Krankenhaus München Schwabing
Akademisches Lehrkrankenhaus
Max-Planck-Institut für extraterrestrische Physik
AD-TEC Plasma Technology co.,ltd.

MICROWAVE PLASMA TORCH FOR BACTERIAL STERILIZATION

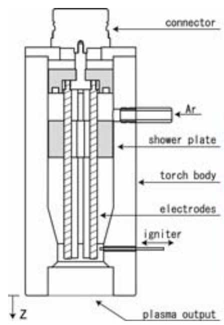
Tetsuji Shimizu [1], Bernd Steffes [1], René Pompl [1], Ferdinand Jamitzky [1], Wolfram Bunk [1], Katrin Ramrath [2], Birgit Peters [2], Wilhelm Stolz [2], Hans-Ulrich Schmidt [3], Takuya Urayama [4], Kazunari Fujioka [4], Raju Ramasamy [4], Shuitsu Fujii [4], Gregor Eugen Morfill [1]

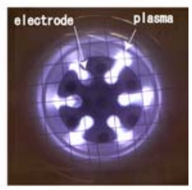
[1]Max-Planck Institute for Extraterrestrial Physics, Giessenbachstraße, D-85748 Garching, Germany.
[2]Clinic of Dermatology, Allergology and Environmental Medicine, Hospital Munich Schwabing, D-80804 Munich, Germany.
[3]Institute for Medical Microbiology, Hospital Munich Schwabing, D-80804 Munich, Germany.
[4]ADTEC Plasma Technology Co. Ltd., Fukuyama 721-0942, Japan.

Abstract

An atmospheric low-gas temperature plasma torch using microwave (2.45 GHz) has been developed and applied to sterilization of *Escherichia coli* and other bacteria. The plasma torch consists of an Al cylinder and 6 stainless steel electrodes. Ar gas of 4 slm is applied from the base of the torch and microwave power of 95 W is applied to the electrodes. Plasma discharges are produced between the tip of each electrode and the inner surface of the cylinder. At a position 17 mm away from the torch, the gas temperature is 28 degrees, sufficiently cool so that the plasma doesn't harm living organisms. Floating potential of a grid electrode placed at the position is 0.3 V. This indicates that charged particles (electrons, positive and negative ions) exist.
When an *E.coli* culture (on an agar plate) is placed at this position for 2 minutes, the bacteria are almost completely sterilized in a 40 mm diameter circle.

Experimental Setup

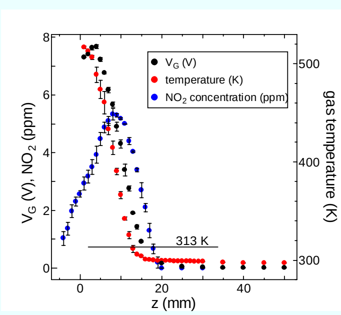




In the figure, a detailed view of the plasma torch is shown. The plasma torch consists of 6 stainless steel electrodes placed inside an aluminum cylinder of 135 mm in length. The centers of the 6 electrodes, whose surfaces are serrated, are distributed equally at a distance of 6 mm from the inner surface of the cylinder. The diameter of the electrodes and the distance between the electrodes and the surface of the cylinder are 4 mm. The diameter of the opening for plasma output is 35 mm. The tips of the electrodes are at 20 mm from the opening of the torch. Usually the torch is placed with the principal axis perpendicular to the ground.

In this study, only Ar gas (purity 99.998%) is used in order to minimize the production of toxic gases. 4 slm is applied from the base of the electrodes through a Teflon shower plate which regulates gas flow around the electrodes. Microwave power of 2.45 GHz is applied to the electrodes through coaxial cables via a 2 stub tuner. The input power is 95 W. 6 small plasmas are produced between each of the electrode's tips and the inner surface of the cylinder as shown in the figure.

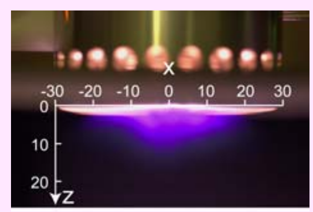
Experimental Result



We have investigated the axial profile of the gas temperature, NO_2 density and the floating potential of the grid. The room temperature was 25 degrees. The figure shows the *z*-profiles (*z*: distance from the torch) of the measured temperature and NO_2 density at the torch axis and the floating potential of the grid electrode. In the vicinity of the torch, the gas temperature is relatively high. However, just after the opening of the toch (z = 2 mm) until z = 13 mm, the gas temperature has decreased drastically. As z increases further, the temperature decreases more gradually. At z = 13 mm, the temperature is 40 degrees, low enough so that the plasma does not harm human skin.

From the measurement of the NO_2 density profile, at z = 8 mm there is a maximum (5.4 ppm). This indicates that the plasma flow from the torch faces the ambient air around the position and the gas is cooled drastically.

Inside the plasma torch the (bright) plasma production region (between the electrodes and the cylinder) is visible (figure above). However, the plasma flow exiting the torch is not visible. In order to determine how the plasma is distributed below the torch, the floating potential of the grid is measured. The potential also decreases as z increases, almost in the same way as the gas temperature.



To increase an exposure time of a camera (30 s), the plasma light can be detected below the torch. The main light emission source is supposed to be the Ar ions and excited atoms in the air.

Bacterial experiment

We observed the plasma exposure effect on bacteria. For example, when an *E.coli* culture is placed 17 mm away from the output of the torch for 2 minutes, a sterilizing effect on the bacteria can be observed as shown in the figure above. In a circle of 40 mm diameter, a high level of sterilization has been achieved. The boundary of the sterilized area is a little fuzzy and the sterilized area is slightly larger than the opening of the torch. We measured the surface temperature of the agar plate during the treatment. In 2 minutes, the temperature increased 5.7 degrees and reached 28 degrees. Sterilization can be due to a number of effects, which are all present –charging in the plasma, radicals which are produced in the air and UV light. We are still investigating which factor is the most important for bacterial sterilization in our system.

Summary

1. A microwave plasma torch has been developed for the purpose of "in vivo" bacterial sterilization.
2. Using 4 slm of Ar gas flow and 95 W of microwave power at atmospheric pressure, we obtain a plasma with suitable characteristics for medical applications and treatment.
3. Tests with *E.coli* cultures (and others) have shown that bacterial sterilization occurs.

We consider that this technique can be applied to the medical field, such as wound healing.

Acknowledgement

The authors would like to thank Dr. T. Sato at Tohoku University and Dr. K. Takahashi at Kyoto University for fruitful discussions and useful suggestions.

Appendix -MicroPlaSter-

We have started clinical a study with a view to applying this new technique to the therapy of chronic foot and leg ulcers as well as other skin diseases at Hospital Munich Schwabing. All the functional units, including the torch, a power supply, etc., are incorporated in a trolley. The torch is placed on a counterweighted arm in order to use it flexibly. Moreover the torch can be used vertically and at angles.