2nd AAPPS-DPP, November 12-17, 2018, Kanazawa, Japan

Summary of Applied Plasma Program

On behalf of all contributors

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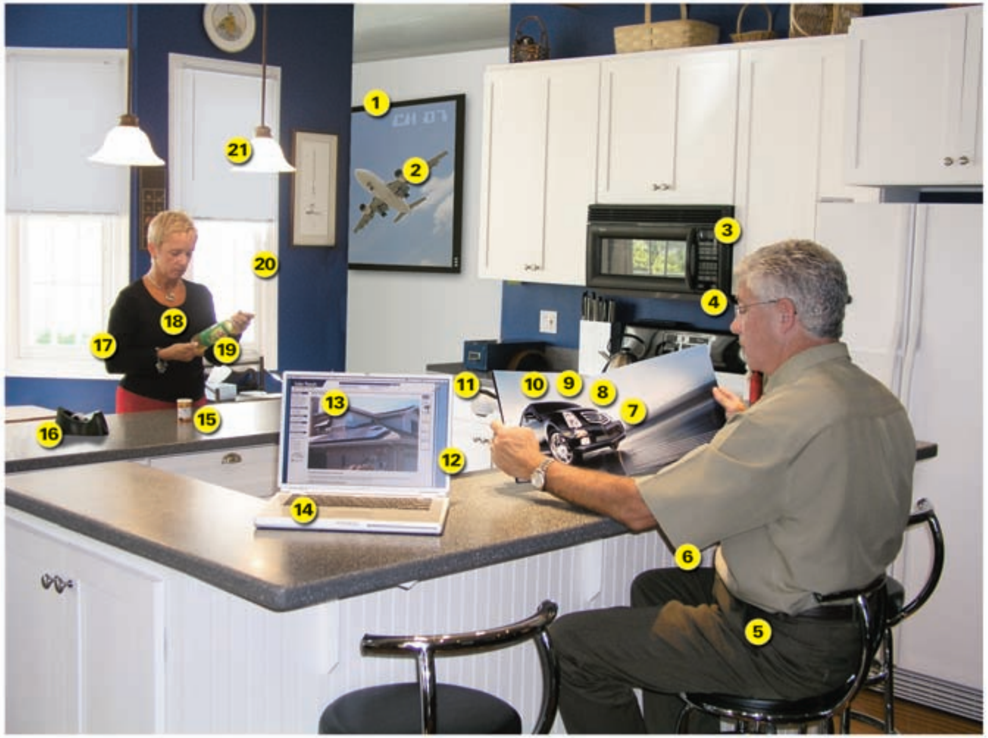
National Fusion Research Institute, Plasma Technology Research Center

Plasma technology has already been put to practical use and applied to many products.

- In addition to conventional semiconductor manufacturing, exhaust gas treatment, **waste disposal, air cleaning, purification of contaminated water**, it has recently been applied to **medical fields** such as treatment of cancer and skin diseases.

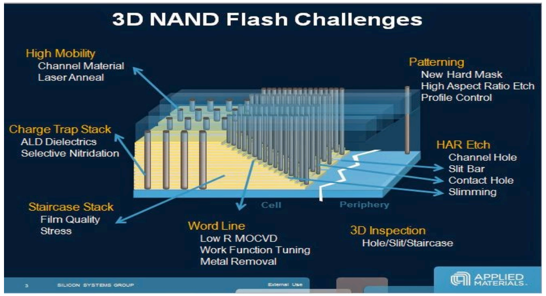


01—Plasma TV
02—Plasma-coated jet turbine blades
03—Plasma-manufactured LEDs in panel
04—Diamondlike plasma CVD eyeglass coating
05—Plasma ion-implanted artificial hip
06—Plasma laser-cut cloth
07—Plasma HID headlamps
08—Plasma-produced H_2 in fuel cell
09—Plasma-aided combustion
10—Plasma muffler
11—Plasma ozone water purification
12—Plasma-deposited LCD screen
13—Plasma-deposited silicon for solar cells
14—Plasma-processed microelectronics
15—Plasma-sterilization in pharmaceutical production
16—Plasma-treated polymers
17—Plasma-treated textiles
18—Plasma-treated heart stent
19—Plasma-deposited diffusion barriers for containers
20—Plasma-sputtered window glazing
21—Compact fluorescent plasma lamp

Plasma Science, NRC

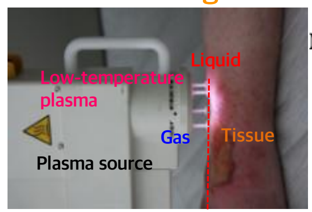
[A-I5: K. Urashima@MEXT] Critical review of plasma Technologies for industrial applications

Semiconductor industry



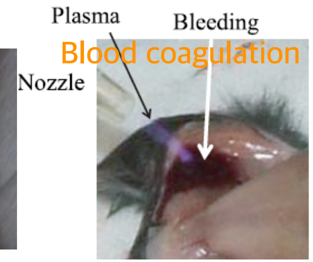
Medical application

Wound healing

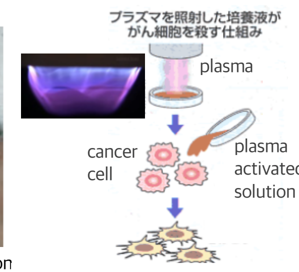


J. Heinlin et al., JEADV, 25, 1 (2011)(Max Planck Institutes)

Blood coagulation

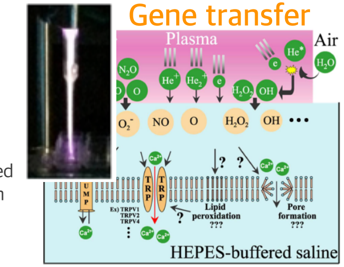


H. Sakakita, et al., Plasma and Fusion Research 5, S2117 (2010).(AIST)

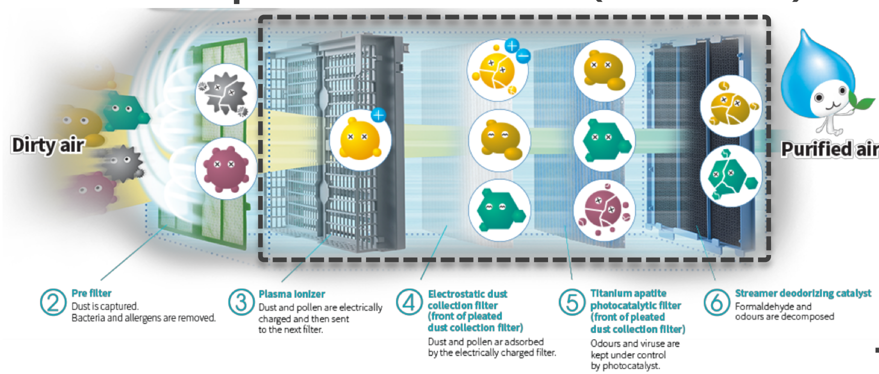


Selective killing of cancer cells

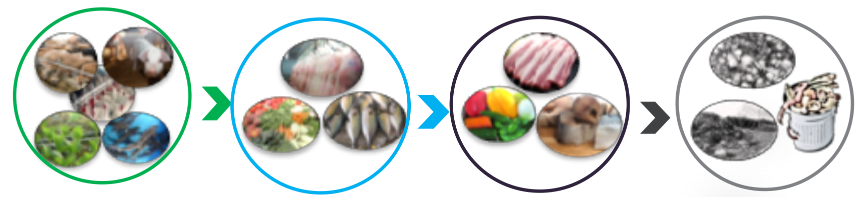
Gene transfer



Gaseous pollution control(fine dust)



Agriculture



Cultivation

Harvest/ Storage

Food Safety

Waste Treatment

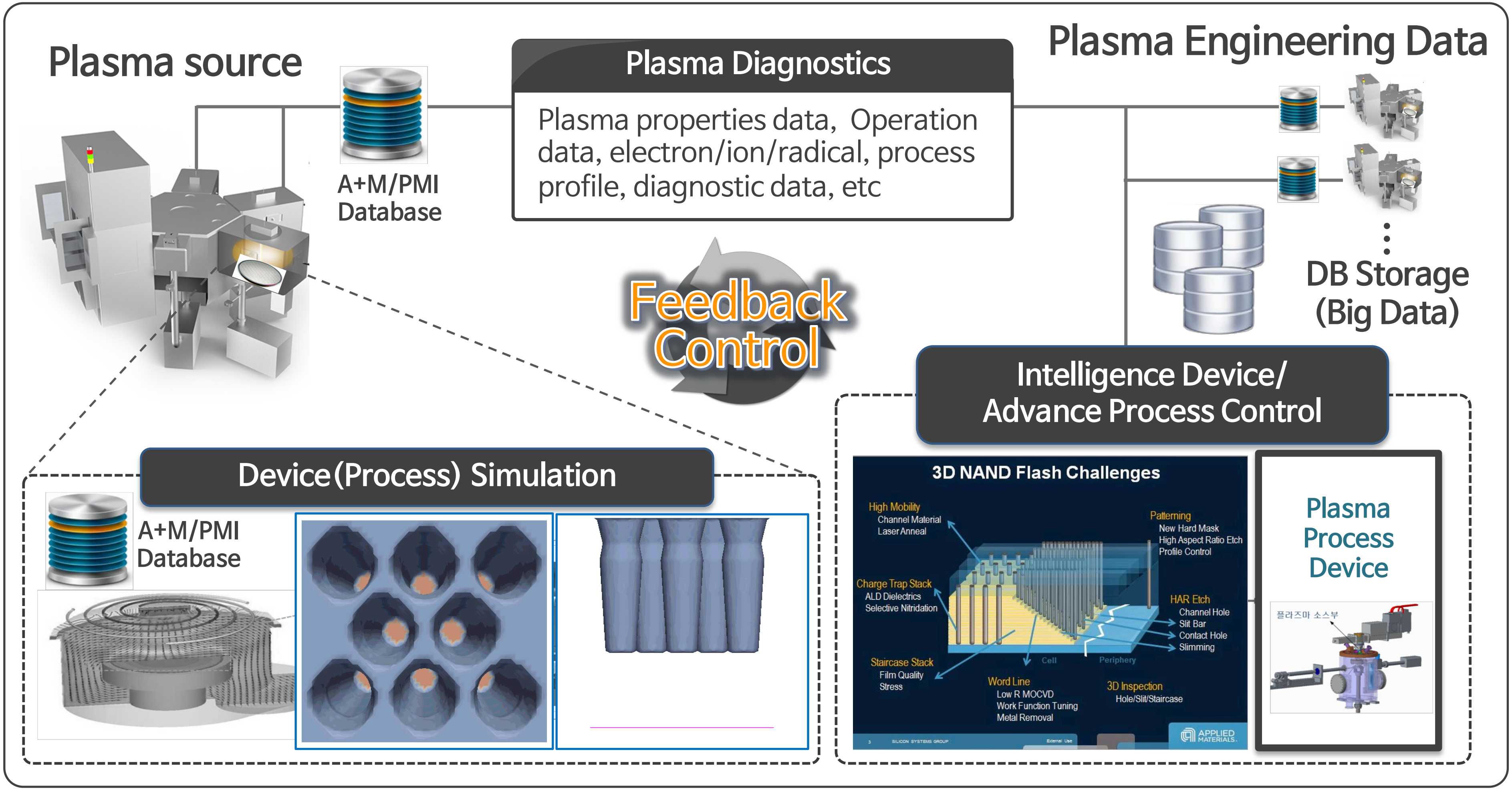
+ Plasma @ Nanoscience & Basic Research

In AAPPS-DPP 2018 @ Applied Plasma Program

Plenary(P: 3), Invite(AI: 24), Oral(AO: 24), *Poster(AP: 64)*

Plasma Technologies @High Tech.(SEMI)

Source, Diagnostics, Simulation, Characteristics → Process: Etching, Deposition ···



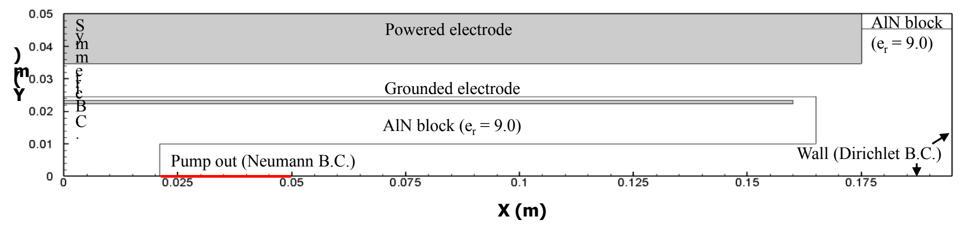
Plasma Technologies @High Tech.(SEMI)

[P16: H. J. Kim@Dong-A. Univ.(Samsung)] Numerical simulation of semiconductor fabrication system

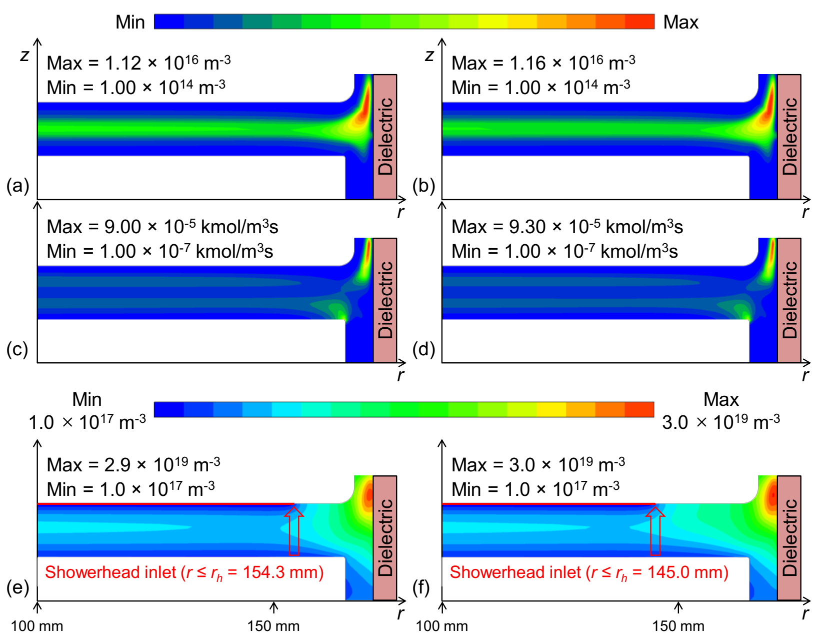
In this study, we numerically demonstrated that modulation of the sidewall conditions could contribute to controlling distributions of the plasma variables in an intermediate pressure CCP-PECVD

Reactor configuration used for SiN_xH_y deposition

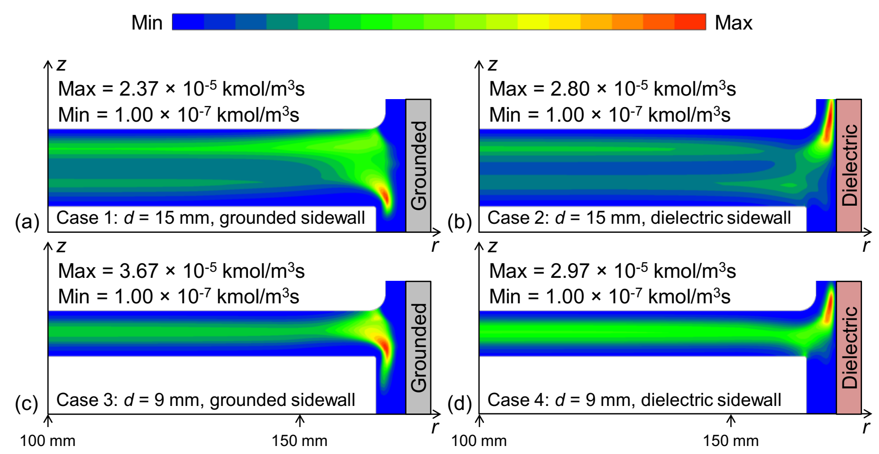
❖ Domain



Effects of the shower radius



Sidewall effects: $SiH_4/NH_3/N_2/He$ mixture



Plasma Technologies @High Tech.(SEMI)

AAPPS-DPP 2018 in Applied Plasma Program

[A-I15: T. Moriya@TEL] Ion energy control in capacitively coupled discharges for Plasma Enhanced Atomic Layer Deposition(PEALD) processes

[A-I22: H. Tamura@Hitachi]

Study on uniform plasma generation mechanism of electron cyclotron resonance etching reactor

→ studied the mechanism of uniform plasma generation of ECR etcher by simulation technique.

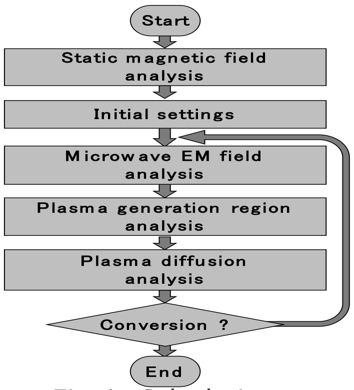


Fig. 1. Calculation procedure

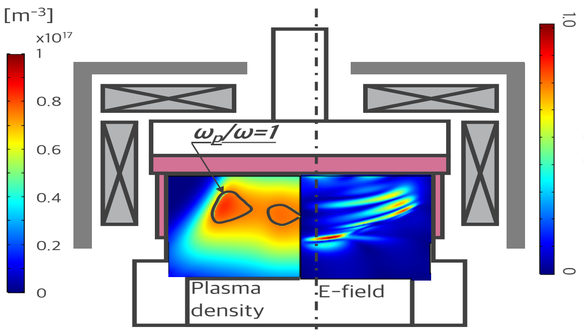
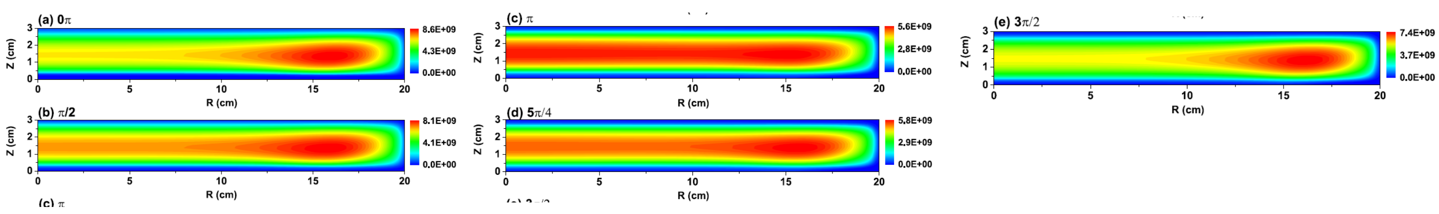


Fig. 2. Plasma density and Microwave electric field

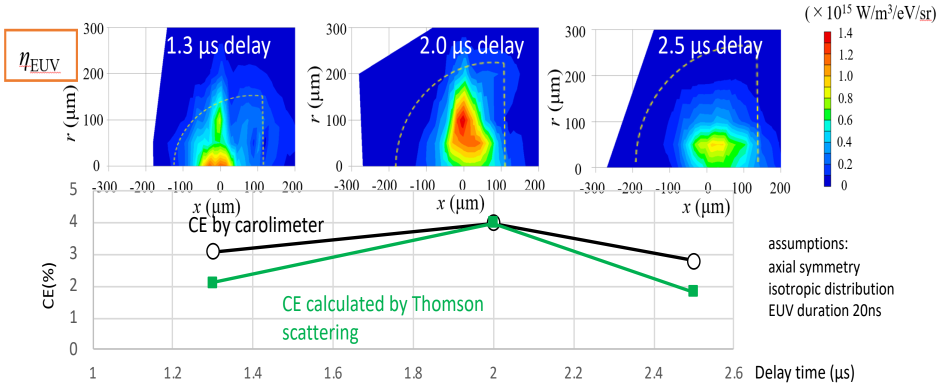
[A-I14: Y. R. Zhang@Dalian Univ.] Basic study of plasma characteristics in an electrically asymmetric capacitive discharge sustained by multiple harmonics: operating in the very high frequency regime



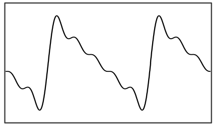
Plasma Technologies @High Tech.(SEMI)

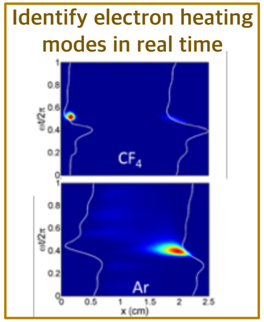
AAPPS-DPP 2018 in Applied Plasma Program

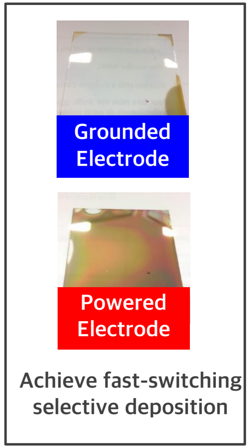
[A-I4: K. Tomita@Kyushu. Univ.] We have revealed the detailed 2D structure of EUV light source plasmas by using collective Thomson scattering technique. → New generation of Lithography

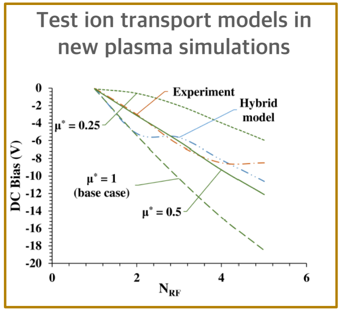


[A-I13: E. Johnson@LPICM-CNRS] Tailored Voltage Waveforms(TVW) plasmas for control of surface processing: Sawtooth Waveforms → Multifrequency machbox





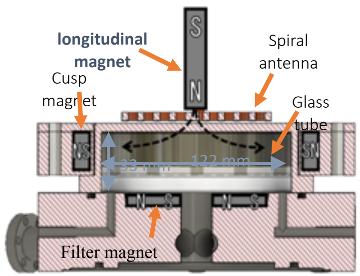




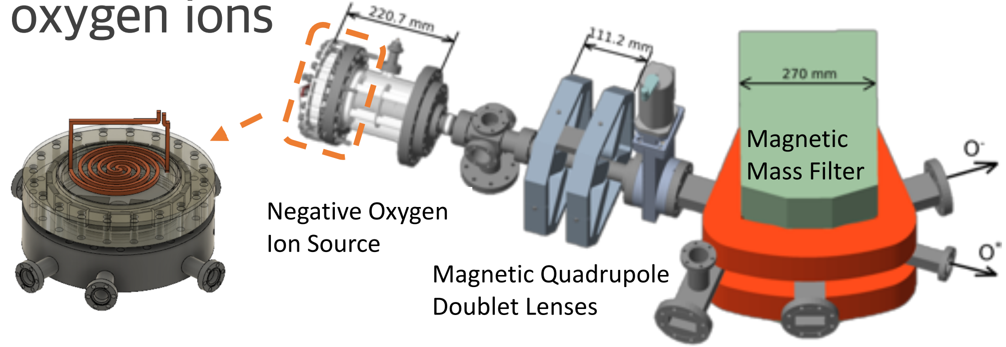
Plasma Technologies @High Tech.(SEMI)

AAPPS-DPP 2018 in Applied Plasma Program

[A-O9: D. Liu@Tokyo Inst. Tech.] Basic study of oxygen plasmas for developing new plasma processing using negative oxygen ions



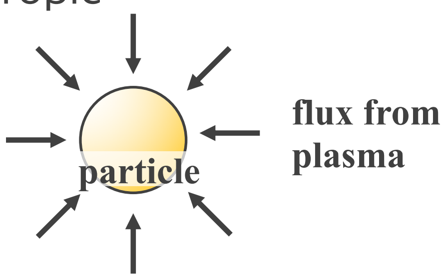
Cross-sectional view of Plasma Production Region



[A-I16: M. Shiratani@Kyushu Univ.] Micron-scale plasma fluctuations(attractive force) detected using paired fine particles → for high-precision nanofabrication

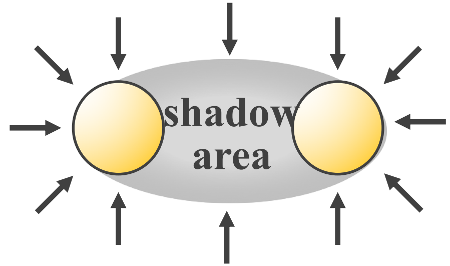
An isolated fine particle

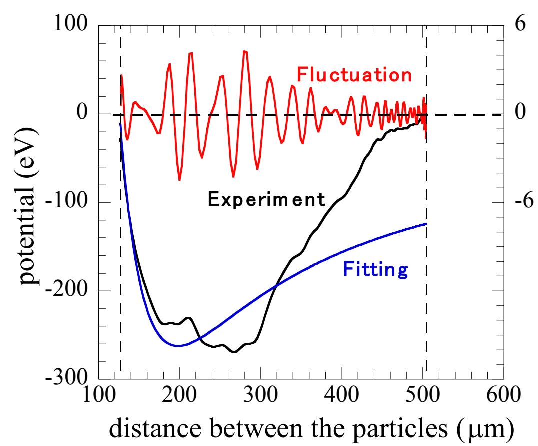
Ion flux to the fine particles is isotropic



A pair of particles

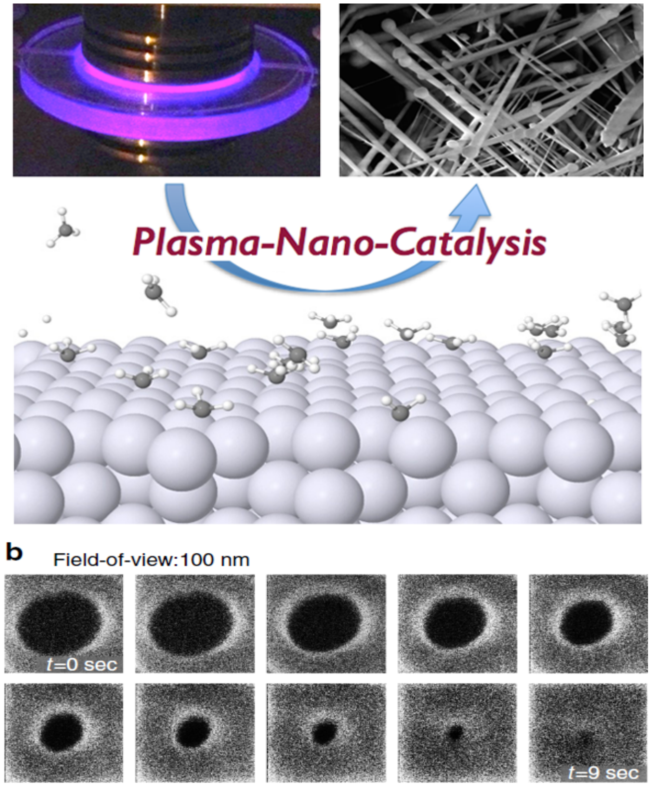
Ion flux to the fine particles is anisotropic⇒Shadow effect





Plasma Technologies @Nanoscience

[P11 : K. Ostrikov@Queensland Univ] Shrinking the plasma: why not the pores?



K. Ostrikov, Nature Comm. 9, 835 (2018)

Precise, gentle extreme:
low-T, non-destructive, synergistic (1 + 1 > 2)

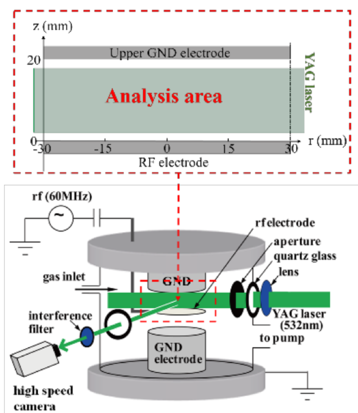
- Control of energy and matter at nanoscales using plasma
- Applications for precision and energy-demanding applications such as catalysis
- Utilizing nanoscale spaces for unprecedented functionality in sensing, energy conversion and other applications
- Relying on plasma-/ion-specific effects in nanoscale interactions with matter
- Multi-scale nature of interactions: from manipulation of atomic bonds to meso- and macroscale patterns
- Controlled manipulation of atomic bonds and charging states within atomic frameworks

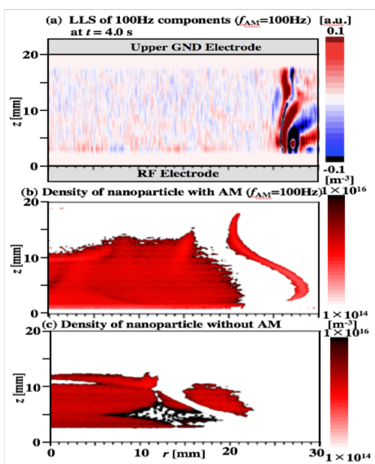
Plasma Technologies @Nanoscience

AAPPS-DPP 2018 in Applied Plasma Program

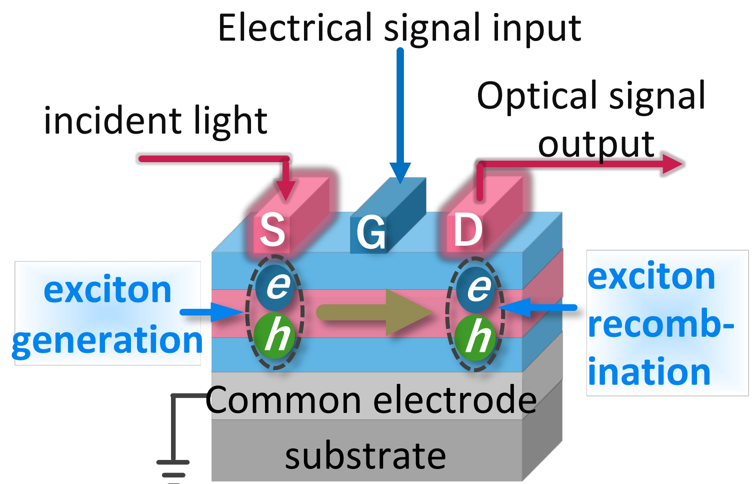
[A-I7: L. Di@Dalian Univ.] Atmospheric-pressure cold plasma for synthesizing supported metal catalysts with the assistance of ethanol

[A-I2: K. Kamataki@Kyushu Univ.] Impact of amplitude modulation of RF discharge voltage on the spatial profile of nanoparticle characteristics in reactive plasma





[A-I3: N. Itagaki@Kyushu Univ.] A new semiconducting materials for excitonic device: high quality $(ZnO)_x(InN)_{1-x}$

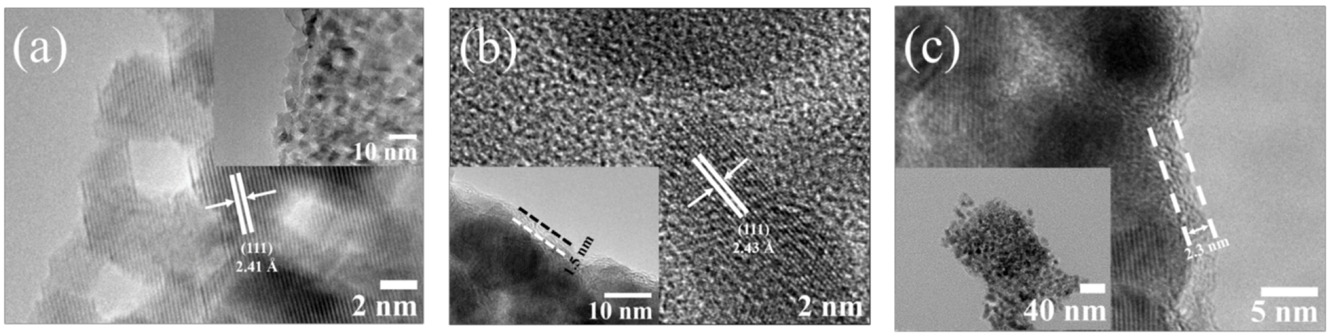


EXOT is a new type of electro-optical signal converters that enables "on-chip" optical interconnect.

Plasma Technologies @Nanoscience

AAPPS-DPP 2018 in Applied Plasma Program

[A-I1: R. Rawat@Nanyang Tech. Univ.] Focus on preparing highly porous 3D nanoassemblies of anode material using plasma based dry approach rather than using wet chemistry for energy storage(LIB)

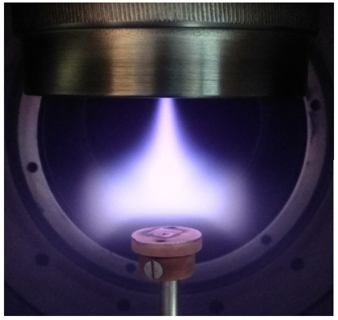


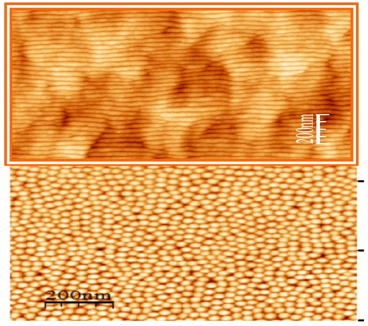
(a) As prepared Layer double oxide (LDO) with NiO lattice spacing of 2.41Å; (b) 30s C-plasma processed LDO with NiO lattice expansion to 2.43Å due to C-doping; & (c) 1.5 nm C-encapsulation on LDO after 30s C-plasma treatment.

[A-O16: T. Nonaka@Kyushu. Univ.] Nanoparticles synthesis of lithium oxide composite with refractory metal for lithium-ion battery electrodes

[A-I9: M. Ranjan@IPR]

Constricted anode fireball for making super-hydrophobic nanodot surfaces and role of plasma flux → sensing & solar cell applications





Plasma Source Technologies

AAPPS-DPP 2018 in Applied Plasma Program

[A-O1: M. Ishiba@Nagasaki Univ.] Development of compact retarding field energy analyzer for measuring ion energy distribution in planar magnetron discharge

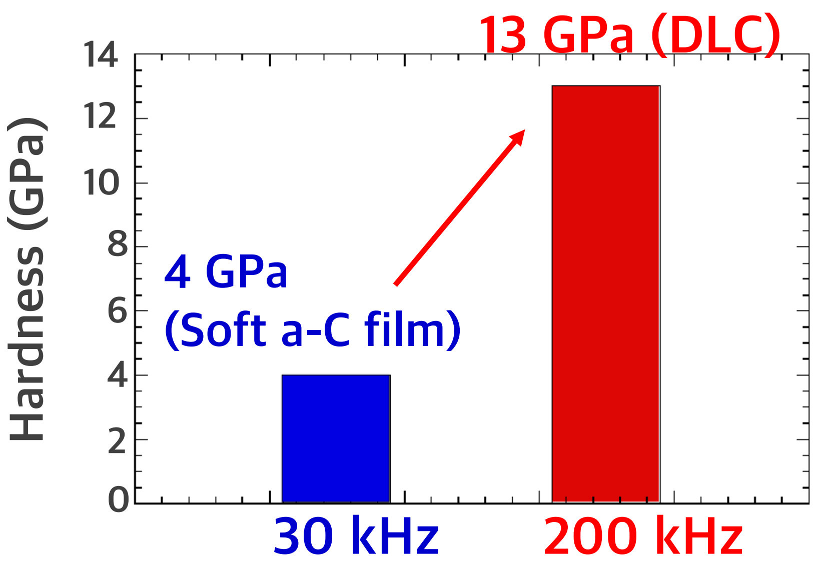
[A-O2: H. Koguchi@AIST] Born-Nitride deposition plasma device

[A-O7: L. Chen@ASIPP] An extraction of microwave ECR plasma cathode based e-beam under ultralow pressure

[A-O10: Y. Kikuchi@U. Hyogo] Surface modifications of materials using high-repetition nanosecond pulsed glow discharges under sub-atmospheric pressure

→ Quasi-continuous plasma source

Improvement of Diamond-like Carbon(DLC) film properties by increasing the repetition frequency

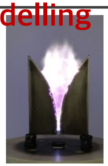


Plasma Source Technologies

[A-I6 : W. Wang@Beihang Univ.] Plasma based CO_2 conversion into value added products: better insights from computer modelling

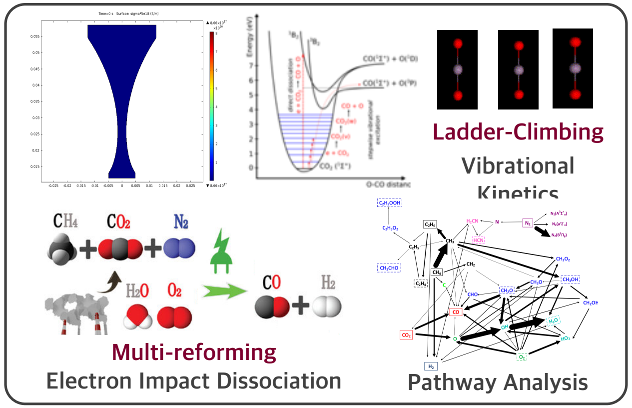
Plasma based CO_2 Conversion into Value-added Fuels

Better Understand Underlying Mechanisms by **Computer Modelling**



Gliding Arc

DBD Plasma



Plasma Chemistry: CO_2

Molecules	Charged species	Radicals	Excited species
CO_2, CO	CO_2^+, CO_4^+, CO^+, $C_2O_2^+$, $C_2O_3^+$, $C_2O_4^+$, C_2^+, C^+, CO_3^-, CO_4^-	C_2O, C, C_2	CO_2 (Va, Vb, Vc, Vd), **CO_2 (V1 - V21)** , CO_2 (E1, E2), CO (V1 - V10), CO (E1 - E4)
O_2, O_3	O^+, O_2^+, O_4^+, O^-, O_2^-, O_3^-, O_4^-	O	O_2 (V1 - V3), O_2 (E1 - E2)
	electrons		

Plasma modeling for CO_2 conversion:

- Plasma chemistry (~ conversion, E-efficiency, products): 0D modeling
- Plasma reactors (GA): 2D or 3D fluid modeling

  (Necessary: CO_2 chemistry reduction)

CO_2: DBD: electron impact (ground state) $\leftrightarrow$ GA: vibrational kinetics

CO_2/CH_4 : formation value-added chemicals

- But selectivity low $\Rightarrow$ Combine with catalysts: Plasma catalysis
- Comparison O_2/CH_4 : different products formed: pathway analysis

Improve the accuracy and reliability, using only verified rate coefficients

General: Modeling useful for better insights

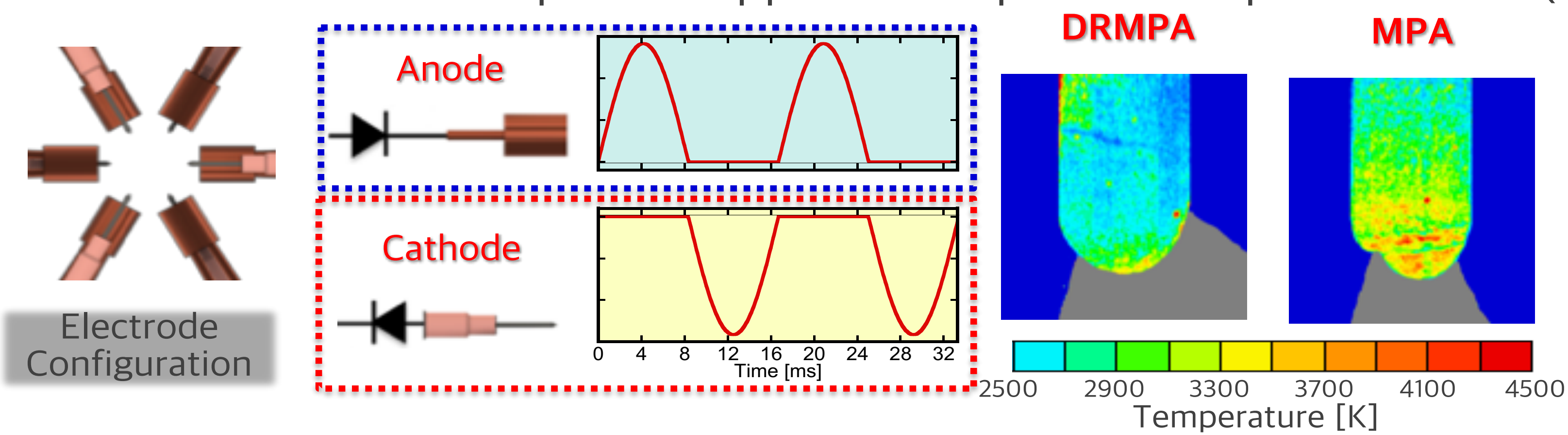
$\Rightarrow$ To improve applications

Plasma Source Technologies

AAPPS-DPP 2018 in Applied Plasma Program

[A-O11 : M. Tanaka@Kyushu Univ.] High-speed measurement of electrode temperature of Diode-Rectified Multiphase AC Arc (DRMPA)

➔ Diode-rectification technique was applied to improve multiphase AC arc (MPA).



[A-I19: H. Li@Tsinghua Univ.]

Non-equilibrium synergistic transport processes in an atmospheric-pressure thermal plasma system

➔ The synergistic mass-momentum-energy transport process is revealed numerically for the first time.

[A-O24: T. Morioka@Osaka Univ.]

Pulsed oxygen negative ion plasmas produced by RF discharge

Plasma Source Technologies

AAPPS-DPP 2018 in Applied Plasma Program

[A-I8: A. Hatta@Kochi Univ. Tech.] Micro-arc discharge plasma in high-pressurized sea water for possible application to on-site element analysis of sea water → mineral resource extraction

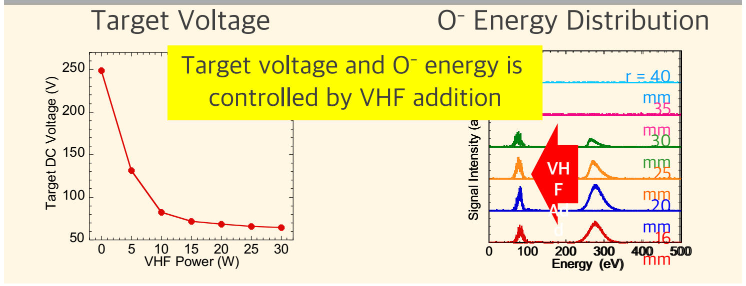
[A-O3: M. K. S. Tial@Yangon Tech. Univ.] Development of dielectric barrier discharge plasma source for ozone generation → water treatment

[A-I21: Q. Nie@Harbin Inst. Tech.] Experimental studies on electromagnetic radiation intensification in GHz band by sub-wavelength plasma structures

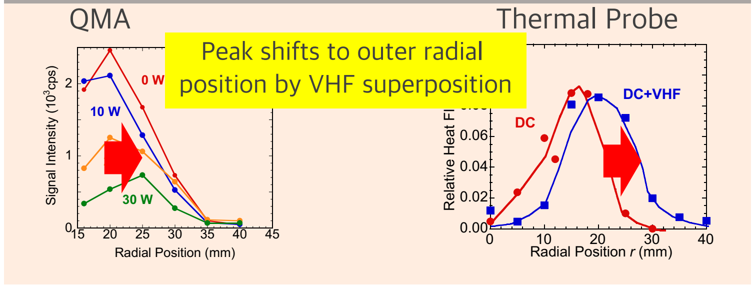
[A-I23: H. Toyoda@Nagoya. Univ.] Influence of magnetic field on high-energy negative ion behavior in magnetron plasma with oxide targets

➔ High energy O^- is investigated with influence of magnetic field

O^- Energy measurement DC-VHF superposition



O^- Radial Profile by DC-VHF superposition



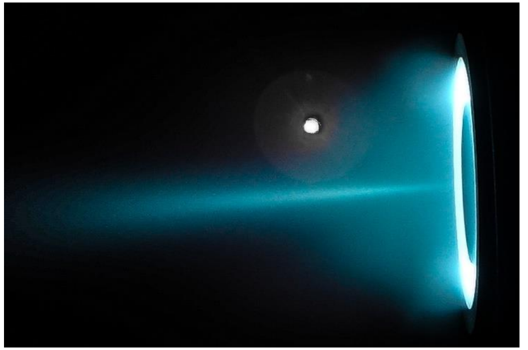
Plasma Source Technologies (Thruster)

AAPPS-DPP 2018 in Applied Plasma Program

[A-I24: S. Xu@Nanyang Tech. Univ.] Miniature hall effect thruster and gradually expanding rotamak thruster for space propulsion

This talk presents the development of solar electric propulsion technology at the Plasma Sources and Applications Centre/ Space and Propulsion Center Singapore (PSAC-SPCS), NIE, Nanyang Technological University, Singapore. These include two types of highly distinctive space propulsion systems: a miniaturized Hall-thruster for cube- and nano-sats propulsion, and a radio frequency rotating magnetic field driven Gradually-Expanded-Rotamak (GER) electromagnetic thruster. The physics, engineering and performances of the thrusters will be discussed. A proposed in space mission will also be briefly discussed.

Figure 1. PSAC's miniature Hall Effect Thruster



[A-O13: S. Ogasawara@Tokyo Univ.] Laboratory experiment of Traveling Magnetic Field(TMF) acceleration method for electrodeless RF plasma thruster

→propose TMF acceleration method for improving performance

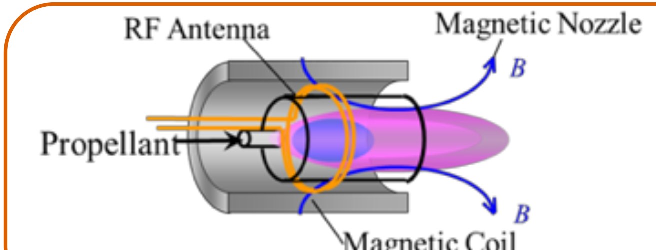


Fig. RF plasma thruster.

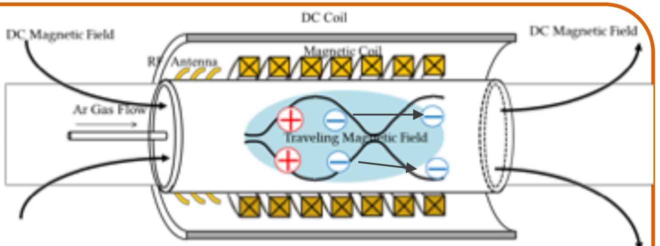
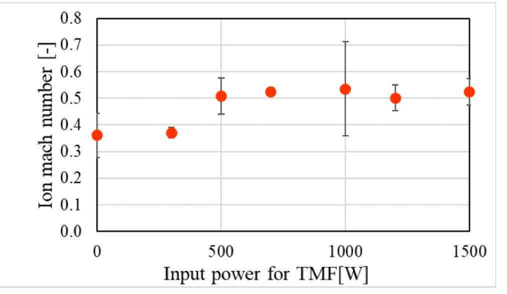


Fig. Mechanism of TMF acceleration



Plasma Source Technologies (Thruster)

AAPPS-DPP 2018 in Applied Plasma Program

[A-O8: T. K. Borthakur@Gauhati. Univ.] Studies of high speed plasma stream generated from a pulsed plasma accelerator

[A-O27: T. Ishiyama@Tohoku. Univ.] Development of a double stage electrostatic accelerated RF plasma thruster

➔ developed a double stage end Hall thruster that operates over 5 kW, and evaluated its basic nature such as plasma production and thruster performance.

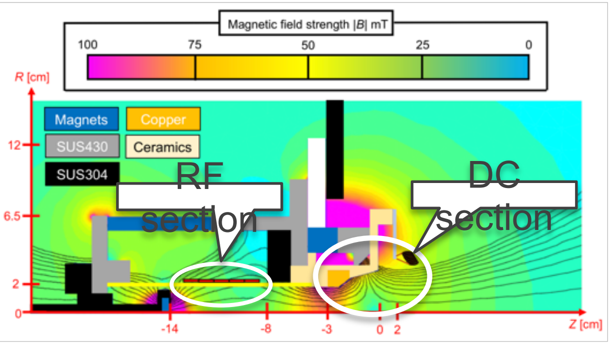


Fig.1 Double stage end Hall thruster

[A-O28: Y. Murayama@Tokai. Univ.] Laboratory experiments of magnetoplasma sail for future deep space missons

➔ summarizes experimental studies of the MagSail and Magnetoplasma(MPS) sail by **"Plasma Sail Working Group" in ISAS/JAXA**.

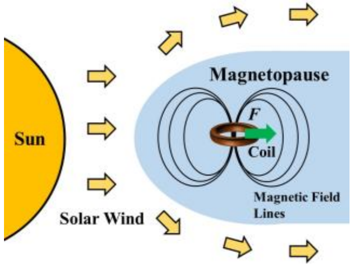


Fig.1 Concept of MagSail

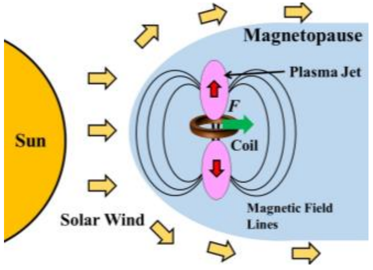
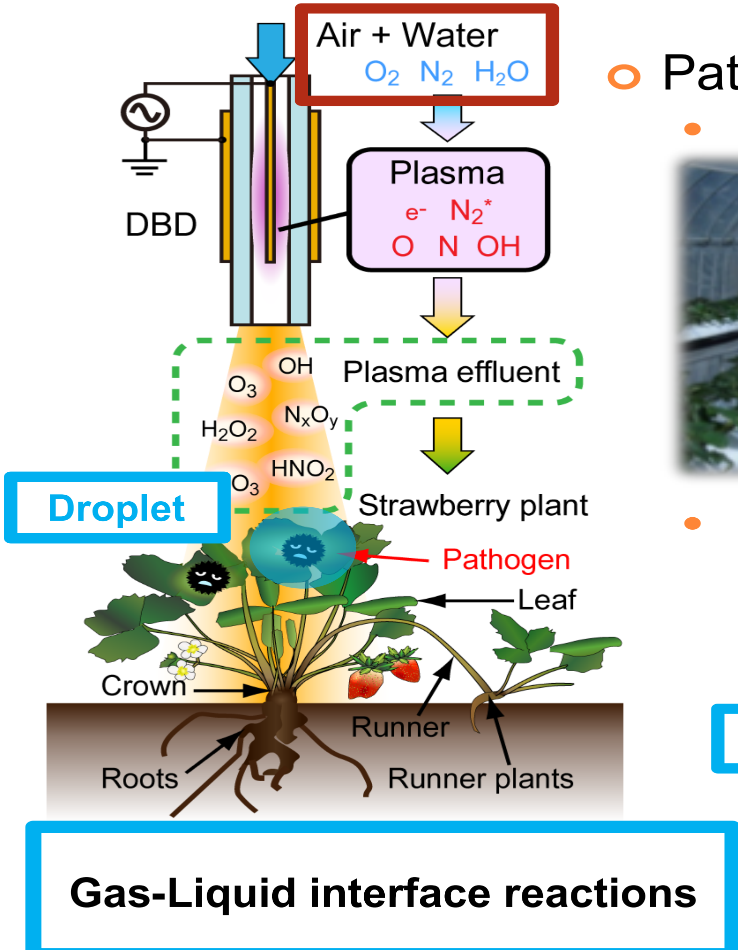


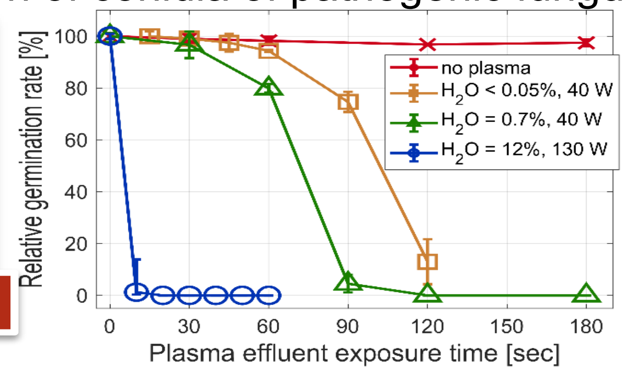
Fig.2 Concept of MPS

Plasma @Agricultural Applications

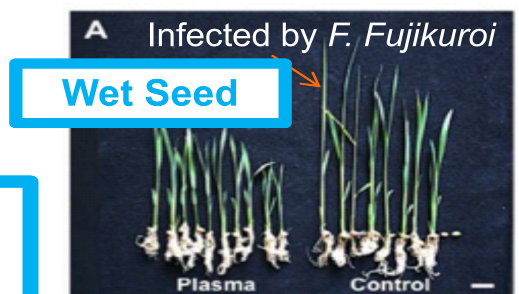
[A-O17 : K. Takashima@Tohoku Univ] Agricultural Application of Gas-liquid Interface Reaction of Dinitrogen Pentoxide Generated by Atmospheric Air Plasma

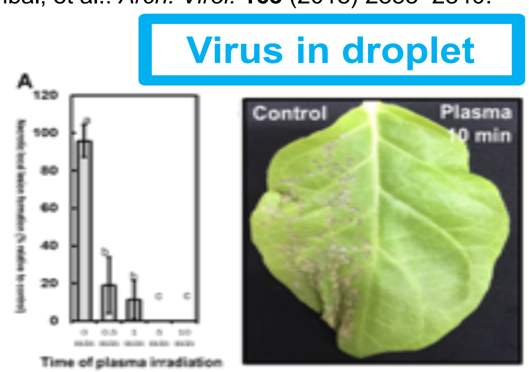


- Pathogen control experiment
  - Germination suppression of conidia of pathogenic fungus



  - Management of plant disease
    - Immune system activation A. Ochi, et al.: *Plant Pathology* **65** (2016) 67-76.
    - Inactivation of TMV S.E. Hanbal, et al.: *Arch. Virol.* **163** (2018) 2835–2840.





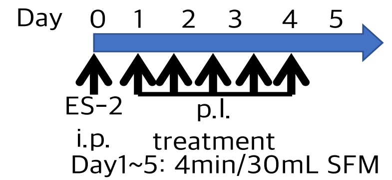
Plasma @Biomedical Applications

[P25: M. Hori@Nagoya Univ.] Challenge to the systematization of the biological interaction by plasmas-PAM opened a new avenue in plasma medicine

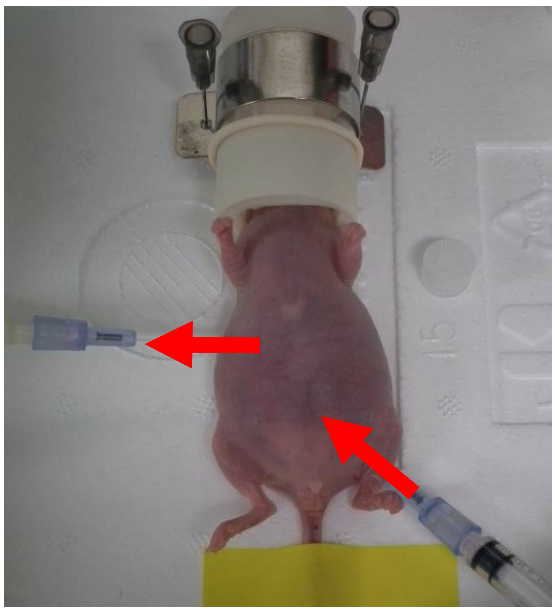
Intraperitoneal treatment

ES-2 Green: 1×10^6 cells i.p.

under anesthesia Treatment: 5 times



PAM : Plasma Activated Medium



In Vivo Confirmation of Validity of PAM for *Ovarian Cancer, Pancreatic Cancer, Gastric Cancer, Age-related macular degeneration, and selective elimination of undifferentiated iPS cells (regenerative therapy) .*

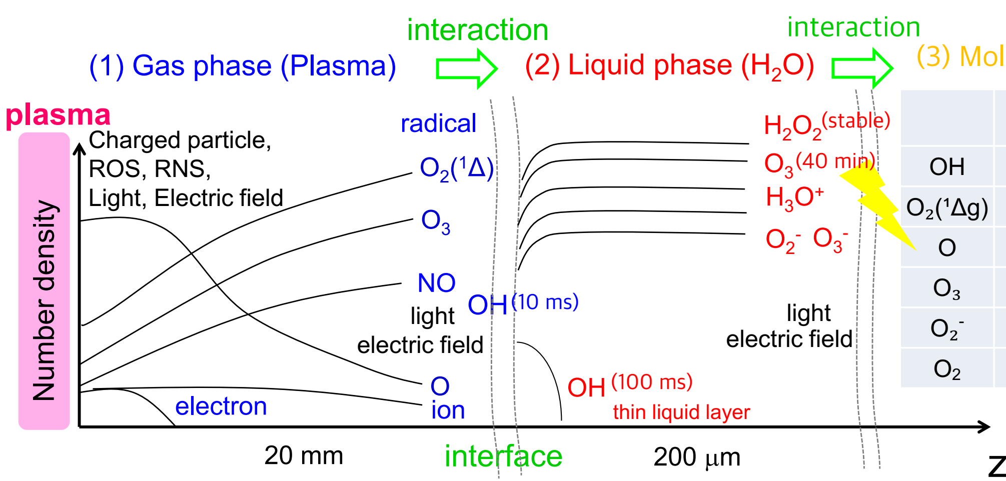
Miyamoto et. al., Arch Biochem Biophys. 2016 Sep 1;605:95-101.

Plasma @Biomedical Applications

[A-I10 : G. Uchida@Osaka Univ] Control of ROS and RNS productions in liquid by using a nonthermal high-frequency plasma jet

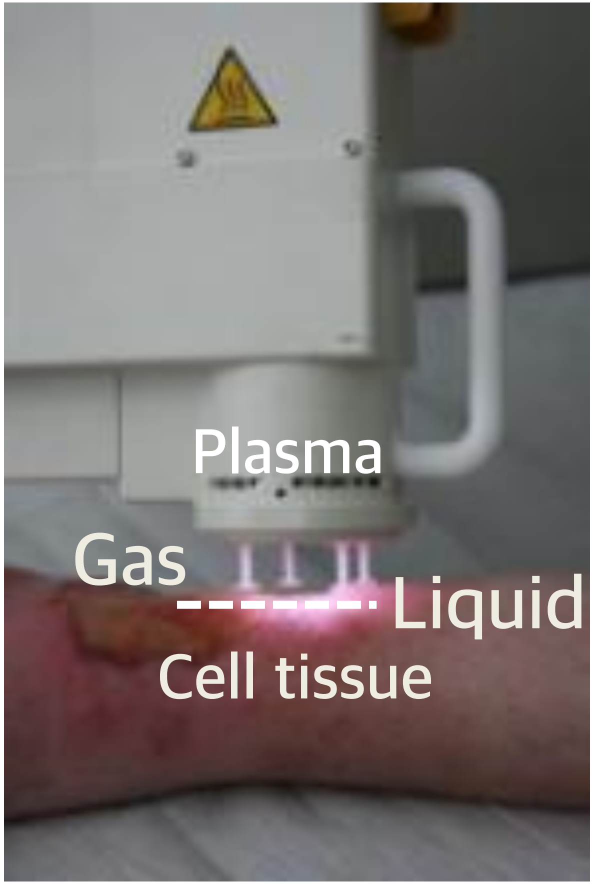
Atmospheric non-thermal plasma (APP) for various material surface treatment.

- APPs induce little thermal damage to material.
- The energetic electrons can produce chemically rich gas-phas environments at room temperature in open air.
- One of interesting applications is in the biomedical field.



	Reaction rate (L/mol/s) to organic material
OH	$10^8 - 10^9$
$O_2(^1\Delta g)$	$10^6 - 10^7$
O	$10^5 - 10^6$
O_3	$10^2 - 10^3$
O_2^-	1 – 10
O_2	10^{-30}

G. Uchida, AAPPS-DPP 2018 [A-I10]

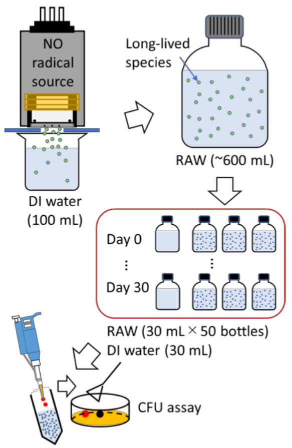


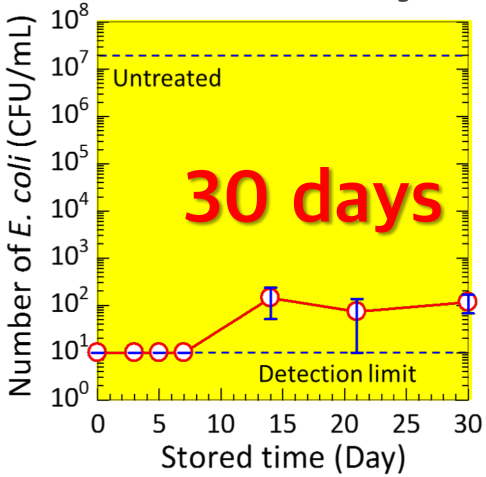
J. Heinlin et al., JEADV, 25, 1 (2011)(Max Planck Institutes)

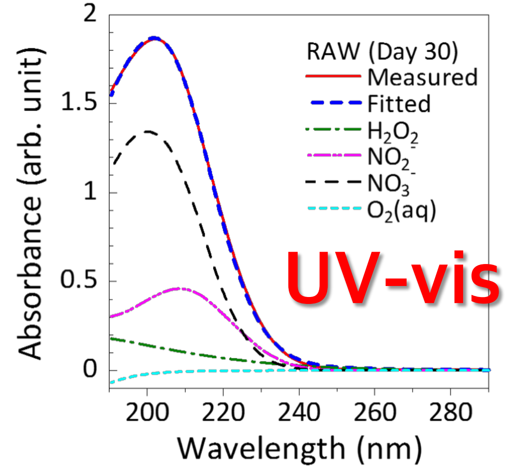
Plasma @Biomedical Applications

AAPPS-DPP 2018 in Applied Plasma Program

[A-O4 : J. S. Oh@Osaka City Univ] Long-term bactericidal effect and reactive oxygen and nitrogen species (RONS) chemistry of radical-activated water



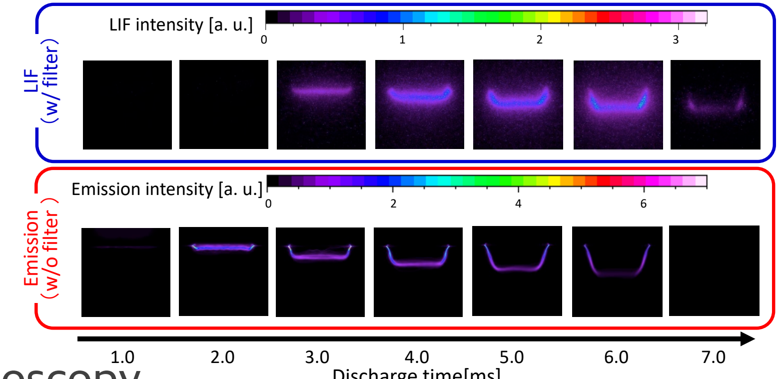




[A-O5 : K. Takeda@Meijo Univ]

Spatial diagnostics of reactive species in AC-excited atmospheric pressure Ar plasma jet generated in open air

→ Spatial distributions of OH radical measured by laser induced fluorescence and optical emission spectroscopy



Plasma @Biomedical Applications

AAPPS-DPP 2018 in Applied Plasma Program

[A-O21 : N.Iwata@Meijo Univ.]

Generation mechanism of bactericidal efficacy in the radical-activated water

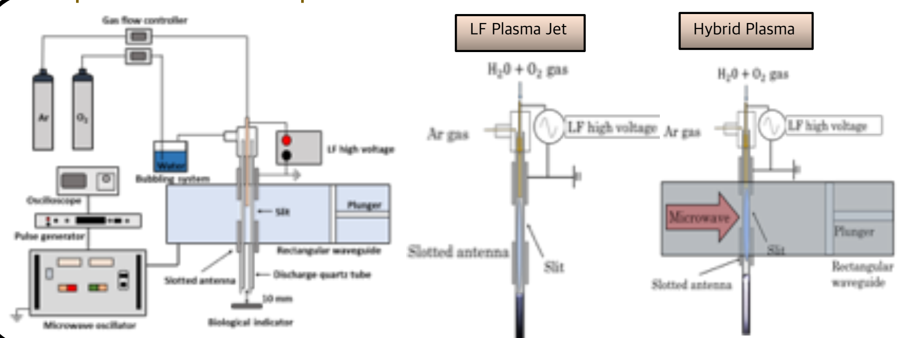
[A-O19 : Y. Sasaki@Tohoku Univ.]

Continuous release of short-lived species induced by plasma irradiation and its application in drug delivery

[A-O22 : N.Tonmitr@U.Ryukyu]

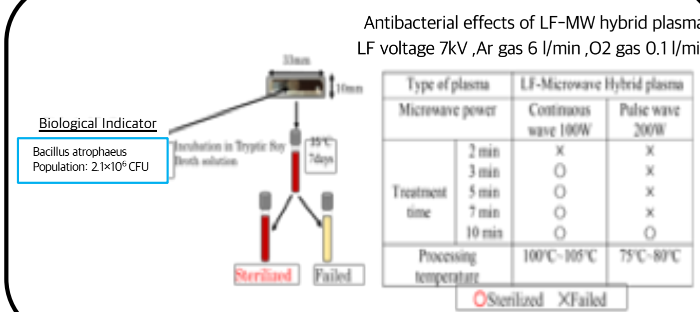
Development of LF-Microwave hybrid plasma source for surface sterilization

Experimental Setup



After the ignition of LF -plasma, LF-Microwave Hybrid Plasma is produced by introducing the microwave in the rectangular waveguide.

Sterilization Test



[A-O23: Nasruddin@U. Muadyah] Evaluation the effectiveness of combinative treatment of atmospheric plasma jet and natural product on wound healing

→ **Evaluation engineer point of view!!**

Plasma @Biomedical Applications

AAPPS-DPP 2018 in Applied Plasma Program

[A-O19 : Y. Sasaki@Tohoku Univ.] Continuous release of short-lived species induced by plasma irradiation and its application in drug delivery

[A-O20 : Y. Kume@Meijo Univ.] To investigate of the effect of long-lived oxygen radical on lipid molecule diffusion, measured the lateral diffusion coefficient of SLB(supported lipid bilayer) as a function of immersion time

[A-I17: E. H. Choi@Kwangwoon Univ.] Plasma medicine and its mechanism for cancer therapy

[A-I18: D. Xu@ Xi'an Jiaotong Univ.] Regulation of reactive species in gas plasma and the application in tumor therapy

[A-O25: R. Honda@Tohoku Univ.] Effects of in-liquid plasma on enhancement of cell membrane permeability

[A-O26: P. Poramapijitwat@Maejo Univ.] The Investigation of Dielectric Barriers Discharge plasma jet (DBDJ) for bactericidal in chronic wound

Statistics (Applied)

In AAPPS-DPP 2018
Plenary(P: 3), Invite(AI: 24), Oral(AO: 24), Poster(AP: 64)

Theory/Simulation : 17, Experiment : 98

Total : 115