Departamento de Física

Departamento de Física

Propuesta Doctor Honoris Causa

Prof. Dr. Michel Moisan (emérito)

Département de Physique

Université de Montréal (Canada)

El 30 de abril de 2024 se envió por sede electrónica, a la Comisión de Másteres y Doctorado, la propuesta de Otorgamiento del Grado de Doctor Honoris Causa al Prof. Dr. Michel Moisan por el Departamento de Física de la Universidad de Córdoba. Dicha propuesta fue aprobada por **unanimidad** en sesión ordinaria del Consejo de Departamento del Departamento de Física celebrada el 2 de abril de este 2024 y se presentó por la rama de conocimiento de Ciencias, para el curso 2024/2025.

De acuerdo al Reglamento 57/2020 de los Estudios de Doctorado de la Universidad de Córdoba: *La Universidad de Córdoba podrá otorgar la distinción de Doctor Honoris Causa a personas de reconocido prestigio académico, científico e investigador y que hayan prestado destacados servicios a la Universidad de Córdoba*

En ese mismo reglamento, en su artículo 76.1, se exige que la propuesta del correspondiente órgano colegiado cuente con el "respaldo, por mayoría absoluta, de dos órganos colegiados de igual naturaleza". Así, esta propuesta cuenta con el respaldo, por mayoría absoluta, de tres órganos colegiados además del proponente: el Departamento de Química Orgánica, el Departamento de Química Física y Termodinámica Aplicada y la Junta de Facultad de Ciencias.

Por otro lado, la propuesta que se formula cuenta con la adhesión de cinco investigadores de reconocido prestigio internacional en el campo científico de la Física de Plasmas, lo que es una muestra más de la relevancia de la trayectoria profesional del candidato propuesto en este campo. Dichos profesores enviaron sendas cartas de apoyo y se mencionan a continuación:

- Prof. Dr. Gary M. Hiefjte, *Distinguished Professor de Indiana University (EUUU).*
- Prof. Dr. David B. Graves, *Professor de Princeton University (EEUU).*
- Prof. Dr. Francoise Massines*, "Directrice de recherche au CNRS and Head" de PROMES laboratory (Francia)*
- Prof. Dr. Slobodan Vukovic, *Professor (retired) de Institute of Physics Belgrade* (República Serbia)
- Dr. Carlos Hidalgo, *Director del Laboratorio Nacional de Fusión-CIEMAT (España).*

Resumen del C.V. del Prof. Dr. Michel Moisan

1. Formación

- Grado en Física por la Université de Montréal (Canada) 1964
- Máster en Física: Especialidad Física de Plasmas 1966
- Doctorado (Doctorat d'État, en francés) por la Université Paris Sud (Paris-XI) 1971
- Estancia postdoctoral: Academia de Ciencias de la antigua URSS 1972

2. Puestos docentes y de investigación

- Profesor emérito del Département de Physique (Université de Montréal, Canada) 2015 (jubilación)-actualidad
- Full Professor del Département de Physique (Université de Montréal, Canada) 1985-2015
- Profesor (Titular) del Département de Physique (Université de Montréal, Canada) 1979-1985
- Profesor (Ayudante) del Département de Physique (Université de Montréal, Canada) 1976-1979
- Investigador asociado del Département de Physique (Université de Montréal, Canada) 1972-1975
- Director del Groupe de Physique des Plasmas de la Université de Montréal (Canada) 1983-2008
- Co-fundador del International Laboratory for Plasma Technologies and Applications 2008

3. Colaboraciones con empresas

- Westinghouse (Pittsburgh, USA) 1980-1982
- Standard Oil of Ohio (Cleveland, USA) 1982-1984
- Singer Corp. (Kearfott gyrolaser guidance division, USA) 1984
- IBM (Central Lab., Yorktown Heights, USA) 1984-1988
- ICI (Manchester, UK) 1985-1988
- Xerox (Webster Research Center, USA) 1988-1989
- Fusion System (Rockville, MD, USA) 1992-1994
- Technologies MPB (Montréal) 1993-1994
- Air Liquide (France) 1994-2005
- Peintures (Paints) Prolux (Montréal) 1997
- Getinge, Infection Control division (Sweden) 2013- 2014
- Cell Foods (Spices) (Montréal) 2014)

4. Estancias en otros centros

- IBM TJ Watson Research Center (Yorktown Heights, NY): 4 months in 1985.

- Centre National d'Études des Télécommunications (CNET) (National Center for Telecommunication Studies), Grenoble: 6 months on 1985-1986.

- Other internship CNET (1997) with (temporary) appointment as Professor of the first class of the Universities.

5. Premios

- Prix Adrien-Pouliot 2005 (France-Quebec Scientific Collaboration), granted by the Association francophone pour le savoir (Acfas) and the Consulat Géneral de France au Québec.

- Innovation Award 2017 conferred by the Division of Plasma Physics of the European Physics Association (EPS), received during their annual meeting in Belfast (June 2017).

- Chevalier dans l'Ordre des Palmes académiques de la République Française (Knight in the Order of Academic Palms of the French Republic) (decree of 11 January 2017) for scientific collaboration with France. Medal bestowed on December 7, 2017 by the Consul General of France in Montreal, Mrs. Catherine Feuillet, in the presence of UdeM Rector professor Breton

6. Otros méritos

- Miembro de numerosos comités científicos y evaluador de proyectos y becas de la agencia de investigación canadiense (NSERC) y francesa (ANR).

- Proyectos de I+D e infraestructura científica subvencionados por entidades públicas y privadas (empresas) por un total de 2,5 millones de euros.

- Publicación de 150 artículos publicados en revistas científicas clasificadas en JCR con un índice H de 44 y 13094 citas (WOS).

- Patentes registradas 35 y un 20% de las mismas con protección extendida a Estados Unidos y Europa.

- Publicación de libros científicos: 1 por la Editorial Elsevier y un segundo por la NATO. Dos libros de texto sobre física de plasmas y un segundo sobre física atómica y espectroscopía óptica.

- Publicación de 19 capítulos de libros.

- Un número de 54 conferencias invitadas en congresos y universidades

- Dirección de 30 trabajos fin de máster y tesis doctorales

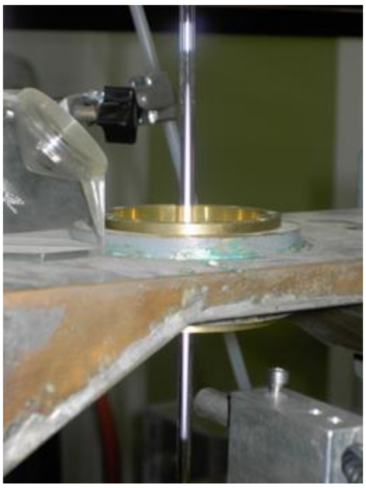
- Supervisión de 18 investigadores postdoctorales

Contribución del Pro. Dr. Michel Moisan a la Universidad de Córdoba

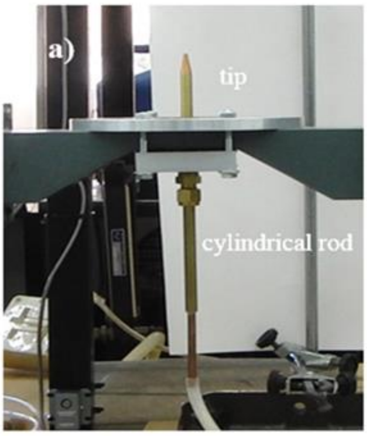
1. Donación de instrumentación científica al Laboratorio de Innovación en Plasmas (LIPs-FQM 301)

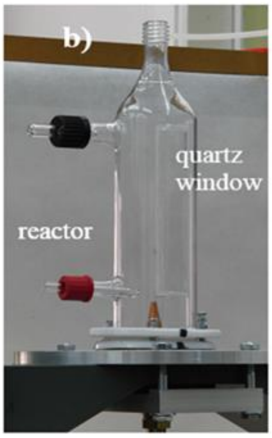
Monocromador Jarrell-Ash (Jobin-Yvon) de 0.5 m de distancia focal. Red de difracción holográfica de 1180 líneas/mm, rendijas de entrada y salida fijas de 50 μm. Detector fotomultiplicador R636-10 (Hamamatsu), tensión de trabajo de 750V e intervalo de respuesta espectral 185-930 nm.

Surfatron: cavidad resonante con cilindro coaxial interior y antena metálica para la sintonización de tipo capacitivo y adaptación de impedancia de potencia de microondas a 2.45 GHz. Conector por cable coaxial para la trasmisión de potencia de un máximo de 200 W.



Surfaguia (Surfaguide): guía de ondas rectangular a la que se le acopla una línea coaxial perpendicular a aquella. Dispone de dos cortocircuitos para el acoplo de microondas a 2.45 GHz y potencia máxima de 2 kW.





TIAGO (Torche à Injection Axiale sur Guide d'Ondes): Guía de ondas rectangular con elemento coaxial acoplado en la zona central donde la altura de la guía se reduce. Dispone de un adaptador de impedancias permitiendo el acoplo de energía de microondas a 2.45 GHz y a un nivel máximo de varios kW de potencia.

2. Resultados derivados de la infraestructura donada

La infraestructura descrita ha contribuido , de una forma decisiva, a la realización de:

- 6 Proyectos del Plan Nacional de I+D
- 1 Proyecto fin de carrera (Escuela Politécnica Superior de la Universidad de Córdoba)
- 5 Tesis de Licenciatura
- 6 Diplomas de Estudios Avanzados (DEAs)
- 8 Tesis doctorales (1 en cotutela con CNRS de Francia y 2 con grado internacional) y 2 nuevas tesis con proyecto de investigación inscrito
- 4 Trabajos Fin de Máster
- 50 artículos científicos
- > 80 comunicaciones presentadas a Congresos internacionales

3. Estancias de personal predoctoral y postdoctoral en el Groupe de Physique de la Université de Montréal (Canada)

- María Dolores Calzada (postdoctoral) 1994

- José Muñoz Espadero (postdoctoral) 2010

- María del Carmen García Martínez (predoctoral) 1994

- Isabel Santiago Chiquero (predoctoral) 2001

- Abel Sainz Serrano (predoctoral) 2005

- Eduardo Castaños Martínez (predoctoral 2005 y Ph.D 2010)

4. Participación en Proyectos del Plan Nacional de I+D

- FTN2002-02595 (Ministerio de Ciencia y Tecnología)

- ENE2005-00314 (Ministerio de Educación y Ciencia)

Michel Moisan

Curriculum vitae

April 2024

Michel Moisan was born in Montréal (Québec) on May first 1942.

Training

- 8 years of *"Classical" studies (comprising Latin, Ancient Greek and Philosophy)* (Collège André Grasset, Montréal) completed in 1961 in Section C (science-engineering) with highest honors *Summa cum laude*.

- *Bachelor of Physics* (1961-1964) and Master of Physics (Plasma physics specialty) (1964-1966) at the Université de Montréal.

- *Doctorat d'État* (State Doctorate) also called *Doctor of Science* (1966-1971) at the Université Paris-Sud (Campus d'Orsay), now known as Université Paris-XI. Title of the thesis: Ionic instabilities in the presence of an intense electromagnetic field. Defense of the thesis with the congratulations of the jury (external examiners: Frederick W. Crawford, Electrical engineering, Stanford University; Paul Vandenplas, École royale militaire, Bruxelles).

- *Post-doctoral internship* (January-October 1972) at the invitation of the academician L.A. Artsimovitch (head of plasma physics in the USSR) for having demonstrated experimentally the validity of a theoretical model developed by scientists (Aliev and Silin) of the Institute of Physics PN Lebedev (Moscow), the most famous physics center in the USSR at that time. According to the administration of the Academy of Sciences, at that time I was their youngest guest as a visiting scientist.

Fellowships

- MSc, Doctorate and Postdoctoral Fellowships (NRC Scholarships, now NSERC).

- Additional Doctorate Fellowship: Québec Ministry of Education Fellow, on an honorary basis (non-cumulative) during the period of validity of the NRC Fellowship, but once this period ended, full-time Fellow (1969-1970). Also: Technical Cooperation Fellowship (France) (1966-1971).

Note on the NSERC Postdoctoral Fellowship: it was canceled without any written notice, probably on the grounds of not having responded to an invitation to meet with the RCMP (Canadian Federal Police) some time before my departure for the USSR. (Partial) funding of the stay in USSR by Canadian External Affairs as part of their Agreement with the USSR Academy of Sciences, and by the USSR Academy of Sciences.

Academic positions

- Research Associate: Plasma Physics Group, Université de Montréal (October 1972-December 1975).

- Professor: Departement de physique, Université de Montréal. Rank: Assistant professor (January 1976-1979), Associate professor (1979-1985), Full professor (1985-2015).

- Professor Emeritus (Physics) at the Université de Montréal (nomination April 2015 upon retirement).

- Co-founder (2008) with Jacques Pelletier (Grenoble) of LITAP, International Laboratory for Plasma Technologies and Applications, now an International Research Group (GDRI).

Sabbatical leaves

- IBM TJ Watson research center (Yorktown Heights, NY): 4 months in 1985.

- Centre National d'Études des Télécommunications (CNET) (National Center for Telecommunication Studies), Grenoble: 6 months on 1985-1986.

- Other internship CNET (1997) with (temporary) appointment as Professor of the first class of the Universities.

Awards

- Prix Adrien-Pouliot 2005 (France-Quebec Scientific Collaboration), granted by the Association francophone pour le savoir (Acfas) and the Consulat Géneral de France au Québec.

- Innovation Award 2017 conferred by the Division of Plasma Physics of the European Physics Association (EPS), received during their annual meeting in Belfast (June 2017).

Short citation: "For pioneering contributions to the development and understanding of microwave plasma sources and their applications to materials processing, healthcare and environmental protection".

Full Citation (nominator Professor David B. Graves, UC at Berkeley)**:** "Professor Moisan has made numerous, profound contributions to plasma physics and especially to the applications of plasma for a variety of commercial and industrial applications. He was the lead inventor appearing on the 1974 patent application disclosing the 'surfatron' and 'surfaguide' electromagnetic field applicators. These devices have been truly enabling for many plasma applications. They are widely used throughout the world for sustaining stable and reproducible plasma columns under a large range of operating conditions. The plasma discharge using these devices is conveniently achieved in dielectric tubing, allowing flowing gases to be utilized. The applied frequency ranges from 150 kHz to 40 GHz with discharge tube diameters from 1 mm to 300 mm radius. Plasma can be sustained with gas pressure as low as 1 mTorr (with electron cyclotron resonance (ECR) operation) to at least 10 times atmospheric pressure. It should be stressed that establishing and maintaining stable plasma under such a wide range of conditions is not possible with any other existing plasma sources.

These devices have enabled fundamental studies into the structure and dynamics of RF and microwave plasmas to a degree heretofore unattained. An especially powerful property is that the EM-field configuration remains the same from 150 kHz to a few GHz, allowing specific plasma studies of the effects of field frequency on plasma parameters.

However, the value of these devices is even more impressive for industrial and many other practical applications. Hundreds of surfatrons are being utilized worldwide in industrial and research labs, and this design is now so widely accepted and integrated into the plasma community that publications no longer refer to its inventors. Among many others that could be cited, the following abbreviated list identifies some examples of practical and novel use: 1) robust, reliable secondary-ion mass spectroscopy (SIMS) in a French-Soviet spacecraft around Phobos, a Mars satellite; 2) efficient, powerful, low damage, room temperature surface sterilization; 3) efficient abatement effluent of difficult-to-treat global warming gases (perfluorocarbons and hydrocarbons) in chemical plants and semiconductor fabs; and 4) highly efficient and powerful purification of Kr and Xe gases obtained from cryogenic distillation in industrial chemical plants. Indeed, many different types of surface-wave launchers and a great variety of applications were developed over the years by the team of Professor

Moisan as well as by many other teams throughout the world. The gas abatement applications were patented, under Prof. Moisan's name, by the French multinational company Air Liquide".

- Chevalier dans l'Ordre des Palmes académiques de la République Française (Knight in the Order of Academic Palms of the French Republic) (decree of 11 January 2017) for scientific collaboration with France. Medal bestowed on December 7, 2017 by the Consul General of France in Montreal, Mrs. Catherine Feuillet, in the presence of UdeM Rector professor Breton.

Other activities

Scientific consulting (details under Scientific collaboration with companies)
Westinghouse (Pittsburgh, USA) 1980-1982
Standard Oil of Ohio (Cleveland, USA) 1982-1984
Singer Corp. (Kearfott gyrolaser guidance division, USA) 1984
IBM (Central Lab., Yorktown Heights, USA) 1984-1988
ICI (Manchester, UK) 1985-1988
Xerox (Webster Research Center, USA) 1988-1989
Fusion System (Rockville, MD, USA) 1992-1994
Technologies MPB (Montréal) 1993-1994
Air Liquide (France) 1994-2005
Peintures (*Paints)* Prolux (Montréal) 1997
Getinge, Infection Control division (Sweden) 2013-
2014 Cell Foods (*Spices*) (Montréal) 2014)

Member of scientific committees

- Organizing Committee, IEEE conference on plasma science (Montréal, 1979)

- Program Committee and co-organizer, First conference on surface waves in plasmas (Blagoevgrad, Bulgaria, 1981)

- International Committee and co-organizer of Second international conference on surface waves in plasmas and solids (Ohrid, Yougoslavia, 1985)

- Member of the executive committee, Gaseous electronics conference (GEC) (1992-1994), and organizer (secretary) of the 46th GEC (Montréal, 1993)

- Co-director (with C M Ferreira) of Summer School (NATO Advanced Study Institute) in Vimeiro, Portugal, 1993.

- Member of the Plasma Chemistry sub-committee, International Union of Pure and Applied Chemistry (IUPAC), 1994-1997

- International scientific committee of the 3rd international workshop on microwave discharges (Fontevraud, France 1997)

- Advisor committee of NATO Summer School (Advanced Study Institute) in Sozopol, Bulgaria, 1998
- Advisor committee (Comite asesor internacional) of the Jornadas Sam'98 Iberomet V (Rosario, Argentina)

- Advisory Committee of CIP (Conférence Internationale Plasmas) 99 and 01 (Antibes-Juan-les-Pins) of the French Vacuum Society (SFV) 1999, 2001

- International Scientific Committee of the 4th international workshop on microwave discharges (Moscow, September 2000)

- International Committee of ECASIA 01 (European Conference on Surface Applications and Interface Analysis, Avignon, France, 2001)

- Chair of (new) ECRIN committee of the Pisa Club on plasma sterilization, a French company-university association located in Paris (2002-2003)

- President of the CIP International Committee 2003 (14th International Colloquium on plasma processes), June 2003, Antibes (France).

- Member of the International Scientific Committee of 5th Int. Workshop on Microwave Discharges: fundamentals and applications, Zinnowitz (Greifswald, Germany), July 2003

- President of the International Committee of the CIP 2005 (15th Int. Colloquium on plasma processes), June 2005, Grenoble (France).

- Member of the multidisciplinary evaluation committee to examine the Team Research Project (FQRNT) program (a Québec funding agency), Fiscal Year 2006-2007.

- Member of the International Scientific Committee of 6th Int. Workshop on Microwave Discharges: fundamentals and applications, Zvenigorod (Russia), September 2006

- Member of the International Committee of the CIP 2007 (16th Int. Colloquium on plasma processes), June 2007, Toulouse (France).

- Member of the CIP International Committee 2009 (17th Int, Colloquium on plasma processes), June 2009, Marseille (France).

- Member of the International Scientific Committee 7th Int. Workshop on Microwave Discharges (MD-7): fundamentals and applications, Hamamatsu (Japan), September 2009.

- Member of the editorial board of the journal of Plasma Medicine (since 2011).

- Member of the International Scientific Committee of 9th Int. Workshop on Microwave Discharges (MD-9): fundamentals and applications, Córdoba, Andalusia (Spain), September 2015.

- Member of the International Scientific Committee of 10th Int. Workshop on Microwave Discharges (MD-10): fundamentals and applications, Zvenigorod (Russia), September 2018.

Member of peer committees

- President of the Research Committee of the Université de Montréal and its affiliated schools (1980-1983), elected by the Assemblée Universitaire. Université de Montréal et ses Écoles affiliées (HEC, Poly Montréal) are French-speaking institutions with more than 70 000 students.
- NSERC (Canada's research agency: Committee 29 (General Physics), 1992-1995).
- FCAR (Québec's research agency:Young researchers 1991-1992, Team 1999-2000).

Academic, industrial and commercial achievements

- Lead inventor of the surfatron and surfaguide, EM field applicators that allow to achieve producing plasmas with RF and microwaves fields. Available from the French company Sairem: 99 surfatrons had been sold till 2017.
- Director (1983-2008) of the Groupe de physique des plasmas (Plasma Physics Group) at the Université de Montréal (UdeM) who developed an ecological purification technique (to remove hydrocarbons and fluorinated compounds) from rare gases such as Krypton and Xenon obtained by cryogenic distillation of air (Industrial respondent: DGR (Rare Gases Division) of Air Liquide (France)). Production Center of Moissy-Cramayel, France and German production center of the Air Liquide Company.
- The UdeM plasma team also developed a technique for the environmentally friendly elimination of greenhouse gases (for example, CF_4, SF_6) used in the manufacture of microelectronic chips. UPAS system (Universal Plasma Abatement System), marketed by Air Liquide. (Air Liquide Electronic System (ALES) industrial respondent) in collaboration with the Claude-Delorme (main) Research Center (CRCD) of Air Liquide (AL, France).[1]
- Scientific Director of the UdeM plasma team (with the Laboratoire de contrôle des infections, a microbiology group) which came up with a new process for sterilizing low-temperature medical devices (<70^0 C). Research and Development contract, signed through our valuation company (Univalor) and with funding 2013-2014 ($ 90,000), from the Swedish multinational Getinge, a company operating in the field of medical techniques. The present competition with the use of ethylene oxide (still accepted despite all its carcinogenic, greenhouse and even toxic (lethal) disadvantages for humans) makes our system, for the moment, economically unprofitable.

Patents

The fact that 35 patents (many of Air Liquide applications constituting a *family* possibly counting up to 50 countries) were filed was recognized by the 2017 Innovation Award granted by the European Physical Society. Noteworthy patents: surfatron and surfaguide (e.g. US 4 049 940 (1977)). These are EM field applicators serving to generate microwave sustained gas discharges, mostly in the form of surface-wave (SW) plasma columns. Worldwide usage: 1/3 of surfaguide and almost ½ of surfatron mentions in papers no longer refer to the inventors: it has become a lab tool. In passing, the surfatron was part, at one point, of an ion-plasma source launched at Baikounour as part of a French-USSR joint experiment (1989) for surveying Phobos surface (Mars satellite): a Kr ion-plasma source (DION) designed for SIMS measurements equipped with a surfatron chosen because of its light weight and perfect reliability of operation under pre-launching stress tests.

A series of patents (own by Air Liquide), in particular for the Universal Plasma Abatement System (UPAS), for eliminating greenhouse gases in microelectronics fabs (e.g. SF_6, CF_4) and, more important for the company, for purifying krypton and xenon gases obtained from cryogenic distillation of air, Xe being used, for example, as ion-thruster "fuel" to reposition daily communication satellites (very high purity Xe required for an envisaged 25 year life-time of the satellite). Both techniques are fully *green* (Air Liquide is actually controlling the xenon world market with this low-cost, ecological and high-level purification technique). Details on Patents on pages 38-50.

Research financing

Besides industrial contracts (e.g., 3.47 M$ from Air Liquide plus government contributions), an absolutely continuous sponsoring by NSERC (Canada federal research council) with my (possibly) last individual (*discovery*) grant coming to an end on March 31 2022.

Scientific achievements

1) Generation, experimental data gathering and modeling of surface-wave (SW) sustained plasma column.

The perfectly reproducible properties of SW plasmas obtained with surfatron and surfaguide devices as EM field applicators (wave launchers: Moisan and Zakrzewski, J. Phys. D: Appl Phys. 1991) paved the way to the generation, observation and modeling of RF and microwave surface-wave sustained discharges (SWDs). Research interest on this topic showed up in most European countries including Russia besides Middle-East (in particular Iran), China and Japan. The surprising features of SWDs, particularly the fact that the plasma column can extend far away from the field-applicator (up to 4.5 m demonstrated) attracted and puzzled many scientists. Also noteworthy is that SWDs provide the broadest operating range of all plasma sources: from reduced gas pressure (mTorr, through ECR conditions) up to at leat 10 times atmospheric pressure, field frequency ranging from ≈ 10 MHz up to 40 GHz, discharge tube diameter from 1 mm to at least 300 mm, features that generated extended modeling and specific applications such as *greenhouse* gas remediation, rapidly reconfigurable (warfare) antennas, to mention only a few. The TIAGO plasma torch (patented too), which also provides a SWD, is a highly efficient plasma source for generating all kinds of materials (e.g., abundant graphene “powder”).

Noteworthy of mentioning besides SWDs is the original plasma system where the applied EM ***E***-field is confined within a volume smaller than that of the plasma generated determined by antenna aperture. It allowed a unique demonstration of periodic (ion plasma oscillations) parametric instabilities that were predicted to occur in an extremely high intensity ***E***-field. By the same token, it showed how to raise the intensity of EM fields to achieve higher excitation, ionisation and molecular dissociation rates, a clear way of attaining higher process efficiencies (Moisan and Nowakowska, PSST (Topical review) 2018).

2) Sterilization using SWD plasmas.

A thorough investigation of the “good and bad properties” of using SWDs to perform sterilization of bacterial spores (the thoughest to inactivate micro-organisms) and to eliminate pathogenic prion proteins (Creutzfeld Jakob disease) has been conducted and reported in the European physical journal of applied physics, as an invited paper. A specific method for sterilizing medical devices (MDs) was elaborated that called on the late flowing-afterglow (absence of charged particles) of a N_2-O_2 discharge, which creates enough (and therefore irreversible) lesions to the micro-organisms DNA through UV irradiation. The UV photons are provided by NO molecules resulting from the combination of N and O atoms obtained from the dissociation of the N_2 and O_2 molecules in a SWD, providing a broad UV (180-350 nm) spectrum. The N and O atoms can infiltrate in-between stacks of spores before turning into NO molecules, ensuring better spore inactivation than direct UV irradiation from excited/metastable state atom/molecule (not to mention UV light) (Moisan et al., Europ. Phys. J. Appl. Phys. 2014). Nonetheless, possibly the most important result from our work, applicable to all plasma sterilization methods, is the fact that bacterial spores get charged up with electrons in a discharge, and then these microorganisms are released (most of them having not been inactivated yet) at the very initial stage of the sterilization process by electrostatic force: this point had escaped researchers and is still not recognize as it “impairs the real potential and validity of all sterilization methods taking place in discharges” (Moisan et al. *J. Phys. D: Appl. Phys.*, 2014). Our late flowing-afterglow system received industrial approval (Getinge Healthcare UK), but it implied a higher operating cost as compared to Ethylene oxide (EtO), of worldwide use, although toxic (at the ppm level) and on the long run, at lower levels, cancerogenous, additionally a *greenhouse* gas and a potentially explosive gas;

3) concerning the most recent advances:

a) the documented disclosure of the antenna-like region (space-wave radiation) that precedes SWD generation (Moisan et al., AMPERE Newsletter 2019). Our experimental study and analysis of this region throw some specific light on this region, which was ignored although SWDs had become the subject of many publications. It shows, in the end, that the EM radiation coming out from SWD (and spreading into the ambient) is not related to the EM radiation from the SW plasma column, but to this antenna-like far-field radiation region, which can be eliminated by surrounding the SWD with a Faraday cage at (circular waveguide) wave cut-off. Since it reduces radiative power loss, it increases the plasma column length (larger total number of electrons in the SWD) (AMPERE Journal attached);

b) the SW propagates along the dielectric discharge tube without being influenced by the properties of the plasma column: a change in paradigm. I have demonstrated from available experimental results that the plasma column properties do not affect the SW features. Theorists had all assumed that the SW properties depended on the plasma column, which leads to results in contradiction with experiments at the plasma column end, as elaborated in a manuscript to be submitted shortly.

c) I have developed and significantly expanded the power per electron concept (manuscript ready for submission). This approach, initially limited to microwave discharges (such that only electrons gain energy from the EM field) provides additional light not only on microwave discharge operation and mechanisms but, qualitatively, to all kinds of discharge. In particular, it shows that confining the EM field sustaining the discharge to a volume smaller than that of the plasma volume leads to increasing the intensity of the (maintenance) EM electric field component, allowing higher efficiency processes such as molecular dissociation. Using earlier the power per electron procedure, it had been shown (2018 PSST paper) that the ***E***-field intensity is an internally-set quantity, not directly related to the power or voltage applied by the operator. A further issue of our model concerns pulsed-operated discharges. It shows that pulse time duration and repetition rate can be adjusted to reach the highest possible ***E***-field intensity, a valuable feature when, for example, looking for the most efficient discharge for splitting CO_2 molecules.

In conclusion, my work started with the invention of surfatron and surfaguide ***E***-field applicators generating surface-wave plasma columns of the utmost (and puzzling) interest for lab work, discharge modeling and industrial/lab related original inventions: I not only participated in all these aspects, but often I was the initiator of a topic that developed afterwards. A sideline of my work, but closely related to the availability with SWDs of a N_2-O_2 late afterglow (no ions present), led to propose achieving *green* and efficient sterilization of dielectric made MDs. Although I am basically an experimentalist, almost all my publications comprised some degree of explanations of the physical phenomena involved, often accompanied by original modeling concepts.

Publication metrics (May 2023):
Approximately 150 peer-reviewed articles, with an average paper length over last 10 years of 18 pages. 21 papers are cited at least 100 times and a H index of 44 according to Web of Science (Clarivate) while Google Scholar yields an H index of 54 with 13094 total number of citations.

Complementary material

Congratulation e-mail about 2017 Innovation Award from the President of the Russian Academy of Sciences

De : Глуховцева О.Э. [mailto:oeglukhovtseva@presidium.ras.ru]
Envoyé : 16 mars 2017 08:11
À : michel.moisan@UMontreal.CA
Objet : Congratulations

Dear Professor Moisan,

Please find attached a letter from the President of the Russian Academy of Sciences Academician V.E. Fortov.
Yours sincerely,

Olga Glukhovtseva

Head
Foreign Relations Department
Russian Academy of Sciences

Prof. Michel Moisan,
Université de Montréal
Québec, Canada

Dear Professor Moisan,

On behalf of the Organizing Committee of the International Conference "Physics of Low Temperature Plasma" (PLTP-2017, Russia, Kazan, 5-9 June, 2017) and from myself personally allow me to congratulate you on being awarded the Prize of the Plasma Physics Division of the European Physical Society "The 2017 Innovation Award" for "pioneering contributions to the development and understanding of microwave plasma sources and their applications for materials processing, healthcare and environmental testing".

Your outstanding contribution to the physics of low-temperature plasma and gas discharges cannot be overemphasized. It is a great honour for us that you are the member of the Organizing Committee of the PLTP-2017.

We wish you continued success in your work.

Sincerely,

Professor
Vladimir Fortov

President of the Russian Academy of Sciences,
Chairman of the Organizing Committee of PLTP-2017

Position offered to put up a plasma physics department at the Epidemiology and Microbiology Magalaya Institute (Moscow), Academy of Medecine

In March 2016, members of this Institute (where the Sputnik V vaccine was conceived) proposed to hire me in the frame of their program « collaboration projects with prominent foreign researchers » to establish and run a plasma lab destined to medical studies. I had to refuse because I had to go through an immunotherapy treatment for leukemia (from January to July 2017).

Scientific collaboration with companies

Québec companies

Métal 7, Sept-Îles

Company using very high power plasma torches.

Peintures Prolux (Paints), Montréal

We have conceived a (microwave) plasma afteglow technique to increase paint adhesion on recycled polymers (of various origin). Prolux found a less costly plasma system than ours, but they use it with « our recipe ».

Fordia, Montréal

Company own description: « Global solutions for drilling providing a large range of diamond coated tools for mine and geotechnic suveys… ». At that time, I had a team of 3 researchers working on obtaining high quality polycrystalline diamond deposits, which led us to file a patent which shows how to obtain a greather adhesion on ferrous surfaces. US 5,759,623

Outils Gladu, Marieville

Manufacturer of diamond (and diamond-like) coated tools. Same topics and objectives as for Fordia above..

MPB Technologies (space and photonic division), Pointe-Claire

We participated with MPB in the Federal program called Stear VI aiming at ensuring that the materials covering the space shuttle and other satellite surfaces can resist to oxigen collisions (interaction) in the upper atmosphere.

BOMEM, Québec

Design and realization of a microwave sustained plasma adapted to the detection of analytical signals from gaseous chromatography systems using the Ro-Box field applicator (operating frequenceies as low as 27 MHz,). US 4,810,933. Actually, we assembled a 40 MHz transistored (300 W) power supply to go along with the plasma source. The company manufactured top Fourier-transform spectrometer. Québec FCAR financing program sponsoring this collaborative work.

CELL FOODS, Pointe-Claire

A company selling spices (e.g.,. coriandre, paprika) after using ethylene oxide to make sure that their product is free from micro-organisms. Such a decontamination method (potentially toxic for employees and cancerogenous for consumers) is not accepted by EC.regulations. Our N_2-O_2 flowing afterglow was shown, in contrast, to be totally safe and *green*. However, the handling of powder would have required a specific engineering technique to ensure that all the spice-powder grains, in their entirety, would be exposed to the late flowing-afterglow of the N_2-O_2 discharge during the process.

American companies

XEROX, Webster, N.Y.

Potential and limitations of microwave deposition technologies for Xerox's critical materials need. In January 1998, we deliverded to Xerox a surfaguide (SW) plasma source and then particpated in the training of their personnel on microwave sustained discharges. We provided the required modifications to improve and optimize their plasma reactor. Non-disclosure agreement (NDA) signed.

IBM, Yorktown Heights and Essex Junction, N.Y.

Microwave-plasma etching of polyimide (part of the process of chip manufacturing).

The Company wanted my group to check polyimide etching with a 2450 MHz sustained discharge. A plasma reactor of our own was designed and put up that could operate from 13.56 MHz to 2450 MHz, allowing looking for the EM field frequency that would provide the fastest etching and be the less damage to polyimide samples. Such a possibility of using the same plasma configuration throughout such frequency span ensured determing the sole influence of the field frequency on etching rate, if any, and on susbstrate heating. Contrary to the initial solution promoted by IBM engineers, we showed that such etching must not be performed at 2450 MHz (non only etch rate was very low but there was overheating leading to destruction of the polyimide substrate), but rather at 27 MHz. According to "my" manager at Yorktown Heights, avoiding a 2450 MHz etching process of polyimide on production line saved millions of dollars to the Company.

SINGER (gyrolaser guidance and navigation Kearfott division), Little Falls, N.J.
NDA signed to examine the substitution of DC discharges by a high frequency (HF) discharge for gyrolaser (ring lasers configuration) systems operation for increased reliability in trajectory guidance.

Fusion system, Rockvile, MD

NDA on high power UV lamps using microwave sustained plasma technology.

SOHIO (Standard oil of Ohio) (1982-1984)

Frequency dependence of the deposition rate of amorphous Si:H produced by a surface wave (surfatron) generated plasma.

WESTINGHOUSE (lighting division) (1980-1981) at Pittsburgh

NDA on various aspects and possibilities of using SWDs for lighting purposes.

Elsewhere in the world

ICI (Imperial Chemical Industries), Manchester, EnglandAngleterre

Novel microwave plasma techniques and treatments (material eposition).

NDA, meeting in Manchester (December 1985) leading to a significant research contract. With Professor Zakrzzewski (invited professor) a microwave-field applicator was designed (the main point for ICI was coming up with a system not already covered by a competitor patent). Two different, efficient, leaky-wave-antenna system were designed, additionally paying attention Moreover, numerically solved plasma and Maxwell equations were numricaly solved to yiel the radiated EM field.

SNLS, St-Romans, France

The multipolar magnetically confined plasma-reactor, designed at the Centre National d'Études des Télécommunications (CNET) of Grenoble, was equiped with a waveguide-surfatron.

SAIREM, Neyron, France

Designer and manufacturer of radio-frequency and microwave generators and of EM field applicators to go along with these generators as well as for corresponding industrial applications. I have been acting as consultant for this company since 1994 and their first sales of surfatrons started in 1998 (more than 100 sold). The surfaguide is now marketed by SAIREM (see their site).

GETINGE HEALTHCARE, Getinge, Sweden

This company defines itself as the leader in infection control solutions in healthcare centers, public or private. The Getinge Infection Control entity, according to its own advertisement, promotes innovation and technological progress in the fields of disinfection and sterilization, having a global presence with 31 subsidiaries spread over five continents. This company secured for the year 2013-2014 a license for our patents in sterilization / disinfection for evaluation. Our R&D work in this area received a positive review from Getinge Infection Control (UK) and its subsidiary La Calhène (Vendôme, France). However, the cost of implementing and operating our device is not competitive with the ethylene oxide sterilization process currently used by Getinge.

Edition of books and text-books

As publisher (implementation of a collective work):

With Jacques Pelletier (Grenoble): Microwave excited discharges (Elsevier, 1992; reprinted in 2005).

With C.M. Ferreira : Microwave discharges : fundamentals and applications (NATO ASI Series, 1992).

Publication of a manual on plasma physics and a manual on atomic physics and optical spectroscopy (in French).

Physique des plasmas collisionnels (2006), by M. Moisan and J. Pelletier, published by editions EDP (France). A second edition, revised and enlarged (80 additional pages for a total of 504 pages), entitled (english translation) Collisional Plasma. Physics of RF and Microwave Discharges has been available since 2014. The publication of this manual in English (2012) by Springer Verlag seems to be well appreciated, more than 1000 downloads (between July 2013 and the end of December 2014). The impact of scientific books is now measured not only by the number of copies sold, but also by the number of downloads (those controlled by the Publisher!).

Physique atomique et spectroscopie optique, by M. Moisan, D. Kéroack and L. Stafford (455 pages including 46 problems with complete solution), appeared in July 2016 under EDP editions (Grenoble-sciences collection) (France).

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NB: My latest manuscript, still in progress, available in arXiv as paper 2106.11404 Plasma columns generated by the propagation of an electromagnetic surface wave have no effect on the properties of the wave, contrary to what is generally advocated. They in fact depend only on the discharge operating conditions, specifically wave frequency, tube radius, gas nature and density*

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Popularization article published in the British magazine *Scientia*

Moisan M. (2023) Providing stable and power-efficient plasma using microwaves. To appear in the *Scientia* issue of July 2023. 5 pages.

Invited conferences[2]

1. Moisan M., Nowakowska H. (2019) Generation and modeling of gaseous plasmas using microwave power. 17*th* *International Conference on Microwave and High Frequency Heating* (AMPERE 2019). Proceedings pages 27-34. ISBN: 978-84-9048-719-8. DOI: http//dx.doi.org/10.4995/Ampere2019.2019.9989. **(Spain).** Note: Key-Note Speaker.

2. Moisan M., Levif P., Nowakowska H. (2018) Unrevealed feature of surface-wave sustained tubular discharges (SWDs): space-wave radiation region in the immediate vicinity of the wave launching interstice before the SWD develops. 10*th* *workshop on microwave discharges (MD-10)*, Zvenigorod (Moscow oblast)**.** Proceedings pages 97-110. **(Russia).**

3. Moisan M., Nowakowska H. (2017) The remarkable contribution of surface-wave sustained plasma columns to the modelling of RF and microwave discharges. In this plenary session, the 2017 Innovation Prize of the European Physical Society (Plasma physics division) was awarded to M. Moisan at its 44th Annual meeting in Belfast (**UK**).

4. Moisan M. (2015) The power θ_a absorbed per electron from the E-field and the power θ_l lost per electron under various processes as meaningful physical parameters allowing characterizing and modeling DC, RF and microwave discharges as functions of operating

[2] Many-in-person conferences that I intended to attend in 2020-2021 were cancelled: I particularly regret the (invited) conference (Workshop on microwave discharges) that was planned to take place in Kazan, Tatarstan (Russian Federation). On the other hand, I did not feel at ease with providing *zoom* (or other similar means) conferences.

conditions. IX International workshop on microwave discharges: fundamentals and applications, Cordoba (**Spain**). Note: inaugural presentation.

5. Moisan M., Levif P., Séguin J., Barbeau J. (2013) Sterilization/disinfection using reduced-pressure plasmas : comparison between direct exposure to a discharge and to a flowing afterglow *Central European Symposium on Plasma Chemistry (CESPC-5)*, Balatonalmadi (**Hungary**). Note : inaugural presentation.
6. Kilicaslan A., Roy-Garofano V., Levasseur O., Stafford L., Moisan M., Côté C., Sarkissian A. (2013) Formation dynamics of organosilicon and organotitanium nanopowders in microwave-sustained plasmas at atmospheric pressure. *Congrès de l'ACP* Montréal (**Québec**).
7. Stafford L., Boucher A., Iarotsky L., Hamady M., Moisan M. Development and characterization of a new microwave plasma source in contact with liquids. (2013). *Congrès de l'ACP* Montréal (**Québec**).
8. Moisan M., Levif P., Séguin J., Barbeau J. (2013) Stérilisation de dispositifs médicaux par plasma à pression réduite : comparaison des avantages et inconvénients d'une exposition directe à la décharge relativement à une post-décharge (2013). Congrès de l'Association Canadienne des Physiciens (ACP), Montréal (**Québec**).
9. Moisan M., Levif P., Séguin J., Carignan D., Kéroack D., Barbeau J., Leduc A., Elmoualij B., Gofflot S., Heinen E., Thellin O., Zorzi W., Kutasi K. (2012) The flowing afterglow of the N_2-O_2 discharge as a means of decontaminating/sterilising thourgh UV radiation: summary of the results achieved and recent results. *The 39th IEEE International conference on plasma science (ICOPS2012)* Édimbourg (**UK**).
10. Moisan, M., Using gaseous plasmas to inactivate microorganisms: a possible alternative to conventional sterilization techniques (2011) Institut d'immunologie Cantacusino, Bucarest (**Romania**).
11. Moisan M., Barbeau J., Boudam M.K., Carignan D., Levif P., Séguin J., Soum-Glaude A. (2010) Sterilization of medical devices using plasma: advantages and limitations. The reduced-pressure flowing-afterglow of the N_2-O_2 discharge as the biocidal medium. *11 th High-Tech Plasma Conference (HTPP-11)*, Bruxelles (**Belgium**).
12. Moisan M., Pelletier J. (2009) Advances and drawbacks of microwave plasmas. *7th workshop on microwave discharges (MD-7)* Hamamatsu (**Japan**).
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Other conferences not reported (265 participations in Conferences in numerous countries)

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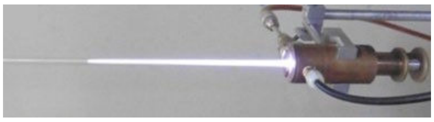
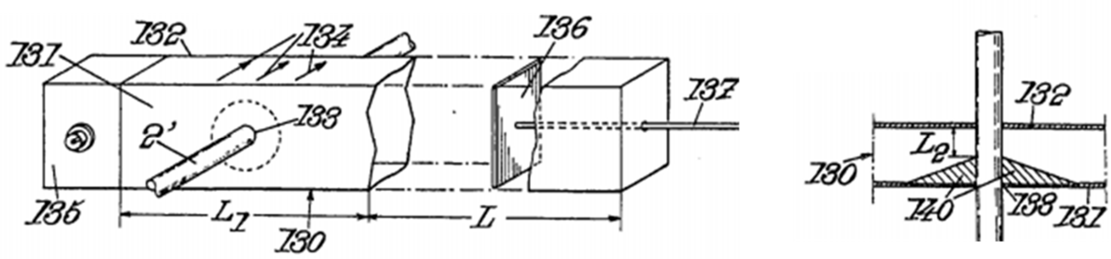
Photo and schematic descriptions of some of the devices and systems patented by Moisan (with comments)

1- EM field applicators for sustaining gaseous discharges

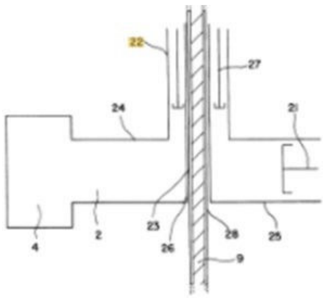
Surfatron



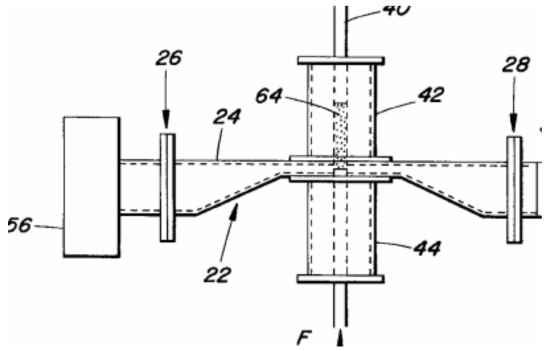
Surfaguide (first design). (left) Microwave power supplied directly to the waveguide through a coaxial cable (entry 135). (right) Internal impedance transformer at the interstice location



Surfatron-guide (waveguide-surfatron) (two impedance tuning means, 21 and 27. No tapering down of the waveguide at the *launching* interstice, but direct waveguide power feeding (higher power level operation).



Surfaguide (commonly adopted design) Tapering down of the waveguide narrow wall at the interstice.

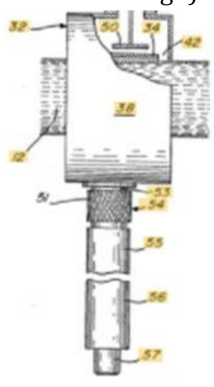


Only one impedance tuning means (56). MW waveguide power input (before 28).

The tapering of the waveguide narrow wall with its gradual transitions plays the role of impedance transformers. When the height of the narrow wall section is appropriately chosen, the surfaguide characteristic impedance at the interstice aperture is (approximately) made equal to that of the characteristic impedance of the surface-wave plasma column (considered as a transmission line). The reflecting plane (short-circuiting plane of the wave) axial position in the waveguide then no longer needs to be adjusted as operating conditions are varied in contrast to previous surfaguides and waveguide-surfatrons designs., a precious industrial operating feature.

NB: Many researchers believe that the narrower the surfaguide diminished wall height, the more intense is the *E*-field of the wave on the discharge tube. Experiments show that shortening too much the narrow wall height affects negatively the impedance matching, which not only becomes bad, but varies with operating conditions.

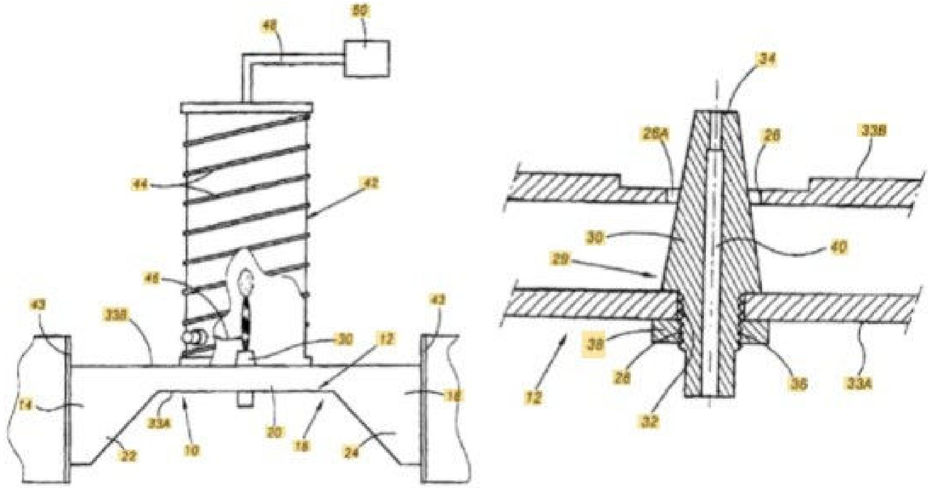
Ro-Box (stub Ro-Box design)



Stub: a conducting cylinder (55-56) in which an internal piston 57, ending with a short-circuiting conducting plane, allows sliding it for impedance matching.

TIAGO

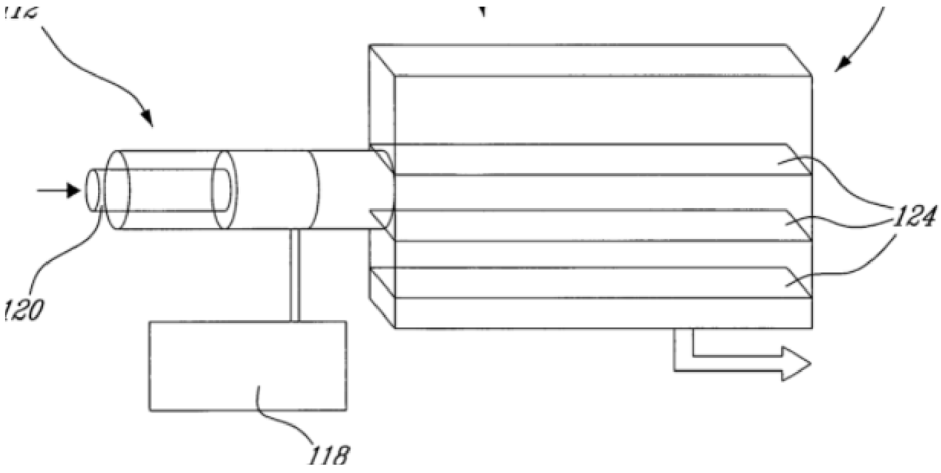
A plasma torch system where a gas flow (e.g. argon) exits at a (conducting) nozzle past which a surface-wave (SW) discharge is sustained at atmospheric pressure, either in the ambient or within a confining vessel. Microwave power is transferred to the nozzle either from a surfaguide field-applicator or directly along a nozzle (30) partly inserted in a waveguide, perpendicularly to its axis. The broad wall material is thinned (26) around the conical nozzle, which is separted from the wall by an air space 25A.



(left) TIAGO system within a sealed (and water cooled) vessel (many kW device) or (right) exiting in the ambient (low power system, with possibly many of them distributed along the waveguide).

N_2-O_2 SW flowing afterglow design of a sterilization chamber.

Inside the chamber there are, e.g., supporting plates for the medical devices (MDs) to be sterilized. Inactivation takes place due to UV (180-350 nm) irradiation by the NO molecules formed by combination of N and O atoms. These are provided by a surfatron discharge that dissociates the N_2-O_2 gas mixture into N and O atoms. At a short enough distance from the chamber, the plasma source provides into the chamber an early flowing afterglow (ions are present) whereas at a far enough distance (>820 mm), the late afterglow entering the chamber is free from electrons and ions (preventing microorganisms from being released (due to electrostatic charging by electrons) from their susbstrate before being inactivated).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List of patents (applied for/granted). A given patent application can be filed in many countries, resulting in a *family* of patents

1. M. Moisan, P. Leprince, C. Beaudry, E. Bloyet, (Inventors) "Perfectionnements aux dispositifs d'excitation d'une colonne de gaz enfermée dans une enveloppe", French patent 2 290 126 (1974). Assignee : (French) Agence Nationale de Valorisation de la Recherche (ANVAR). *Surfatron, an EM field-applicator for sustaining surface-wave plasma columns.*
2. M. Moisan, P. Leprince, C. Beaudry, E. Bloyet, "Perfectionnements aux dispositifs d'excitation par des ondes hyperfréquences, d'une colonne de gaz dans une enveloppe allongée", Demande de certificat d'addition (continuation in part). French patent 2 346 939 (1975). "Perfectionnements apportés aux dispositifs et procédés d'excitation par des ondes HF, d'une colonne de gaz enfermée dans une enveloppe isolante", Canadian patent 1 056 961 (1979). "Vorrichtung und Verfahren zur Anregung einer in einer isolierenden Hülle eingeschlossenen Gassaüle durch Hyperfrequenz", Federal Republic of Germany 25 48 220 (1976). "Improvements relating to devices and methods of using HF waves to energize a column of gases enclosed in an insulating casing", US 4 049 940 (1977), patent applied for in Japan (1975). Assignee: ANVAR. *Surfatron* and *surfaguide, field applicators for sustaining surface-wave plasma columns.*
3. M. Moisan, Z. Zakrzewski, "New surface wave launchers to produce plasma columns and means for producing plasmas of different shapes", Canadian patent 1,246,762 (Dec. 1988), US patent 4,810,933 (March 1989). Assignee: Université de Montréal, patemt acquired later on by Air Liquide *Ro-Box (EM field applicator operating below 100 MHz) for sustaining surface-wave plasma columns..*
4. M. Moisan, Z. Zakrzewski, "New surface wave launchers to produce plasma columns and means for producing plasmas of different shapes", Canadian patent 1 273 440 (a division of the Canadian parent patent. 1,246,762) (August 1990), US patent 4 906 898 (March 1990) (a division of US parent patent 4,810,933). Assignee: Université de Montréal, patemt acquired later on by Air Liquide. *Surface-wave plasmas allows achieving various shapes of discharge vessel (lighting lamp shapes)..*
5. P. Bou, L. Vandenbulcke, A. Quilgars, M. Coulon, M. Moisan, "Dispositif et procédé de dépôt de diamant par DCPV assisté par plasma microonde", French patent 2 678 956 (24 September 93); South Africa 9205157 (31 March 1993); European patent (DE, ES, GB,IT, SE) 522 986 (1993). "Apparatus and process for diamond deposition by microwave plasma", US 5 360 485 and patent applied for in Canada (1993). Assignee: Pechiney (France) (July 1992). *Achieving polycrystalline diamond deposition (on large substrates) with surface-wave microwave discharges. The system comprises a plasma formation region provided by a surfaguide and a diamond deposition zone of enlarged discharge-tube diameter, located at some distance from the surfaguide.*
6. C. F. M. Borges, M. Moisan, F. Roy, "Method for producing a high adhesion thin film of diamond on a Fe-based substrate", US patent 5 759 623 (02/06/1998) filed on 14/09/1995. Assignee: Université de Montréal. *Achieving a high adhesion thin film of diamond deposited with a surface-wave plasma (surfaguide, 915 MHz) on a Fe-based substrate.*

7. J. C. Rostaing, F. Coeuret, C. de Saint Étienne, M. Moisan, "Procédé et installation de traitement de gaz perfluorés et hydrofluorocarbonés en vue de leur destruction", french patent 2 751 565 (filed: 26 July 1996), European patent application EP 0820801 A1 (08/07/1997). Designated Countries : AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE, Extended designated countries : AL LT LV RO SI. "Process and installation for the treatment of perfluorinated and hydrofluorocarbon gases for the purpose of their destruction", US patent 5 965 786 (12/10/1999), and Japan 10 165 753 (23/06/1998). Assignee: Air Liquide. *Methods for eliminating effluents containing fluorocarbons such as hfc and pfc (plasma is instrumental in dissociating these molecules).*

8. Same authors as above in 7: US 6 290 918, a division of the US parent patent 5,965,786. *Process as described above, indicating that the plasma is obtained by the propagation of a surface wave (achieved with a waveguide-surfatron).*

9. J. C. Rostaing, J. C. Parent, F. Bryselbout, M. Moisan, "Procédé d'épuration d'un gaz, et installation pour la mise en oeuvre d'un tel procédé", french patent FR 2 757 082 (13/01/1996), European patent application, EP 0847794 A1 (09/12/1997). Designated countries : AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE, Designated « extended » countries: AL LT LV MK RO SI. "Process for purifying a gas", US patents 5 993 612 (30/11/1999), Japan 10 277 354 (20/10/1998). Assignee: Air Liquide. *A process using plasma to purify a gas by dissociating impurity molecules and eliminating them (used, for instance, for purifying krypton and xenon gases).*

10. Same authors as in 9. "Process for purifying a gas and apparatus for the implementation of such a process". US Patent 6 190 510, a division of US parent patent 5,993,612. *A waveguide-surfatron is used to provide a surface-wave plasma allowing to achieve the process.*

11. M. Moisan, R. Etemadi, J. C. Rostaing, "Dispositif d'excitation d'un gaz par plasma d'onde de surface et installation de traitement de gaz incorporant un tel dispositif", french patent 2 762 748 (filed : 25 April 1997 ; publication: 31 October 1998), European patent application, EP 0874537 A1 (21 April 1998). Designated countries: AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE, « Extended » countries designated : AL LT LV MK RO SI. "Device for exciting a gas by a surface wave plasma and gas treatment apparatus incorporating such a device", US 6,224,836 (01/05/2001), Canadian 2,235,648 (25/10/1998). Assignee: Air Liquide. *A device for exciting a gas (describing the surfaguide EM field applicator) through which (perpendicularly) passes the discharge tube for the purpose of producing a surface-wave plasma, the discharge tube being surrounded by a conducting (Faraday) cage "to concentrate microwave radiation".*

12. M. Moisan, Z. Zakrzewski, R. Etemadi, J. C. Rostaing, "Dispositif d'excitation d'un gaz par plasma d'onde de surface", French patent 2 766 321 (filed : 16 July 1997 ; publication : 22 January 1999) ; second European patent EP0995345. PCT WO9904608 (22 January 1999) European patent application : 98936460.9-2208, filed 7 July 1998. Designated countries DE GB IT NL. US 6 298 806 (9/10/2001). Assignee: Air Liquide. *Filling more than a single discharge tube with plasma (multitube system through a surfaguide) to increase process throuhput.*

13. J.C. Rostaing, M. Moisan, R. Etemadi, D. Guérin, "Éléments de canalisation pour dispositif de traitement de gaz et dispositif incorporant un tel élément de canalisation", french patent FR

2 787 677 (filed 22/12/1998), European EP 1014761 (filed 03/12/1999), US 6 541 917 (01/04/2003). Designated countries : AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE. Assignee: Air Liquide. *Surfaguide EM field applicator for treating a gas by achieving a surface-wave plasma in a tube that "comprises, over at least part of its length, a double wall".*

14. M. Moisan, Z. Zakrzewski, D. Kéroack, J-C. Rostaing, "Dispositif de traitement de gaz par plasma", French patent application 00 13840 (27/10/2000). PCT application (23/10/2001) published (02/05/2002) as (PCT) WO2002-035575. French patent FR 2 815 888, US 6 916 400, TW519856, PT1332511, JP2004512648, ES2219573, DE60103178, AU1408902, AT266257. Assignee: Air Liquide. *TIAGO plasma torch system*.

15. J.C. Rostaing, D. Guérin, C. Larquet, C. H. Ly, M. Moisan, H. Dulphy, "Application des plasmas denses créés à pression atmosphérique au traitement d'effluents gazeux", French patent application number 0107150 (31/05/2001). PCT application (21/05/2002) published (05/12/2002) under number WO02097158. French patent : FR 2 825 295 (06/12/2002), EP1397529 (2004-03-17), US patent application 2004/0195088, CN1543515 (2004-11-03), DE60218305T (2007-11-15). Assignee: Air Liquide. *System for treating gases such as pfc or hfc with plasma, diluted into N_2, comprising pumping means such that the outlet is at a pressure substantially equal to atmospheric pressure such as to produce a plasma (waveguide-surfatron) at atmospheric pressure.*

16. • J.C. Rostaing, D. Guérin, C. Larquet, C. H. Ly, M. Moisan, H. Dulphy, Referring to entry 15, the present US patent application 2010/0155222 is a division of US parent patent application 2004/0195088 . Assignee: Air Liquide. *The system ensuring the process is descred. For safety reasons, the gaseous effluents coming from the reactor or from the production chamber are, downstream or in the exhaust of the roughing pump or the rough-vacuum pumping, set highly diluted in nitrogen (with an additive gas, namely oxygen) or air at substantially atmospheric pressure.*

17. M. Moisan, J. C. Rostaing, M. Carré, K. C. Tran, "Procédé de traitement des gaz par des décharges hautes fréquences", French patent FR 2 864 795 PCT application published on 18 August 2005 under number WO2005075058, KR20060128905 (2006-12-14), EP1703961 (2006-09-27), US patent application 2007/0284242 (2007-12-13). Assignee: Air Liquide. *RF (ICP) inductive discharge for purifying gases containing impurities.*

18. Y. Kabouzi, M. Moisan, J. C. Rostaing, D. Guérin, H. Dulphy, P. Moine, V. Laurent, B. Depert "Traitement d'effluents gazeux par plasma à pression atmosphérique", French patent FR 2 873 045 (filed as FR0451527 on 13/07/04), PCT application WO2006008421 published on 26/01/2006), CN101065182 (31 October 2007). Assignee: Air Liquide. *Swirling flow (vortex) gas input at atmospheric pressure increases plasma destruction efficiency of fluorinated effluents (in fact by 15%).*

19. Z. Zakrzewski, D. Czyskowski, M. Jasinski, M. Moisan, D Guérin, C. Larquet, J. C. Rostaing, "Excitateurs de plasma micro-ondes", French patent FR 2 880 236, PCT application as WO 2006090037 (published on 31/08/2006), US 7 799 119. Assignee: Air Liquide. *A variant of the surfaguide field applicator where the narrowing of the wall (to ensure adequate impedance matching, at the launching interstice, with the surface-wave plasma column "seen as a transmission line" of given characteristic impedance) is arranged within a standard*

section of the waveguide, reproducing inside the waveguide similar step-transitions as achieved with the tapering down of the genuine surfaguide.

20. D. Guérin, C. Larquet, A. El-Krid, J.-C. Rostaing, M. Moisan, P. Moine, H. Dulphy, A.L. Lesort, E. Sandre, "Procédé de traitement, par plasma, d'effluents gazeux", French patent FR 2 888 519 (filed FR0552149 on 12 July 2005), EP1904664 (2 April 2008), Korea KR20080032089 (14 April 2008). PCT application as WO2007007003 (published on 18/01/2007). Assignee: Air Liquide. *Plasma torch system for treating gaseous effluents substantially at atmospheric pressure with water vapour injection, up and dowstrean the generated plasma.*

21. Y. Kabouzi, M. Moisan, J-C Rostaing, D. Guérin, "Traitement d'effluents gazeux par plasma à pression atmosphérique", French patent application FR04515227 on 13 July 2004. French patent FR 2 873 045. Assignee: Air Liquide. *Swirling gas flow injection (first design).*

22. H. Dulphy, P. Moine, V. Laurent, B. Depert, Y. Kabouzi, M. Moisan, J. C. Rostaing, D. Guérin, "Traitement d'effluents gazeux par plasma à pression atmosphérique", French patent FR 2 888 130 (2007-01-12), PCT WO2006008421 (2006-01-26), EP1768776 (2007-04-04), US application 2008 0234530 "Gas conversion by chemical bond cleavage in an electric and-or magnetic field, e.g. for treatment of fluorinated effluents from semiconductor production, involves injecting gas into the field in a non-rectilinear manner". Assignee: Air Liquide. *A device providing a swirling flow for the treatment of fluorinated effluents by surface-wave plasmas (electric field) to increase the effectiveness of the conversion of the gas or gas mixture molecules.*

23. C. Larquet, D. Guérin, J-C Rostaing, H. Dulphy, M. Moisan, "Procédé et dispositif de traitement d'effluents gazeux de procédés industriels", French patent FR 2 886 866 (2006-12-15) (Filed 9 June 2005). Assignee: Air Liquide. *TIAGO plasma torch system within a sealed vessel comprising cooling means (intended for TIAGO industrial gas remediation unit operating at 10s of kW).*

24. •M. Moisan, D. Guérin, C. Larquet, J.-C. Rostaing, A.L. Lesort, A. El-Krid, H. Dulphy, P. Moine, B. Depert, V. Laurent, E. Sandre, "System for the destruction of PFC molecules using an aluminum nitride comprising dielectric tube". European application as EP 08305205.0 filed on 28 May 2008. Assignee: Air Liquide. *System for the destruction of PFC molecules using an aluminum nitride comprising dielectric tube.*

25. •J.-C. Rostaing, D. Guérin, C. Larquet, P. Moine, B. Depert, V. Laurent, M. Moisan." Procédé de refroidissement d'un plasma micro-onde et système de destruction sélective de molécules chimiques utilisant ce procédé". Patent applications European EP2131633 (2009-12-09), US 2011073282, TW200352568, KR201100121816, JP2011522691, WO2009144110. Methods for cooling the discharge tube in microwave abatement system. Assignee: Air Liquide. *A process for selective destruction of chemical molecules where the coolant flow is in thermal contact with the outer wall of the tube to be cooled*, ***the coolant is a linear alpha-polyolefin oil having a carbonated chain of at least ten carbonatoms and/or perfluorocarbonated liquids having a dielectric permittivity lower than 2.5, a microwave loss tangent tan δ between 10^{-2} and 10^{-4}, and a specific heat Cp-0.6 g. cal/g. C.***

26. •Z. Zakrzewski, T. Fleisch, J. Pollak, M. Moisan, D. Guérin, M. Jasinski, D. Czylkowski, C. Larquet, A.L. Lesort, J.-C. Rostaing, " Système de couplage micro ondes - plasma et son

application à la destruction sélective de molécules chimiques" European application as EP 08305208.4 filed on 28 May 2008. Assignee: Air Liquide.

27. J. Pelletier, A. Lacoste, T. Lagarde, M. Moisan, Y. Arnal, Z. Zakrzewski, "Diviseur de puissance pour dispositif à plasma" (French patent application filed on 13 September 1999 as FR 99/11422). PCT publication (22/03/2001) under WO 01/20710. US patent 6,727,656. Assignee: CNRS, Université de Montréal and Metal Process (French company). *Equal part microwave power divider into many ports along a waveguide, ensuring absence of influence of any port on others.*

28. M. Moisan, S. Moreau, M. Tabrizian, J. Pelletier, J. Barbeau, L'H. Yahia, "Système et procédé de stérilisation par plasma gazeux à basse température". European patent EP 1 181 062 (2004), validity: France, Belgium, Spain, Switzerland, Italy, Germany, UK., US 6 707 254 (2004) (restricted author list in the USA : M. Moisan, S. Moreau, M. Tabrizian, J. Pelletier). Assignee: Université de Montréal. *Early afterglow of a surface-wave sustained N_2-O_2 discharge as a means of filling a sterilization vessel ensuring bacterial spore inactivation by UV irradiation from the NO molecules generated from the combination of N and O atoms (first sterilization chamber concept).*

29. M. Moisan, N. Philip, B. Saoudi, "Système et procédé de haute performance pour la stérilisation par plasma gazeux à basse température", provisional Canadian application 2395659 (26/07/2002). PCT application filed on 24/07/2003, published on 5 February 2004 under WO2004/011039 A2. US patent 7 695 673. European patent EP 1 526 875, validity: Sweden, France, UK and Germany. Applicant: Université de Montréal. *Depending on the distance between the N_2-O_2 discharge and the sterilization chamber entrance, the sterilization chamber is filled with an early (flowing) afterglow (short distance) or a late afterglow (no ions present). UV biocidal irradiation action is maximized by adjusting the N_2/O_2 ratio (second sterilization plasma-vessel configuration).*

30. M. Moisan, B. Saoudi, J. Pollak, Z. Zakrzewski, "Procédé de stérilisation par plasma d'objets de nature diélectrique et comportant une partie creuse", provisional Canadian application 2412997 on 24 March 2003. PCT application (01/12/2003), published on 17 June 2004 as WO2004050128. European patent EP 1 567 200, validity France, UK and Germany. US patent application 2005 269199. Assignee: Université de Montréal. *Process for the plasma sterilization of dielectric objects comprising a hollow part, e.g. endoscope. The internal and external parts are sterilized sequentially using the N_2-O_2 discharge flowing afterglow.*

31. J. Pollak, M. Moisan, "Appareil et procédé d'inactivation et/ou stérilisation par plasma", US patent application 60/884,344 filed on 11 January 2007, PCT application: CA2008/000032 filed on 9 January 2008. US patent 8 277 727. Assignee: Université de Montréal. *A linear conducting strip is used to carry microwave field within and along a rectangular vessel in which bacterial spores to be inactivated are in direct contact with plasma.*

32. •Z. Zakrzewski, M. Moisan, D. Guérin, J.-C. Rostaing, "Dispositifs générateurs de plasmas micro-ondes et torches à plasma", French patent application FR0757719 on 20 September 2007. PCT application (16 September 2008), published under number WO 2009/047441 A1 on 16 April 2009 : 34 designated countries. US patent application publication as 2012/0018410 : Microwave plasma generating plasma and plasma torches. Assignee: Air

Liquide. *Plasma is generated by an EM field radiating from of a conductor (rod or micro-strip line surface), "attached" to a dielectric (the dielectric covers the conducting rod or substrate).*

33. •A. Mahfoudh, J. Séguin, M. Moisan, J. Barbeau, P. Levif, "Biocidal polymers, methods of preparation thereof, and methods for disinfecting and/or sterilizing objects", American provisional application 61/165,589 on first of April 2009.. PCT appliation WO 2010/111790 filed on April first 2010, published on 7 October 2010. US patent application: 200961165589. Assignee: Université de Montréal. *When pre-exposed to an ozone flow, some polymers determine a biocidal surface under a relative humidity atmosphere above 50 % as ozone is being slowly released.*

34. P. Levif, J. Séguin, M. Moisan, "Methods for plasma sterilization using packaging material" provisional US application 61/ 371429 on 6 August 2010, provisional PCT application WO2012/016329 A1 published on 9 February 2012. US patent 8,980,175. Assignee: Université de Montréal. *A process where plasma flowing afterglow sterilization is associated with non-porous packaging material to be sealed afterwards (infinite on shelf time).*

35. J. Pelletier, A. Lacoste, M. Moisan, "Gas discharge lamp, has casing comprising active gas containing oxygen and/or nitrogen oxide, where mixture of plasma gas and active gas emits UV or visible radiation and mercury content in casing is zero", French Patent FR 2 980 912. Assignee: CNRS and Université de Montréal. *Gaseous fluorescent-like lamps without mercury.*

Remarks:

1- Each entry ends, in italic font, with a sentence (that I wrote) summarizing the core of the invention.
2- Some patent applications were not pursued past the first examination report (none rejected) due either to lack of funds (UdeM) or, in the case of Air Liquide, for limiting expenses, making sure nonetheless that competition could not then patent an application that could prevent them from using a main patent: entries 16, 24, 25, 26 and 32 belong to that latter category.
3- The US Patent and Trade Office (USPTO) considers that, when a patent application describes a process and, additionally, a way of achieving it, it corresponds to two inventions and, therefore, should be identified by to two distinct patent applications and, later on if the case, by to two distinct patent numbers. This process is designated *a division of parent applications/patents*.
4- The order in which inventors appear in an application/patent is set, in principle, by the patent agent of the applicant. However, sometimes USPTO (and in Canada IC) modifies this order (why?).
5- Since 1995, patent validity (protection) is 20 years in all countries.

List of US patent applications (10) officially published by USPTO (disclosing patent content and drawings) and US patents granted (19).

US patent applied for:NO.	Title

1	20140138361	Microwave plasma generating devices and plasma torches
2	20120018410	Microwave Plasma Generating Plasma and Plasma Torches
3	20110073282	Method for cooling microwave plasma and system for the selective destruction of chemical molecules using said method
4	20100155222	Application of dense plasmas generated at atmospheric pressure for treating gas effluents. A division of the parent US application 20020195088.
5	20090020009	Microwave plasma exciters
6	20080234530	Gas conversion by chemical bond cleavage in an electric and-or magnetic field, e.g. for treatment of fluorinated effluents from semiconductor production, involves injecting gas into the field in a non-rectilinear manner
7	200961165580	Biocidal polymers, methods of preparation thereof, and methods for disinfecting and/or sterilizing objects
8	20080234530	Atmospheric Pressure Plasma Treatment of Gaseous Effluents
9	20050269199	Process for the plasma sterilization of dielectric objects comprising a hollow part
10	20040195088	Application of dense plasmas generated at atmospheric pressure for treating gas effluents

US patents granted

	PAT. NO.	Title
1	8,980,175	Methods for plasma sterilization using packaging material
2	8,277,727	Device and method for inactivation and/or sterilization using plasma
3	7,799,119	Microwave plasma exciters
4	7,695,673	Processes and devices for sterilizing contaminated objects
5	6,916,400	Device for the plasma treatment of gases
6	6,727,656	Power splitter for plasma device
7	6,707,254	Low temperature plasma sterilising system and method
8	6,541,917	Section of pipe for a gas treatment device and device incorporating such a section of pipe
9	6,298,806	Device for exciting a gas by a surface wave plasma

10 6,290,918 Process and apparatus for the treatment of perfluorinated and hydrofluorocarbon gases for the purpose of destroying them A division of the parent US patent 5,965,786

11 6,224,836 Device for exciting a gas by a surface wave plasma and gas treatment apparatus incorporating such a device

12 6,190,510 Process for purifying a gas and apparatus for the implementation of such a process A division of the parent US patent 5,993,612

13 5,993,612 Process for purifying a gas and apparatus for the implementation of such a process

14 5,965,786 Process and apparatus for the treatment of perfluorinated and hydrofluorocarbon gases for the purpose of destroying them

15 5,759,623 Method for producing a high adhesion thin film of diamond on a Fe-based substrate

16 5,360,485 Apparatus for diamond deposition by microwave plasma-assisted CVPD

17 4,906,898 Surface wave launchers to produce plasma columns and means for producing plasma of different shapes A division of the parent US patent 4,810,933.

18 4,810,933 Surface wave launchers to produce plasma columns and means for producing plasma of different shapes

19 4,049,940 Devices and methods of using HF waves to energize a column of gas enclosed in an insulating casing

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From Air Liquide 2008 annual report, following a share holder question, comments made by Mr. Thierry Sueur, V-P Head of Air Liquide Intellectual Property:

Share holder question: "Can you cite a recently registered patent that makes an important contribution to sustainable development"? Answer: "The Universal Plasma Abatement System (UPAS) is an undeniably prominent invention. It meets environmental challenges posed by the semiconductor industry, where production methods require the use of gases that can harm the environment. Thanks to this plasma-based technology which destroys these gases, the environmental impact in this process is now under control".

6,290,918 Process and apparatus for the treatment of perfluorinated and hydrofluorocarbon gases for the purpose of destroying them A division of US parent patent 5,965,786

5,965,786 Process and apparatus for the treatment of perfluorinated and hydrofluorocarbon gases for the purpose of destroying them.

M. Sc. and Ph. D graduated students

- Gary MITCHEL (M. Sc.), Le surfaguide, une nouvelle source de longues colonnes de plasma H.F. (mars 1976).
- Christopher MOUTOULAS (M. Sc.), Réalisation et étude du gain d'un laser He-Ne pompé par une décharge microonde d'ondes de surface (juin 1985).
- Gaston SAUVÉ (M. Sc.), Effet de la fréquence d'excitation d'un plasma d'ondes de surface sur la gravure du polyimide (octobre 1988).
- Claude BARBEAU (M. Sc.), Étude expérimentale du bilan énergétique d'une décharge entretenue par une onde de surface (octobre 1988).
- Joëlle MARGOT (D. Sc.), Étude théorique et expérimentale des plasmas de grand diamètre entretenus par une onde électromagnétique de surface de haute fréquence se propageant sur le mode à symétrie, soit azimutale, soit dipolaire (juillet 1989). - Codirection avec A. Ricard (thèse soutenue à Paris-XI).
- Richard CLAUDE (Ph. D.), Polymérisation par plasma: effet de la fréquence de l'onde électromagnétique entretenant la décharge (juin 1990). - Codirection avec M.R. Wertheimer.
- Serge LEVESQUE (M. Sc.), Étude de l'effet de fréquence sur les caractéristiques d'un plasma entretenu par une onde de surface à des pressions voisines de l'atmosphère (octobre 1991).
- Fouad BOUNASRI (M. Sc.), Effets de la tension et de la fréquence de polarisation du substrat sur la vitesse de gravure par plasma du polyimide (février 1992).
- Louis ST-ONGE (M. Sc.), Caractérisation de décharges d'hydrogène entretenues par un champ de haute fréquence (40-2450 MHz) et optimisation de leur rendement en hydrogène atomique (novembre 1992).
- Iscra BOYADJIÉVA (M. Sc.), Laser CO_2 en guide d'ondes à excitation par ondes de surface électromagnétiques: étude expérimentale (décembre 1992).
- Carlos DE MELLO BORGES (Ph. D.), Élaboration de couches minces de diamant à partir d'un plasma d'onde de surface non conventionnel (juin 1996).
- Fouad BOUNASRI (Ph. D.), Étude de la gravure du tungstène, du silicium, du carbure de silicium et d'une résine en fonction de la température du substrat dans un magnétoplasma à onde de surface (juin 1996). – Codirection avec M. Chaker.
- Patrice JONES (M. Sc.), Destruction de gaz moléculaires à effet de serre au moyen d'un plasma micro-ondes fonctionnant à la pression atmosphérique (juin 1996).
- Céline CAMPILLO (M. Sc.), Dépôt et caractérisation de couches de diamant polycristallin sur du carbure de tungstène cémenté au cobalt (WC-Co) (mars 1999).
- Stéphane MOREAU (M. Sc.), Stérilisation par plasma différé : compréhension et optimisation du procédé (février 2000).
- Philippe MÉREL (Ph. D.), Conception et mise au point d’un système combinant l’ablation laser et une source d’azote atomique pour la synthèse de nitrures (CN_x et GaN) sous la forme de couches minces (avril 2001). Codirection avec M. Chaker.

- Yassine KABOUZI (Ph. D.), Contraction et filamentation des décharges micro-ondes entretenues à la pression atmosphérique : application à la détoxication des gaz à effet de serre (juin 2003).
- Marie-Charlotte CREVIER (M. Sc.), Effets de la stérilisation par plasma N_2-O_2 en post-décharge sur des spores de B. subtilis et surface de bio-polymères (juin 2003). Codirection avec L'H Yahia.
- Nicolas PHILIP (M. Sc.), Stérilisation à basse température et à pression réduite en post-décharge de plasma: étude et analyse du rôle des UV dans l'inactivation de spores bactériennes (juin 2003). Codirection avec J. Barbeau.
- Eduardo CASTAÑOS-MARTINEZ (M. Sc.), Influence de la fréquence d'excitation des décharges entretenues par onde de surface sur la contraction et la filamentation à la pression atmosphérique (mars 2005).
- Jérôme POLLAK (M. Sc.), Applicateurs linéaires de champs EM utilisant la technologie triplaque pour l'entretien de décharges HF (50-2450 MHz) (août 2005).
- Thomas FLEISCH (M. Sc.), Adaptation d'impédance des applicateurs de champ HF servant à l'entretien de plasmas d'onde de surface (mars 2006).
- Crina Anca POPOVICI (M. Sc.), Caractérisation de la post-décharge à pression réduite d'un plasma de N_2-O_2 : optimisation des conditions opératoires et maximisation de l'intensité UV émise dans la chambre de stérilisation. Application de la loi de fluence à l'inactivation de spores bactériennes par les photons UV (mai 2006).
- Martin NANTEL-VALIQUETTE (M. Sc.) Destruction de gaz à effet de serre par un plasma micro-ondes entretenu à la pression atmosphérique (mars 2007).
- Mustafa-Karim BENHACENE-BOUDAM (Ph.D.) Contribution à l'étude de l'inactivation de micro-organismes par plasma (novembre 2007).
- Jérôme POLLAK (Ph.D.) Développement et utilisation de sources de plasma pour stériliser des instruments médicaux (février 2009).
- Ahlem MAHFOUDH (Ph. D.) Étude des mécanismes d'inactivation des microorganismes suite à un traitement à l'ozone (décembre 2009).
- Eduardo CASTAÑOS-MARTINEZ (Ph. D.) Contraction et décontraction des décharges micro-ondes entretenues à la pression atmosphérique (novembre 2010).
- Denis CARIGNAN (M. Sc.) Étude de l'influence de la réassociation en surface des atomes N et O sur l'inactivation de spores bactériennes dans une post-décharge N_2-%O_2 basse pression en flux (février 2013).
- Amaury KILICASLAN (M. Sc.) Étude spectroscopique d'un plasma micro-onde à la pression atmosphérique et son application à la synthèse de nanostructures (août 2013).

Post-doctoral students (18)

- R. Pantel 1979
- H. Malvos 1993
- M.D. Calzada, 1994

- C.F.M. Borges, 1996
- R. Etemadi, 1996
- C. Galos, 1996
- S. Schelz, 1996
- S. Ilias, 1998
- B. Saoudi, 2000-2005
- M. Gaillard, 2000
- K. Makasheva, 2003-2006
- Y. Kabouzi, 2003
- S. Villeger, 2004
- M. Zoulgami, 2005
- K. Benhacene Boudam, 2007
- P. Levif, 2007
- A. Soum-Glaude, 2008
- J. Muñoz, 2010
- J. Henrique, 2014

HIGH DENSITY PLASMA SOURCES

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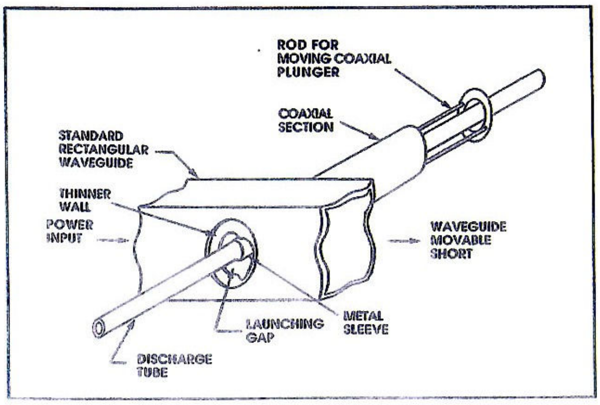

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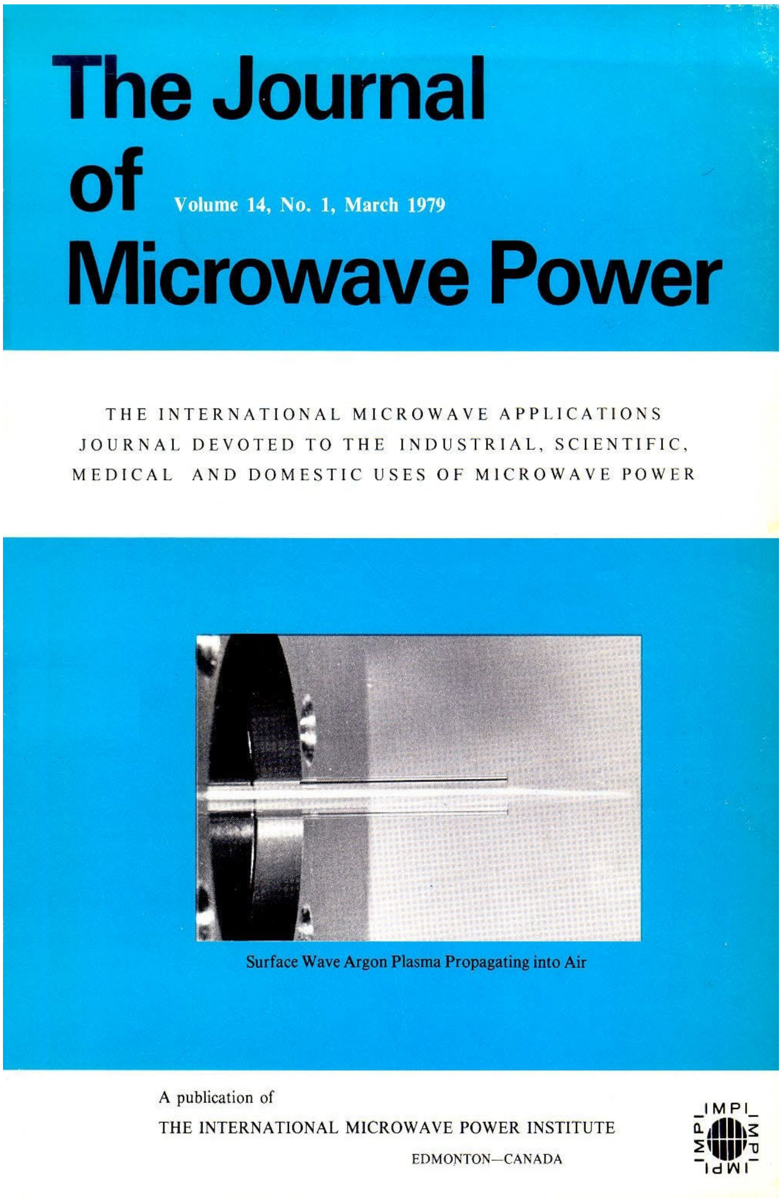
Waveguide – surfatron schematic description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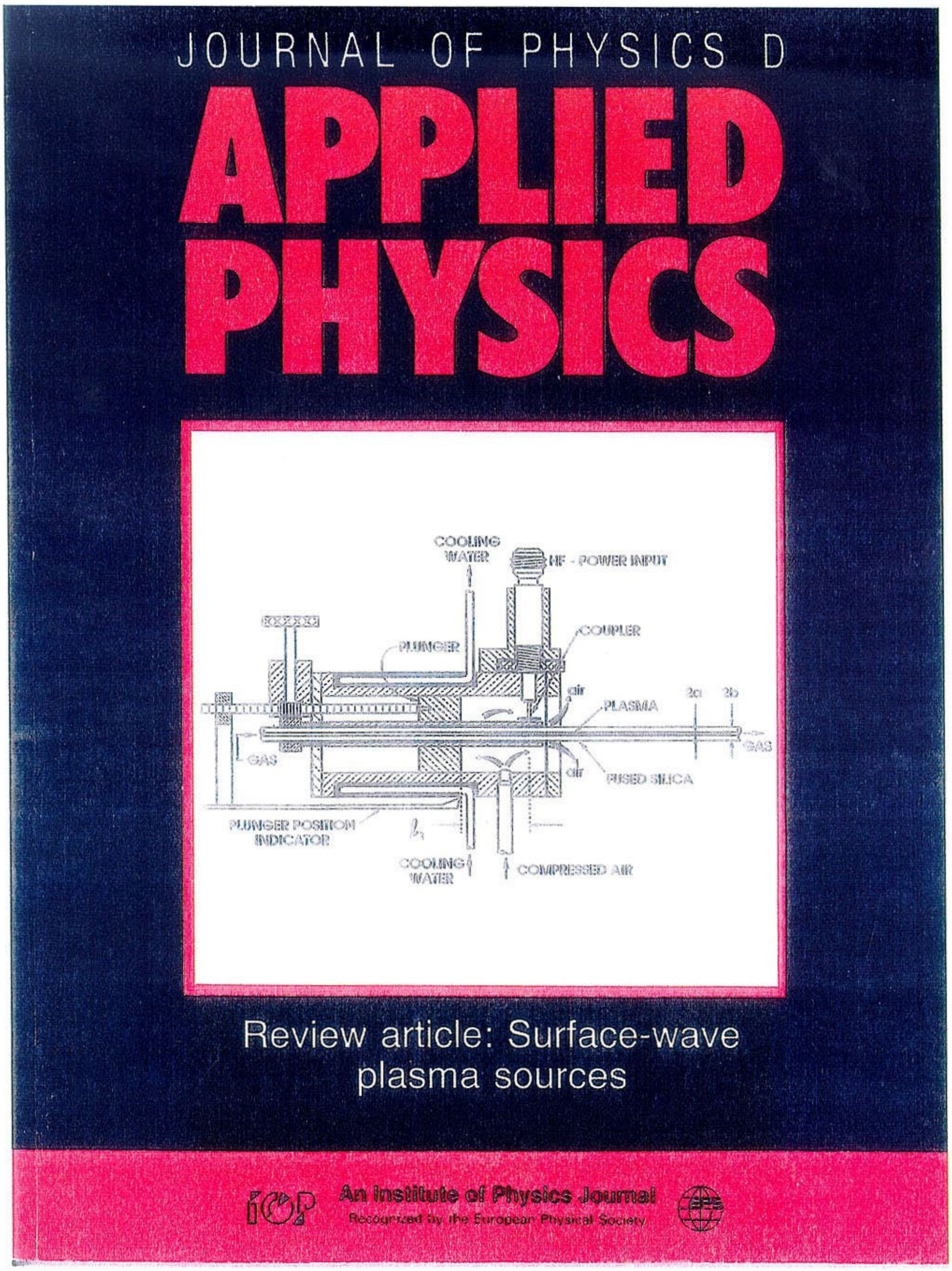

Schéma du surfatron

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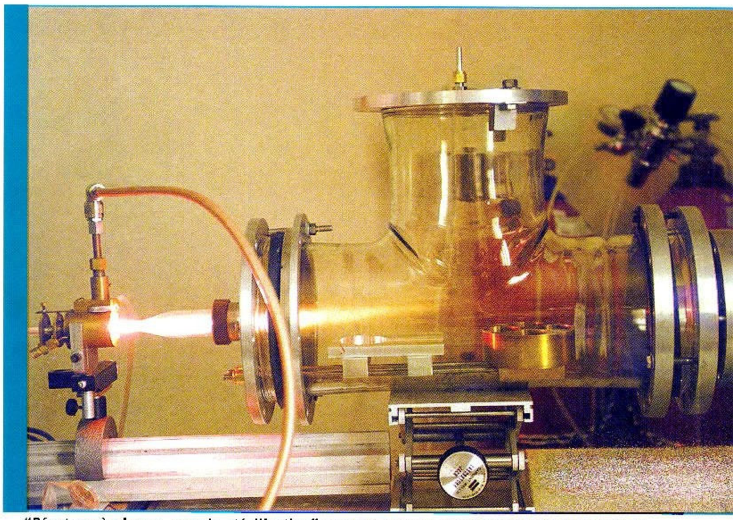

"Réacteur à plasma pour la stérilisation" - Photo de Bernard Lambert / Laboratoire de Michel Moisan, Université de Montréal.

Stérilisation - Plasmas froids

sfv

First surface-wave plasma reactor, which was instrumental in understanding plasma sterilization
(Groupe de physique des plasmas, Université de Montréal)

303 **Le Vide** : science, technique et applications **"Procédés plasmas froids - Stérilisation médicale & alimentaire"** 1/4 2002

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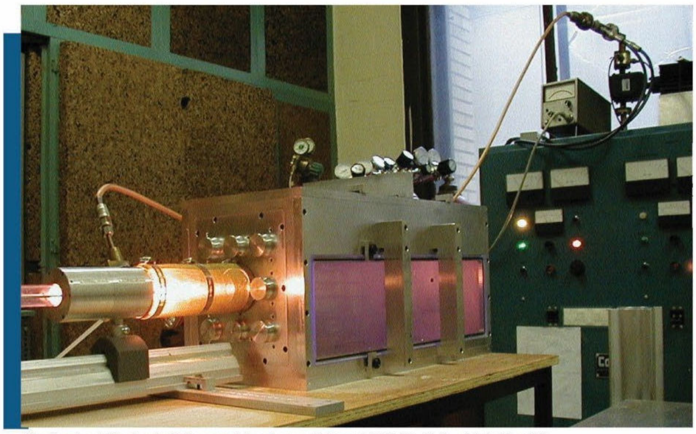
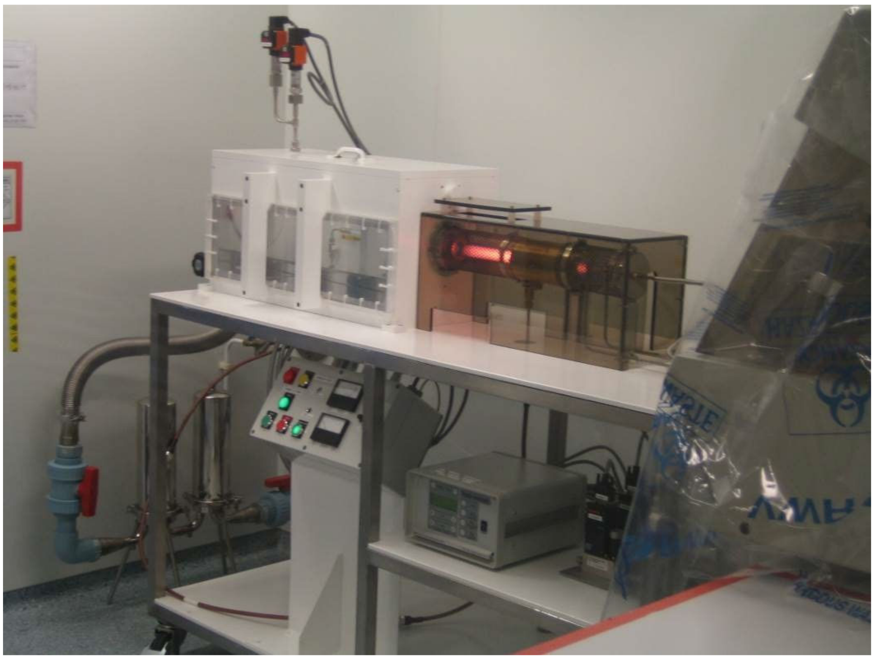


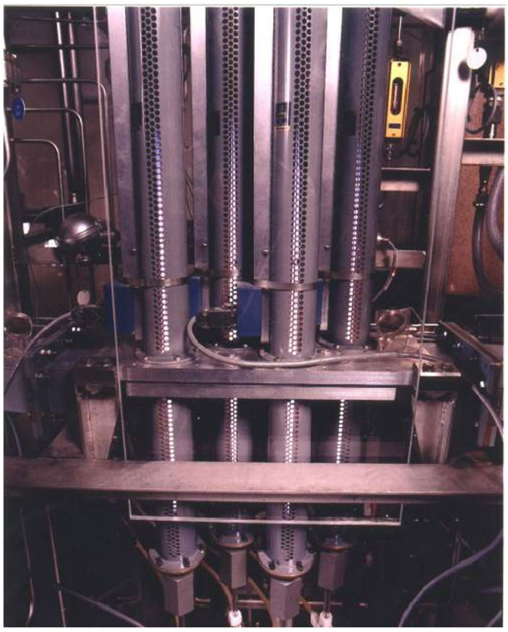
Chambre de stérilisation de 50 litres en régime de post-décharge à 915 MHz (Université de Montréal).
Photo : Nicolas Philip

Procédés plasmas froids
Stérilisations médicale & alimentaire

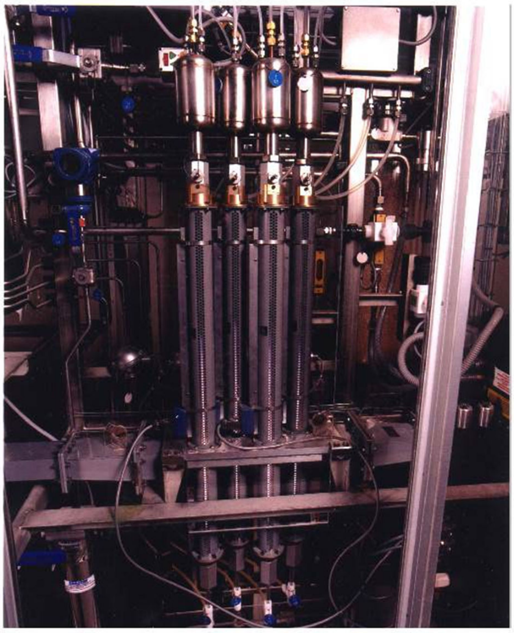
sfv

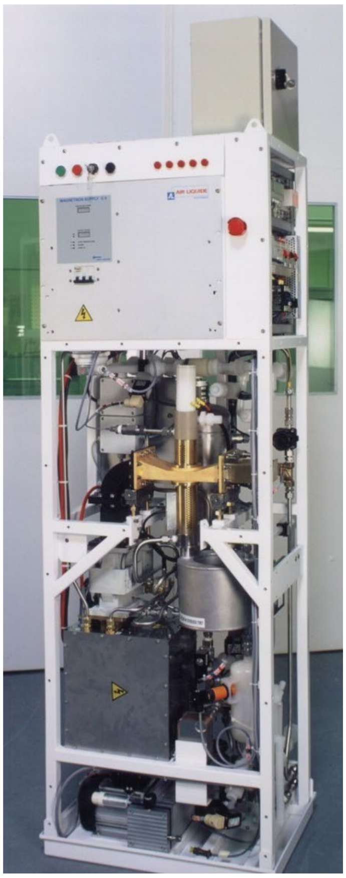


Sterilization system designed and realized by Moisan's team, implemented at the Centre Hospitalier Universitaire (CHU) in Liège, Belgium where it was installed by Air Liquide plasma physics engineering group (CRDP, Versailles, France). The experiments, conducted by Dr. W. Zorzi (CHU Liège), aimed at investigating the inactivation of the pathogenic Prion protein (mad cow disease) by the late flowing-afterglow(meaning no electrons left) of a N_2-O_2 discharge sustained by a propagating EM surface wave. Work performed in a P3 biological safety level environment.



First automated system, installed at Moissy-Cramayel (France) for ensuring Kr and Xe very high-level purification. A whole factory building is now dedicated to such rare gas purification and the process is fully computer-control, working 24/24. A similar factory has been put up in Germany





First Air Liquide prototype assembled to eliminate green-house gases currently used in micro-electronics fabs (chips manufacturing), built according to Moisan’s team indications

More advanced greenhouse gases remediation system commercialized under UPAS (Universal Plasma Abatement System) by Air Liquide company for microelectronics fabs at different locations in the world. It can handle up to 4 production plasma reactors (total gas flow up to 120 slm). Maximum MW power consumption 6 kW. From left to right, system computer controlled, surfaguide plasma abatement system, alkaline-bed unit for collecting process residue (scrubber).

Still more compact UPAS system (not shown) are now being commercialized: proprietary informatio

UNIVERSIDAD DE CÓRDOBA

Departamento de Física

Córdoba, 30 de abril de 2024

Sra. Vicerrectora de Estudios de Posgrado
Instituto de Estudios de Posgrado (IdEP)
Rectorado
Universidad de Córdoba

Propuesta de Otorgamiento del Grado de Doctor Honoris Causa al Prof. Dr. Michel Moisan que presenta el Departamento de Física de la Universidad de Córdoba.

En sesión ordinaria del Consejo de Departamento del Departamento de Física celebrada el 2 de abril de este 2024, se aprobó por **unanimidad** solicitar el otorgamiento del grado de Doctor Honoris Causa, máxima distinción de la Universidad de Córdoba, al Prof. Dr. Michel Moisan del *Département de Physique* de la *Université de Montréal* (Canada) por la rama de conocimiento de Ciencias, para el curso 2024/2025, así como proponer tanto Relator/a y Padrino (Madrina) a la Prof. Dra. María Dolores Calzada Canalejo, Catedrática de Física Aplicada del Departamento de Física.

De acuerdo al Reglamento 57/2020 de los Estudios de Doctorado de la Universidad de Córdoba, nuestra institución podrá otorgar la distinción Doctor Honoris Causa a personas de reconocido prestigio académico, científico e investigador y que haya prestado destacados servicios a la Universidad de Córdoba

En ese mismo reglamento, en su artículo 76.1, se exige que la propuesta del correspondiente órgano colegiado cuente con el "respaldo, por mayoría absoluta, de dos órganos colegiados de igual naturaleza". Sin embargo, la propuesta que se presenta cuenta con el respaldo, por mayoría absoluta, de tres órganos colegiados además del proponente:

1. En primer lugar, el Departamento de Química Orgánica, reunido el 15 de abril de 2024, en sesión extraordinaria, acordó por **unanimidad** adherirse a la propuesta realizada por el Departamento de Física.

2. En segundo lugar, el Departamento de Química Física y Termodinámica Aplicada, en sesión extraordinaria celebrada el 22 de abril de 2024, aprobó por **mayoría absoluta** su adhesión a la solicitud objeto de este escrito.

3. En tercer lugar, la Junta de Facultad de Ciencias, en sesión extraordinaria celebrada el 30 de abril de 2024, decidió por **unanimidad** adherirse a esta propuesta del Departamento de Física.

Por otro lado, la propuesta que se formula cuenta con la adhesión de cinco investigadores de reconocido prestigio internacional en el campo científico de la Física de Plasmas, lo que es una muestra más de la relevancia de la trayectoria profesional del candidato propuesto en este campo. Dichos profesore son:

- Prof. Dr. Gary M. Hiefjte, *Distinguished Professor de Indiana University (EUUU).*
- Prof. Dr. David B. Graves, *Professor de Princeton University (EEUU).*
- Prof. Dr. Francoise Massines, *"Directrice de recherche au CNRS and Head" de PROMES laboratory (Francia)*
- Prof. Dr. Slobodan Vukovic, *Professor (retired) de Institute of Physics Belgrade* (República Serbia)
- Dr. Carlos Hidalgo, *Director del Laboratorio Nacional de Fusión-CIEMAT (España).*

Además de cumplir con los requisitos establecidos en el reglamento esta solicitud se basa en diversas razones, entre las que destacan las siguientes:

1. El Prof. Moisan ha mantenido una vinculación permanente con la Universidad de Córdoba desde 1994, quedando reflejada en la participación en proyectos de I+D con miembros del Departamento de Física, la donación de instrumentación científica, la publicación conjunta de artículos científicos en revistas de alto impacto, el acogimiento y la formación de personal investigador en etapas pre y post-doctoral, miembro de tribunales de tesis doctorales y la impartición de diferentes conferencias científicas en la Facultad de Ciencias.

2. Desde el punto de vista científico, el Prof. Michel Moisan es reconocido como una figura de referencia en su campo, la Física de Plasmas y sus aplicaciones en áreas tan diversas como energía, materiales, esterilización, eliminación de gases contaminantes, etc. Por otra parte, la extensa y excelente calidad de su bibliografía le han llevado a ser uno de los investigadores más citado en su campo, alcanzando un número de citas superior a 6000. Por otra parte, su transferencia de conocimiento se ha materializado en alrededor de 40 patentes y el haber sido galardonado con el prestigioso premio *"European Physical Society's Plasma Physics Innovation Prize"* en 2017.

3. Por último, desde un punto de vista humano, el Prof. Moisan cumplirá 83 años en mayo de 2025. Pese a su edad continúa como profesor emérito de la Université de Montreal desde abril de 2015, haciendo llegar sus conocimientos a la comunidad científica a través de la publicación de artículos en revistas científicas de alto impacto, datado el último en 2022.

Es de destacar, la ilusión que el Prof. Moisan mostró al comunicarle que se iba a iniciar el trámite para la solicitud de su nombramiento como Doctor Honoris Causa por nuestra universidad y en la que ha reconocido el agradecimiento implícito que desde nuestra institución y desde el propio Departamento de Física se le hace al poner en valor su contribución al posicionamiento de los investigadores de la Universidad de Córdoba en el mapa mundial de la investigación en el campo de la Física de Plasmas.

LA SECRETARIA

Fdo. Prof. Dra. Rocío Rincón Liévana

UNIVERSIDAD DE CÓRDOBA
Departamento de Química Orgánica

Córdoba, 15 de abril de 2024

Nuestra referencia:
Salida nº 013

Asunto:
Propuesta de otorgamiento de Doctor Honoris Causa
Destinatario:
Dra. Mª Dolores Calzada
Directora del Departamento de Física
Catedrática de Física Aplicada

Le comunico que el Consejo de Departamento de Química Orgánica, en la sesión extraordinaria de fecha 15 de abril de 2024, ha aprobado por unanimidad de los presentes, la adhesión a la propuesta de otorgamiento del grado de Doctor Honoris Causa al Prof. Dr. Michel Moisan del Département de Physiquede la Université de Montreal (Canadá) solicitada por el Departamento de Física Aplicada.

Atentamente,

EL DIRECTOR DEL
DEPARTAMENTO DE QUÍMICA ORGÁNICA,
Fdo.: Antonio Ángel Romero Reyes

ROMERO REYES ANTONIO ANGEL - 30506285M

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UNIVERSIDAD DE CÓRDOBA

Departamento de Química Fisica y Termodinámica Aplicada

Asunto: Solicitud Adhesión del Dpto. Química Física y T. Aplicada Propuesta Otorgamiento Dr. Honoris Causa

EJECUCIÓN DE ACUERDO

En la sesión de Consejo de Departamento con carácter Extraordinario celebrada el día 22 de abril, se aprueba, por mayoría absoluta, la solicitud recibida desde el Departamento de Física de la Universidad de Córdoba, esta es: Adhesión del Departamento de Química Física a la propuesta de otorgamiento del grado de Doctor Honoris Causa al Prof. Dr. Michel Moisan de la Universidad de Montreal (Canadá).

Córdoba, 22 de abril de 2024

Secretario del Departamento

CAMACHO DELGADO LUIS - 28510539S

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Luis Camacho Delgado

Vº Bº Directora de Departamento

MARTIN ROMERO MARIA TERESA - 80131168L

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María Teresa Martín Romero

UNIVERSIDAD DE CÓRDOBA

Facultad de Ciencias - Campus de Rabanales

Secretaria Académica

MARTA ROSEL PÉREZ MORALES, Secretaria Académica de la Facultad de Ciencias de la Universidad de Córdoba

CERTIFICA:

Que la Junta de la Facultad de Ciencias, reunida en sesión extraordinaria el día 30 de abril de 2024, en su punto 3º del orden del día, aprobó por unanimidad de los 32 asistentes respaldar la propuesta, realizada por el Departamento de Física de la Universidad de Córdoba, de otorgamiento del Grado de DOCTOR "HONORIS CAUSA" por esta Universidad al Prof. D. MICHEL MOISAN de la Université de Montréal (Canadá), en virtud a sus méritos científicos y por su estrecha colaboración con dicho Departamento, con esta Facultad y con la Universidad de Córdoba.

Y para que conste y surta los efectos oportunos, firmo el presente en Córdoba, a 30 de abril de 2024.

MINISTERIO
DE CIENCIA,
INNOVACION
Y UNIVERSIDADES

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

A la atención de:
Vicerrectora de Estudios de Posgrado
Universidad de Córdoba

Madrid 22 de abril 2024

Estimada Vicerrectora,

Esta carta tiene la finalidad de apoyar la candidatura del Prof. Michel Moisan como Doctor Honoris Causa por la Universidad de Córdoba.

Durante mi mandato (2008 – 2012) como Presidente de la División de Física de Plasmas de la Sociedad Europea de Física (EPS) se acordó crear un premio a la Innovación en Física de Plasmas. El propósito de este premio era mostrar el gran impacto de la física de plasmas en la industria.

Como científico fuertemente comprometido con la EPS he sido testigo de primera mano de las importantes contribuciones del Prof. Michel Moisan al campo de la física y la innovación de plasmas, contribuciones que le hicieron merecedor del premio EPS a la Innovación en Física de Plasmas (2017). El Prof. Michel Moisan ha estado a la vanguardia de la investigación para el desarrollo y la comprensión de fuentes de plasma de microondas y sus aplicaciones en el procesamiento de materiales, la atención médica y la protección medio-ambiental. Su trabajo pionero no sólo ha avanzado en la comprensión científica de las fuentes de plasma de microondas, sino que también ha dado lugar a aplicaciones con impacto para la sociedad.

Además de su investigación innovadora, Michel Moisan ha demostrado un liderazgo excepcional en el campo de la física del plasma y ha trabajado incansablemente para promover la colaboración y el intercambio de conocimientos entre investigadores en el campo, entre los que se incluyen a grupos de la Universidad de Córdoba. Su dedicación al avance de la física del plasma y sus aplicaciones es verdaderamente encomiable.

Como director del Laboratorio Nacional de Fusión – CIEMAT soy testigo directo de cómo en la actualidad los grandes desafíos a los que se enfrenta la humanidad precisan de un enfoque interdisciplinar. La interconexión de diferentes desarrollos en áreas separadas de la ciencia, tal y como ha desarrollado el Prof. Michel Moisan, es crucial para abordar los grandes desafíos científicos y sociales que tenemos por delante.

Por todos los motivos expuestos, otorgo mi máximo apoyo al reconocimiento del Prof. Michel Moisan como Doctor Honoris Causa por la Universidad de Córdoba.

Atentamente,

C. Hidalgo

Carlos Hidalgo
Director, Laboratorio Nacional de Fusión-CIEMAT

CORREO ELECTRÓNICO
carlos.hidalgo@ciemat.es

AVENIDA COMPLUTENSE, 40
28040 - MADRID
TLF: 91 649201562

НАША ИНСТИТУЦИЈА

INSTITUTE OF PHYSICS BELGRADE

Letter of Support

I strongly support Professor (Emeritus) Michel Moisan from University of Montreal, Canada to be awarded "honoris causa doctorate" at the University of Cordoba, Spain. I have been introduced to Michel more than 50 years ago. Therefore, I have been able to follow his research throughout his fruitfully long career, as well as the work of several his collaborators. Although I am a theoretical physicist, as an expert in the field of surface states and surface waves, naturally I have been interested in his experiments and work more devoted to applications. We have followed the research of each other, mainly through publications and international scientific meetings.

His research work started by invention of Surfatron and Surfaguide in 1974, EM-field generators of surface wave plasma columns. The design has been of utmost interest for many years. Hundreds of surfatrons are being utilized worldwide in industrial and research labs. Many different types of surface-wave launchers, as well as the variety of applications were developed over the years by the team of Professor Michel Moisan.

His pioneering and profound contributions to the development and understanding of microwave plasma sources and their applications to material processing, healthcare and environmental protection, were finally recognized in 2017 when Innovation award was granted to Professor Michel Moisan by the European Physical Society.

He published more than 150 peer-reviewed articles and 19 chapters in the books with total number of 13094 citations. This revealed, according to Google Scolar H-index of 54. In addition, he gave 54 Invited Lectures at international conferences and published a textbook on Plasma Physics and another one on Atomic Physics and Optical Spectroscopy.

Moreover, his 35 patents were filed. Notewothy patents are Surfatron and Surfagide (e.g. US 4 049 940 /1977). Really, hundreds of surfatrons are being utilized worldwide in research and industrial labs. This design is now accepted and integrated into the plasma community.

Best regards,

Slobodan Vuković,

Research Professor of Physics (retired)

David B. Graves
Professor
Princeton University
E-Quad G203, 41 Olden Street
Princeton, NJ 08544
T: (609)-258-3756
E: dgraves@princeton.edu

Chemical and Biological Engineering
PRINCETON

Princeton University
School of Engineering
and Applied Science
Engineering Quadrangle
Princeton, N.J. 08544

April 18, 2024

Vice-Rector of Postgraduate Studies
Universidad de Córdoba, 14071 Córdoba (Spain)
(via Prof. Dr. Mª Dolores Calzada; md.calzada@uco.es)

RE: Support for the nomination of Prof. Dr. Michel Moisan (Université de Montréal) to be awarded the title of Doctor Honoris Causa

To Whom It Concerns:

I would like to support the nomination of Professor Michel Moisan to be awarded the title of Doctor Honoris Causa at the Universidad de Córdoba.

Professor Moisan has been a Professor of Physics at the University of Montreal since 1972. He is author or co-author of over 150 publications. His Google Scholar h-index is currently 55 and he has over 20 publications with over 100 citations. He was co-founder (with J. Pelletier) of the LITAP, International laboratory of technologies and applications of plasma.

Professor Moisan has made numerous, profound contributions to plasma physics and especially to the applications of plasma for a variety of commercial and industrial applications. He was the lead inventor appearing on the 1974 patent application disclosing the 'surfatron' and 'surfaguide' electromagnetic field applicators. These devices have been truly enabling for many plasma applications. They are widely used throughout the world for sustaining stable and reproducible plasma columns under a large range of operating conditions. The plasma discharge using these devices is conveniently achieved in dielectric tubing, allowing flowing gases to be utilized. The applied frequency ranges from 150 kHz to 40 GHz with discharge tube diameters from 1 mm to 300 mm radius. Plasma can be sustained with gas pressure as low 1 mTorr to at least 10 times atmospheric pressure. Establishing and maintaining stable plasma under such a wide range of conditions is not possible with any other existing plasma sources.

In terms of fundamental physics of plasmas, Moisan made many fundamental contributions, including but not limited to the following areas:
1. Moisan elucidated the problems associated with 'contraction phenomena' in electrical discharges (DC, RF and microwaves). See, e.g. Castaños-Martínez E., Moisan M., Kabouzi Y. (2009) He showed how to achieve non-contracted and non- filamentary rare-gas tubular discharges at atmospheric pressure. J. Phys. D., 42 012003.
2. Moisan's work clarified that electron power absorbed and lost should be locally balanced at steady state, implying that the EM E-field is operator-independent. Raising microwave power increases electron density, not the EM E-field intensity. Moisan’s team was first to clearly demonstrate this fact. (Moisan, Nowakowska in: doi:10.1088/0022-3727/48/45/455201)

These and related studies involving the physics of discharge structure and power balances had numerous other implications as well. From a practical point of view, hundreds of surfatrons have been utilized worldwide in industrial and research labs and this design is now so widely accepted and integrated into the plasma community that publications no longer refer to its inventors. Among many others that could be cited, the following abbreviated list identifies some examples of practical and novel use: robust, reliable secondary-ion mass spectroscopy in a French-Soviet spacecraft around Phobos, a Mars satellite; 2) efficient, powerful, low damage, room temperature surface sterilization; 3) efficient abatement effluent of difficult-to-treat global warming gases (perfluorocarbons and hydrocarbons) in chemical plants and semiconductor fabs; and 4) highly efficient and powerful purification of Kr and Xe gases obtained from cryogenic distillation in industrial chemical plants. Indeed, many different types of surface-wave launchers and a great variety of applications were developed over the years by the team of Professor Moisan as well as by many other teams throughout the world.

A second area of key contribution involves the use of low-pressure plasmas for sterilization. Moisan and colleagues developed an original sterilization method exploiting UV photons formed in the late afterglow of a N2-O2 discharge. N and O atoms are obtained from the dissociation of the N2 and O2 molecules. These species are long-lived, typically 100 ms (or more). They can penetrate between bacterial spores, forming at some point NO molecules. In turn, NO emits photons in the 180-350 nm range, which is useful for damaging the spore DNA. The late afterglow is preferred because in the absence of charged particles, no electrostatic charging by electrons of micro-organisms will occur. Such charging is to be avoided because it can lead to contamination of the sterilization chamber. The late afterglow is also less damaging to medical devices surfaces. This is consistent with observations of little structural damage of the spores. The work provides insight into inactivation mechanisms based on both experiments and modeling.

Professor Moisan's most recent work (arXiv 2106.11404 v8, 2014) is exciting evidence that he continues to be an important intellectual force and strong contributor to the worldwide plasma physics and engineering community!

In summary, I strongly support the nomination of Professor Moisan to become Doctor Honoris Causa from the University of Córdoba.

Sincerely,

David B. Graves
Professor of Chemical and Biological Engineering, Princeton University
Associated faculty, Princeton Plasma Physics Laboratory
Professor Emeritus, Chemical and Biomolecular Engineering, UC Berkeley

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Tel. 33 (0) 468 662 064
Fax. 33 (0) 468 662 287

Perpignan, April 17th, 2024

Dear Vice-Rector of Postgraduate Studies of the University of Córdoba,

It is with great pleasure that I write a letter for Prof. Dr. Michel Moisan from the University of Montreal to be awarded the title of Doctor Honoris Causa from the University of Córdoba.

Prof. Dr. Michel Moisan is an internationally recognized expert in the field of cold plasmas and their applications. One of the characteristics of his career is thematic mobility. Seeking to solve societal problems, he has contributed significantly to areas as varied as thin-film diamond deposition, greenhouse gas destruction, gas purification and object sterilization. For each subject, he was able to establish collaborations that allowed him to quickly contribute in a very relevant way to the progress of work at the global level. However, above all, Michel Moisan is the International Expert in microwave plasma, the scientist who can be said to have the best theoretical and experimental knowledge of the physics of microwave plasmas but also of reactors using this mode of plasma generation. He had a remarkable impact on the diffusion of these reactors around the world and even launched an international conference, "Conference on Surface Waves in Plasmas," on a particular type of microwave plasmas, surface wave-sustained plasmas. Today, he still participates in the scientific excitement of the plasma community by bringing a new way of considering electron density in a surface wave plasma.

Prof. Dr. Michel Moisan is one of the rare researchers who have successfully completed all stages of understanding from physics to the process used industrially. This approach requires very multidisciplinary skills concerning the generation of the electric field, its application to gas, the transformation of energy into active species adapted to the targeted application. With more than 150 articles in quality journals, 21 of which have been cited more than 100 times, an h-index of 54 and a constant progression in the citation rate, his work undoubtedly constitutes a reference for the entire scientific community. This is the results of an uncompromising scientific approach and its permanent concern to advance the understanding of the physics of plasmas and their interactions with a surface.

At the same time, he led his scientific discoveries into technological innovations, as evidenced by the 35 families of patents filed throughout his career. These patents have led to several industrial devices which is quite remarkable. Thus Prof. Dr. Michel Moisan is a co-inventor of surfatron and surfaguide; solutions marketed by the French company Sairem and widely used to generate plasmas using radiofrequency and microwave fields. The Air Liquide company also uses 2 processes discovered and developed by Prof. Dr. Michel Moisan and his team. One is a solution for removing, in an ecological way, hydrocarbons and fluorinated compounds from Kripton and Xenon, rare gases obtained by distillation of air. The other meets a need of the microelectronics industry: it eliminates, always in an ecological manner, gases with a strong greenhouse effect such as SF_6 or CF_4 which are very present in this field. The first is used in Air Liquide's German and French production centers. The second is marketed by Air Liquide under the name UPAS (Universal Plasma Abatement System). These developments result from 10 patents filed by the University of Montreal and purchased by Air Liquide and 17 inventions by Prof. Dr. M. Moisan protected by the Air Liquide company. Péchiney and Metal Process also bet on the economic interest of Michel Moisan's work. He also has 6 patents filed by the University of Montreal in the field of low temperature sterilization of medical devices.

Throughout his career, this great scientist, internationally recognized for the quality and rigor of his work in fundamental science, also acted as a consultant to companies. Thus, Quebec, Canadian, American, English and French industries have recognized the skills of Michel Moisan who, through these companies, has influenced and continues to influence the development of plasma processes in the world.

Prof. Michel Moisan has remained a very cutting-edge scientist while broadening his disciplinary field in order to apply his knowledge on the generation of microwave plasmas to the etching, the deposition of diamond layers, the destruction of perfluorocarbon, purification of rare gas and sterilization of objects he pioneered. For example, he is at the origin of the modeling of high frequency plasmas using the parameter [illegible], (ratio between the average power per electron lost by collision and absorbed from the high frequency field) and has largely contributed to the development of the scientific theme of plasma sterilization.

For each new area tackled, he was able to surround himself with competent researchers and engineers, open up to the appropriate community, knowing how to acquire the language and way of thinking while always pushing further his skills in microwave plasma. Thus, many experienced researchers have spent time at the University of Montreal and Prof. Dr. Moisan has co-signed articles with more than forty internationally recognized researchers from thirty-seven different laboratories and twelve countries, which confirms his ability to establish solid collaborations while respecting the skills and contribution of each person. The multiple collaborations of Prof. Dr. Michel Moisan have led him to welcome numerous students. He has very actively participated in the training of researchers, directing the work of numerous master's or PhD who are today plasma physics leaders.

Finally, we cannot talk about the contribution of Prof. Dr. Michel Moisan to the scientific community without talking about the quality of his articles. Michel Moisan chisels an article more than he writes it, always looking for the right word which ensures both a good understanding of the text and perfect scientific rigor. His articles are always complete, sufficiently detailed and precise. He never loses sight of the educational aspect and has written numerous summary articles, book chapters, two reference books. These texts serve as very comprehensive and educational references to both young and experienced researchers.

Prof. Dr. Moisan was awarded the 2005 Adrien-Pouliot Prize (France-Quebec Collaboration), awarded by the Association francophone pour le savoir – Acfas and the European Physical Society Plasma Physics Innovation Prize – 2017.

To conclude, I would say that that Prof. Dr. Michel Moisan is a leader in the field of Plasma Physics. His work has been instrumental in shaping the discipline. Throughout his career, he remarkably managed to maintain the balance between science and technology and between cutting-edge skills and multidisciplinary. He has significantly contributed to the advancement of plasma physics, to the diffusion of microwave plasmas in laboratories and above all led to the successful development of processes used in industry. Thus, I very strongly support the awarding of Doctor Honoris Causa from the University of Córdoba to Prof. Dr. Michel Moisan in acknowledgment of his exceptional contributions to science.

Yours sincerely,

Dr. Françoise Massines
Directrice de recherche au CNRS
Head of PROMES laboratory

INDIANA UNIVERSITY
DEPARTMENT OF CHEMISTRY
College of Arts and Sciences
Bloomington

April 13, 2024

To whom it may concern:

This letter is in support of Professor Michel Moisan, Professor *emeritus* at the University of Montreal, who is being nominated for an *Honoris Causa* Doctorate at the University of Cordoba. I understand that the primary nomination is being prepared by Professor Maria-Dolorès Calzada of the Physics Department at that university. Here, I will attempt not to repeat the facts cited by Prof. Calzada but rather will try to provide a different point of view.

Let me begin by placing my comments in perspective. I am an analytical chemist, not a physicist, but have spent a good share of my 55-year academic career in the study and application of plasmas and other ionized gases useful for chemical (atomic and molecular) analysis. As a result, I consult regularly the plasma-physics literature, employ many of the same measurement and modeling tools, and have exploited for chemical analysis a number of plasmas that were originally developed in the physics community. It is in this last realm that I first became acquainted with Prof. Moisan and specifically in his development and characterization of surface-wave launchers and discharges. My remarks will then naturally focus on this area of overlap.

The surface-wave-sustained plasmas developed by Prof. Moisan are particularly attractive for atomic and molecular emission and mass-spectrometric analysis. Unlike many plasmas sustained at microwave driving frequencies, the “surfatron” produces a toroidal plasma, in which power is coupled into the periphery of the discharge, along the inner boundary of a confining capillary, typically made of quartz. As a result, a chemical sample, in either vapor or aerosol form, can be introduced into the center of the capillary, within the toroidal discharge, and energy coupling is not perturbed significantly by the introduced material. In addition, emission from atoms, molecules and ions can be viewed from the end of the plasma, within the center of the toroid, where emission from the target species is concentrated and where background emission from the plasma support gas is weakest. Moreover, a range of plasma-support gases can be used, including helium, which is required to excite and ionize species such as non-metals and especially the halogens, with rather high energies of excitation and ionization. These features have combined to make Prof. Moisan’s surface-wave plasmas potentially strong competitors to the radiofrequency-sustained argon inductively coupled plasma (ICP), long viewed as the standard for elemental analysis. Indeed, we have published several papers in which the surfatron plays a key role, in two cases sufficiently importantly to be featured in the title.

These findings were important not only in their direct application to chemical analysis, but also in their influence on the conception and development of other wave-launching devices, such as the so-called “Microwave Plasma Torch” (MPT), which originated in China and which is now being marketed commercially.

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Clearly, even in this single area, Prof. Michel Moisan has had a tremendous impact on a field (analytical chemistry) nominally not his principal focus. When combined with his additional important contributions, he seems to be a compelling candidate for an *Honoris Causa* Doctorate at the University of Cordoba. He has my strongest possible support.

Please let me know if you would like me to amplify any of the foregoing comments.

Sincerely,

Gary M. Hieftje
Distinguished Professor

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