Modifying atmospheric pressure surface-wave-sustained plasmas with silicon plates for discharge stability

G. Regodon[1], H. Acosta-Rivera[2], R. Alvarez[2,3], V. Rico[2], A. Palmero[2], M.C. García[4,*]

[1] *Departmento de Física, Campus Rabanales, Edificio C2, Universidad de Córdoba, 14071 Córdoba, Spain*

[2] *Instituto de Ciencia de Materiales de Sevilla (CSIC-US), Américo Vespucio 49, 41092 Sevilla, Spain*

[3] *Departamento de Física Aplicada I, Escuela Politécnica Superior, Universidad de Sevilla, c/Virgen de África 7, 41011 Sevilla, Spain*

[4] *Departmento de Física Aplicada, Radiología y Medicina Física, Campus Rabanales, Edificio C2, Universidad de Córdoba, 14071 Córdoba, Spain*

(*) *fa1gamam@uco.es*

Surfatron coupling devices can be used to maintain columnar microwave argon plasmas within dielectric tubes sustained by an azimuthally symmetric TM_{00} [1,2]. Typically, a part of the plasma column forms in the tube region inside the surfatron. At 2.45 GHz and under atmospheric pressure conditions, these plasma columns experience radial contraction and do not entirely fill the tubes containing them [3]. At elevated feed-gas flow rates, this phenomenon results in the splitting of the plasma column into two or more smaller-diameter filaments, rendering it highly unstable.

In this work, the changes experienced by these plasma columns when introducing small silicon pieces of different sizes and nature are studied as a mean to modify the propagation of the electromagnetic signal and the features of the plasma, aiming to avoid both, plasma formation inside the surfatron and the filamentation phenomenon. For this purpose, the plasma was generated inside a quartz tube (6-8 mm inner and outer diameters), using different microwave power levels (P = 100, 140, 180 W), and argon flow rates (F_{Ar} = 200, 400 sccm), while small rectangular silicon pieces of different lengths (4 mm × Length × 300 µm) were introduced to check their influence. Using the 3 cm long Si (intrinsic) piece, the original multi-filamented plasma transformed into just one stable plasma column at the region outside the surfatron (Fig. 1a). Remarkably, higher argon flows lead to the formation of a rather unstable plasma in the region inside the surfatron, whose instability was enhanced at higher powers (Fig. 1b). When using shorter Si pieces (L = 1 and 2 cm), the plasma only formed outside the surfatron if the outer end of the Si piece was placed at the surfatron gap (Fig. 1c), otherwise the plasma also appears at the back part of the piece inside the surfatron. Under the studied experimental condition, it was not possible to generate plasmas of this type using dielectric SiO_2 pieces (L = 1, 2, 3 cm long) (Fig. 1d). No differences were observed when using doped and intrinsic silicon pieces of the same geometry and size.

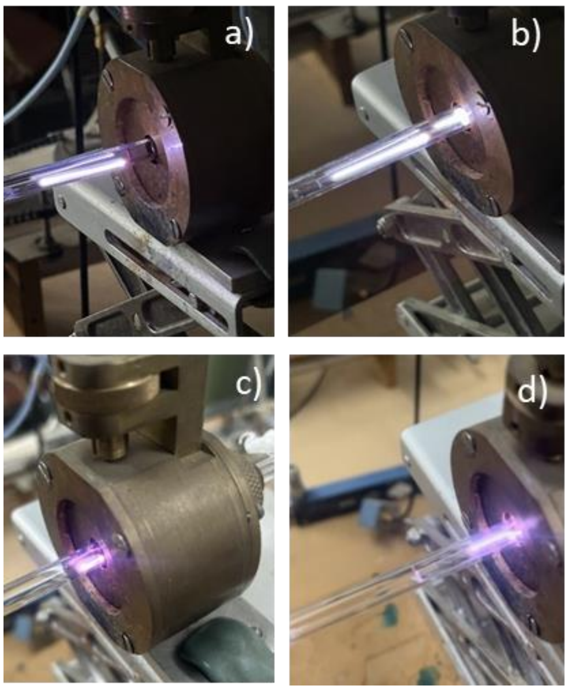

Fig. 1: (a) L = 3 cm, P = 140 W, FAr = 400 sccm; (b) L = 3 cm, P = 180 W, F = 600 sccm, (c) L = 2 cm, P = 100 W, F = 200 sccm

Optical Emission Spectroscopy techniques were used to diagnose the plasma and understand the changes experimented when introducing the Si pieces. A Czerny-Turner type spectrometer of 1 m focal length (with a 1200 grooves/mm holographic grating and a photomultiplier as a detector) was used for

the analysis of the plasma emission. From the collisional broadening of the Ar I 840 nm line [5], the gas temperature (T_g) was measured. On the other hand, the electron density (n_e) was measured from the collisional broadening of the H_β line [6].

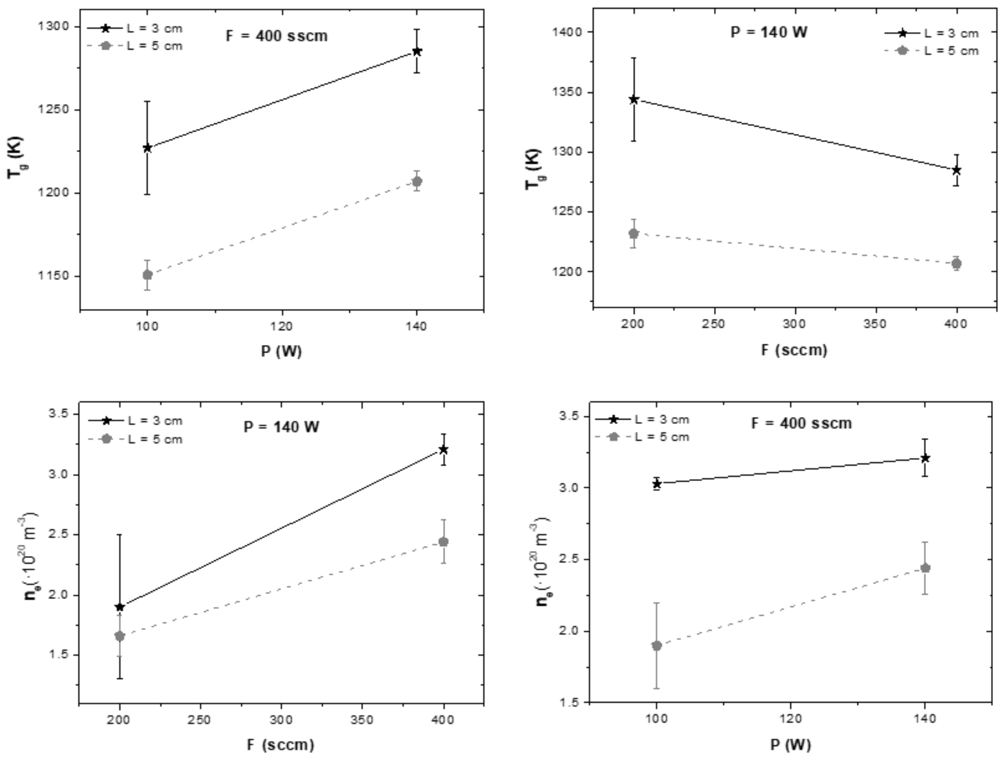

Fig. 2: Measured values of T_g and n_e with power (P) and argon flow rate (F), when using a 3 and 5 cm Si pieces.

In terms of electron density and gas temperature, these plasmas are different from classical surface wave-maintained discharges produced in the original (non-modified) configuration, which suggests that they do not likely fall within the same category, as the surface wave propagation is most likely disrupted by the Si plate. Actually, simulations with COMSOL Multiphysics show that the electric field can be more than doubled at the edge of the silicon piece during surfatron start up. This explains that the device start up is easier with the silicon piece in the dielectric tube, and that the plasma column starts beyond the silicon piece.

Acknowledgements.- The authors acknowledge projects PID2020-112620GB-I00 and PID2020-114270RA-I00 funded by MCIN/AEI/10.13039/501100011033 and project TED2021-130124A-I00 funded by AEI/10.13039/501100011033/Unión Europea Next Generation EU/PRTR

[1] C.M. Ferreira and M. Moisan, *Microwave Discharges: Fundamentals and Applications* (1993) NATO ASI Series B. Plenum Press, Springer Science & Business Media, New York.
[2] J. Henriques, E. Tatarova, F. Dias, C. Ferreira, *J. Appl. Phys.* **109** (2011) 023302.
[3] E. Castaños Martinez, Y. Kabouzi, K. Makasheva, M. Moisan, Phys. Rev. E **70** (2004) 066405.
[4] E. Castaños Martinez, M. Moisan, Y. Kabouzi, *J. Phys. D Appl. Phys.* **42** (2009) 012003.
[5] M.C. García, C. Yubero, A. Rodero, *Spectrochim. Acta B: Atomic Spectroscopy* **193** (2022) 106437
[6] C. Yubero, M.D. Calzada, M.C. Garcia, *J. Phys. Soc. Japan* **74** (2005) 2249–2254.