# Observation of secondary ionization by photon feedback in a Townsend discharge

E. Basurto[1], L.N. Serkovic[2], J. de Urquijo[2]

[1]*Departamento de Ciencias Básicas, Universidad Autónoma Metropolitana-Azcapotzalco, Av. San Pablo 180, 02200, México D.F., México.*
[2]*Instituto de Ciencias Físicas, Universidad Nacional Autónoma de México, PO Box 48-3, 62251, Cuernavaca, Mor., México*

The secondary ionization process due to the decay of $N_2$ metastables that emit UV light reaching the cathode (also known as photon feedback) has been observed under pre-breakdown conditions in a pulsed Townsend discharge from the electron avalanche for E/N=180-260 Td. A reaction scheme has been proposed and simulations have been compared with the measurements. Good agreement between simulation and measurement has been found. Reaction rates for metastable $N_2$* formation and decay have been derived. Our findings indicate that the photon feedback processes plays an important role in the $N_2$ discharge with an aluminium cathode.

## 1. Introduction

Most gas discharge processes are accompanied by light emission due, for instance, to collisions of electrons forming metastables, followed by light emission due to their decay over a fairly wide range wavelengths. In particular, the ultraviolet light (UV) emission is of importance when the discharge exceeds breakdown, such as in coronas or glows. Notwithstanding this fact, little has been done since the early experiments summarized by Raether [1] dealing with photon feedback effects observed with the pulsed Townsend experiment under pre-breakdown conditions. It is clear from this work that a full analytical solution to this phenomenon was practically impossible.

## 2. Details of the measurement

A pulsed Townsend apparatus was used to measure the total current of electronic avalanches produced by the release of photoelectrons from an aluminium cathode, with a pulsed (3 ns) Nd-YAG laser emitting at 266 nm. These photoelectrons and those produced by the decay of metastables emitting UV light that strikes the cathode, produce peculiar signals such as those shown in Figs. 1 and 2. The oscillatory character of the signals is due to the UV light emitted near the anode by metastable decay. These electrons together with their ionic progeny drift to their corresponding electrodes under the influence of a homogeneous electric field produced by a set of parallel-plate electrodes separated by a 3.1 cm gap. All the details of the experiment are given in [2]. Measurements were carried out at room temperature (293-300 K).

Over the E/N range from 180-260 Td and a pressure range from 5 to 15 Torr, the oscillatory, decaying behaviour following the main, first electron transient, is shown to follow secondary electron avalanches, each separated by an electron transit as is shown in Figs. 1 and 2.

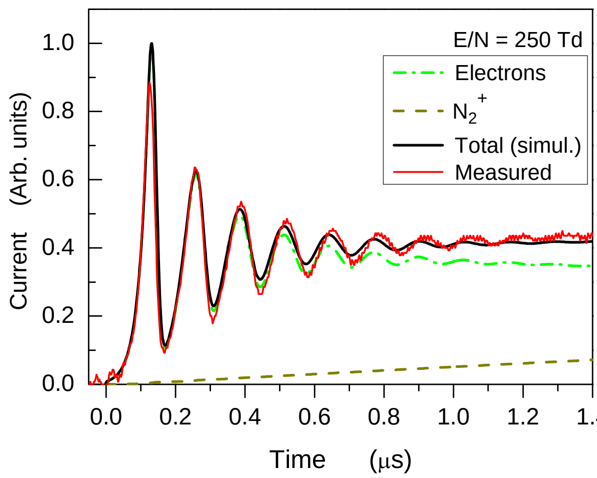


Figure 1. Measured and simulated electron avalanches in $N_2$ at E/N=250 Td. See Table 1 for details.

## 3. The photon feedback reaction scheme in $N_2$

In order to explain the behaviour of the electronic transient shown in figure 1, a basic, though meaningful reaction scheme has been used, which starts with electron impact ionization,

$$e + N_2 \xrightarrow{\alpha} N_2^+ + 2e\,, \quad (1)$$

metastable formation,

$$e + N_2 \xrightarrow{\alpha_m} N_2^* + e\,, \quad (2)$$

followed by metastable decay,

$$N_2^* + N_2 \xrightarrow{k_m} h\nu \,, \qquad (3)$$

and photoelectron production at the cathode

$$h\nu\ on\ cathode \xrightarrow{\gamma} e \qquad (4)$$

Here, e, $N_2^+$, $N_2^*$ and $h\nu$ correspond to electrons, positive ions, metastables and photons. $\alpha/N$ and $\alpha_m/N$ are the ionization and metastable production coefficients, $k_m$ is the reaction rate coefficient for $N_2^*$ decay leading to UV emission. The number of electrons produced at the cathode by photon feedback, $N_{e,pf}$ is given by

$$N_{e,pf} = \gamma\, k_m \int_{x=0}^{d} \rho_m(x)\, dx \,, \qquad (5)$$

where $\gamma$ is the coefficient for production of electrons by photon impact, which is given by

$$\gamma = \frac{Number\ of\ electrons\ produced}{Number\ of\ photons\ produced\ from\ N_2^*} \qquad (6)$$

## 4. Simulation procedure and comparison with measurements

The solution of the system of continuity equations corresponding to the reaction scheme given by equations (1-4), and the calculation of the total current was carried out with the avalanche simulator SIMAV-4 [4,5], modified here to include photon feedback. Values of the swarm parameters used for the simulations of Figs. 1 and 2 are given in Table 1, where $v_e$ and $v_{N2+}$ are the electron and $N_2^+$ drift velocities, $ND_{Le}$ is the density-normalised diffusion coefficient of electrons, and $Ne(x=0,t=0)$ is the initial, laser-produced photoelectron number.

**Table 1. Parameters used for the simulation**

| | Fig. 1 | Fig. 2 | Unit |
|---|---|---|---|
| $E/N$ | 200 | 250 | Td |
| Pressure | 15.00 | 16.73 | Torr |
| $T$ | 295.3 | 299.8 | K |
| $d$ | 3.1 | 3.1 | cm |
| $v_e$ | 2.21 | 2.25 | $10^7$ cm s$^{-1}$ |
| $v_{N2+}$ | 6. | 8.5 | $10^4$ cm s$^{-1}$ |
| $\alpha/N$ | 3.15 | 4.1 | $10^{-18}$ cm$^2$ |
| $\alpha_m/N$ | 2.50 | 3.00 | $10^{-20}$ cm$^2$ |
| $k_m$ | 25 | 25 | $10^{-7}$ cm$^3$s$^{-1}$ |
| $\gamma$ | 2 | 2 | $10^{-11}$ |
| $ND_{Le}$ | 7.8 | 7.8 | $10^{22}$ cm$^{-1}$ s$^{-1}$ |
| $N_{e(x=0,t=0)}$ | 1 | | |

Figures 1 and 2 are two examples of the measurement and simulation of electron avalanches according to the collision model described above. One can see that the agreement is fairly good throughout, with the main features of the pulses well reproduced. Initial values of $v_e$, $\alpha/N$, and $ND_{Le}$ were obtained by fitting the first electron transient, using a method previously discussed [2], and the $N_2^+$ drift velocity was taken from [3]. Then, the best fit to the secondary electron transients was accomplished by varying $k_m$ and $\gamma$.

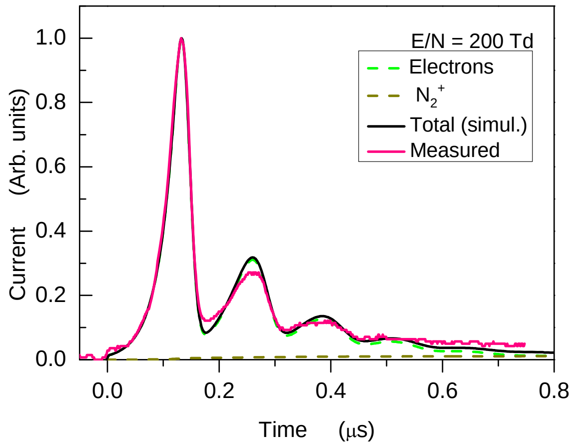


Figure 2. Comparison between experimental and simulated electronic transient in $N_2$ at $E/N=200$ Td.

## 5. Conclusion

The use of the pulsed Townsend technique together with a powerful avalanche simulator, capable of solving the continuity equations of the charged carrier species involved in the discharge, provides a new and promising method to study the influence of photons released by metastable species in the midst of the gas discharge. Moreover, this method is also capable of providing hitherto unknown swarm/reaction coefficients.

**Acknowledgements.**
This work has been supported by Project IN111014 DGAPA-UNAM

**References**

[1] H. Raether, *Electron avalanches and Breakdown in Gases*; Butterworts:London, 1964

[2] J L Hernández-Ávila, E Basurto and J de Urquijo, *J. Phys. D: Appl. Phys.* **35** 2264 (2002)

[3] J. T. Moseley, R. M. Snuggs, D. W. Martin, and E. W. McDaniel, *Phys. Rev.* **178** 240 (1969).

[4] J de Urquijo et al, IEEE Trans. Plasma Science, **35** 1204 (2007)

[5] A Bekstein et al, J. Phys. Conf. Series, **370** (2012)