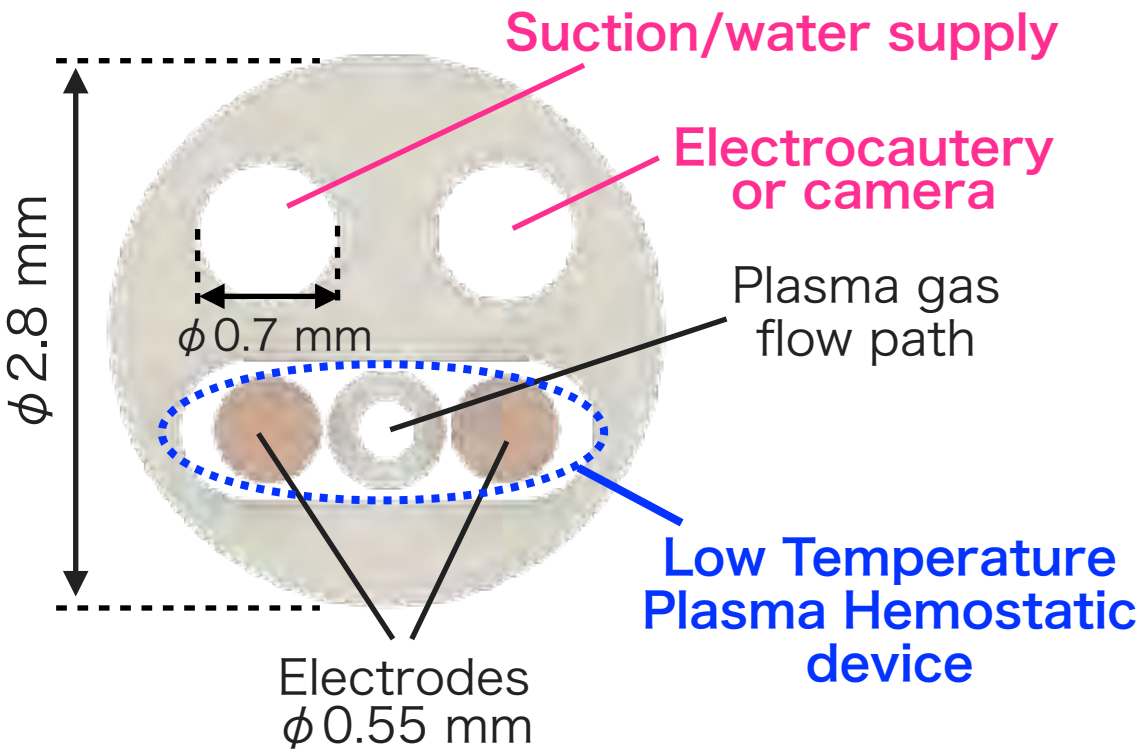


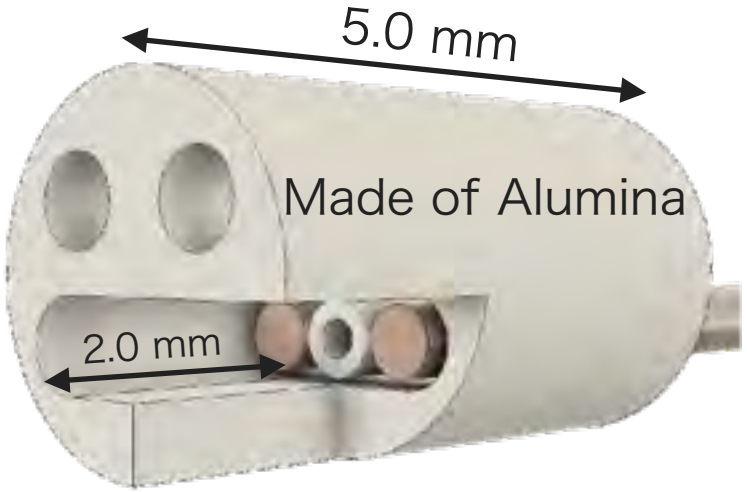


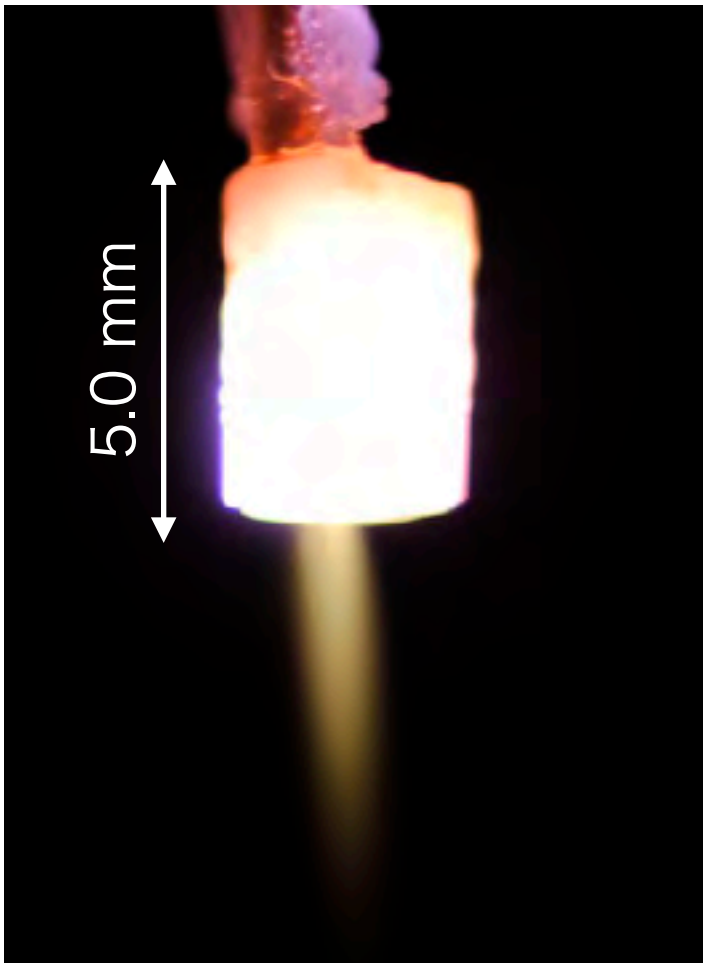


Multifunctional endoscopic hemostatic device

PAT. P







CO_2 Plasma
(1.0 L/min, 2.5 kV, 50 Hz)

Highly durable water repellency fishing lines (P-lon)

MUSLARD II

ROCK HUNTER II

開発に携わった東京工業大学の宮原秀一博士と、テスター久保野孝太郎氏による「プラズマイオンテクノロジーについて」などが予定されている。スケジュールの詳細は公式HPをチェックしよう。

プラズマ装置と宮原秀一博士

Shooter
MACHINEGUN CAST

On sale in Japan/US

The Strength To Guarantee Your Confidence
SUNLINE

Okino Lab., Tokyo Tech.

Development of original atmospheric plasma sources

- Multi-gas high temperature plasma
- Multi-gas low temperature plasma
- Linear type plasma, Large sized plasma, Microplasma
- Temperature-controllable plasma

Application for sensing/analysis

- Droplet nebulizer for single cell elemental analysis
- Measurement of surface adhesion materials
- Ultra high sensitive plasma detector for GC

Application for medical/environmental field

- Plasma medicine (Sterilization, Blood coagulation,,,)
- Application for Life science/Foods/Agriculture
- Direct protein introduction into plant cells
- Decomposition of waste/hazardous gases (N_2O, EOG, salin)