Bacterial experiments with PCB and SSS*

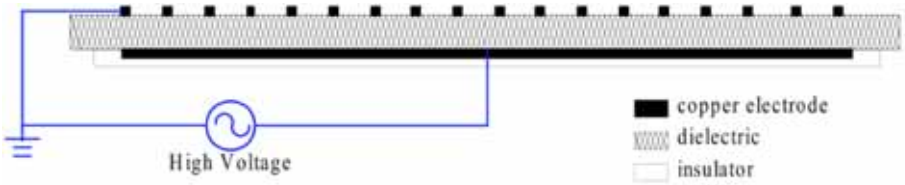
Yangfang Li, Tetsuji Shimizu, Lukas Milles, Julia Zimmermann, and Gregor Morfill

Max-Planck-Institut für Extraterrestrisches Physik, 85741 Garching, Germany

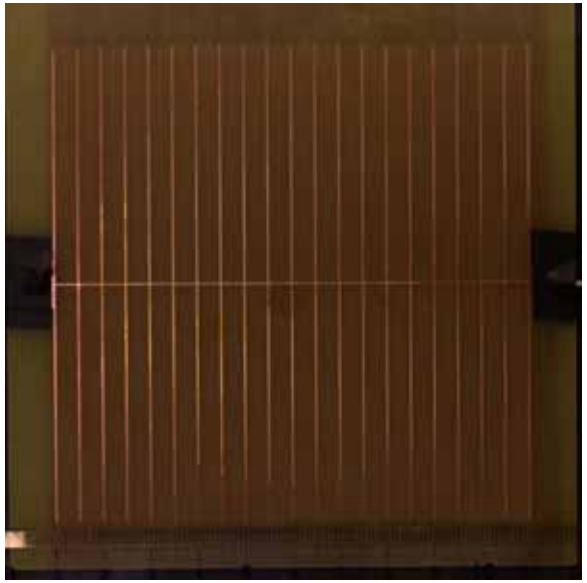
*Plasma Medicine Project, initiated by MPE

Introduction (1)

- PCB Printed Circuit Board

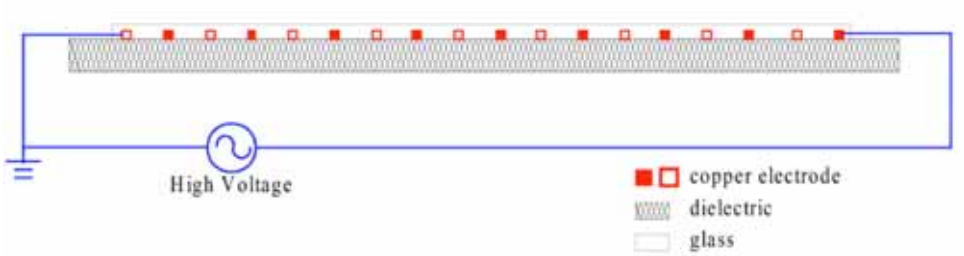


  - Grounded finger-shaped electrode
  - Dielectric barrier
  - Powered plate electrode
  - Insulating layer

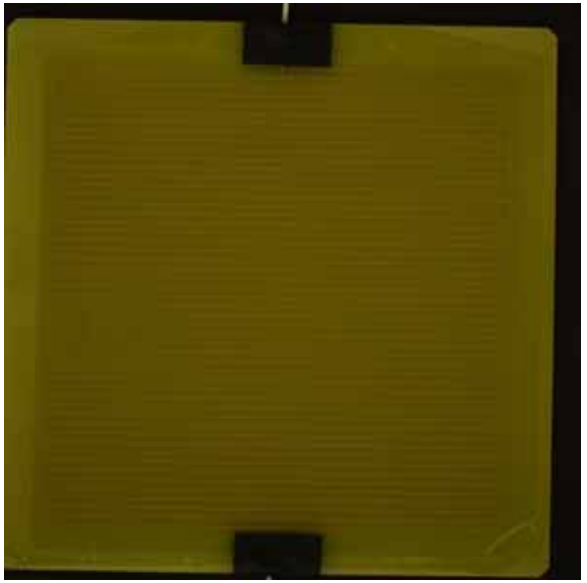


20100409_PCB/images_of_discharges/img_0541_c1.jpg

- SSS Self-Sterilizing Surface



  - Glass surface
  - Encapsulated electrodes
  - Dielectric base/surface



20100331/img_0023_c.jpg

Introduction (2)

Bacteria preparation: secondary culture

Stock culture* → Smear on agar plate → secondary culture

16 hour incubation

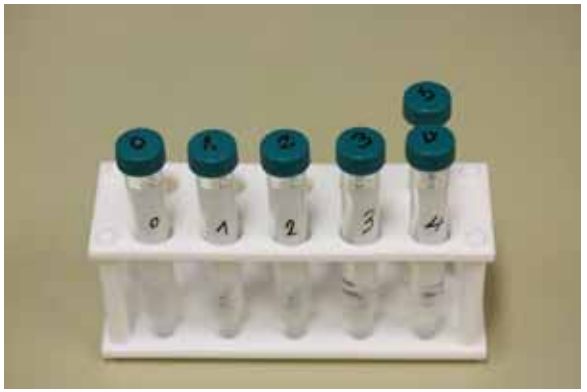
E_coli: Escherichia coli

From Partner of plasma medicine project: Dr. Hans-Ulrich Schmidt
Städt. Klinikum München GmbH, Mikrobiologie Zentrallabor Schwabing, Germany

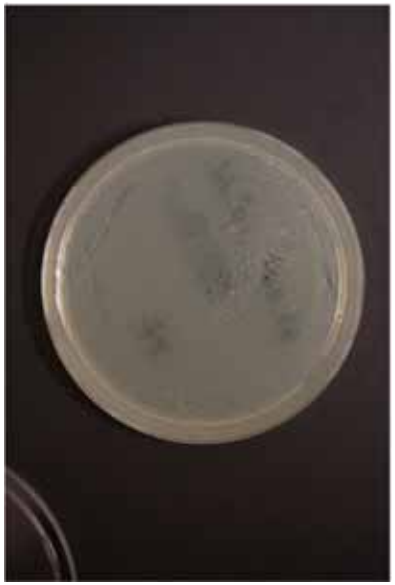
Introduction (3)

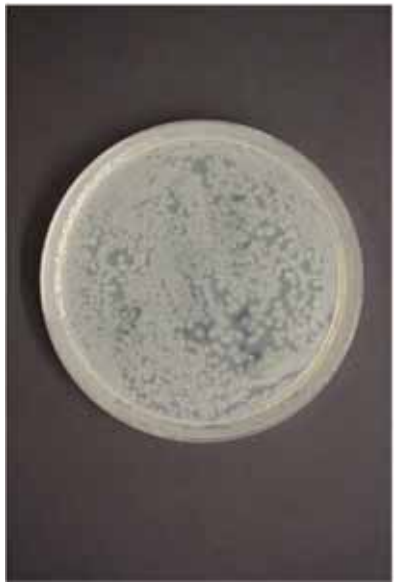
Bacteria preparation: suspension and dilution

secondary culture → Suspension (50ml PBS) → dilutions



Smear on the agar plates (100 µl) → Incubate (16 h, 35 ºC) → Colony on agar (no plasma)

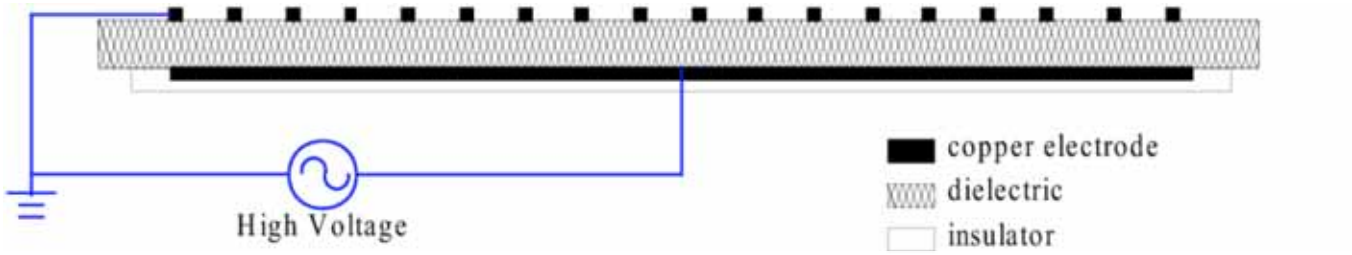




10^0 suspension 10^1 dilution 10^2 dilution 10^3 dilution 10^4 dilution

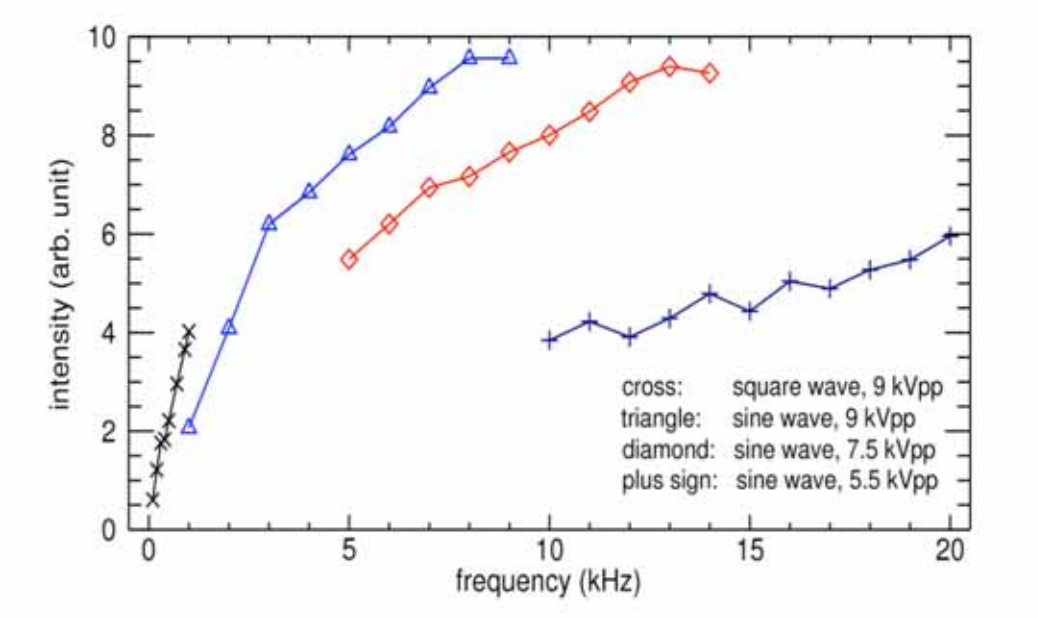
Experiments with PCB (1)

Plasma intensity and board temperature



Finger electrode: 0.5 mm, 5 mm
Board: 12 cm x 12 cm
Plate electrode: 10 cm x 10 cm
HV: 4.5 kVpp -9 kVpp
Frequency: 0.1 kHz -20 kHz
Square Wave for lower frequencies (< 1 kHz)
Sinusoidal Wave for higher frequencies (> kHz)

Sound of the discharges with respect to
Different frequencies and different design
Of the board.



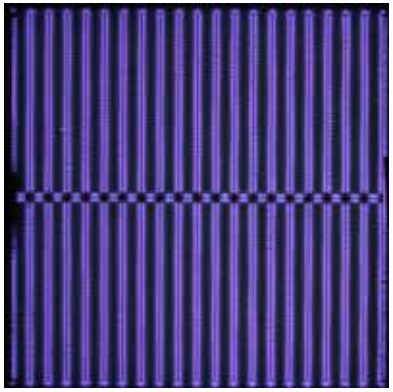
20100409_PCB/images_of_discharges/light_intensity_B.pdf

The temperature of the board is less than 30 ºC within 6-minute operation for all the conditions.*

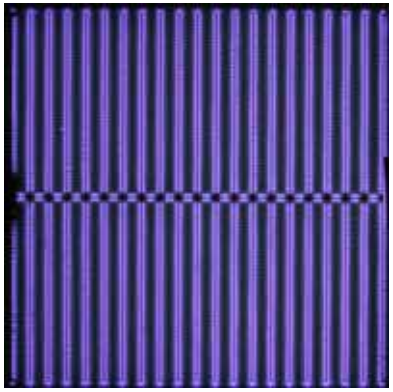
*Done by Lukas Milles, April 22, 2010 with Voltcraft 320 K/J thermometer

Images of the PCB discharge (1)

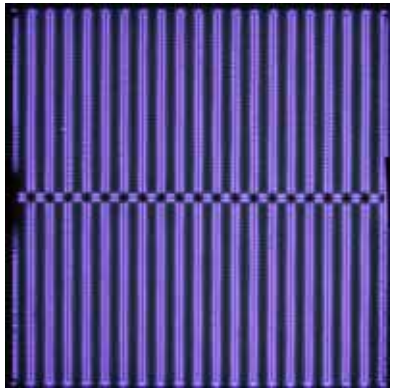
PCB, 0.5 mm, 5 mm
9 kVpp, sine wave (1-9 kHz)



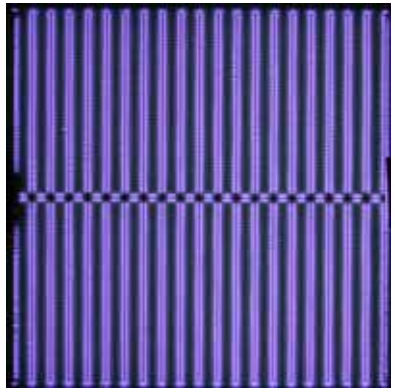
1 kHz



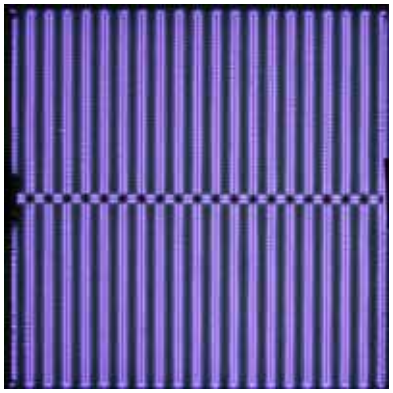
2 kHz



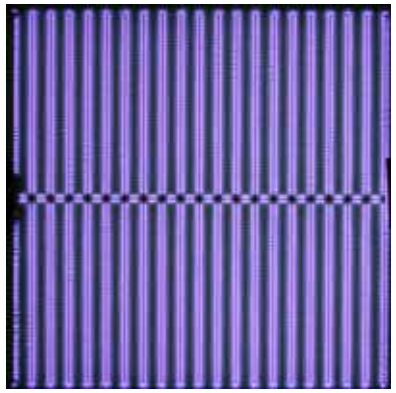
3 kHz



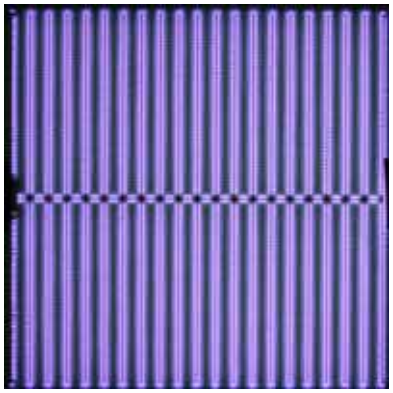
4 kHz



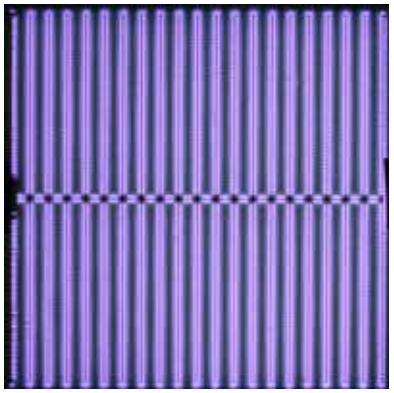
5 kHz



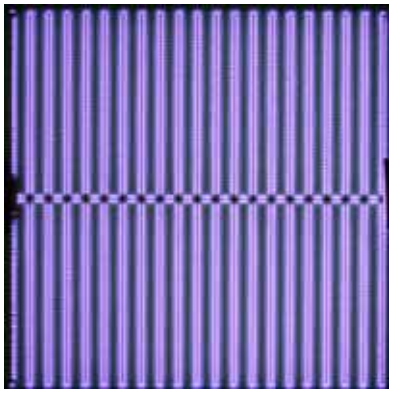
6 kHz



7 kHz



8 kHz

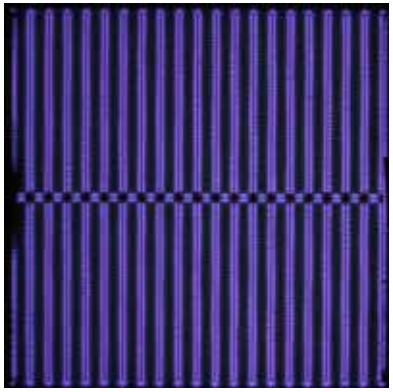


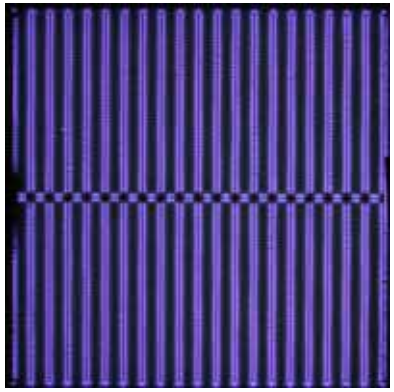
9 kHz

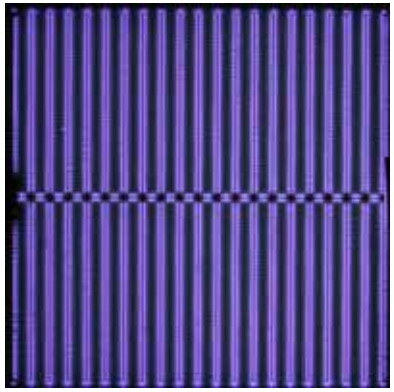
20100409_PCB/images_of_discharges, CANON 450D + EF-S 60 mm 1:2.8, F2.8 ISO800 1”

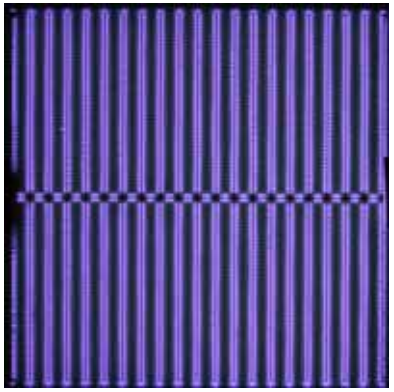
Images of the PCB discharge (2)

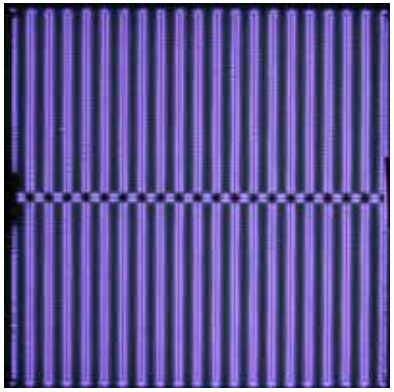
PCB, 0.5 mm, 5 mm
7.5 kVpp, sine wave (5-14 kHz)

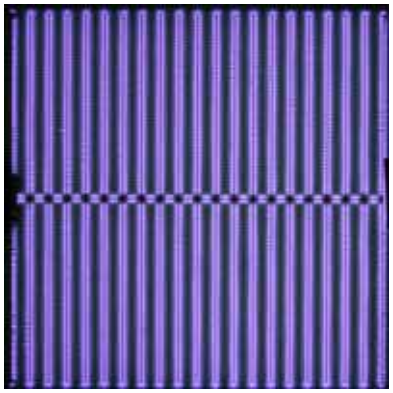

5 kHz

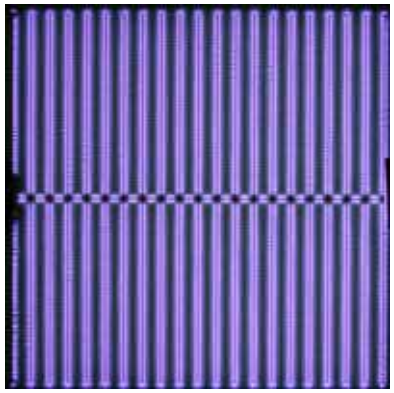

6 kHz

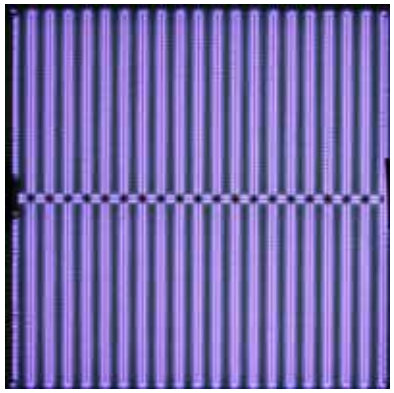

7 kHz

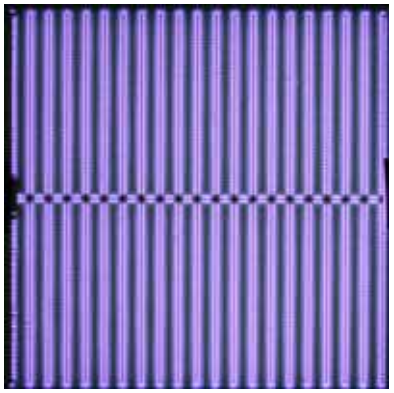

8 kHz

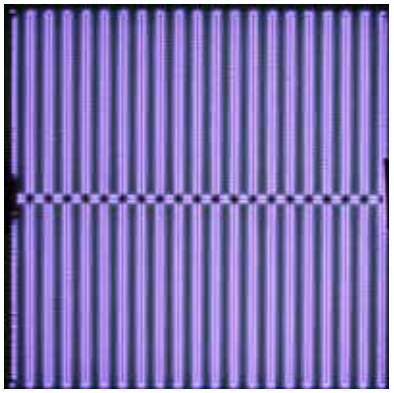

9 kHz


10 kHz


11 kHz

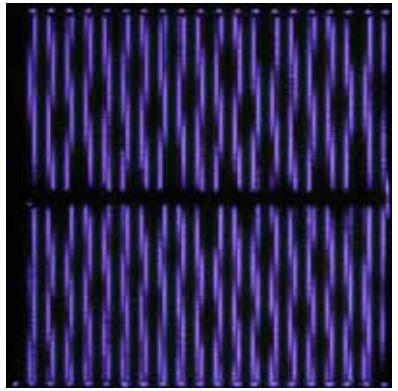

12 kHz


13 kHz

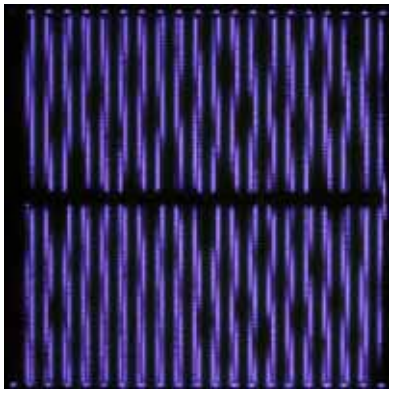

14 kHz

Images of the PCB discharge (3)

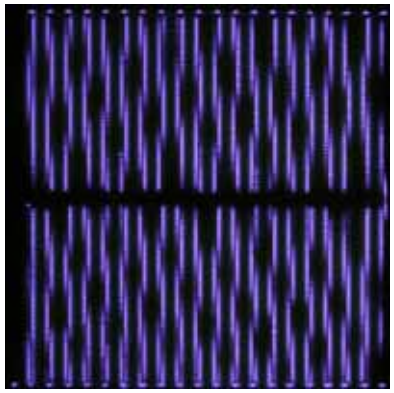
PCB, 0.5 mm, 5 mm
5.5 kVpp, sine wave (10-20 kHz)



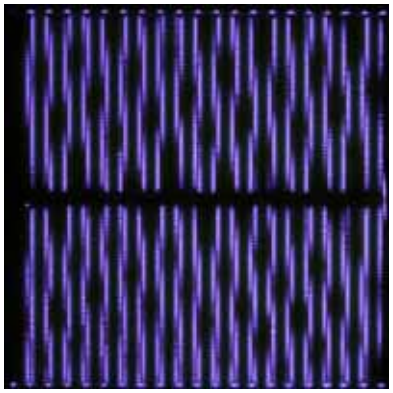
10 kHz



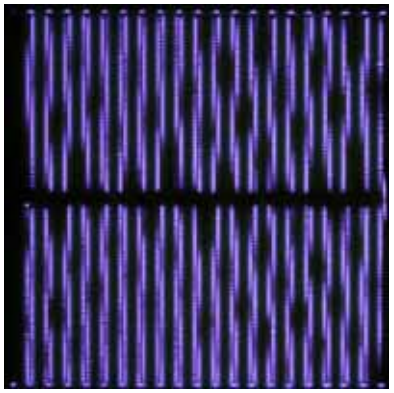
11 kHz



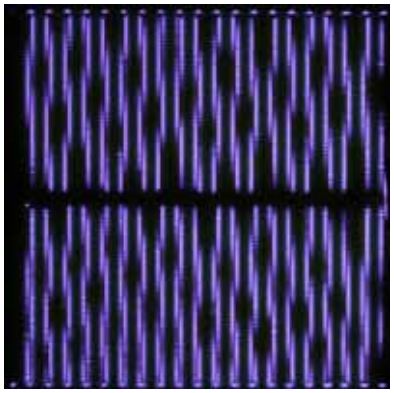
12 kHz



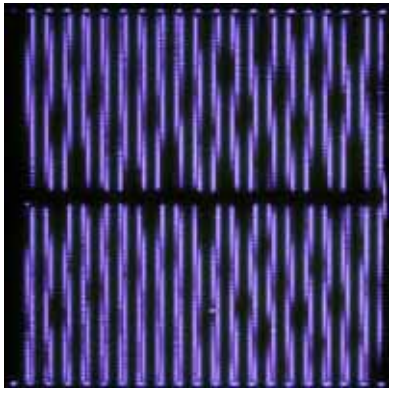
13 kHz



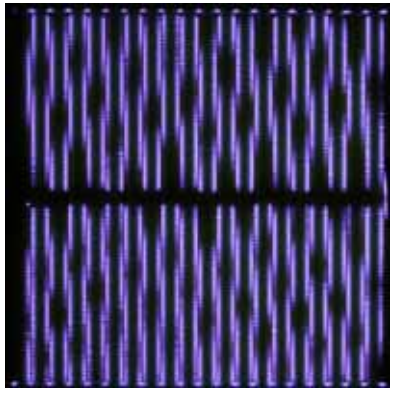
14 kHz



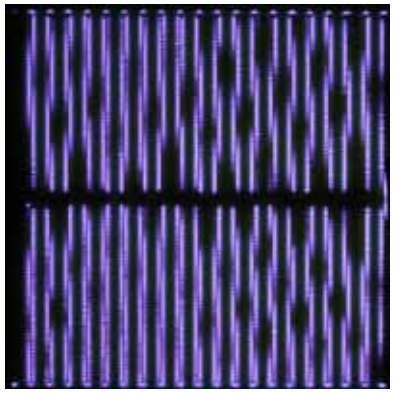
15 kHz



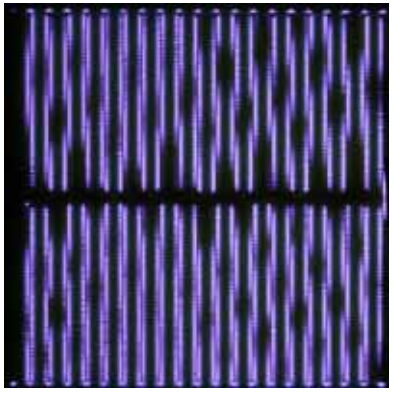
16 kHz



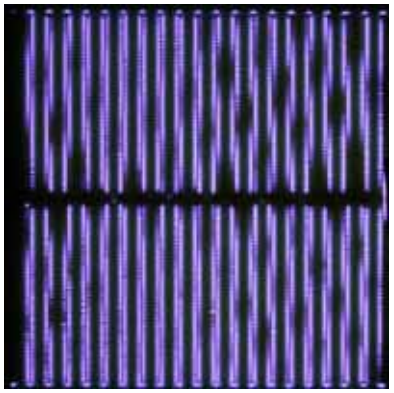
17 kHz



18 kHz



19 kHz



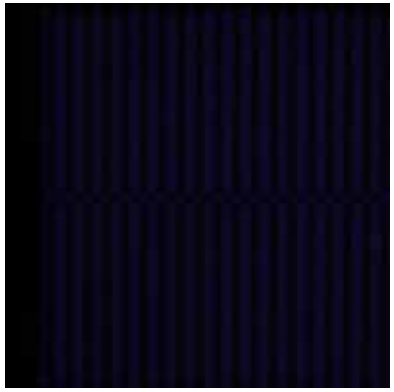
20 kHz

20100409_PCB/image_of_discharges, CANON 450D + EF-S 60 mm 1:2.8, F2.8 ISO800 1”

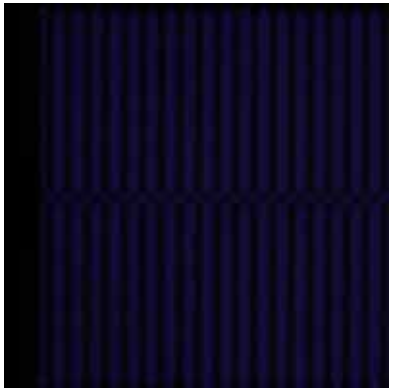
Images of the PCB discharge (4)

PCB, 0.5 mm, 5 mm
9 kVpp, square wave (0.1-1 kHz)

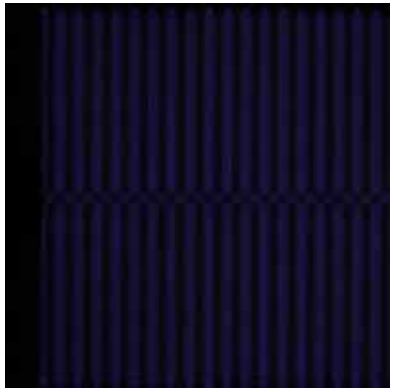
0.1 kHz



0.2 kHz

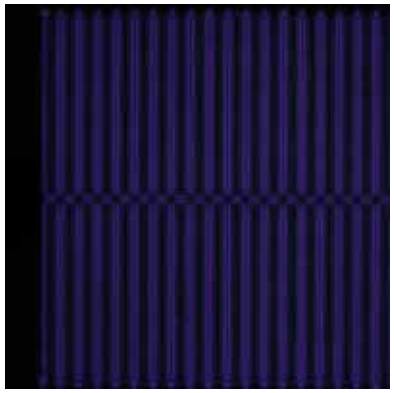


0.3 kHz

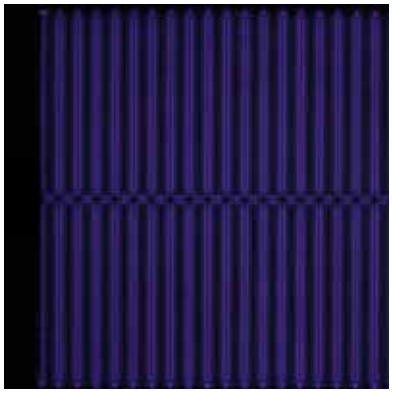


0.4 kHz

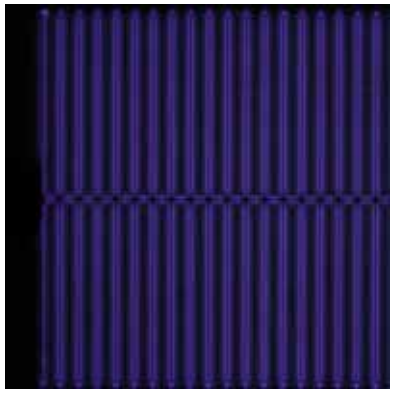
0.5 kHz



0.7 kHz



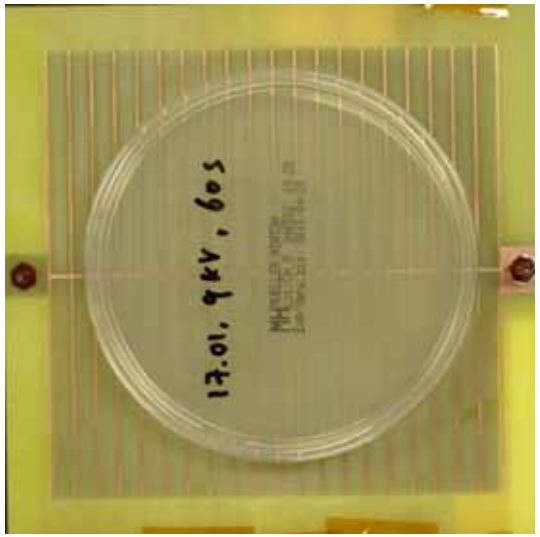
0.9 kHz



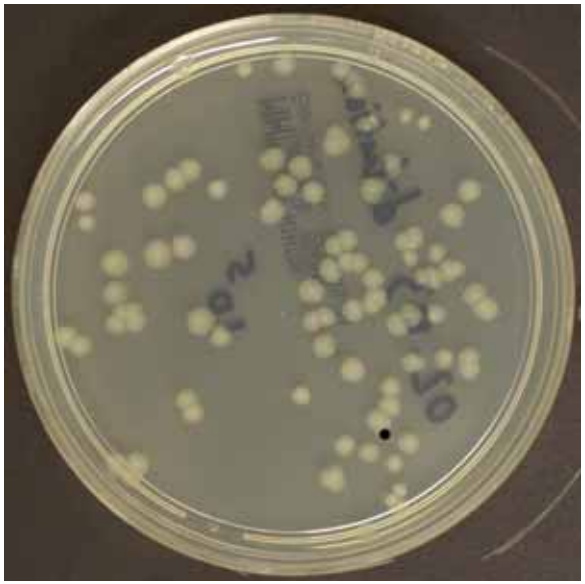
1 kHz

Experiments with PCB (2)

Bactericidal effect

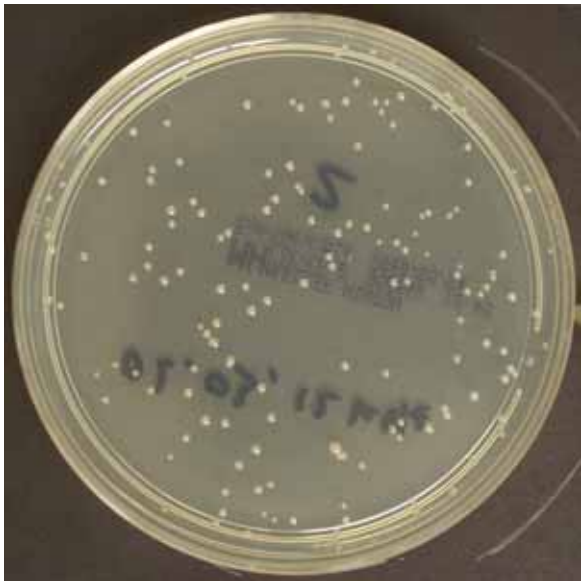


- ✓ 100 µl suspension on agar plates
- ✓ Plasma treatment
- ✓ 10^5 dilution without plasma treatment for control
- ✓ 16 hours incubation



20100303/images_of_agarPlates/pict1258_c.jpg

10^5 dilution



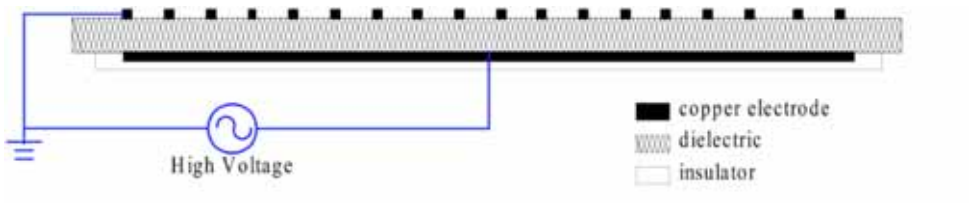
20100303/images_of_agarPlates/pict1263_c.jpg

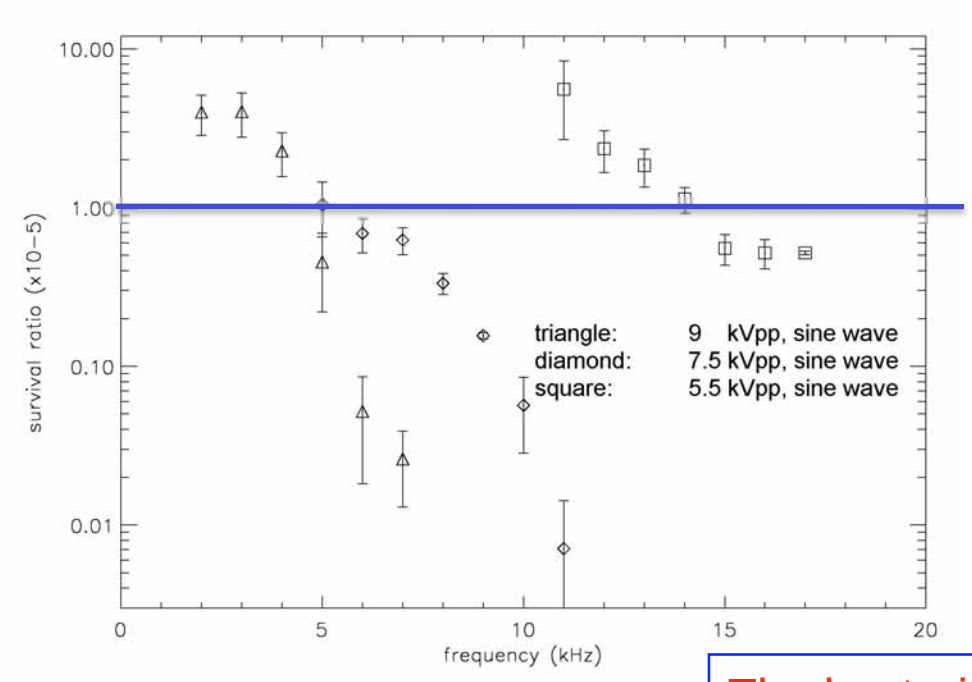
30s, 5.5 kVpp, 12 kHz

Experiments with PCB (3)

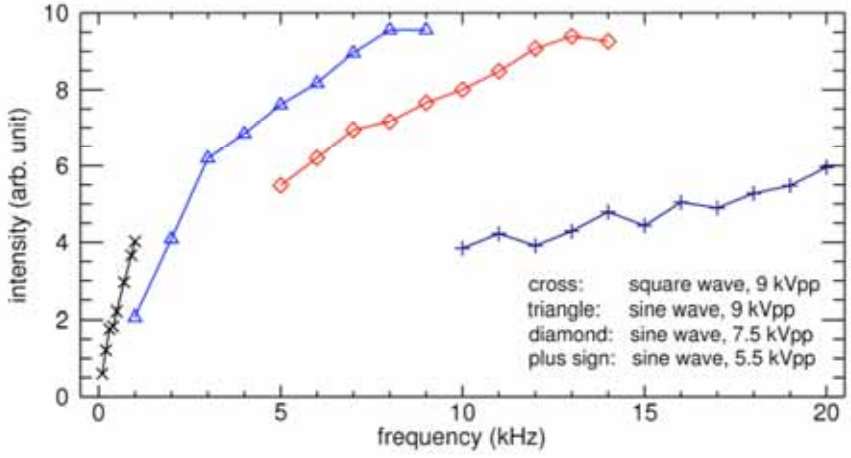
Bactericidal effect

PCB:	0.5 mm, 5 mm
Bacteria:	E_coli
Control:	10^5 dilution
Treating time:	30 second
Repeating:	3 times
Error bar:	standard error





20100303/0.5mm_5mm_PCB_sterilization.jpg



20100409_PCB/images_of_discharges/light_intensity_B.pdf

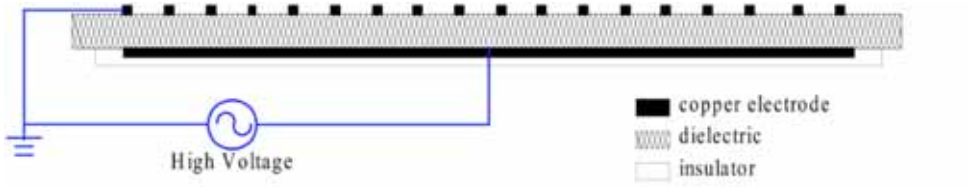
The bactericidal effect increases with the plasma intensity.

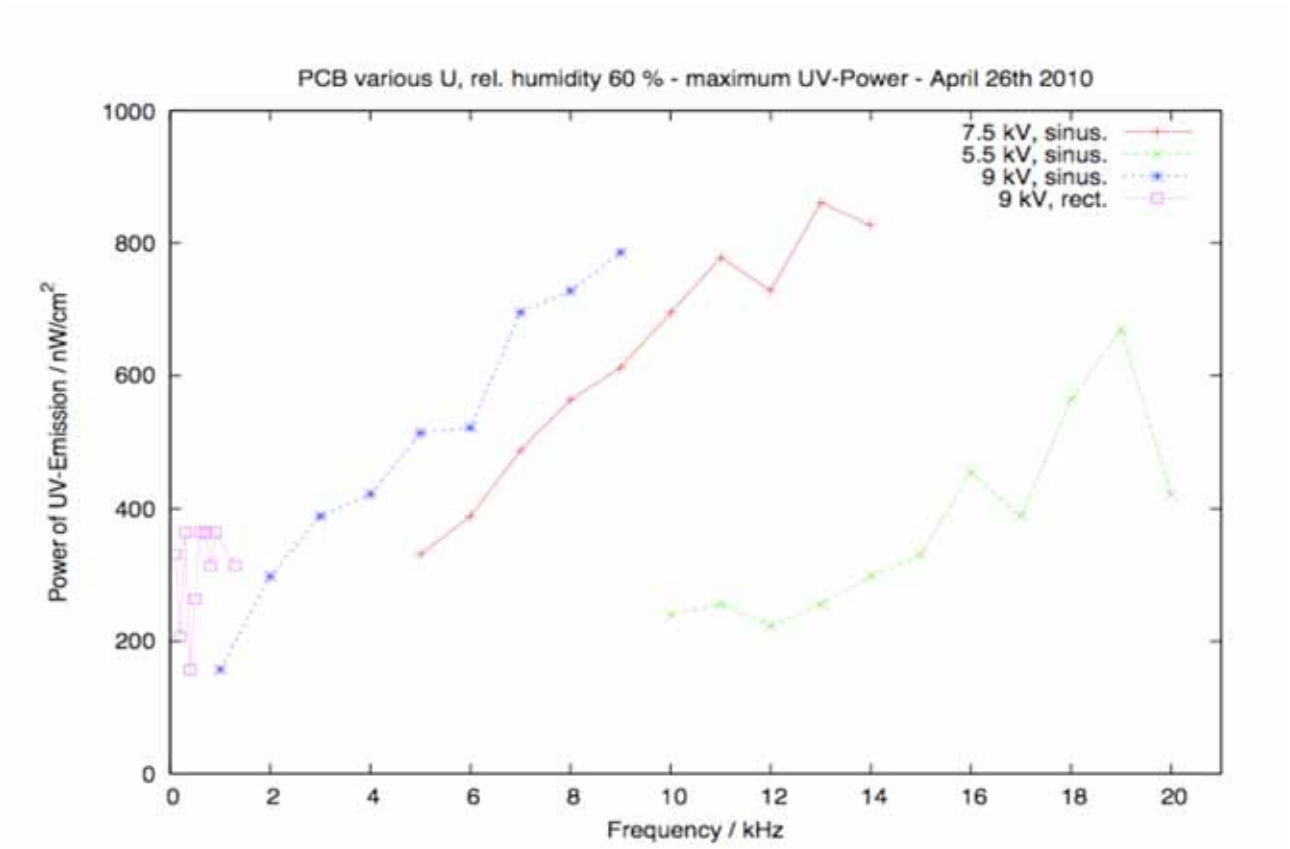
99.999% of the E_coli can be easily killed by PCB within 30 seconds treatment.

Experiments with PCB (4)

UV power measurement*

PCB:	0.5 mm, 5 mm
Distance:	~ 3 cm
WHO:	30 µW/cm





*Done by Lukas Milles, April 26, 2010 with Voltcraft 320 K/J thermometer

Experiments with PCB (5)

Spectral of current flow (micro-discharges)

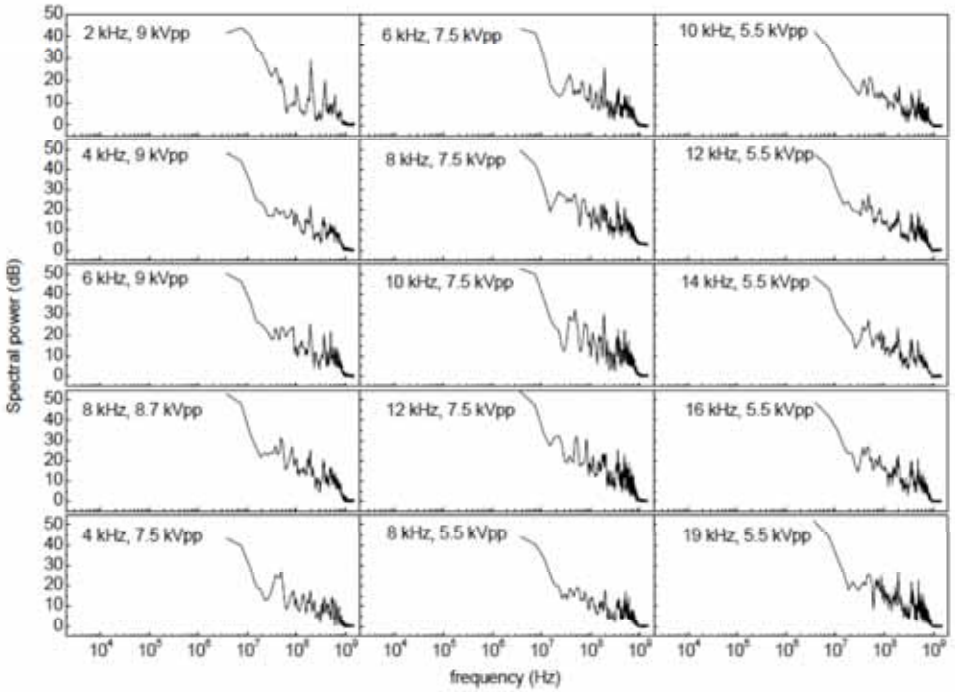
Current flow was sampled by a 10 Ohm pure resistor

- Spectrum analyzer

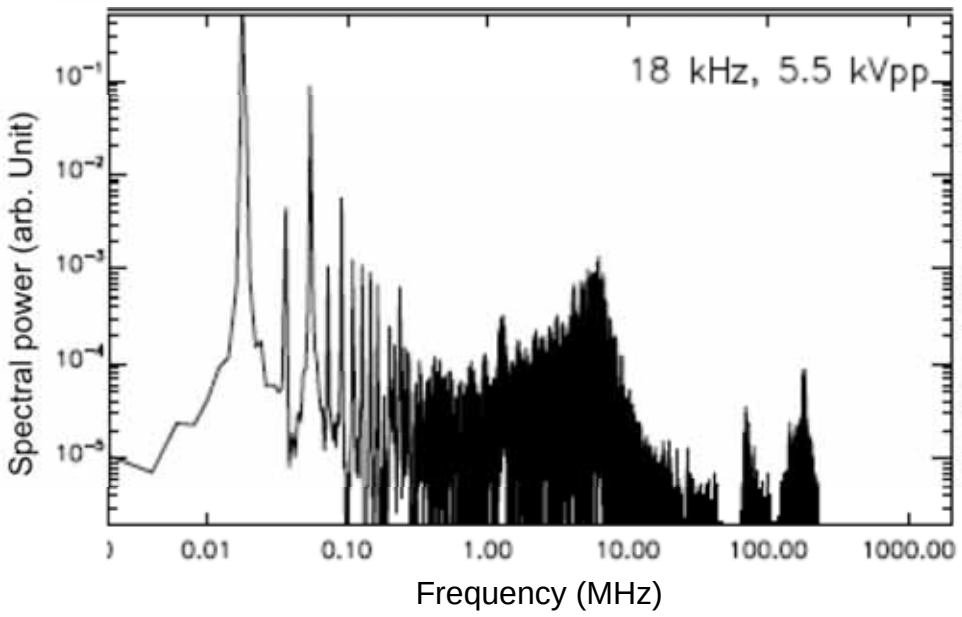
Agilent ESA E44118 (9 kHz – 1.5 GHz, 400 points/every 3.75 MHz)

- High-frequency oscilloscope (20 GS/s for data recording) + FFT

Lecroy WavePro 725Zi (2.5 GHz, 40 GS/s) + Lecroy ZS1500 (1.5 GHz)



Spectral Power from spectrum analyzer



Spectral Power from FFT of current flow

20100318/SpectrumAnalyzer_pcb_05mm_5mm/SpectraPower_from_SpectrumAnalyzer.pdf

20100312//HF_PowerMeasurement/SpectralPower_all.PS..pdf

Summary with PCB

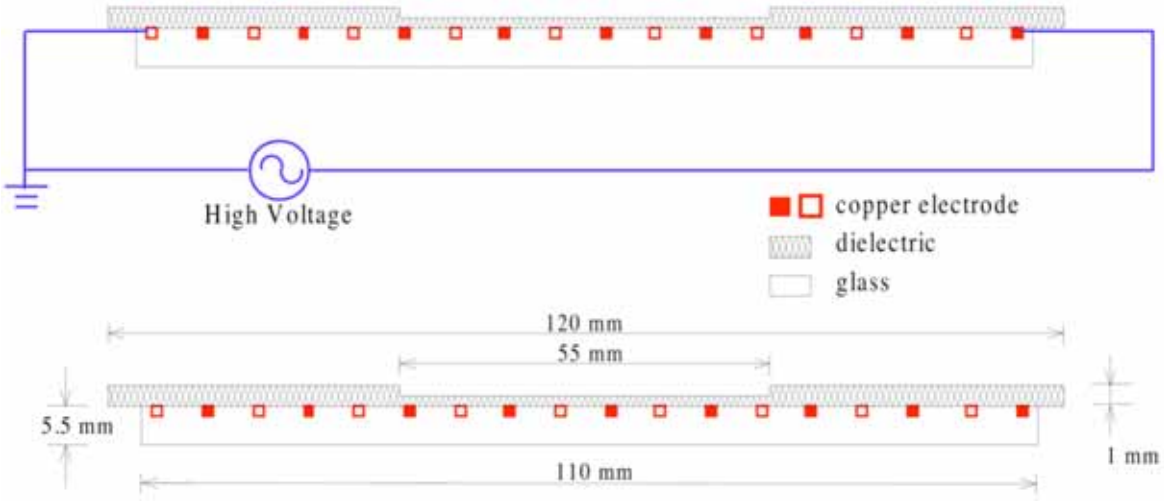
- ✓ PCB discharge 4.5 - 9 kVpp, 0.1-20 kHz (square, sine)
- ✓ Plasma intensity increases with frequency and voltage.
- ✓ Bactericidal effect increases with plasma intensity.

  10^{-5}-10^{-7} survival rate, 30s, growth rate of bacteria decreased

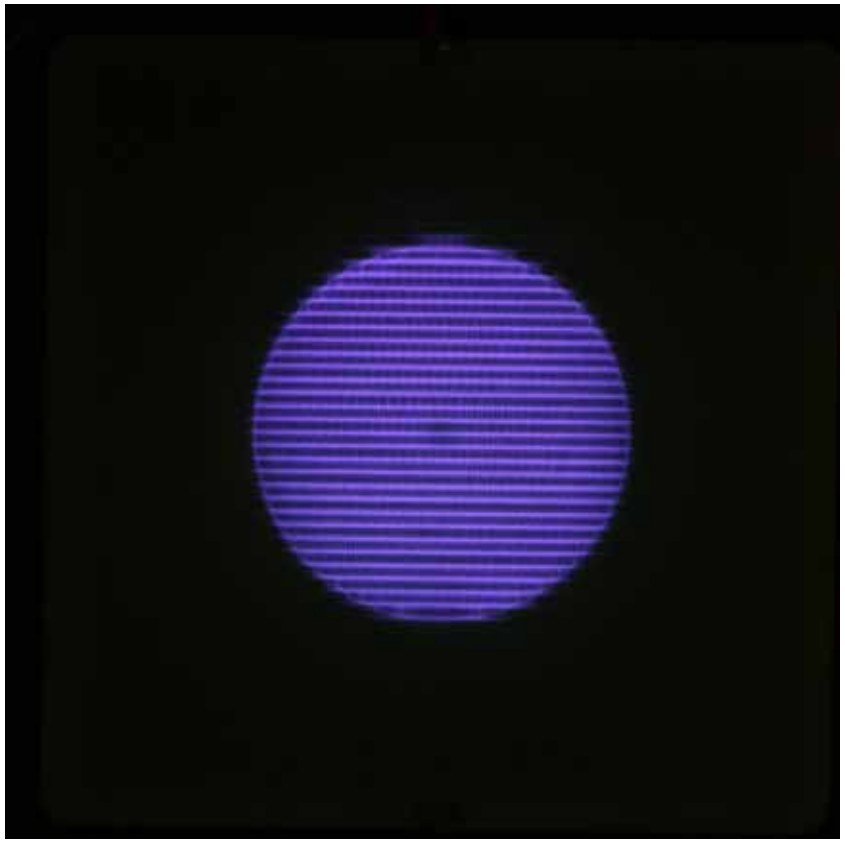
- ✓ Sound of the discharge depends on the applied frequency and electrode design.
- ✓ The sterilization of PCB can be optimized by adjusting the thickness and/or the distance between finger shaped electrode.
- ✓ The naked electrode can be contaminated by the bacteria during the treatment.

Experiments with SSS (1)

Overview of the electrode



The plasma is ignited on the dielectric surface. Compared to a glass surface, the plasma is much stable and homogeneous. In addition, for a bacterial experiment, surface wettability is very Important because we need to smear the PBS suspension on the surface. For a glass surface, it is not possible to smear the PBS suspension on it, however, the dielectric surface is perfect wetting.

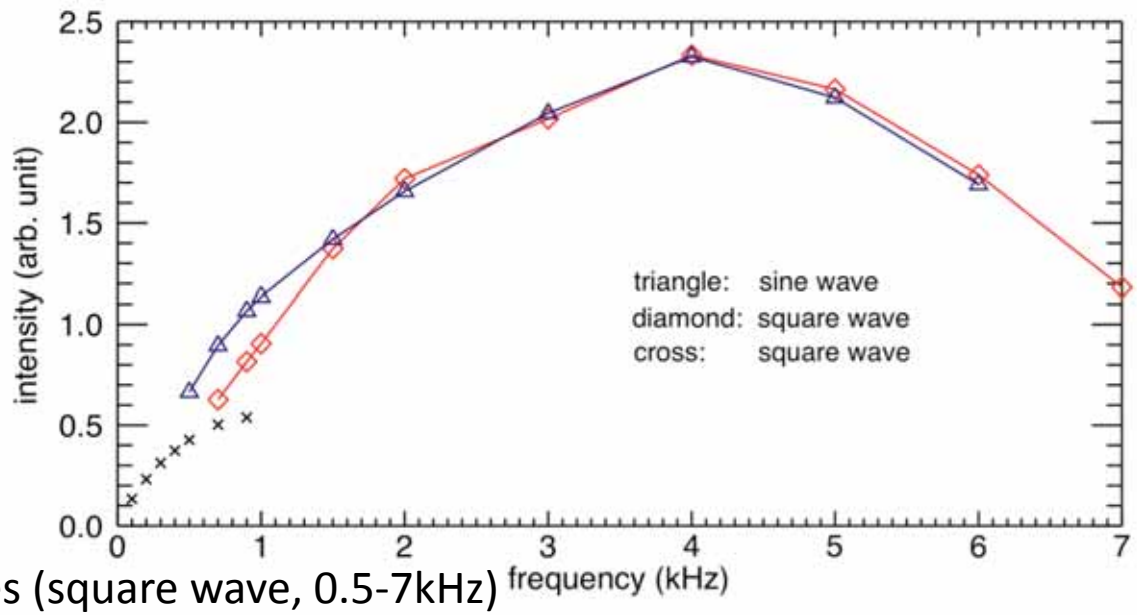


My special acknowledgement goes to Bern Steffes.

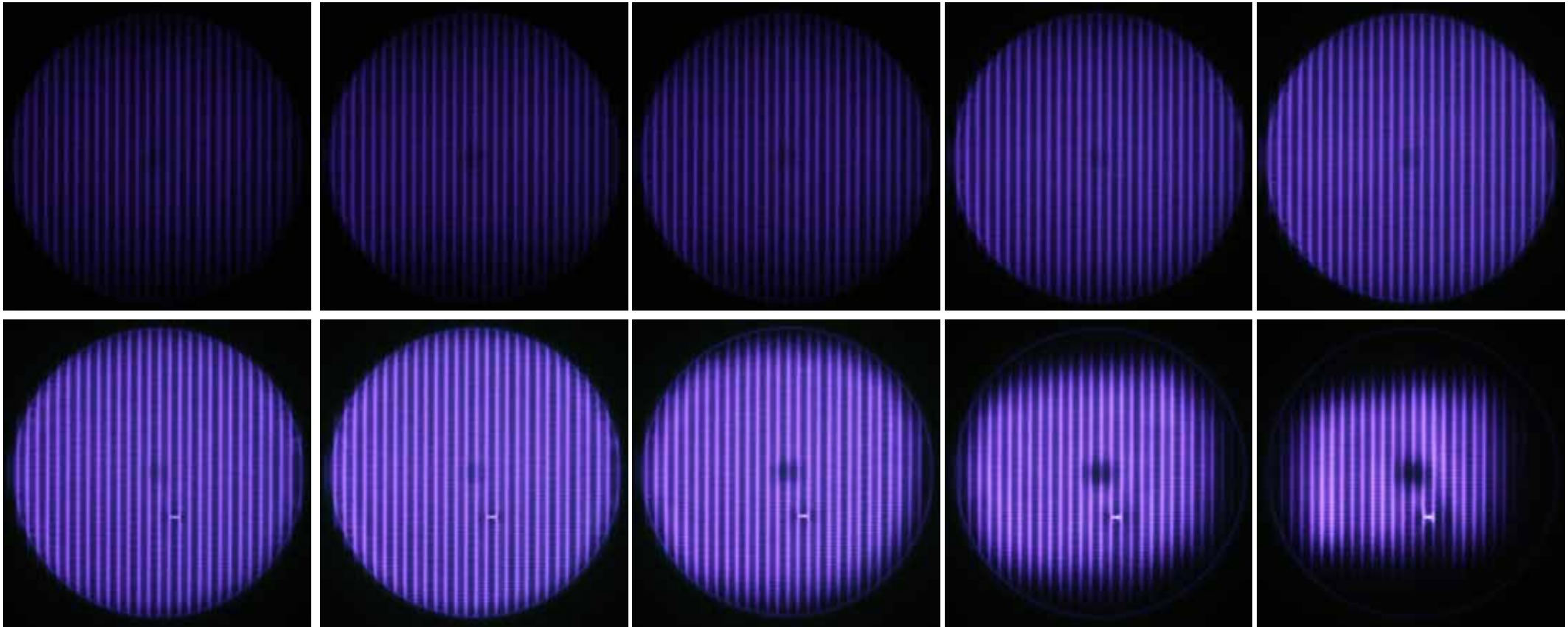
Experiments with SSS (2)

Plasma intensity

Voltage: 22 kVpp, square or sine wave
Camera: CANON EOS 450D
+EF-S 60 mm 1:2.8
F2.8, ISO800, 1”
Background subtracted



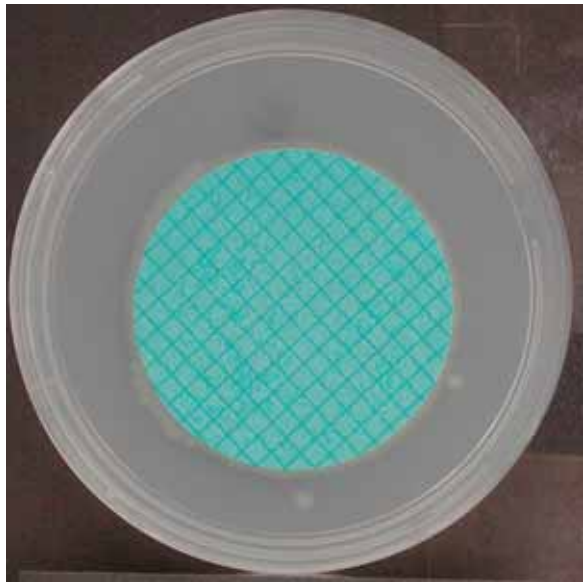
Images of discharge with different frequencies (square wave, 0.5-7kHz)



Experiments with SSS (3)

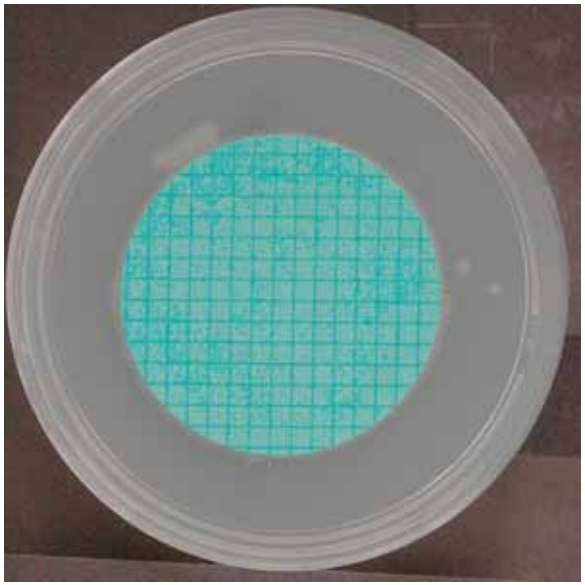
Experiments with membrane filter

100 µl suspension smearing on the circular region until it is dry (~10 minutes)
Wetting membrane filter (by PBS) placed on the surface
Put the sampling membrane filter on the agar surface
Incubate for 16 hours



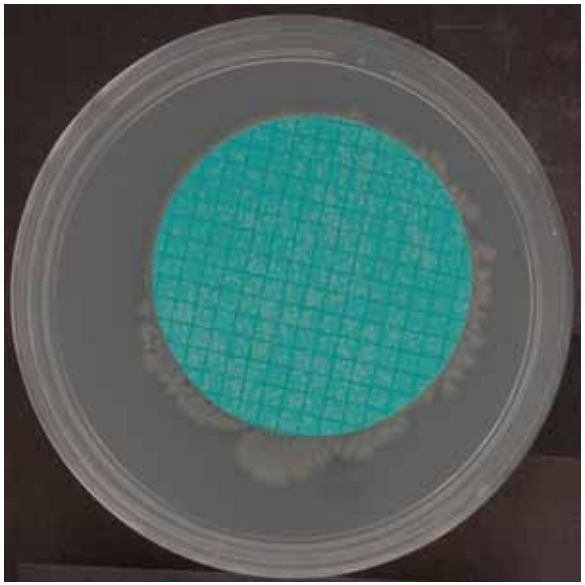
20100426/IMG_0997_c.JPG

10^0 suspension



20100426/IMG_0998_c.JPG

10^1 dilution



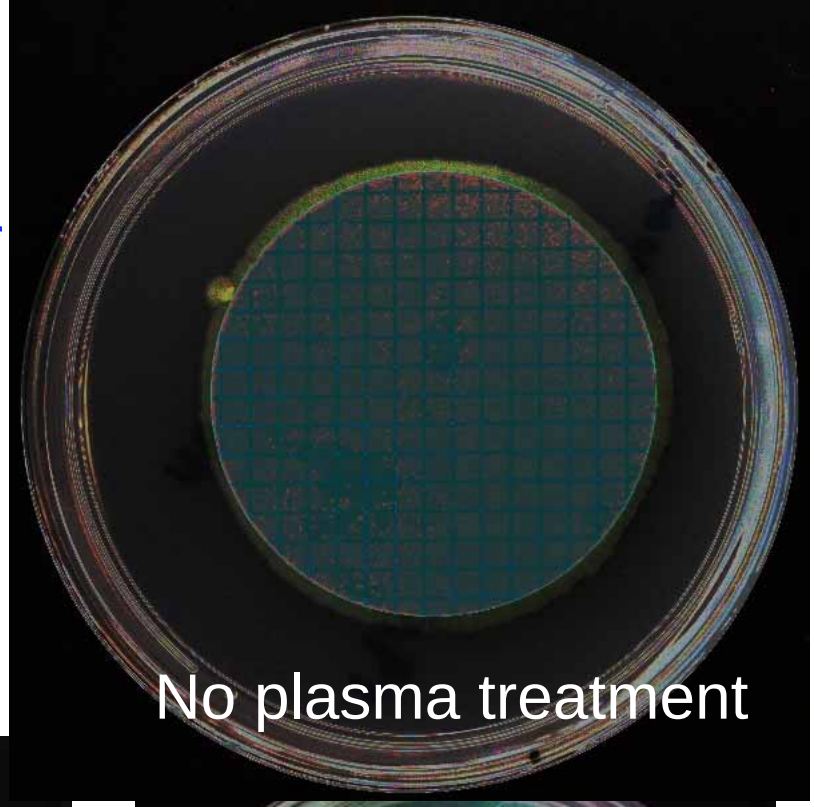
20100426/IMG_0999_c.JPG

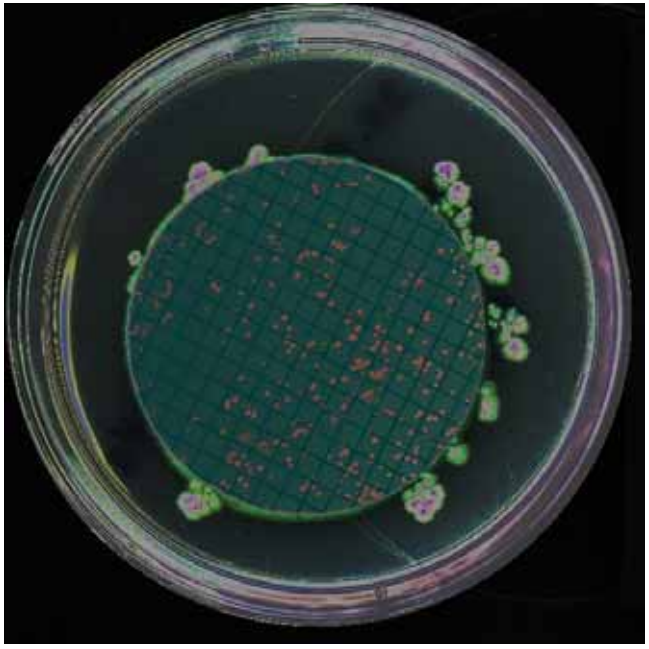
10^2 dilution

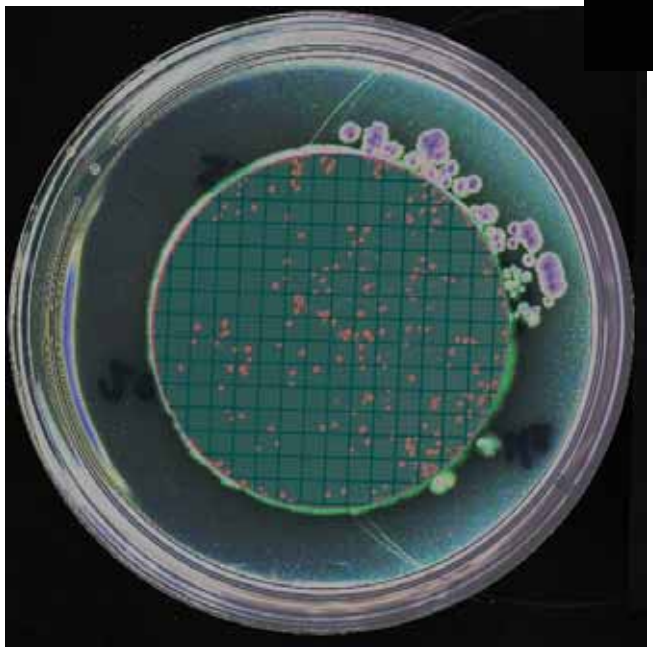
Experiments with SSS (4)

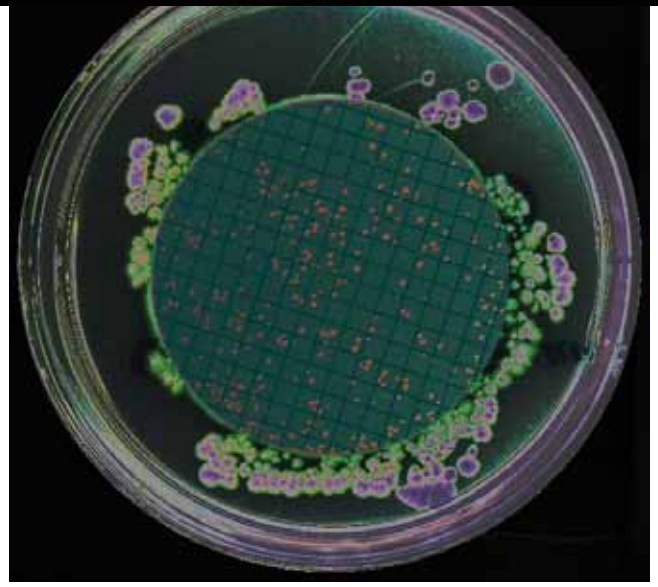
Bacterial experiments with membrane filter

E_coli
30 second
16 hours for incubation
1 kHz, square, 22 kVpp









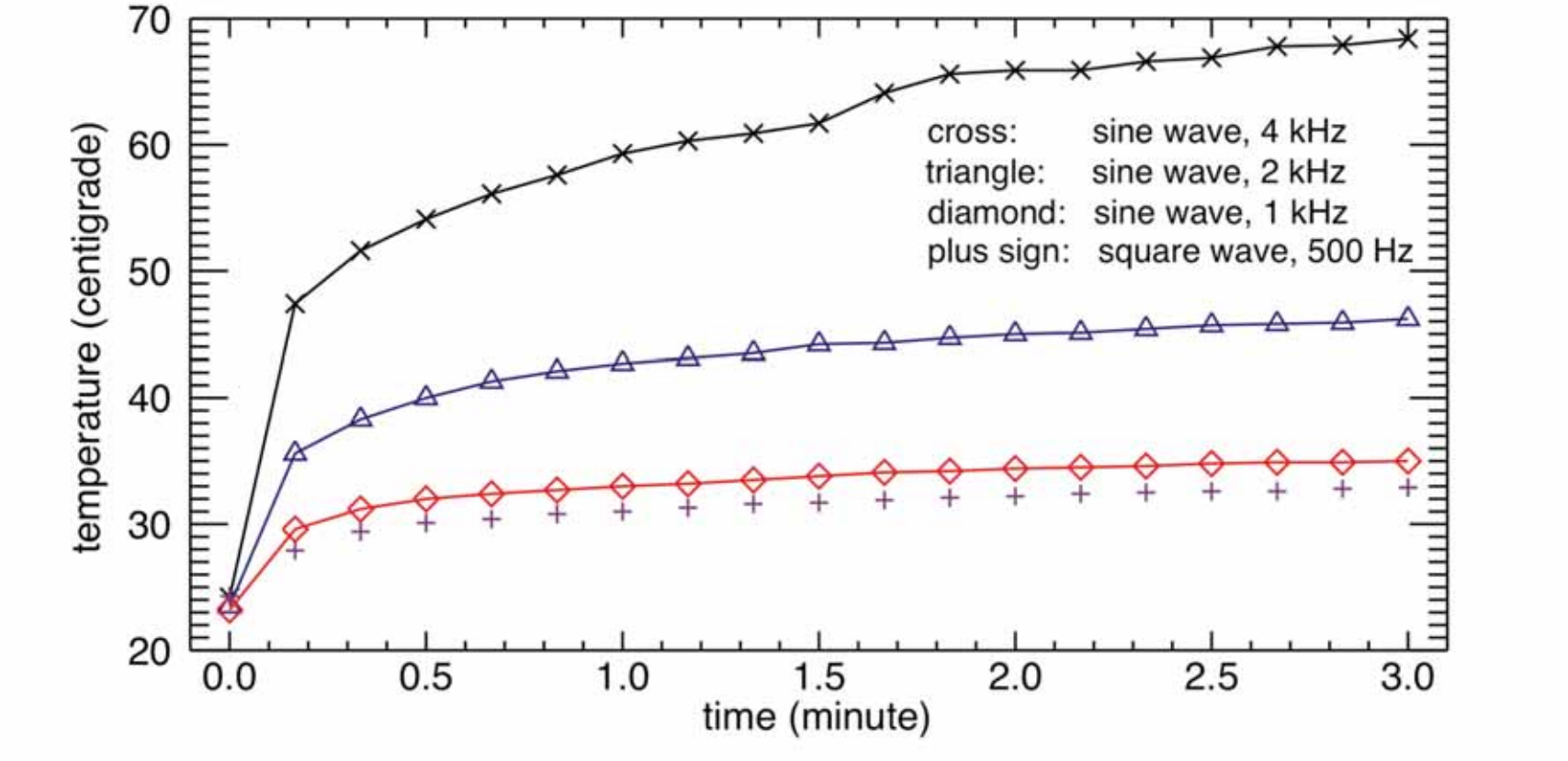
After 30s plasma ignition, 1 kHz, square, 22 kVpp

20100419/img_0794_c1.jpg, /20100420/img_0808_c1.jpg, img_0809_c1.jpg, img_0910_c1.jpg

Experiments with SSS (5)

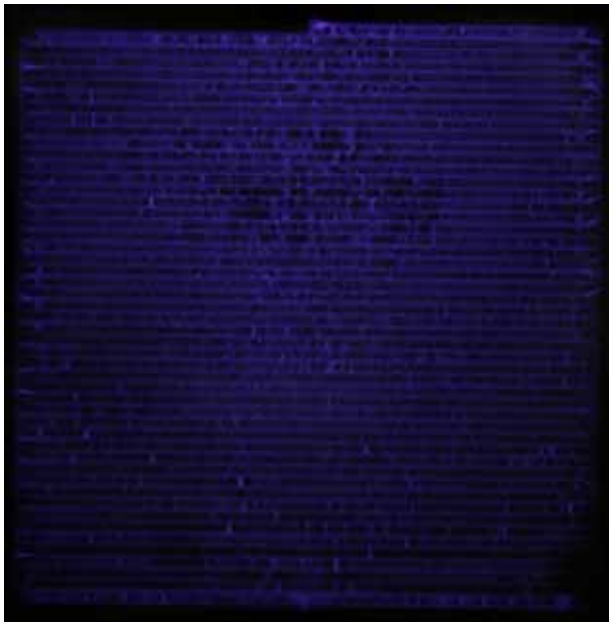
Surface temperature measurement:

thermometer: Voltcraft 320 K/J

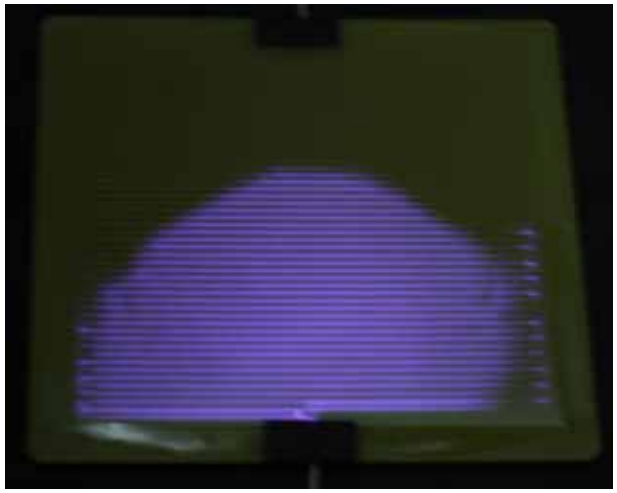


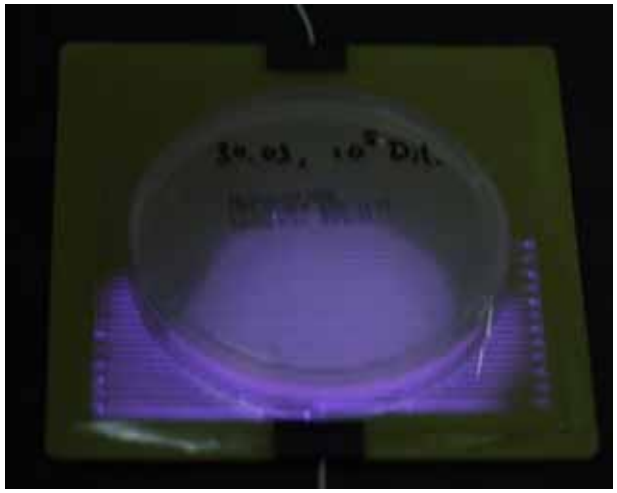
Experiments with SSS (6)

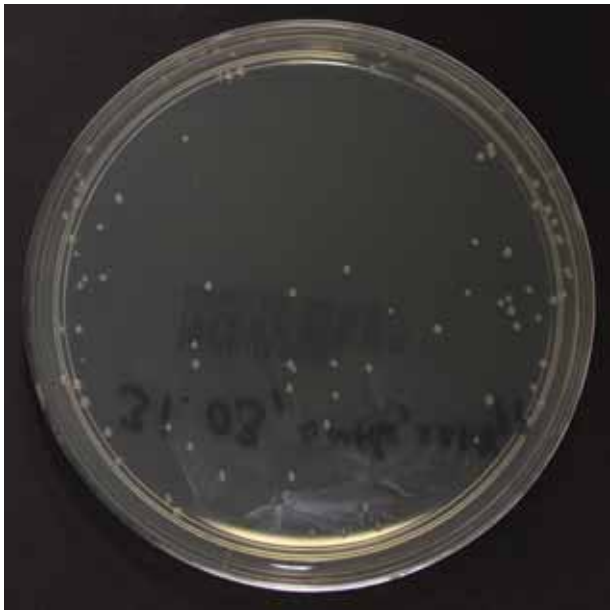
SSS with glass surface (0.3 mm)



E_coli
April 01, 2010
30 seconds treatment
4 kHz, 22 kVpp







High frequency (>1 kHz): plasma is strong but does not fill all the surface
Low frequency (< 0.5 kHz): plasma is weak and homogeneous.

Summary for SSS

- The discharge of SSS with different surfaces (glass, plastic, Epoxy) is tested.
- Depending on the thickness of the surface, the breakdown voltage varies from 15 kVpp to 24 kVpp in a frequency range between 0.1 kHz and 7 kHz.
- A slight change of the circuit impedance affect the surface plasma significantly. (surface humidity, contamination, construction)
- The bactericidal effect of the SSS is quite strong. It is convincing for a surface decontamination.

  - The SSS discharge can be optimized.
    Material, surface thickness, electrode arrangement
  - Characteristic of the SSS.
    UV emission, power consumption, Ozone rate
  - More bacterial experiments are necessary.

Thank you
for your kind attention.