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► **To cite this version:**

Simon Dap, Clémence Tyl, Xi Lin, Hans Höft, Manfred Kettlitz, et al.. PRE-IONIZATION IN ATMOSPHERIC PRESSURE TOWNSEND DISCHARGES (APTD): SURFACE VS VOLUME MECHANISMS. 17th International Symposium on High Pressure Low Temperature Plasma Chemistry (HAKONE XVII ), Aug 2022, Kerkrade, Netherlands. <hal-03798398>

**HAL Id: hal-03798398**

**<https://hal.science/hal-03798398v1>**

Submitted on 5 Oct 2022

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## **PRE-IONIZATION IN ATMOSPHERIC PRESSURE TOWNSEND DISCHARGES (APTD): SURFACE VS VOLUME MECHANISMS**

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To obtain a Townsend discharge in N<sub>2</sub>-O<sub>2</sub> mixtures, a source of seed electrons between two discharges is necessary to enable uniform breakdown at low electric field strengths. This is referred to as the memory effect, which slows down the ionization process during the gas breakdown and avoids streamer formation leading to filamentary regime. Seed electrons between two discharges can come from the dielectric surfaces but also from the gas bulk.

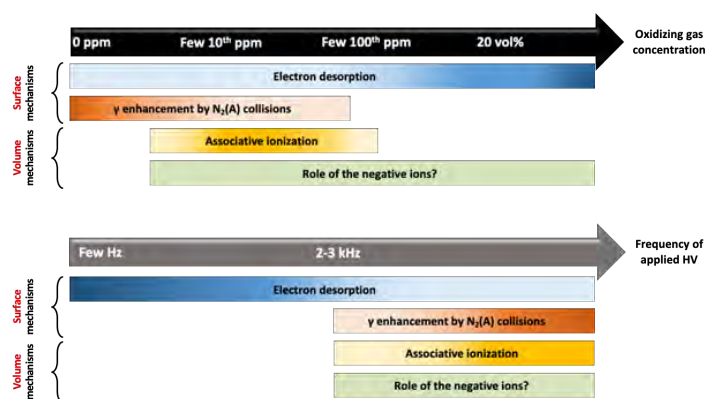
Generally, the dielectric covering the anode is charged with electrons during the discharge. These electrons could be released in the gas gap when the anode becomes the cathode during the subsequent half-period. The mechanisms related to the surface charges can be separated into two categories. First, the secondary electron emission leads to the release of trapped electrons from the surfaces. It can be enhanced by collisions of metastable species N<sub>2</sub>(A<sup>3</sup> Σ<sub>u</sub><sup>+</sup>) with the dielectric surface [1]. These particles are not charged and remain near the anode where they are created during the discharge. According to the literature, the N<sub>2</sub>(A<sup>3</sup> Σ<sub>u</sub><sup>+</sup>) lifetime is a few tenths of μs for low concentrations of oxidizing species [2]. Depending on the frequency, it may be shorter than the time between two discharges (roughly corresponding to 1/4th of the period). Thus, their density can remain high enough between two discharges to have a significant impact on the production of seed electrons for frequencies down to 2.5 kHz. However, the enhancement of the secondary electron emission by the N<sub>2</sub>(A<sup>3</sup> Σ<sub>u</sub><sup>+</sup>) collisions on the dielectrics could be negligible for lower frequencies. Moreover, the addition of oxidizing gas to nitrogen increases the quenching of the metastable species and reduces their contribution to the memory effect.

Second, the electrons trapped on the dielectric surfaces can also be released spontaneously into the gas gap [3]. This mechanism allows releasing seed electrons in the gas under low electric field, independently of the gas composition and the applied voltage frequency. At very low frequencies, when the species in the gas bulk are completely renewed between two subsequent discharges this mechanism prevails in the memory effect. It can also play a significant role in air, as the quenching rate of the metastable species of nitrogen such as N<sub>2</sub>(A<sup>3</sup> Σ<sub>u</sub><sup>+</sup>) is high. It depends of the nature of the dielectric surfaces [4] and in particular to their capacity to retain electrons [5-6]. Their role seems only predominant at very low frequencies, where no other memory effect mechanisms come into play.

The other type of mechanism responsible for the memory effect concerns the production of seed electrons in the gas bulk. Indeed, different chemical reactions occurring in the gas bulk can produce electrons. These mechanisms have been highlighted by the addition of small concentrations of oxidizing gas in nitrogen [7-8]. The creation of seed electrons by the associative ionization of O(<sup>3</sup>P) and N(<sup>2</sup>P) is currently the most likely assumption that can explain the origin of the memory effect in presence of an oxidizing gas [8-9]. However, the

positive ions in the gas created by the associative ionization reactions (for example  $\text{NO}^+$  ions produced by the reaction between  $\text{O}(^3\text{P})$  and  $\text{N}(^2\text{P})$ ) can also contribute to the memory effect, as it was suggested by F. Massines [1] and Nemschokmichal *et al.* [10]. When the gas gap voltage increases just before the breakdown voltage, these positive ions increase the secondary electron emission at the cathode and then the production of seed electrons. This hypothesis requires further investigations to be confirmed.

The different mechanisms responsible for the memory effect in APTDs and their quantification depending on the experimental conditions, are summed up in Figure 1. In Figure 1(a), the different memory effect mechanisms are compared as a function of the oxidizing gas concentration, for a fixed power supply frequency of a few kHz. In Figure 1(b), they are compared as a function of the power supply frequency, for gas mixture of nitrogen with a small concentration of oxidizing gas (few 10<sup>th</sup> of ppm). It shows that the dominant physical and chemical mechanisms involved in the memory effect are strongly related to the experimental conditions (gas composition, dielectric material, operating HV, ...). The seed electrons necessary to obtain an APTD are created through a combination of different mechanisms on the dielectric surfaces and in the gas gap, which are named in Figure 1. The understanding of the predominant mechanisms depending on the experimental conditions allows of better control of discharge stability, and the power dissipated in the discharge, for further plasma processes development.



**Fig. 1:** Schematic representation of the dominant memory effect mechanisms as a function of: (a) the oxidizing gas concentration at a fixed frequency of a few kHz, and (b) the power supply frequency in nitrogen with a small concentration of oxidizing gas.

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