The International Symposium 2022 on "Plasma Tech – Driving Sustainable Future": Agri–Food and Bio Plasma Innovation Research and Business Development Network, Chiang Mai, Thailand, 10 November, 2022.



















Northern Science Park



High-voltage plasma for farming and food safety;

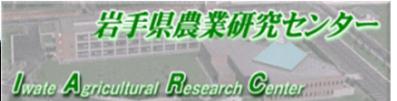
Development of Compact High-Voltage Rulsed Power Plasma Devices

不思議な関係

K.TAKAKI (Iwate University), K.Takahashi, C.Yuan (Iwate

University), Fukuoka Ágric, Research Center, Kyushu Univ., AIST, Iwate Agri. Research Center, Iwate biotech. research center.









Nature scene







Outline



- 1 History and basis of application to agriculture
 - # History; Electrostatics to agriculture
 - # Basis; E-stress, ESP by ions, reaction by plasma
- 2 Design of HV generator and its applications
 - # HV generator ; AC, DC, Pulse HV power supplies
 - # Applications; non-thermal plasma, E-stress to Bio
- 3 Applications in food supply chain
 - # in preharvest; germination, growth, fruition,...
 - # in postharvest; keeping freshness,....
 - # in food process; drying, enzyme activity,...

Pulsed Power & Plasma Lab., Iwate University



History of electricity to plant



International Journal of Current Research and Academic Review

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Table 1 History of early-stage study for effect of electric field applying on plant growth (Barman and Bhattacharya 2016)

Impact of Electric and Magnetic Field Exposure on Young Plants-A Review

Year	Events (experiments and results)	References P. Barman* and R. Bhattacharya
1746	Enhancement of plant growth under electric field cultivation was firstly confirmed by Maimbray	Dorchester (1937)
1775	Vegetation of plant was affected by exposure in electrical currents	Beccaria (1775)
1783	Growth and fertility of plants were affected by electricity (ions, electrical potential) in atmosphere	Bertholon (1783)
1840	Growth and harvesting of potato was enhanced by electrical treatment using galvanic cell	Ross (1844)
1845	Growth and harvesting were evaluated using different crops by inserting the high-voltage electrodes into bed soil. The positive and negative effects are confirmed depend on the test conditions	Solly (1845), Wollny (1893), Basty (1908)
1878	Growth of tomato, corn and wheat was affected by the electricity (ions, electric field) in atmosphere	Grandeau (1878)
1880	Growth of tree increased at active in Aurora event	Lemström (1904)
1881	Roots of different seedlings grew toward the positive potential electrode by applying electric field to the roots	Elfving (1882)
1889	Plant fresh weight after the growth under H.V. transmission line network is more than that of other field when the AC transmission line was first constructed in United State	Berthelot (1889), Rustebakke (1983)
1898	Influence of atmospheric electricity (ions and electric field on earth) on plant growth was confirmed through the comparison between with and without Faraday shielding metal mesh. The growth rate of plants without the shield (in atmospheric electricity) was 50–60% higher than those with shielding	Stone (1904)
1904	Harvesting yield of radish and lettuce increased 22–58% by plants exposure to electrical current of 0.2–0.4 mA	Stone (1904), Dorchester (1937)
1907	Plant growth was affected as negative effect by charging up the bed soil. Influence of electrical stimuli on plant growth Plant-electrical activity was studied by some researchers	Bose (1907), Gassner (1907), Gassner (1909), Brauner (1927), Clark (1937), Schrank (1947)
1909	Number of bacteria in bed soil was increased more than 600% by applying a few pulsed discharges (sparks) with small input energy (static electricity) to the soil	Stone (1909)
1920	10 kV/500 W Tesla coil was used to supply the electricity over 200 square-feet agriculture field by Curtis. The growth rate of radishes and lettuce increased 50% by supplying the electrical current	Paleg and Aspinall (1932)

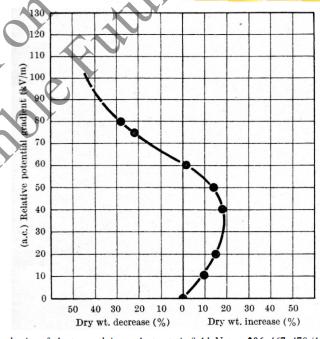
Iwate Network for Energy and Environment Education

History of electricity to plant





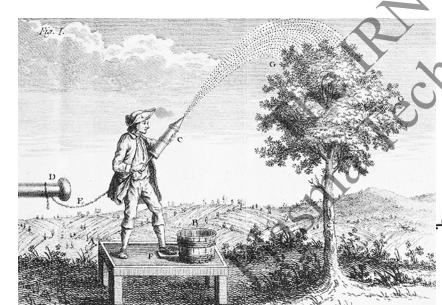


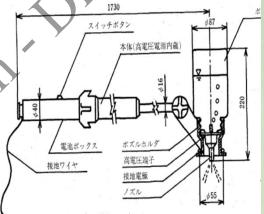


M. Shibusawa, K. Shibata, The effect of electrical discharges on the rate of growth of plants. J. Inst.

Electr. Eng. Jpn. 47, 1259–1300 (1927)

L.E. Murr, Biophysics of plant growth in an electrostatic field. Nature **206**, 467–470 (1965)





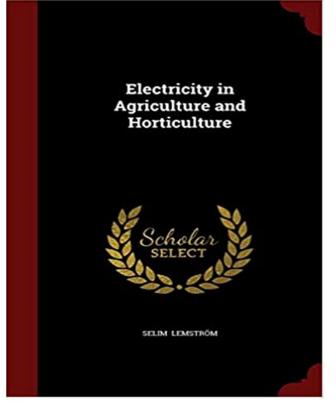


Electrodyn (ICI Co. UK)

静電気により植物に引きつけられる粒子

農業機械学会誌 48(1):25~31, 1986





ELECTRICITY IN AGRICULTUR

AND

HORTICULTURE.

Published in 1904

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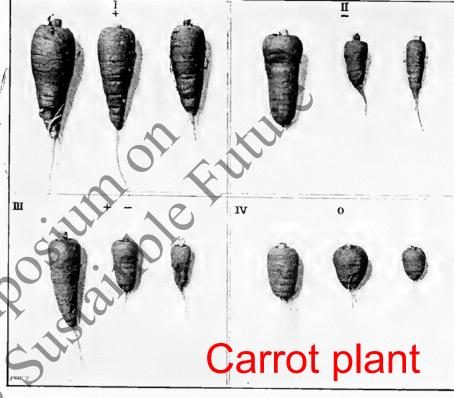
Prof. S. LEMSTRÖM.

WITH ILLUSTRATIONS.

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United States: THE D. VAN NOSTRAND Co., 23, Murray Street, New Yor Japan: Z. P. Maruya & Co., 14, Nihonbashi Tori Sauchome, Tokyo.



6.—The above figure, from a photograph, shows the development of the carrots in the different sections. The Roman figures indicate the different compartments and the signs +, -, + -, the direction of the electric current and o no current.

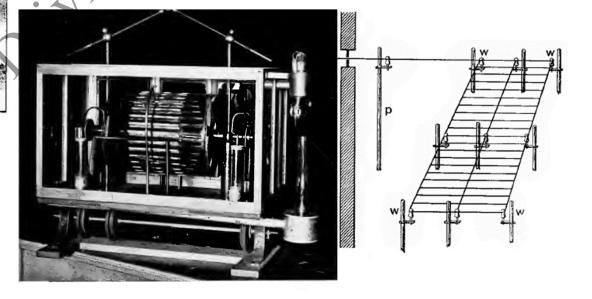


FIG. 1.—Experimental Field

Tabaco plant



FIG 2 .- Control Field.



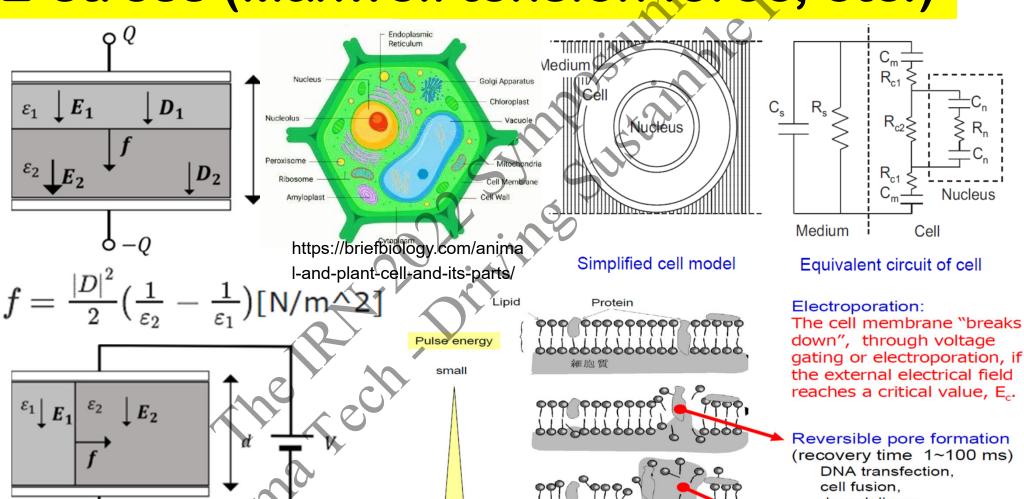


Basis; E-stress, Electrostatic, plasma reaction



Nucleus

E-stress (Maxwell tension force, etc.)



sterilization, juice extraction

Reversible pore formation (recovery time 1~100 ms) DNA transfection. drag delivery

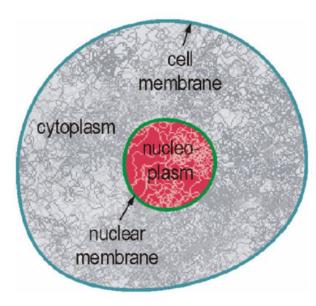
Irreversible pore formation

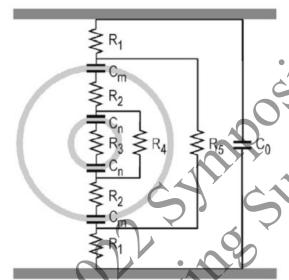
 $\land \bigcirc$ Pulse energy expenditure = $E^2 \triangle t$ field strength Δt : pulse duration



Voltage buildup across cell membrane







- K.H. Schoenbach, B. Hargrave, R.P. Joshi, J.F. Kolb, R. Nuccitelli, C. Osgood, A. Pakhomov, M. Stacey R.J. Swanson, J.A. White, S. Xiao, J. Zhang, S.J. Beebe, P.F. Blackmore, E.S. Buescher, Bioelec tric effects of intense nanosecond pulses. IEEE Trans. Dielectr. Electr. Ins. 14, 1088–1109 (2007)
- K.H. Schoenbach, S. Xiao, R.P. Joshi, J.T. Camp, T. Heeren, J.F. Kolb, S.J. Beebe, The effect of intense subnanosecond electrical pulses on biological cells. IEEE Trans. Plasma Sci. 36, 414–422 (2008)

$$\tau_{\rm r} = \varepsilon / \sigma, \qquad v_{\rm m}(r) = fE(D/2) \left[1 - e^{-t/\tau_c}\right] + v_{0,r}$$

$$E_{\rm crit} = V_{\rm crit} / fa,$$

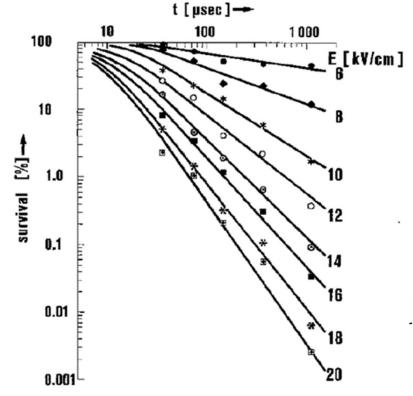
$$f = l / \left(l - \frac{D}{3}\right), \qquad \tau_{\rm c} = \left[\left(\frac{1 + 2V}{1 - V}\right) \frac{\rho_1}{2} + \rho_2\right] C_{\rm m} a,$$

duration. The typical values of V_{crit} for lysing or poration are on the order of 1 V, for gating is approximately 100 mV (Schoenback et al. 1997).

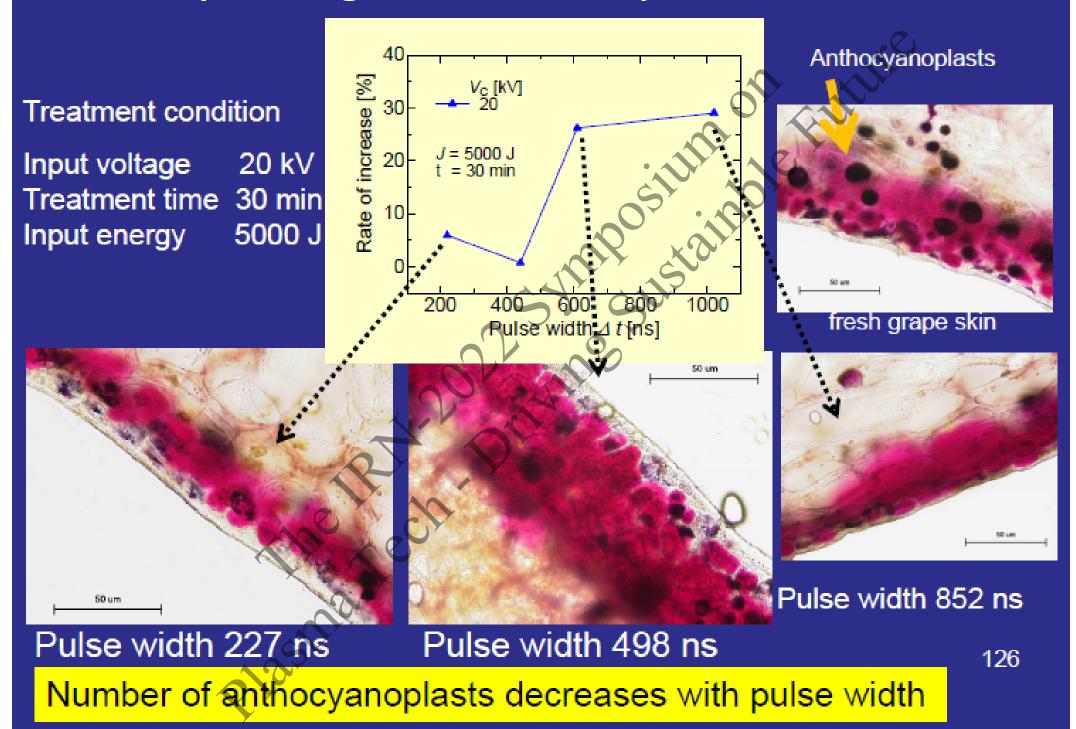
$$s = \left(\frac{1}{\tau_0}\right) \left(\frac{E - E_{\text{crit}}}{E_0}\right)$$

ity as shown in Fig. 30 by best fitting with $E_{\text{crit}} = 4.9 \text{ kV/cm}$, $E_0 = 6.3 \text{ kV/cm}$, an 12 ms (Hülsheger et al. 1981). From this empirical law, the required electrical

$$W = \tau \sigma E^2$$
,



Microscopic images for various pulse width

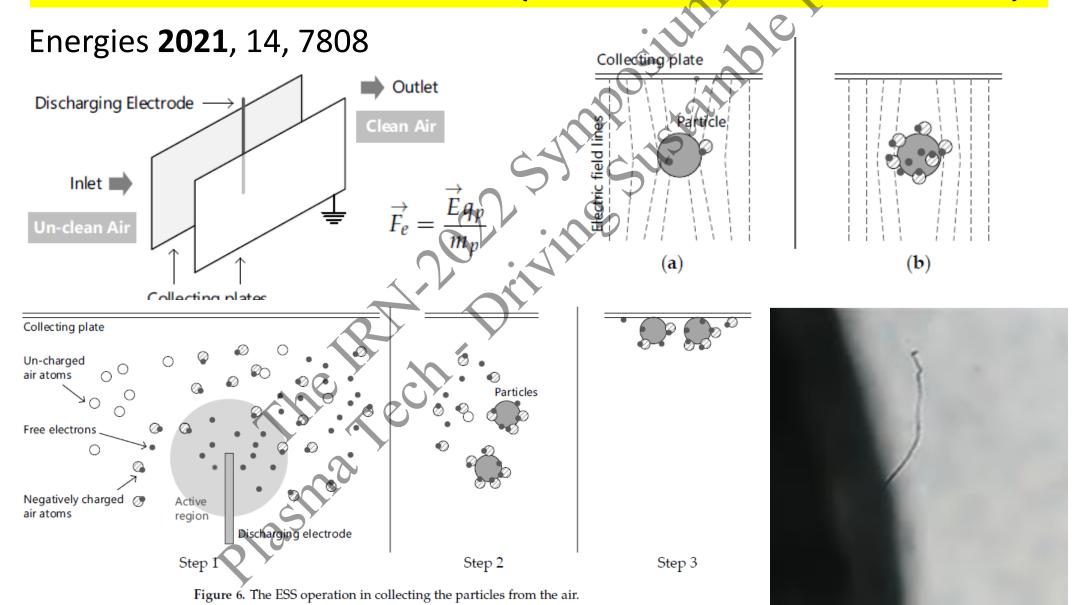




Basis; E-stress, Electrostatic, plasma reaction



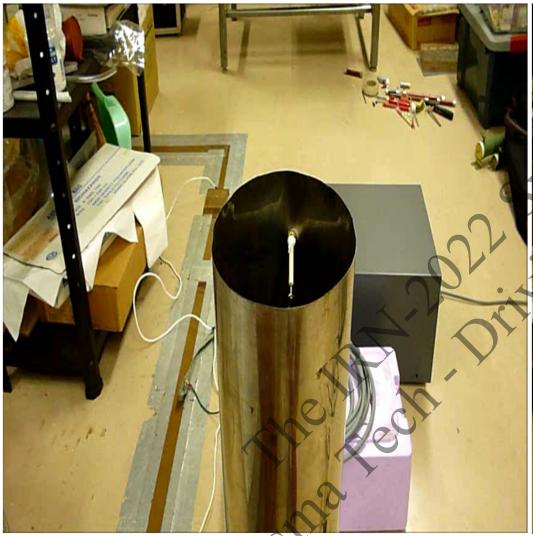
Electrostatic effects (Coulomb's force, etc.)

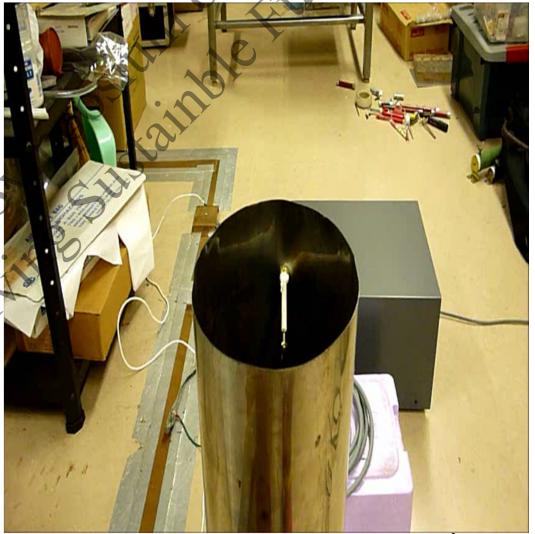




Electro-precipitation









Applied:0kV

Applied:-15kV



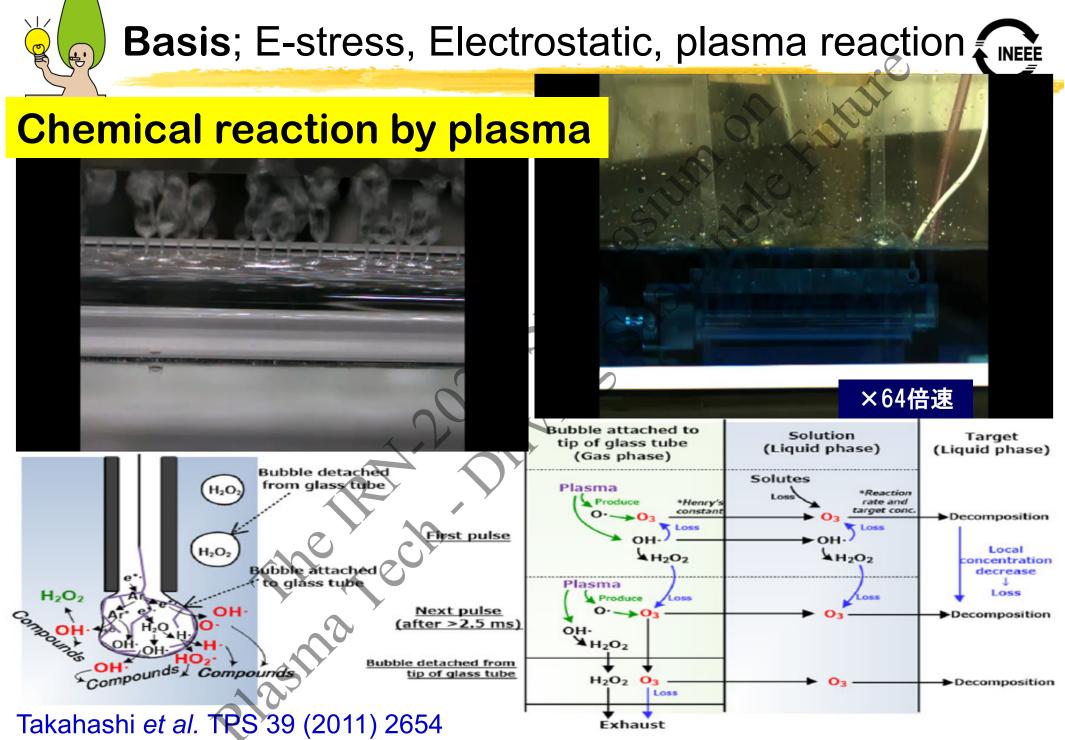


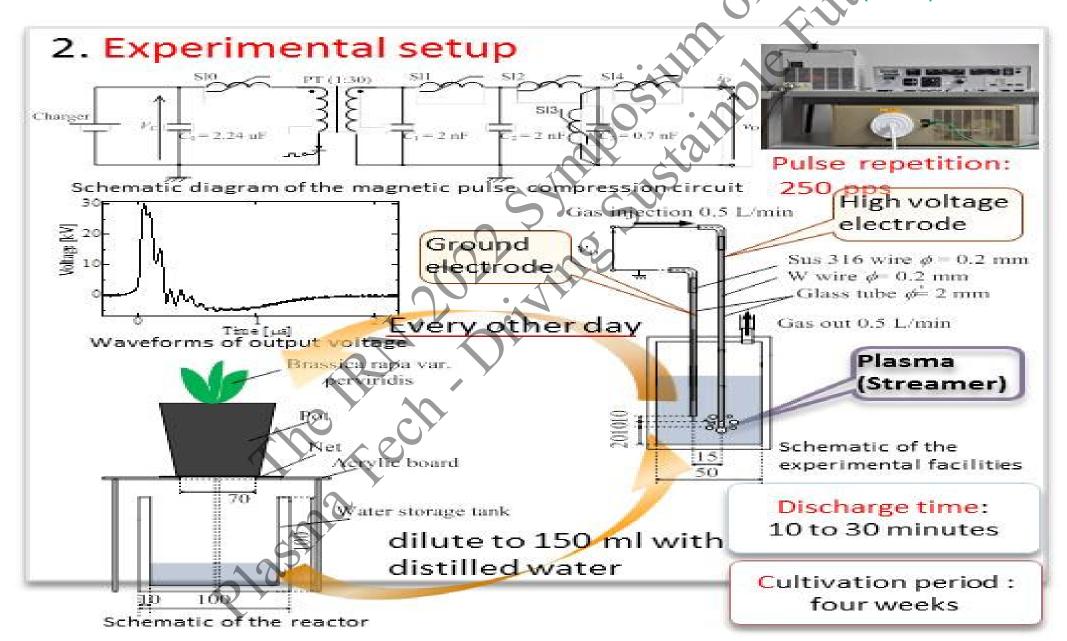
Figure 19. Schematic diagrams of chemical reactions in gas and liquid phases by non-thermal plasmas in the bubble underwater.



Plant growth promotion



Takaki et al. JPCS 418 (2013) 012140, Takahata et al. JJAP 54 (2015) 01AG07

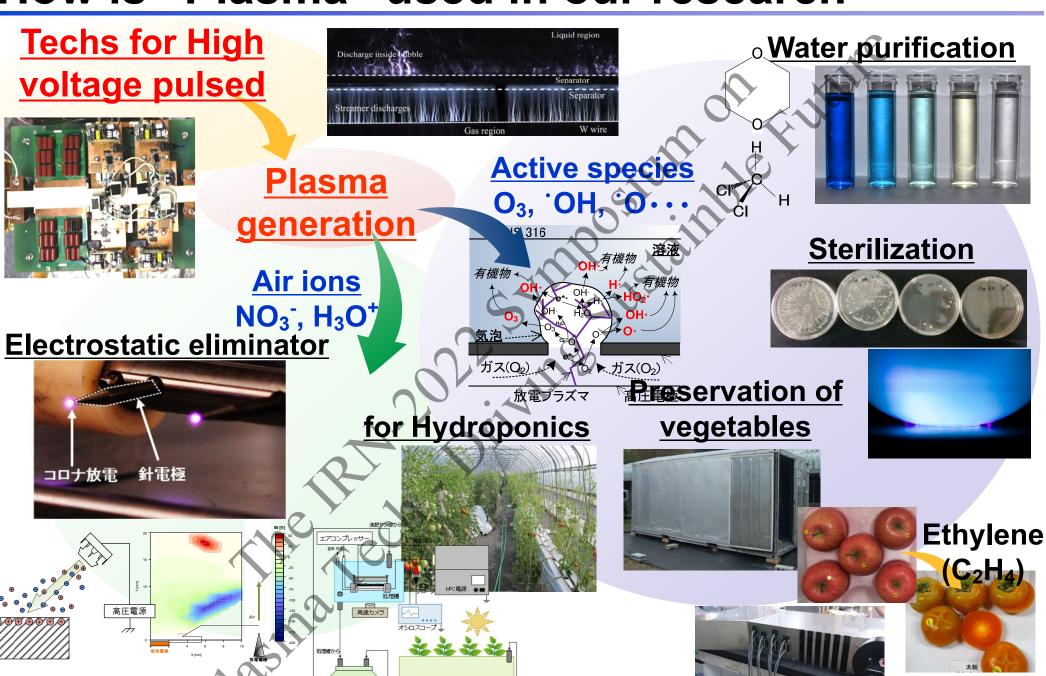


Outline



- Design of HV generator and its applications # HV generator; AC, DC, Pulse HV power supplies # Applications; non-thermal plasma, E-stress to Bio
- Applications in food supply chain
 # in preharvest; germination, growth, fruition,...
 - # in postharvest; keeping freshness,....
 - # in food process; drying, enzyme activity,...

How is "Plasma" used in our research



For plasma controlling Why we need pulsed power? Glow-like discharge Arc discharge 200 Applied voltage, kV What is pulsed power? 80 160 Corona Glow 120 Power $1TW \times 100ns = 100kJ$ Consumption in 1000GW 20 (at 0.01pps) the world Consumption in 10GW 150 200 100 Japan Time [ns] Corona $100MW \times 10ns = 1$ Consumption of 100MW (at 1000 pps) 30000 houses Primary streamer Secondary streame 1MW **Glow** 10kW $1kW \times 100s = 100kJ \text{ or } 1kW \times 1ms = 1J$ 100W T. Namihira et al., IEEE Trans. Arc Time Stimulate cell membrane organism in cell 50 MHz 500 kHz 5 MHz cytoplasm 2 V_{rms} **Nucleus** (a) Cell Membrane (c) Nuclear Membrane 20 um (2D Finite element method)

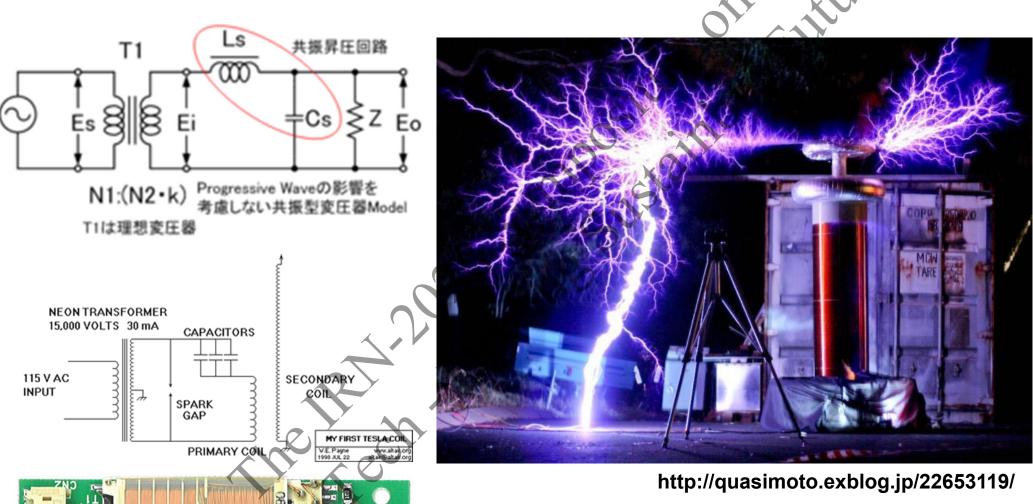
100

Frequency [MHz]

3 For electric field distribution controlling

High voltage power supply (AC)

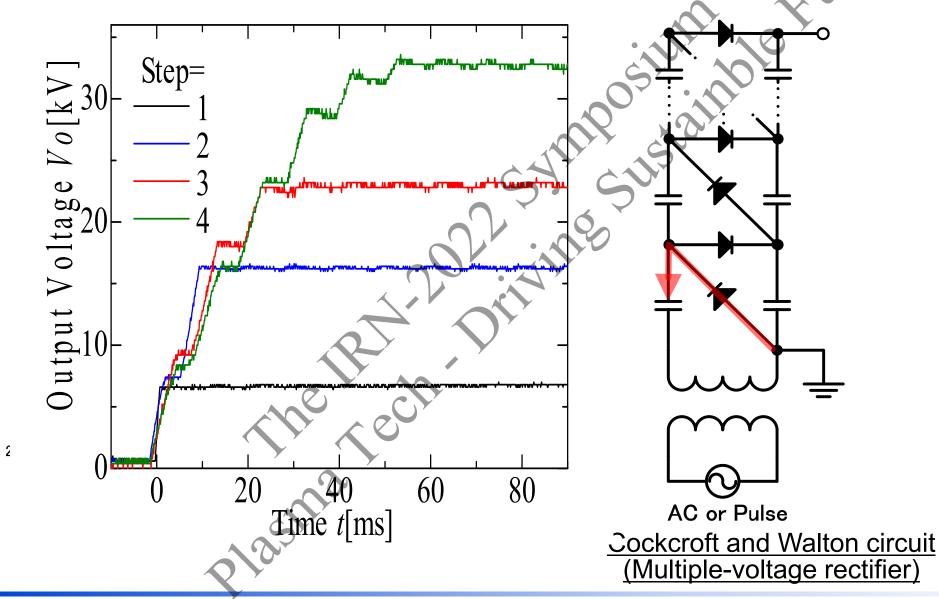
Tesla Coil: with resonance circuit



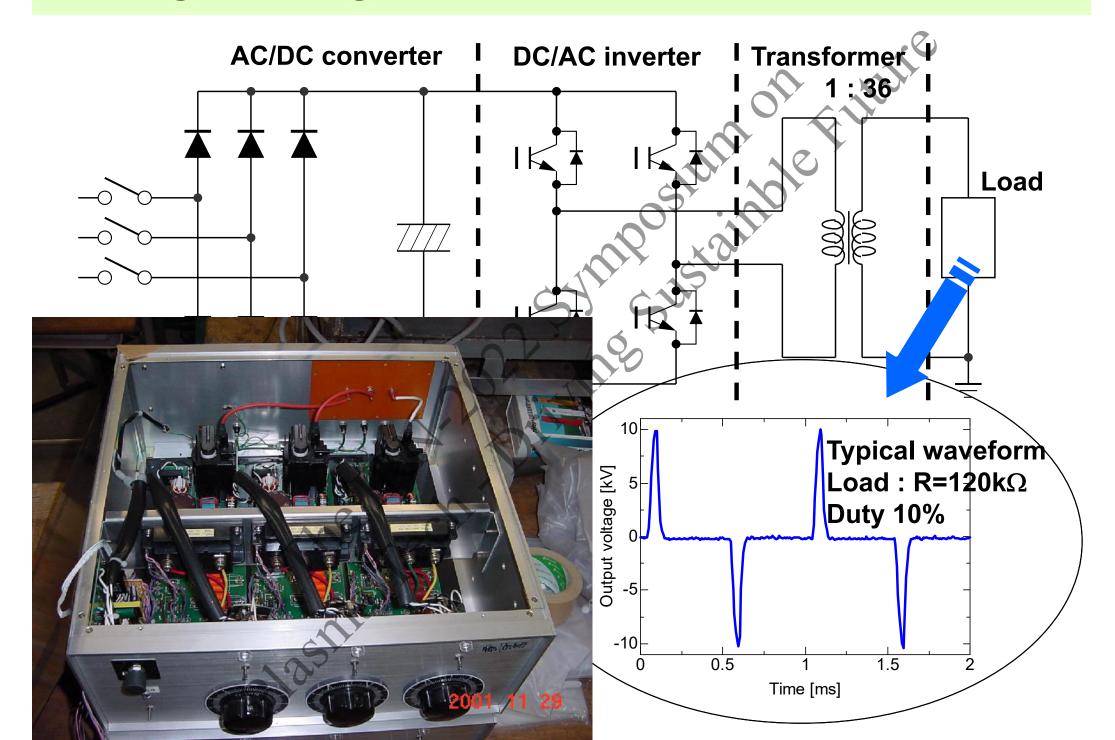
https://ja.wikipedia.org/wiki/%E3%83%86%E3%82%B9%E3%83%A9%E3%82%B3%E3%82%A4%E3%83%AB

High voltage power supply (DC)

In the case of DC, rectifier system is required



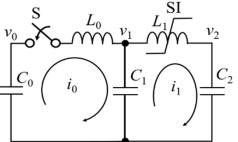
H-bridge pulse generator circuit





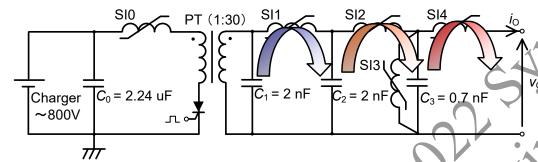
Magnetic pulse compression: MPC

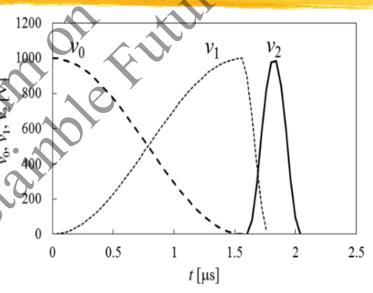


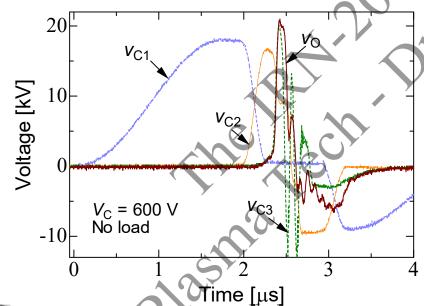


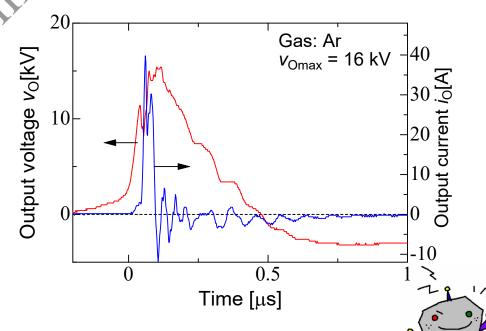
$$v_1 = \frac{1}{C_1} \int_0^t i_0 dt = \frac{V_0}{2} \left(1 - \cos \frac{t}{\sqrt{L_0 C}} \right)$$

$$v_2 = \frac{1}{C_2} \int_0^t i_1 dt = \frac{V_0}{2} \left(1 - \cos \frac{t}{\sqrt{L_1 C'}} \right)$$





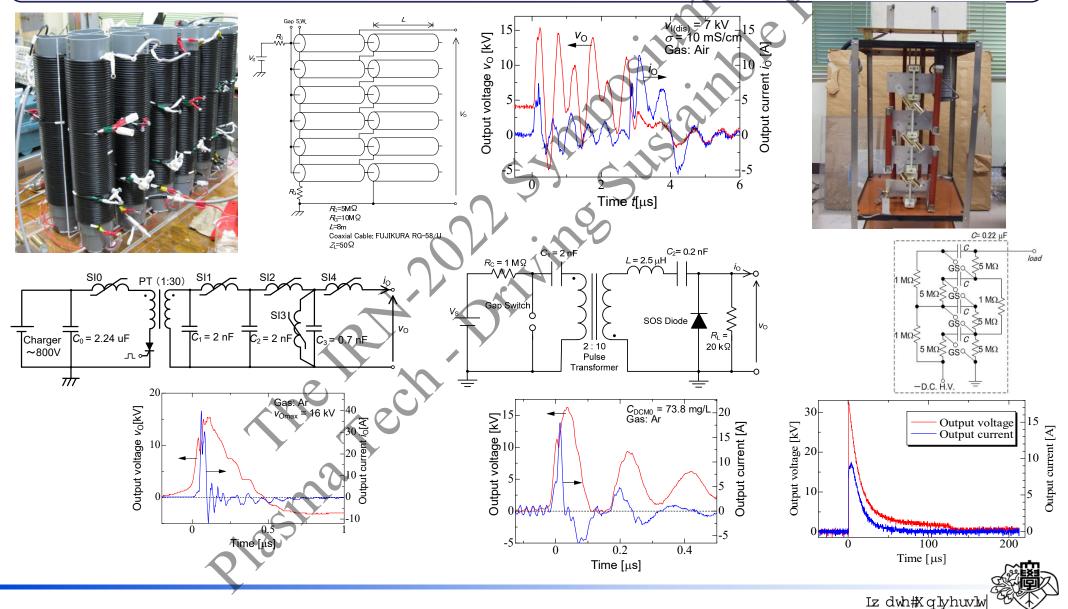




High voltage power supply (ns pulse)

Required spec: 10~20kV, several ten ~ hundred ns, several hundred pps

- PFN ·Blumelein line type ·Magnetic pulse compression
- Induction energy storage using semiconductor opening switch (SOS diode)



Satoshi Horikoshi Graham Brodie Koichi Takaki Nick Serpone *Editors*

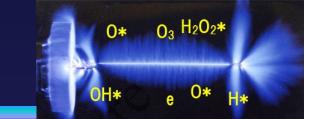
Agritech:
Innovative
Agriculture Using
Microwaves and
Plasmas

Thermal and Non-Thermal Processing



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Outline



3 Applications in food supply chain

in preharvest; germination, growth, fruition,...

in postharvest; keeping freshness,....

in food process; drying, enzyme activity,...

Agricultural applications (3 stages)

Before harvesting (Pre-harvest)

- Improvement of productivity
- Decrease infection risk of plants
 - *Hydroponics, mushrooms





After harvesting (Post-harvest)

 Keep freshness of products and decrease losses in preservation and transportation

*Transportation of fruits and vegetables







- Extraction of valuable components
- Additional value

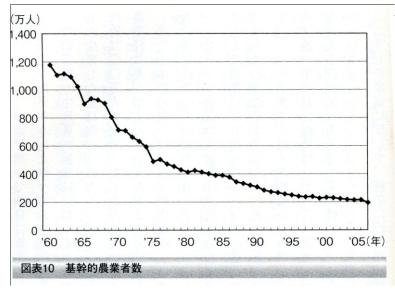


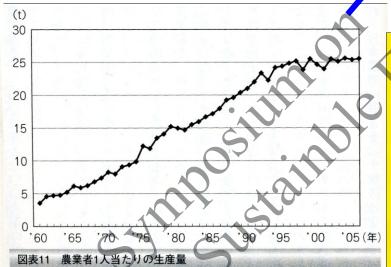




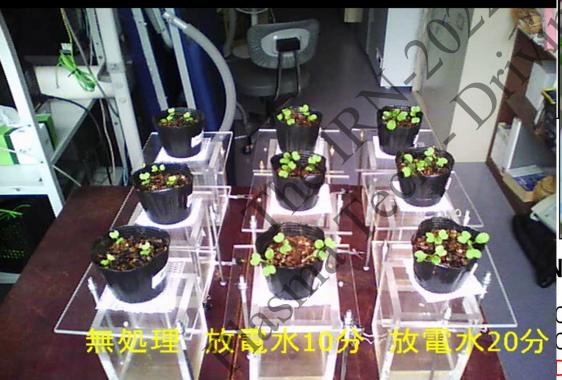
1. PRE harvest; improve yielding

30 ton/farmer 8 trillion JPY











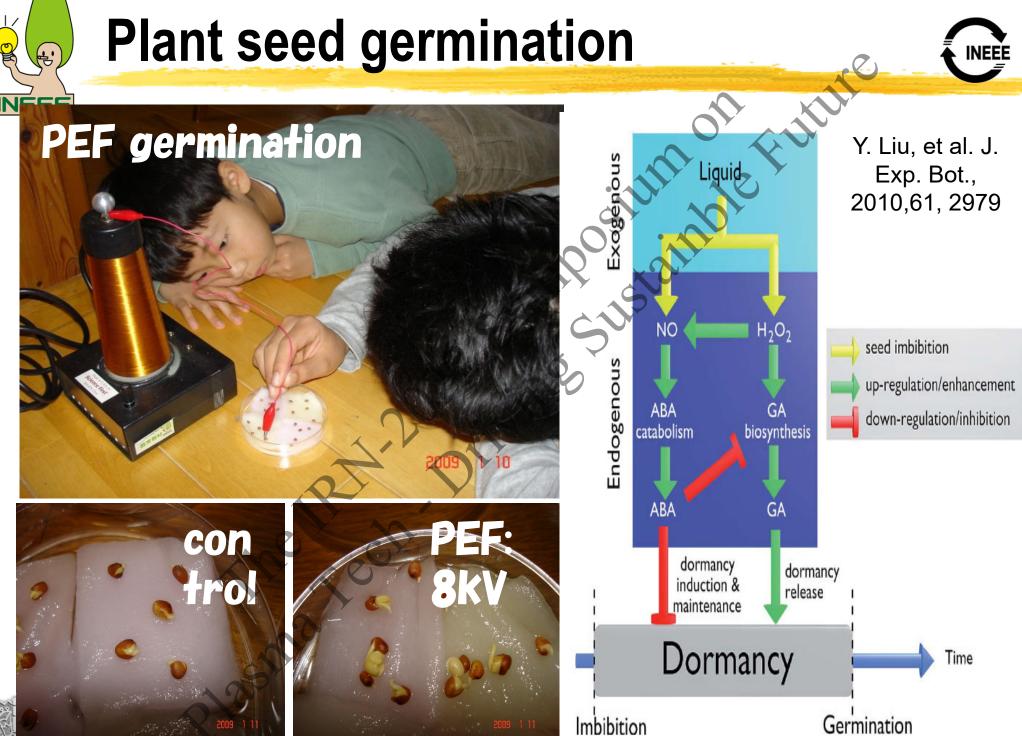


I: Negative

Positive

Negative

Control (-): No bacterium/No Discharge Plasma
Control (+): Bacterial contamination/No Discharge Plasma
DP: Bacterial contamination/Discharge Plasma



Nutrient solution treatment

Hydroponics, method of growing plants using nutrient solution without soil.

- ·Widely used because of easy management, high productivity
- Plants are cultivated in cultivation bed filled with nutrient solution.

Nutrient solution supply

■ Run-to-waste system:

- **Casy to manage nutrient**
- ×High cost, heavy environmental load (N2/P flow out to river)
- Re-circulation system:
 - OLow cost (save up to 40%)
 - ×High risk for plant diseases caused by microbial contamination



Pathogen (Ralstonia solanacearum, Fusarium oxysporum)
Contamination via water supply, air, insect, grower, seedlings

Solution addition

Cultivation bed

Circulation system

Rapidly spread in circulation system→ Serious damage to entire plant

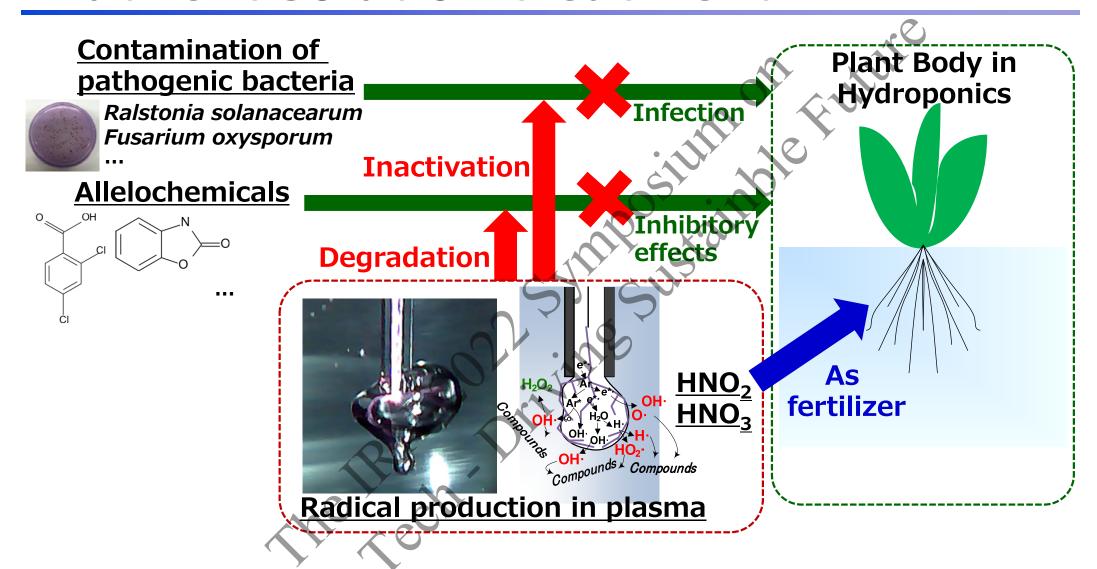
Undesirable organic compounds from water and root exudates:

Crop yield can also be seriously lost

Nutrient solution should be remediated by continuous treatment during cultivation period:

Heat treatment, UV: Various limitation such as low oxidation power, high cost, maintenance

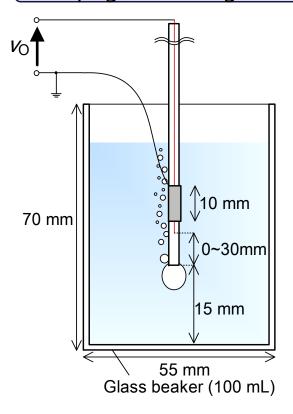
Nutrient solution treatment

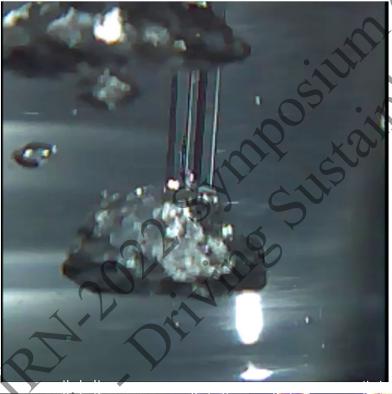


- Control environment for plant growth
 by inactivation of bacteria and degradation of allelochemicals
- ·Supply nitrogen fertilizer

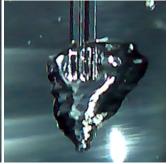
Discharges inside bubble K. Takahashi et al.: "Observation of the development of pulsed discharge inside a bubble under water using ICCD cameras", Vacuum, Vol. 182, 109690 (2020)

- •The injection of gas bubbles into the vicinity of electrode to reduce energy loss caused by ohmic loss and vaporization
- •Propagates along bubble surface with a speed in order of 105 m/s









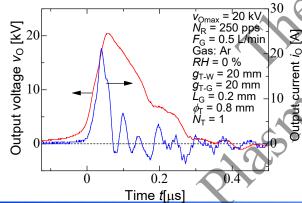
0 ms

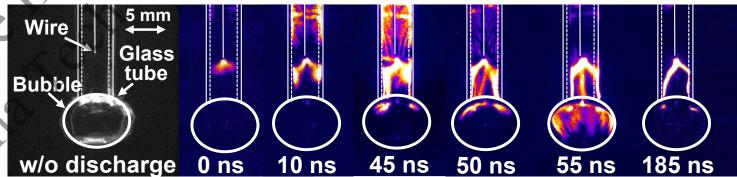
12.5 ms



Taken by high-speed video camera

25 ms





Taken by ICCD camera (5ns exposure time)

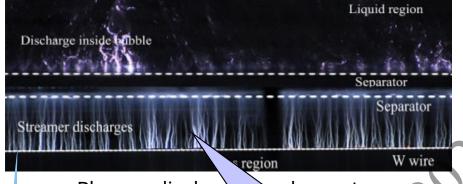


Hydroponic plant cultivating system

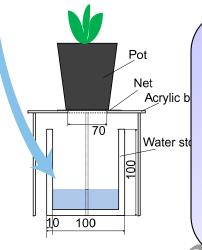
Plasma treatment of artificial nutrient solution:

- Plasma treatment of nutrient solution using pod cultivation (Japanese mustard spinach)
- Growth rate increases with plasma treatment

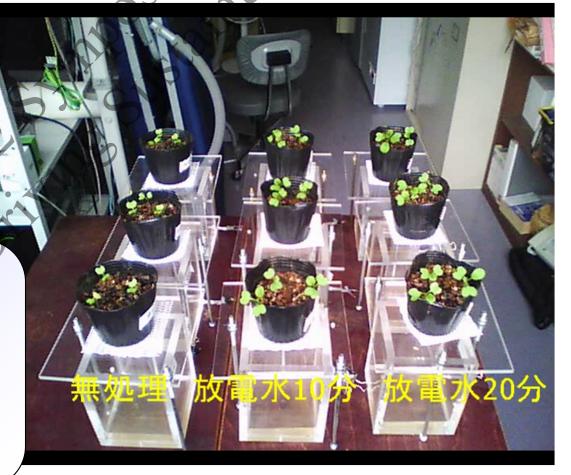




Plasma dischard nder water



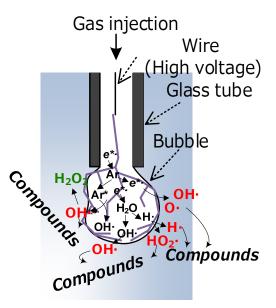
 $N_2+\cdot O \rightarrow \cdot N+\cdot NO$ $\cdot NO+\cdot OH \rightarrow HNO_2$ $\cdot NO_2+\cdot OH \rightarrow HNO_3$ $\cdot NO_2\cdot +\cdot OH \rightarrow \cdot NO_2+OH^ 3HNO_2 \rightarrow HNO_3+2NO+H_2O$ $HNO_2+H_2O_2 \rightarrow$ $H^++NO_3+H_2O$ $HNO_2 \rightarrow H^++NO_2^ HNO_3 \rightarrow H^++NO_3^-$



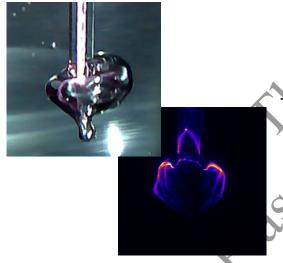
Radical production

K. Takahashi, S. Kawamura, I. Yagi, M. Akiyama, K. Takaki and N. Satta, International Journal of Plasma Environmental Science and Technology, Vol. 13, No.2, pp.74-82 (2019. 12)

Chemical species produced at vicinity of water surface contribute to bacterial inactivation and chemical degradation



Discharge model



In Plasma in gas phase:

e + Ar \rightarrow Ar(${}^{3}P_{2}$) + e Ar(${}^{3}P_{2}$) + H₂O \rightarrow Ar + OH(A²S⁺ H₂O + e \rightarrow H₂O⁺ + 2e H₂O⁺ + H₂O \rightarrow H₃O⁺ + OH H₃O⁺+e \rightarrow H₂ + OH(A²S⁺) O₂ + e \rightarrow O(1 D) + O(3 P) + e O(3 P) + O₂ + M \rightarrow O₃ + M H₂O + O(1 D) \rightarrow 2OH

(OH: Penetration depth on order of 10^{-5~-6}m)

Under Water:

 $Ar^+ + H_2O \rightarrow H_2O^+ + Ar$

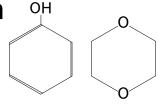
 $H_2O + e \rightarrow H_2O + 2e$

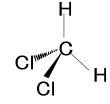
 $H_2O^+ \rightarrow OH + H^+$ (Water Cathode)

 $2e^{-}_{(aq)} + 2H_2O_{(aq)} \rightarrow 2OH^{-}_{(aq)} + H_{2(aq)}$ (Water Anode)

Oxidation







Mineralization CO₂ + H₂O

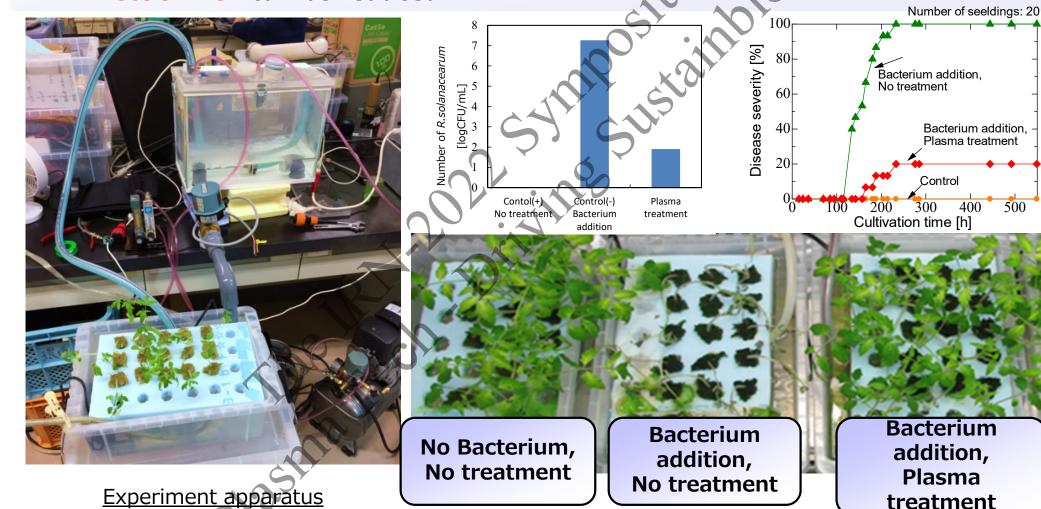
Bacteria Inactivation

Inactivation effect

T. Okumura et. al., Plasma Medicine, Vol. 6, No. 3-4, 247-254 (2017) K. Takahashi et. al., J. Electrostat. Vol. 91, pp.61-69 (2018)

Plasma treatment of artificial nutrient solution:

- Active species such as OH and O also contributes to inactivation of bacteria
- Inactivation of Ralstonia solanacearum, a plant pathogenic bacterium, in the nutrient solution with tomato seedlings
 - → Infection risk can be reduced



Photos of seedlings after 12th day

Iz dwh#Xalyhuvlw

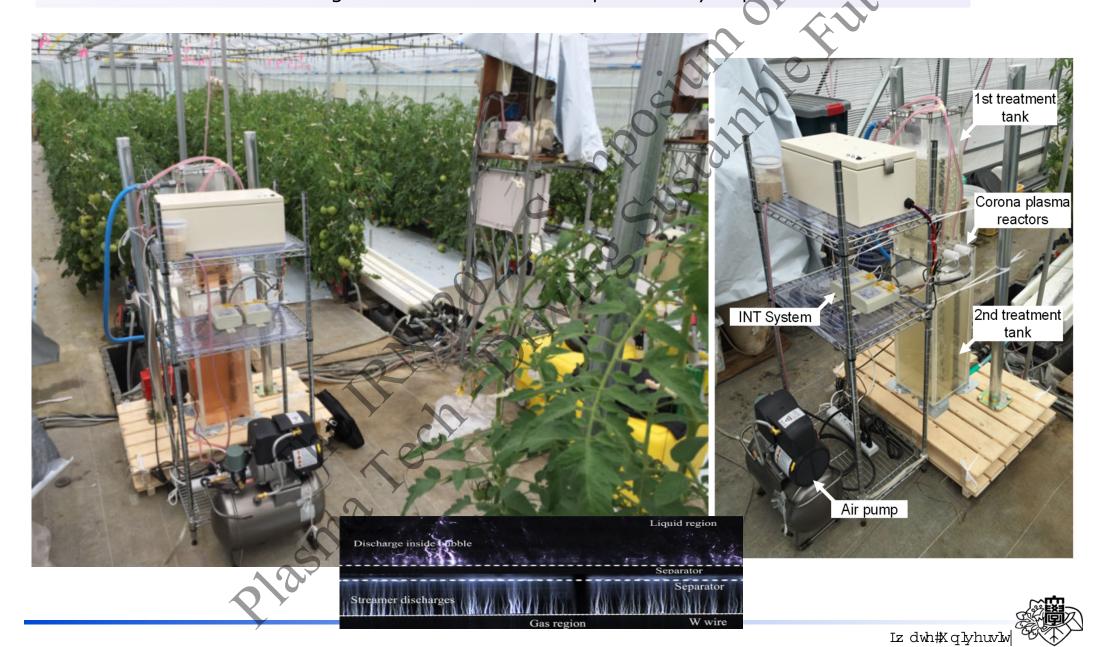
400

500

Treatment system for practical use

Plasma treatment of artificial nutrient solution with Tomato cultivation:

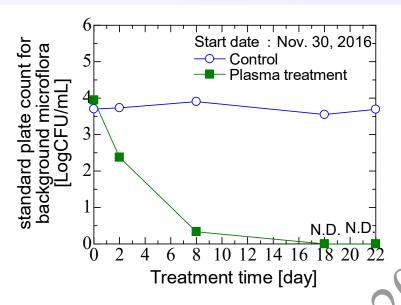
•Pilot test for 5 months in a green-house with tomato plants in hydroponics

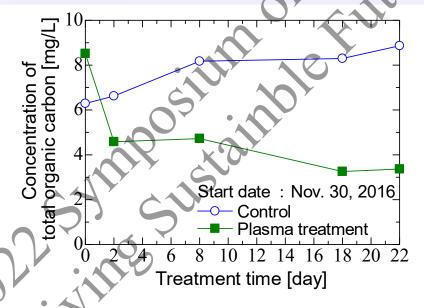


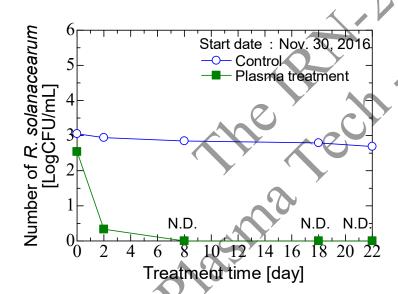
Treatment system for practical use

Plasma treatment of artificial nutrient solution with Tomato cultivation

•Pilot test for 5 months in a green-house with tomato plants in hydroponics







- Bacteria (standard plate count and R. solanacearum) are reduced and is not detected after 8days
- →Infection risk of the plant is significantly reduced by the continuous treatment
- **OTOC** decreases with Plasma treatment
- →Plasma also contributes to decontamination of water contaminated by organic compounds
- No harmful effect on plant and fruit bodies



Stimulation for fruit body formation



Heat • Light water

Beat Vib. Light







Hypha growth

Induce for fruit body generation

Fruit body formation

Bed browning

3 months / 2 years

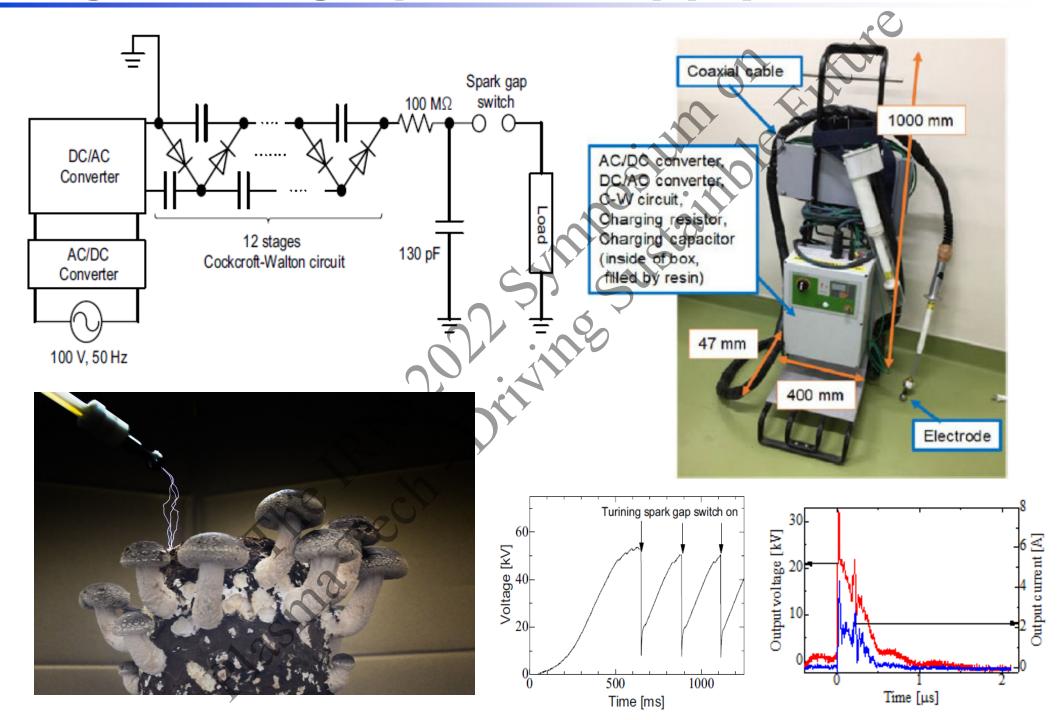
Harvest term

1 month / 3 years





High voltage power supply

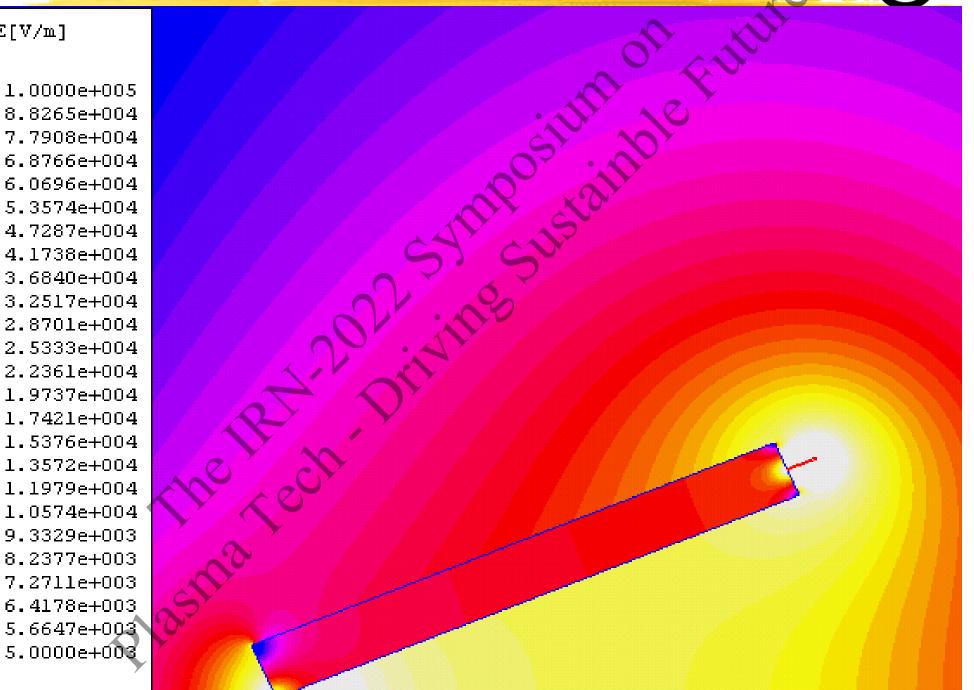






E[V/m]

Stimulations by Water, shock and PEF





Preliminary study of the effects of high voltage stimulation on Hed Har (5th May 2017)

Asst.Prof.Rattanaporn (RMUTL, Chiang Rai)



"Find only in raining

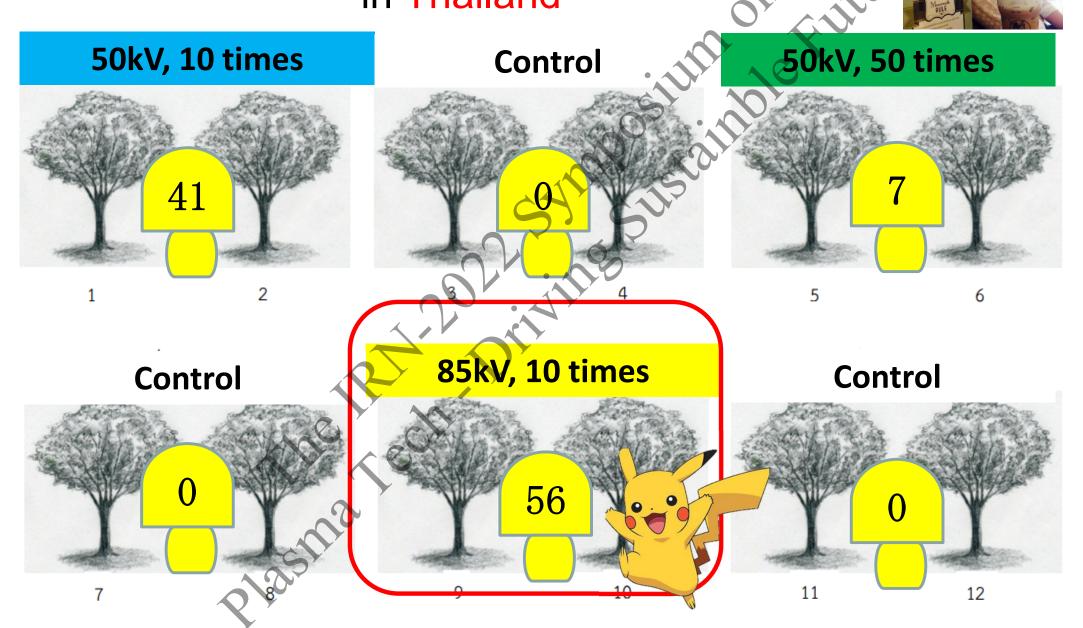
season

(Price: 200-500 Baht/kg)

Increased 56 ishrooms by applied compared with the control 0 mushroom



Effect of high voltage stimulation on fruit body formation of Hed Har (*Phlebopus portentosus*) in Thailand



w/o EF + 5°C

W/ EF + 9 °C

sportation cost









試験開始5日目からカビ; (写真は10日目)





K. Takaki et.al, IEEE Trans. Plasma Sci., Vol. 43, pp. 3476-3482 (2015)

1. Nichimura et al. Trans. MPS1 Vol. 41. nn. 41-45 (2016)

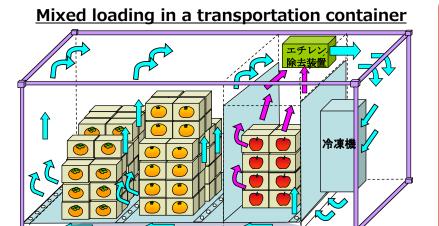
J. Nishimura et.al, Trans. MRSJ, Vol. 41, pp. 41-45 (2016)

K. Takaki et.al, IEEE Trans. Plasma Sci., Vol. 49, pp. 61-68 (2021)

K. Takaki et.al, Jpn. J. Appl Phys., Vol. 60, 010501 (2021)

- •Quality loss by ethylene(C₂H₄), a plant hormone released by respiration
- Low temperature injury

Preservation









- High speed treatment by high density radicals
- High safety by removing by products using catalyst
- High maintainability
- Compact and light

Reactions in plasma:

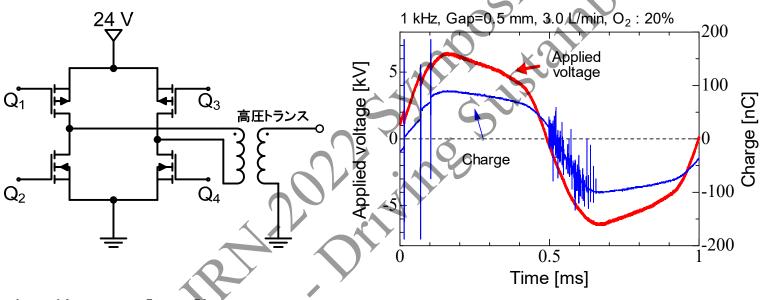
 $C_2H_4 + O \rightarrow Products (k = 1.3 \times 10^{-13} cm^3/s)$

 $C_2H_4 + OH \rightarrow Products (k = 8.0 \times 10^{-12} cm^3/s)$

 $C_2H_4 + O_3 \rightarrow Products (k = 1.9 \times 10^{-18} \text{ cm}^3/\text{s})$

Proto-type for pilot test

- Very compact high voltage power supply used in products of electrostatic eliminator by Shishido electrostatic, LTD.
- ·Small high voltage transformer is driven by full bridge circuit consisted of MOS-FETs
- Voltage: ~10 kV, Frequency: 500Hz~1kHz



Circuit bord(52×80 [mm]



Waveforms



Transformer:

Weight: 411.1 g

Size: 164×41×24 [mm]

Air inside

Container

Axial FAN

Duct type C2H4 remover

DBD

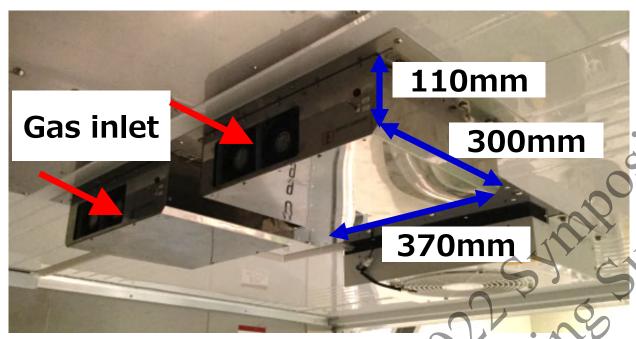
Exhaust to

Catalyst

Iz dwh#Xqlyhuvlw

nside container

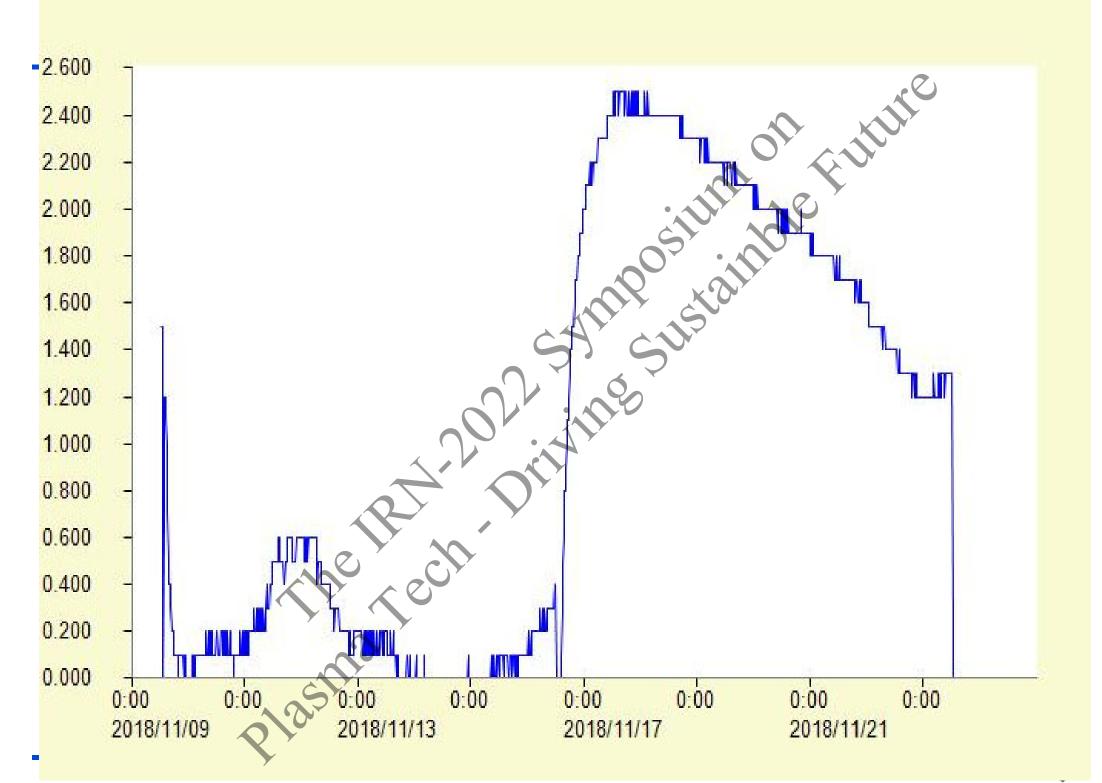
Ethylene removal system



Proto type







空気をキレイに! 身近なブラズマパワー

坂口憲二、※夢の扉

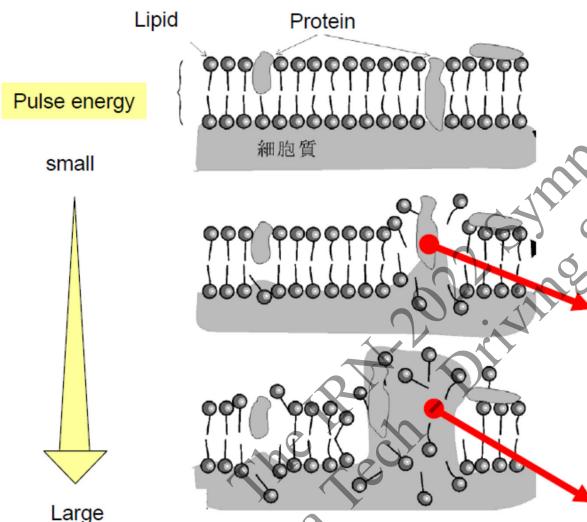
高木 浩一教

コンテンや冷蔵庫の空気をキレイにして 食品保存に役立つ



Biological effect at low frequency (<1MHz)





Electroporation

The cell membrane "breaks down", through voltage gating or electroporation, if the external electrical field reaches a critical value, E_c.

Reversible pore formation (recovery time 1~100 ms)

DNA transfection, cell fusion, drag delivery

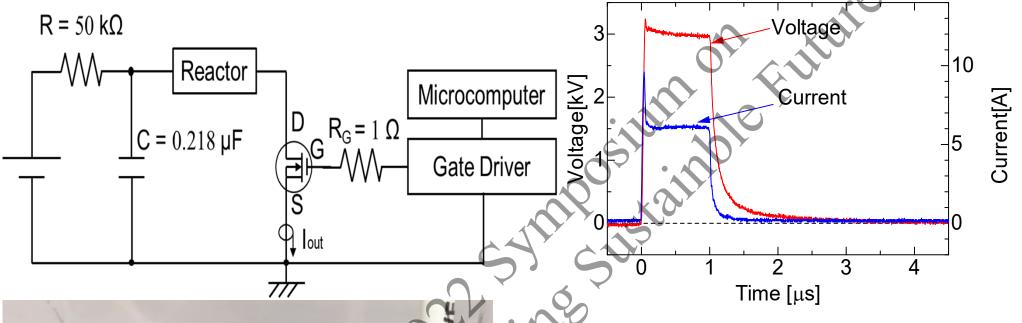
Irreversible pore formation sterilization, juice extraction

Pulse energy expenditure

E : field strength ⊿t :pulse duration



PEF treatment



Sold Sold Sold Sold Sold Sold Sold Sold
TO CE
125

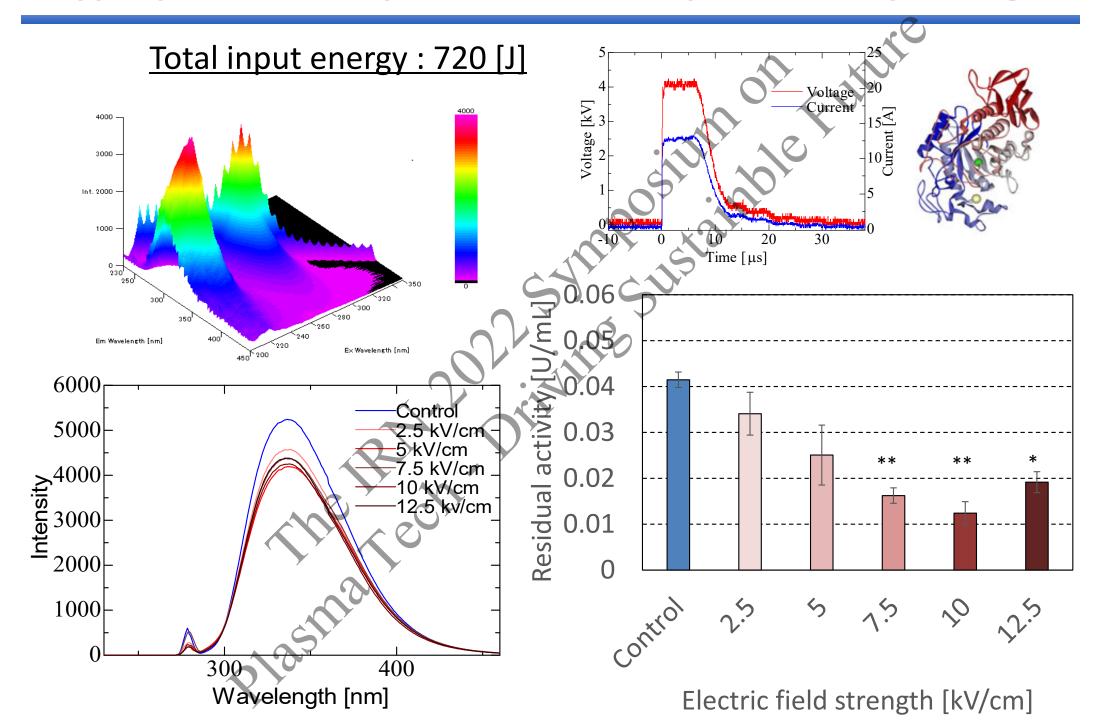
Conditions		
Samples	spinach	
Voltage [kV]	3	
Pulse width [µs]	1	
Frequency [Hz]	30	
Treatment time [min]	0.5, 1, 3	
Input energy [J]	18 mJ/pulse	

rironment Education w/pulse [Z_{cm}] 25 20 15 te electrode decimal) **→**w/pulse -w/o 2\$0

乾燥時間

[min]

Tryptophan decomposition and Enzyme activity change







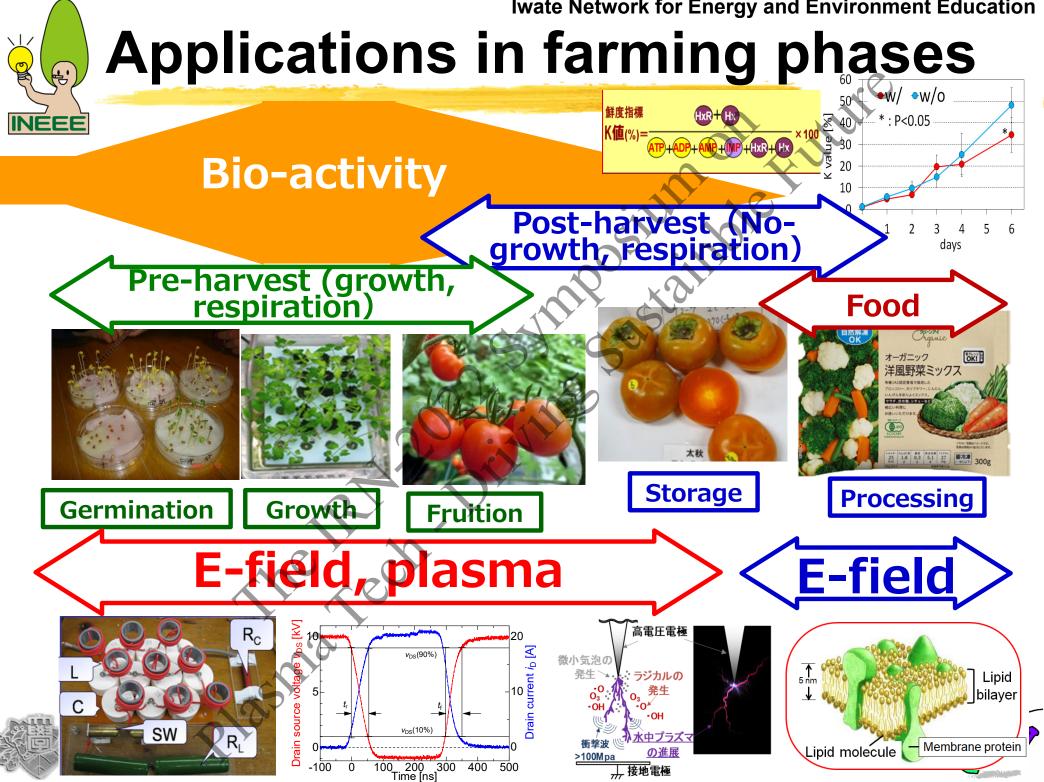
Concluding



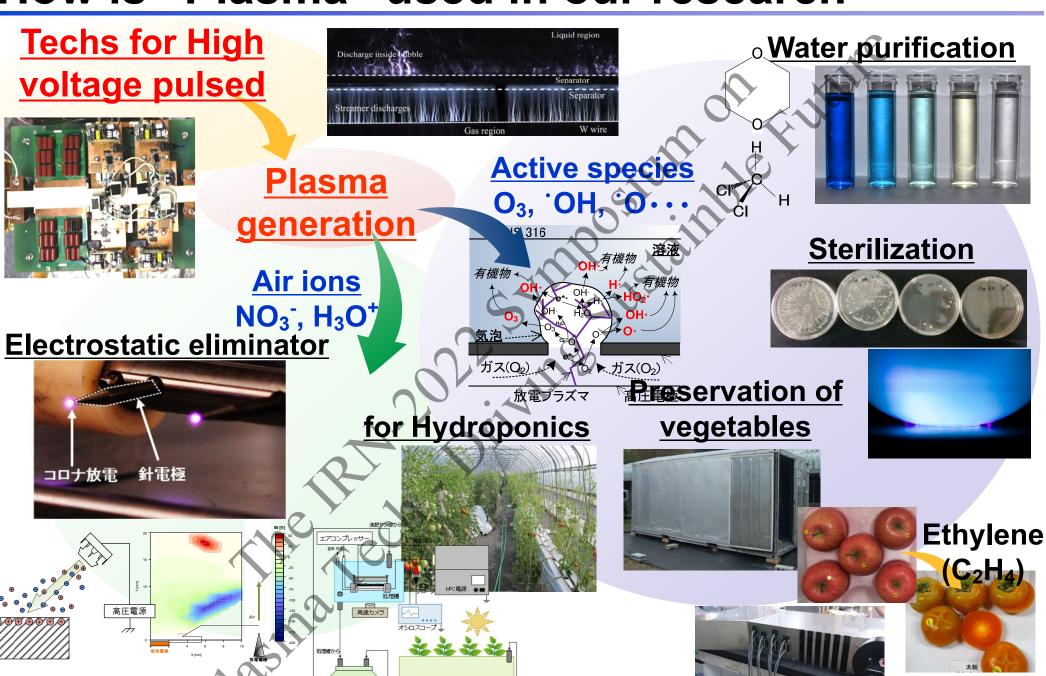
- 1 Pre-harvest applications
 - Plasma in fertilizer: Promotion of plants growth Plasma in pesticide: Reducing risk of the infection
 - Rep. high-voltage: Useful for mushroom stimulation
- 2 Post-harvest application
 ESP for spore: Reducing risk of the infection
 Inactivation of bacteria: Reducing risk of the infection
 C₂H₄ decomposition: Reducing cost of transportation
- 3 Food processing

E-field: Electroporation, Extraction, Drying





How is "Plasma" used in our research





The 7th International Symposium on Plasma & Fine Bubbles to Agriculture and Aquaculture (7th ISPF 2023) will be held at Iwate University, Morioka, Japan, May17-20, 2023 to further provide an open forum for the introduction and discussion of the most current status of innovative scientific and technological achievements in the interdisciplinary versatile fields of high-voltage, plasmas and fine bubbles applied to agriculture, aquaculture and food safety. As joint international symposium, The East Asia Fisheries Technologists Association (EAFTA), Food Society of Modern International Lifestyle Education (FSMILE) will be held by faculty of agriculture, Iwate University on the same schedule. Hosted by Iwate University, cohosted by Kyoto University, Tohoku University of JAPAN, RMUTL, RMUTT of THAILAND, etc.



ISHPMNB history 1







1st International Symposium on Application of High-voltage, Plasmas & Micro/Nano Bubbles to Agriculture and Aquaculture

January 5th - 6th, 2017 at Rajamangala University of Technology Lanna



Assoc. Prof. Dr. Numyoot Songthanapitak President, Rajamangala University of Technology Lanna



Agenda

Date: Thursday 5th January, 2017 Venue: Chalermprakiat 56 years Building, RMUTL





Keynote Speaker

Prof. Koichi TAKAKI Iwate University, Japan Agricultural applications of atmospheric-pressure plasma using pulsed power technology



Keynote Speaker

Prof. Akimi SERIZAWA Kyoto University, Japan

ISHPMNB2018 5.12(sat)

International Symposium on Application of High-voltage, Plasmas & Micro / Nano Bubbles (Fine Bubbles) to Agriculture and Aquaculture
Iwate University & Rajamangala University of Technology Lanna & Rajamangala University of Technology Thanyaburi

2018, Japan





ISHPANB2018 5.9(wed) 5.12(sat)

International Symposium on Application of High-voltage, Plasmas & Micro / Nano Bubbles (Fine Bubbles) to Agriculture and Aquaculture Iwate University & Rajamangala University of Technology Lanna & Rajamangala University of Technology Thanyaburi











Hope to see all at next ISPFB, Morioka!

