N° PROYECTO : 1100065  
DURACIÓN : 2 años  
AÑO ETAPA : 2011

TÍTULO PROYECTO : THE ULTRA LOW INDUCTANCE NITROGEN CAPILLARY DISCHARGE AS A WATER WINDOW SOFT X-RAY SOURCE

DISCIPLINA PRINCIPAL : FISICA DE PLASMAS
GRUPO DE ESTUDIO : FISICA TEORICA Y EXP
INVESTIGADOR(A) RESPONSABLE : EDMUND SYDENHAM WYNDHAM HODDER
CIUDAD : Santiago
REGION : METROPOLITANA

COMISIÓN NACIONAL DE INVESTIGACION CIENTÍFICA Y TECNOLÓGICA

VERSION OFICIAL Nº 2

FECHA: 29/05/2012
INFORME FINAL
PROYECTO FONDECYT REGULAR

OBJETIVOS
Cumplimiento de los Objetivos planteados en la etapa final, o pendientes de cumplir. Recuerde que en esta sección debe referirse a objetivos desarrollados, NO listar actividades desarrolladas.

<table>
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<th>Nº</th>
<th>OBJETIVOS</th>
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<tr>
<td>1</td>
<td>A. Design and Construction second Generation Pulsed Power Driver</td>
<td>PARCIAL</td>
<td>This has been designed, constructed and prepared for testing on Dummy Loads, but as yet has not been installed to drive the capillary. The reasons for this are i. that the First Generation design has performed better than expected under all severe load conditions and ii. extended results sessions, which were very successful and have generated a further publication precluded the shut down of the experiment to install, test and evaluate the new driver</td>
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<td>B. Design and Construction of 2 nF/30 kV Ultra low inductance capillary for N2</td>
<td>TOTAL</td>
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<td>3</td>
<td>C. Characterization of N2 Plasma Source</td>
<td>TOTAL</td>
<td></td>
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<tr>
<td>4</td>
<td>Evaluation and Optimization of capillary for e-beam target production of X-rays</td>
<td>TOTAL</td>
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</table>

Otro(s) aspecto(s) que Ud. considere importante(s) en la evaluación del cumplimiento de objetivos planteados en la propuesta original o en las modificaciones autorizadas por los Consejos.

Additional Objectives have been incorporated as a result of Research.
E. Design, Implementation and a Novel Split Ring Segmented Capillary. This has been operated in nitrogen, argon and xenon and has been found to significantly improve the purity of the Soft X-Ray Spectrum, improving the life time and applicability of the discharge. The highest conversion efficiencies yet achieved in xenon discharges have been achieved. Results so far have been presented in conference proceedings. CUMPLIMIENTO PARCIAL
F. Design, Implementation and Use of a Time-Resolved Swept Monochrometer based Soft X-Ray Spectrum Analyser. This has been designed and implemented giving the first ns time-resolved spectra in argon and xenon. These results are presently in Ph.D. thesis form and will give rise to a publication during 2012. CUMPLIMIENTO TOTAL
G. Design, Implementation and Use giving rise to a ISI publication of a novel moiré schlieren sub 100 ps diagnostic implemented for the first time on a high aspect ration capillary discharge. This has given for the first time the time evolution of the electron line density profile within the capillary during the discharge. The spatial resolution is 0.05 mm. Both zippering and compression on axis have been measured for the first time. The velocity of incoming compressional waves have also been measured. CUMPLIMIENTO TOTAL
RESULTADOS OBTENIDOS:
Para cada uno de los objetivos específicos, describa o resuma los resultados. Relacione las publicaciones y/o manuscritos enviados a publicación con los objetivos específicos. En la sección Anexos incluya información adicional que considere pertinente para efectos de la evaluación. La extensión máxima de esta sección es de 5 páginas (letra tamaño 10, Arial o Verdana).

A. Design and Construction Second Generation Pulsed Power Driver(s)

Preliminary discharges in nitrogen and nitrogen/helium mixes had shown that the electron beam from the hollow cathode during the voltage charging ramp was more effective in causing wall ablation. While this is a secondary effect of the axial e-beam it can dissipate up to 30% of the energy delivered from the pulse power charger to the capillary storage water dielectric capacitor. This generates a weakly ionized plasma of the wall species (aluminium and oxygen) and discharge initiates along the wall rather than along the axis of the capillary. Such a sliding spark discharge is colder and does not lead to significant EUV/soft X-ray emission. By shortening the charging time, significantly less energy is deposited on the walls and the capillary discharge initiates on axis. With this in mind two uprated designs were designed and tested. One was based on six 1700 V /32 Amp continuous/ 200 A pulsed IXYS RF IGBT’s driving a 20:1 autotransformer wound on a Metglas Core. This achieves a charging time of 1.2 microseconds and up to 32 kV on the capillary storage capacitor. The second design achieves faster charging by using a 15:1 autotransformer on the same core. To this end higher voltage IGBT’s must be used. Here we use 2 Powerex 60A/4.5 kV IGBT’s. This circuit is in use and has not failed after many months use. It delivers charging in 1.0 microseconds.

A third circuit has been designed and is now ready for testing. It is based on some new samples: eight 6.5 kV Powerex IGBT’s, each with a nominal 400 A peak current. These devices were given by the manufacturer for trial. By running these at 5 kV we will be able to use a 6:1 autotransformer, significantly reducing leakage inductance and so reducing the charging time to about 500 ns.

This third circuit has not been implemented as the down time for testing and power supply modifications would have interfered with the new and highly successful moiré-schlieren diagnostic, described below at letter “G”.

B. Design and construction of 2 nF/30 kV Ultra Low inductance Capillary Discharge for Nitrogen

Early results on a 36 mm capillary using 1.6 and 3.2 mm internal diameter alumina capillaries and a 1.6 nF capillary charging water dielectric capacitor as the energy source clearly showed that the smaller diameter formed the hot on-axis plasmas that emit in N V stage lines. However N VI emission at 28.8 A was virtually imperceptible once confusion with e-beam generated X-rays had been sorted out. It was resolved to design and construct a 21 mm length discharge. This was found to be highly successful at emitting N VI lines at 24.9 and 28.8 A. Again, when operated in argon, far greater intensity of Ar IX emission at 49 A was observed. Indeed, the 1.6 mm diameter tube emitted some Ar XII lines. The design has been presented in Rev. Sci. Instrum. Vol 81 of Sept 2010 (see reference in sección productos). The operation of the capillary discharge in nitrogen and nitrogen/helium is the subject of publication in March 2012 in Plasma Sources Science and Technology – see reference appended in sección productos), see below.

C. Characterization of the Nitrogen Plasma Source

A full characterization of the five alumina smooth bore capillaries used to generate N V and N VI stages is the subject of the doctoral thesis of M.P.Valdivia L. which was presented in April 2011. The principle scientific
results have been published in Plasma Sources Science and Technology, March 2012, see products section. In addition discharges have been performed using the machinable ceramic AlN, aluminium nitride, thus eliminating oxygen impurities from wall ablation. The AlN ceramic is considerably softer than alumina and much more expensive. We found that it did not merit use. We have also researched into the surface effects of the discharge on the alumina capillary wall, where the extreme heat cycling causes modifications to the surface, that appear to explain the observed variation in time of spurious oxygen content in a nominal nitrogen discharge. The time evolution of the capillary wall morphology may be related with the time variation of the aluminium and oxygen impurity lines in the spectrum. These results will generate a publication with the participation of Dr. Esteban Ramos M.

D. Evaluation and Optimization for e-beam for beam target production of e-beams

The clarification of some earlier experimental results published where confusion as to the production of 13.5 nm photons when observed using Si-Mo optics and Si-Sc filtered diodes is an important result of this project so far. This has been discussed in the Rev. Sci. Instrum. (see “Products”). This publication and has clarified earlier confusion. However, this does not mean that the strong e-beams at the start of breakdown are not responsible for higher stages of ionization, such as N VI and Ar IX to XII stages observed in the spectrometer. On the contrary, the separation of the roles of the e-beams from the X-rays from hot plasma allows a much better understanding of the device. It is clear that the e-beams are entirely responsible for the N VI stages observed by skewing the Maxwellian electron distribution function at early times in the discharge. As a result of this clarification, both the quantity and time-energy relation of the e-beams from the Transient Hollow Cathode Mechanism are now of crucial importance to increasing the energy of the emission from discharge. This discussion has been extended to observations in argon and xenon plasmas in the doctoral thesis of Julio Valenzuela A. which will be defended in April 2012

During the course of the two year research project some Additional Objectives have been incorporated as a direct result of the research.

E. Design, Implementation and a Novel Split Ring Segmented Capillary

Operation of the smooth bore capillary showed serious erosion close to the anode, where the soft X-ray emitting plasma also formed on axis. In nitrogen the effect is especially severe, leading to a high content of O V and VI line emission in the spectrum. While the impurity content was greatly improved on using a 3.2 mm diameter tube instead of the 1.6 mm diameter, a lower output of the desired He-like emission was also encountered. A further disadvantage with nitrogen is that the maximum charging voltage and therefore peak current is significantly lower for operation in nitrogen compared with discharges in argon. This also had the effect of reducing capillary output for the He-like lines. A segmented capillary is mounted within a larger external capillary. Many combinations are possible, but two were tried in preliminary trials. The segmented capillary was able to withstand 50% higher charging voltage. In effect we were able to operate in nitrogen in the shortened anode cathode gap of 16 mm at a higher voltage than that possible using a 21 mm smooth bore capillary. This new design has been operated in nitrogen, argon and xenon and has been found to improve significantly the purity of the soft X-Ray Spectrum, improving the life time very substantially and therefore the potential applicability of the discharge. The highest conversion efficiencies yet achieved in xenon discharges has been recorded. Results so far have been presented in conference proceedings. However a publication is anticipated within the next few months.

A new scheme to use the soft X-ray spectrometer as a swept mode monochromator using a step motor together with a semi-automatic data acquisition system using the new Tektronix’s LabView control software. This is possible because the capillary device is a fast repetition rate device allowing sampling over hundreds, if not thousands of shots. This has been designed and implemented giving the first ns time-resolved spectra in argon and xenon. This has allowed a very good picture of the temporal variation of the average ionization stages both in the smooth bore and in the split ring capillaries when operated in argon and in xenon. A substantially different temporal relation was found. In particular, high ionization state emission (Ar IX) continued well into the third current half cycle in the case of the split ring capillary, highlighting some, as yet, unclear differences in the plasma dynamics. These results are presently in Ph.D. thesis form and will give rise to a publication during 2012.

G. Design, Implementation and Use giving rise to a ISI publication of a novel moiré schlieren sub 100 ps diagnostic.

No measurement of the evolution of the electron density profile within the capillary has been published to date. The traditional Mach Zender and similar interferometry optical methods have not been successful because the plasma is too complex to allow the interference fringes to be followed and second the lasers used have had a pulse length of order ns, which is far too long on the plasma dynamics time scale. The purchase of a unique 12 ps Q-switched 532 nm Nd-YAG laser and the implementation of the more robust technique of moiré deflectometry, which measures the gradient of the refractive index of the plasma along the light path of the laser along the capillary axis, allowed us to obtain the line electron density at intervals during the discharge. This has given for the first time the time evolution of the electron line density profile within the capillary during the discharge. The spatial resolution is 0.05 mm. Both zippering and compression on axis have been measured for the first time. The velocity of the incoming compressional waves has also been measured. We have measured the effect of the initial pressure gradient on the plasma dynamics for argon discharges and have found significant variations between a 10:1 and 2:1 ratio. We have also observed the difference in the plasma dynamics between a 0.8 and 1.6 mm cathode aperture.

Owing to the success of this new diagnostic, we prioritized observations with this diagnostic, leaving the implementation of the new higher power throughput charging unit for later. A paper has been prepared for the Journal of Applied Physics, and is presently at the revision stage, having been submitted at the start of February 2012 (see Products Section).
DESTAQUE OTROS LOGROS DEL PROYECTO TALES COMO:
- Estadías de investigación.
- Actividades de difusión y/o extensión en la temática del proyecto.
- Cualquier otro logro no contemplado en los ítem anteriores y que Ud. quiera destacar.

La extensión máxima de esta sección es de 1 página (letra tamaño 10, Arial o Verdana).


1b. La visita en Abril de 2011 de Prof Serguey Zakharov del Keldesh Institute de Theoretical Physics de Rusia y de Eppra sas. de Francia reafirma un importante eslabon entre el entendimiento teórico de la descarga capilar y su realización práctica. Se entiende que en esto tanto Eppra sas como NanoUV sas. son empresas de desarrollo científico quienes usan y mejor entender la descarga capilar como fuentes de rayos X para microscopía y metrología a 2.88 y 13.5 nm como litografía industrial a 13.5 nm. Metas que aún concentran grandes inversiones industriales.
COOPERACIÓN INTERNACIONAL

N° Proyecto: 1100065
Nombre Colaborador (a) Extranjero (a): FARHAT BEG
Afiliación Institucional Actual: UNIVERSITY OF CALIFORNIA, SAN DIEGO
Fechas de estadía Desde: 18/03/2012 Hasta: 24/03/2012

Describa las actividades realizadas y resultados obtenidos. Destaque su contribución al logro de los objetivos del proyecto. Si es pertinente, indique las publicaciones conjuntas generadas, haciendo referencia a lo informado en la etapa Productos. Agregue en la etapa anexos la información necesaria.

The visit of Prof Beg has been delayed until the second half of March. He will be the external examiner of Ph.D. candidate Julio César Valenzuela A. of the Plasma Physics group. He is programmed to give a Colloquium and a Seminar. We will discuss a new program of scientific collaboration. He is very interested in using our 1 MA generator Llampúdkeñ for experimental work on wire arrays. We have some diagnostic techniques that he is interested in using that are not available yet at UCSD

PRODUCTOS

ARTÍCULOS
Para trabajos en Prensa/ Aceptados/Enviados adjunte copia de carta de aceptación o de recepción.

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<td>Nombre Completo de la Revista:</td>
<td>Plasma Sources Science and Technology</td>
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<td>Observations of the Emission Processes of a Fast Capillary Discharge Operated in Nitrogen</td>
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<td>Valenzuela, JC; Wyndham, ES; Chauqui, H; Cortes, DS; Bhuyan, H.</td>
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Nombre Completo de la Revista: Journal of Applied Physics
Título (Idioma original): Implementation of Moiré-Schlieren Deflectometry on a Small Scale Fast Capillary Discharge
Indexación: ISI
ISSN:
Año: 2012
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Estado de la publicación a la fecha: Aceptada
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Aceptado sujeto a revisión.
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Enviar documento en papel: no
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Valenzuela_Wyndham_JAP_revised_upload.pdf


Nº: 3
Autor (a)(es/as): Wyndham, ES.; Favre, M.; Valdivia, MP.; Valenzuela, JC.; Chuaqui, H.; Bhuyan, H.
Nombre Completo de la Revista: Review of Scientific Instruments
Título (Idioma original): Fast plasma discharge capillary design as a high power throughput soft X-ray emission source
Indexación: ISI
ISSN:
Año: 2010
Vol.: 81
Nº:
Páginas: 93502-93502-8
Estado de la publicación a la fecha: Publicada
Otras Fuentes de financiamiento, si las hay:

Enviar documento en papel: no
Archivo(s) Asociado(s) al artículo:
Capill_RSI_81_093502_2010.pdf


OTRAS PUBLICACIONES / PRODUCTOS

Sin información ingresada.
CONGRESOS

Nº : 1
Autor (a)(es/as) : Valenzuela, JC.; Valdivia, MP.; Wyndham, ES.; Favre, M.; Chuaqui, H.
Título (Idioma original) : Comparative Soft X-ray Spectrum Observations of Segmented and Continuous Wall Geometry Low Energy Fast Discharge Capillary Plasmas
País : FRANCIA
Ciudad : Biarritz
Fecha Inicio : 05/06/2011
Fecha Término : 09/06/2011
Nombre Publicación : Proceedings Eighth International Conference on Dense Z Pinches
Año : 2012
Vol. :
Nº :
Páginas :
Envia documento en papel : no
Archivo Asociado :
JCValenzuela_MPValdivia_EWyndham_.pdf

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Nº : 2
Autor (a)(es/as) : Valdivia, MP.; Valenzuela, JC.; Wyndham, ES.; Favre, M.; Chuaqui, H.
Título (Idioma original) : Discharge Capillary Plasma Characterization as a Table-Top Soft X-Ray Source
País : FRANCIA
Ciudad : Biarritz
Fecha Inicio : 05/06/2011
Fecha Término : 09/06/2011
Nombre Publicación : Proceedings Eighth International Conference on Dense Z Pinches
Año : 2012
Vol. :
Nº :
Páginas :
Envia documento en papel : no
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TESIS/MEMORIAS
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<td>Implementación del diagnóstico óptico de alta resolución espacial de Moiré Schlieren en Plasma Capilar Transientes</td>
<td>Diego Sebastian Cortes Tapia</td>
<td>Edmundo Wyndham Hodder</td>
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ANEXOS

A continuación se detallan los anexos físicos/papel que no se incluyen en el informe en formato PDF.

El paper a J. Appl. Physics ya ha sido publicado con fecha 24 de Mayo 2012. Favor tengan a bien ver la copia adjunta.