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► **To cite this version:**

Clémence Tyl, Antoine Belinger, Simon Dap, Nicolas Naudé. Electrical diagnostics for Dielectric Barrier Discharges: from integrated measurements to spatially resolved measurements. Benefits for plasma processes at atmospheric pressure?. Plasma Processing and Technology International Conference, Apr 2021, Paris (virtuel), France. hal-03324353

HAL Id: hal-03324353

<https://hal.science/hal-03324353>

Submitted on 23 Aug 2021

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Electrical diagnostics for Dielectric Barrier Discharges: from integrated measurements to spatially resolved measurements. Benefits for plasma processes at atmospheric pressure?

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Abstract:

Dielectric Barrier Discharges (DBDs) can be used in many processes as thin-film coating, sterilization, treatment of gases, aerodynamic flow control, and lighting devices [1]. Depending on the gas, electrical operation parameters and discharge geometry, the plasma operates in the classical filamentary mode or in a homogeneous regime [2]. Homogeneous regimes are interesting for surface modification applications as it allows to uniformly transfer the energy to the surface. Consequently, it is easier to get homogeneous and dense layer deposition with a homogeneous discharge than with a filamentary plasma [3].

Electrical measurements are a more convenient than optical measurements to characterize the discharge regime and to study the discharge behavior. However, and because of the dielectric presence, it is not possible to directly measure the electrical parameters of the discharge. Usually, the electrical parameters (gas voltage, discharge current, charge transferred within the discharge, discharge power, ...) are calculated from the measured quantities (*e.g.* total current or charge) under usage of an electrical equivalent circuit [4-5]. Among other parameters, the electrical equivalent circuit depends on the DBD geometry. The key parameter for this approach is the determination of the discharge area, which is usually considered to be equal to the electrode surface as long as the discharge is homogeneous. However, even if the plasma seems to cover the electrodes uniformly, its electrical properties (current density, breakdown voltage, duration of discharge, ...) are not exactly the same at any time and at any point of the surface. The spatial variation can be due to the gas flow circulation as observed in a homogeneous discharge ignited by Townsend breakdown in nitrogen [6].

For example, in surface treatments applications, a gas flow is usually injected from one side of the planar DBD arrangement. The residence time of the gas increases as a function of the position from the gas inlet to the gas outlet. Thus, the species densities are not the same along the gas flow because of the kinetic processes and chemical reactions in the discharge [6]. The discharge

current and the gas voltage are not uniform along the spatial DBD dimensions. Therefore, determination of discharge current and gas voltage from macroscopic parameters of the DBD is often inaccurate. In the best case, the calculated values are spatially averaged but do not allow the interpretation of localized plasma treatment.

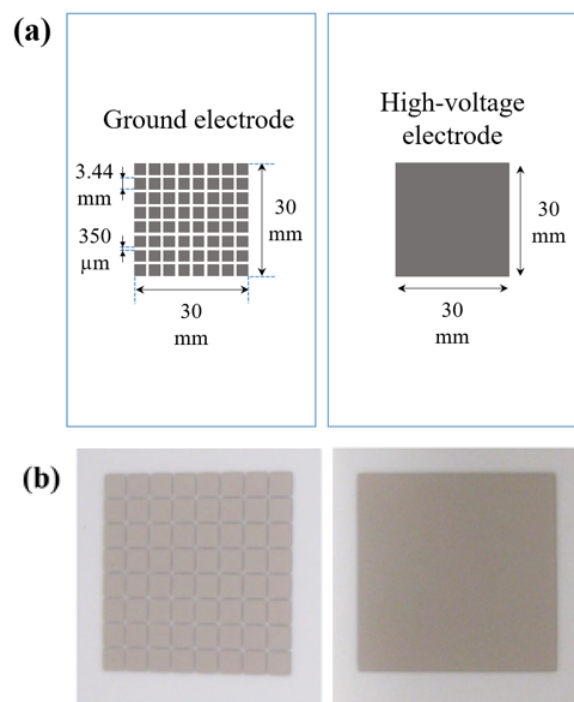


Figure 1: Diagram (a) and photograph (b) of the segmented electrode and the high-voltage electrode.

The spatial inhomogeneity of a diffuse DBD in nitrogen is particularly highlighted with the addition of oxidizing gases or precursors [6]. For example, in the case of a Townsend discharge in N_2 with 30 ppm of NO the discharge is visually different from the gas inlet to the gas outlet; the color changes from violet to green along the gas flow [6]. Even if the discharge is a diffuse one (*i.e.* without filaments appearing on the electrical and optical measurements), its behavior changes along the gas flow direction and, therefore, the electrical characteristics are also varying in the same way.

In order to have a more accurate characterization of the discharge behavior, a measurement of the local current density is required. To get a 2D mapping of the discharge electrical parameters, the ground electrode is prepared as a segmented electrode with 64 equally spaced square segments. The high voltage electrode still remained full. This electrode is a $3 \times 3 \text{ cm}^2$ square, while each square of the segmented electrode has a 3.44 mm side length, a distance of $350 \text{ }\mu\text{m}$ spaced each segments (Figure 1). A prototype, using a ground electrode divided into 64 identical squares and a data acquisition system is developed. This system can be used to study the spatial electrical behavior of a DBD (Figure 1). This set-up allows to correlate the discharge current and light emissions from different species in time and space.

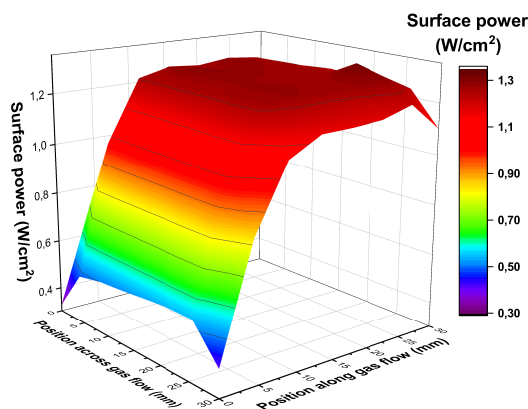


Figure 2: 3D mapping of surface power density from measurements with the segmented electrode in $\text{N}_2 + 30 \text{ ppm NO}$ (gap=2 mm, 2 kHz, 17.12 kVpp, 4 sLm).

It has been successfully validated on planar DBD by the comparison with short exposure time photos taken by a camera from above the discharge cell. It has been used to study the diffuse discharge (APTD) and shows the effect of a gas flow on the local electrical behavior of the discharge. In the case of diffuse DBDs with sinusoidal voltages at frequencies from 1 to 20 kHz, the temporal and spatial resolutions are high enough to characterize the behavior of the discharge with sufficient spatial information.

This electrode arrangement and measuring systems allows a 2D mapping of the discharge electrical parameters (discharge current, power dissipated, gas voltage, etc.) of Townsend but also for Glow discharges, hybrid or patterned regimes. Concerning the plasma processes for surface coatings, this system can be used to monitor the evolution of the local discharge power which

defines the local deposition rate. If we use this segmented electrode as the high voltage electrode with adequate high-voltage switches and power supply, we could reconfigure the electrode (Figure 3) and the power transfer to the discharge. Then this system could be used to realized patterns (Figure 4).

All of this opens up new directions which will be discussed during the presentation.

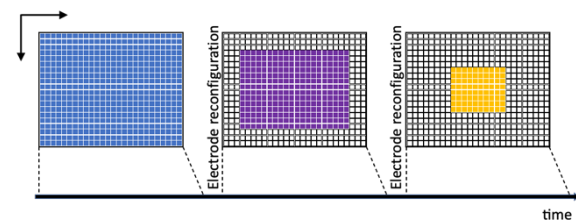


Figure 3: Illustration of the reconfigurable electrode concept.



Figure 4: Illustration of a pattern coating which could be achieved using the configuration of the Figure 3.

Keywords: DBD, APTD, Townsend discharge, electrical measurement, local current, spatially resolved, segmented electrode.

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