Final Report – Public Version
Project LBNL-T2-196

of the
Initiatives for Proliferation Prevention (IPP)
program of the Department of Energy

ULTRA-LOW-ENERGY HIGH-CURRENT ION SOURCE

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Executive Summary

The project is a collaboration of three partners
(1) Lawrence Berkeley National Laboratory (LBNL)
(2) A Russian Institute, here the High Current Electronic Institute of Tomsk, Russia
(3) A US company, here 4Wave, Inc., with facilities in Sterling, VA.
The main technical work was carried out in Tomsk, with technical and logistical guidance of LBNL, and deliverables going to Sterling for potential commercial use.

A main objective of the IPP program is to employ scientists of the former Soviet Union to reduce possible proliferation risks. Given the lower salary levels in Russia compared to the U.S., this project involved at times up to 50 scientific and technical staff, some of them full time. There has been one visit by the US PI (Andre Anders) to Russia in 2003, and several visits by a number of Russian scientific and technical staff to the United States, going to LBNL at Berkeley, CA, and to 4Wave at Sterling, VA. Close ties have been established that lead to working hardware and several publications.

The technical objective of the project was to develop an ultra-low-energy, high-intensity ion source (ULEHIIS) for materials processing in high-technology fields including semiconductors, micro-magnetics and optics/opto-electronics. In its primary application, this ion source can be incorporated into the 4Wave thin-film deposition technique called biased target ion-beam deposition (BTIBD), which is a deposition technique based on sputtering (without magnetic field, i.e., not the typical magnetron sputtering). It is a technological challenge because the laws of space charge limited current (Child-Langmuir) set strict limits of how much current can be extracted from a reservoir of ions, such as a suitable discharge plasma. The solution to the problem was an innovative dual-discharge system without the use of extraction grids.

The project of developing a high current (several amperes) ion source for ultra-low energy (less than the sputtering threshold of 40 eV) was conceived in 2002 and proposed in 2003. Although planned for three years, the total project time stretched to over five years due to factors beyond the participant's control, mainly dictated by difficulties to make funds available in a timely manner. Such fund transfers were affected by legal issues related to US and Russian law. Despite the delays, the objectives have all been fulfilled, and the project can be seen as a success.

The best summary of the technical achievements is given by the final technical report provided by the Russian team, which is attached here as "Attachment A".

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The main results of this work were published in the peer-reviewed journal "Review of Scientific Instruments:

E. M. Oks, A. V. Vizir, M. V. Shandrikov, G. Y. Yushkov, D. M. Grishin, A. Anders, and D. A. Baldwin, "Inverted end-Hall-type low-energy high-current gaseous ion source," *Rev. Sci. Instrum.*, vol. 79, pp. 02B302-3, 2008.

Link: http://link.aip.org/link/?RSI/79/02B302/1

Attachment A:
Final Technical Report provided by the partners of the High Current Electronics Institute, Tomsk, Russia, slightly edited by A. Anders.

ULTRA-LOW-ENERGY HIGH-CURRENT ION SOURCE (ULEHIIS)

Material Support Agreement No.6704561

Between

Ernest Orlando Lawrence Berkeley National Laboratory University of California
and the

High Current Electronics Institute

Milestone # 12:
Final report by Georgy Yu. Yushkov

Principal Investigator *(signatures is removed)*
George Yushkov, Dr. Sci.

Head of the Plasma *(signature is removed)*
Source Department
Efim Oks, Prof.

December, 2008

RUSSIA-TOMSK-Dec. 2008

This is the final report of the Contract. Three Ultra Low Energy High Intensity Ion Sources (ULEHIIS) have been developed and manufactured by Plasma Source Department of the High Current Electronics Institute in the framework of the Contract between Ernest Orlando Lawrence Berkeley National Laboratory University of California (LBNL) and High Current Electronics Institute for 4Wave, Inc., Sterling, USA.

All information regarding the design, parameters, and operating features is presented in the following documents, which were previously sent to 4Wave, Inc and LBNL:

1. ULEHIIS prototype: Milestone#3 Report.
2. ULEHIIS alpha-version: Milestone#6 Report
3. ULEHIIS beta-version Milestone#11 Report

All information about results of testing ULEHIIS prototype and ULEHIIS alpha-version at LBNL and 4Wave, Inc is presented in the following documents, which were previously sent to 4Wave, Inc and LBNL:

1. ULEHIIS prototype: Milestone#4 Report.
2. ULEHIIS alpha-version: Milestone#7 Report

The information is given below related to characterization of the last, Year-Three, beta-version of ULEHIIS installed at 4Wave, Inc. in November, 2008.

1. PARAMETERS ACHIEVED

The Year-Three Ultra Low Energy High Intensity Ion Source (ULEHIIS) (beta-version) has been installed at 4Wave, Inc., which is stated in the Acceptance Report.

Acceptance report

Of Internal-Mount Ultra Low Energy High Intensity Ion Source Beta-Version (ULEHIIS),

delivered and installed at 4Wave, Inc., Sterling, VA in Nov. 2008.

ULEHIIS was designed and manufactured with key participation of A. Vizir, M. Shandrikov, D. Grishin, G. Yushkov, and E. Oks at High Current Electronics Institute (HCEI), SB RAS, Tomsk, Russia, according to contract No. 6704561 (formerly T221096) IPP and CRADA BG03-036, Year 3.

During the tests at 4Wave, the parameters of ULEHIIS were determined. The table below shows planned and actual parameters of the device:

Parameter	Planned	Achieved
Ion current to target	up to 5 amperes	4,6 A*
Beam cross section	500 sq. cm	706 sq. cm
Source-to-target distance	25 cm	40 cm
Mean Ion Kinetic Energy (for single charged ions)	less than 20 eV.	less than 20 eV.
Operating pressure	Less than 0,75 mTorr	Less than 0,05 mTorr
Minimum gas flow rate	< 28 sccm	6 sccm
Maintenance period	100 hours	100 hours

* **NOTE:** Target ion current of 4.6A, which is less than the goal of 5.0A, follows from farther source-to-target distance and is accepted by 4Wave, Inc. as meeting desired specifications.

[redacted]

2. PHOTOS OF THE SOURCE

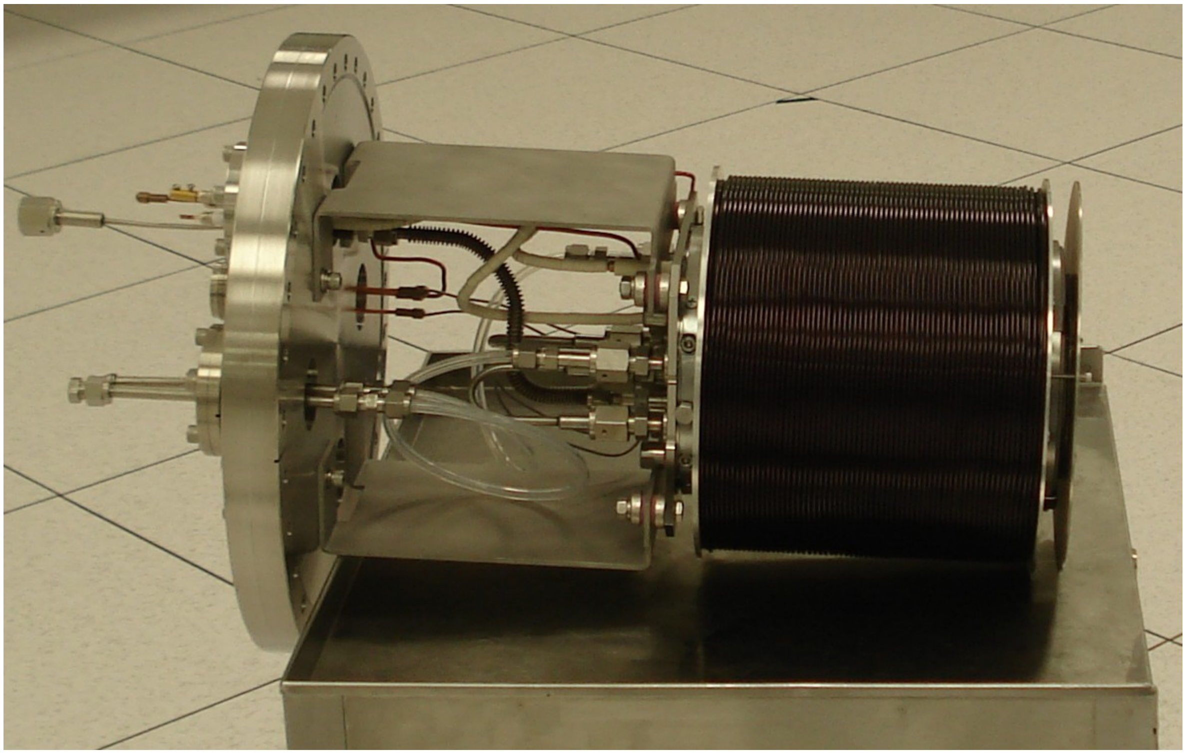

Fig.1. A view of the source

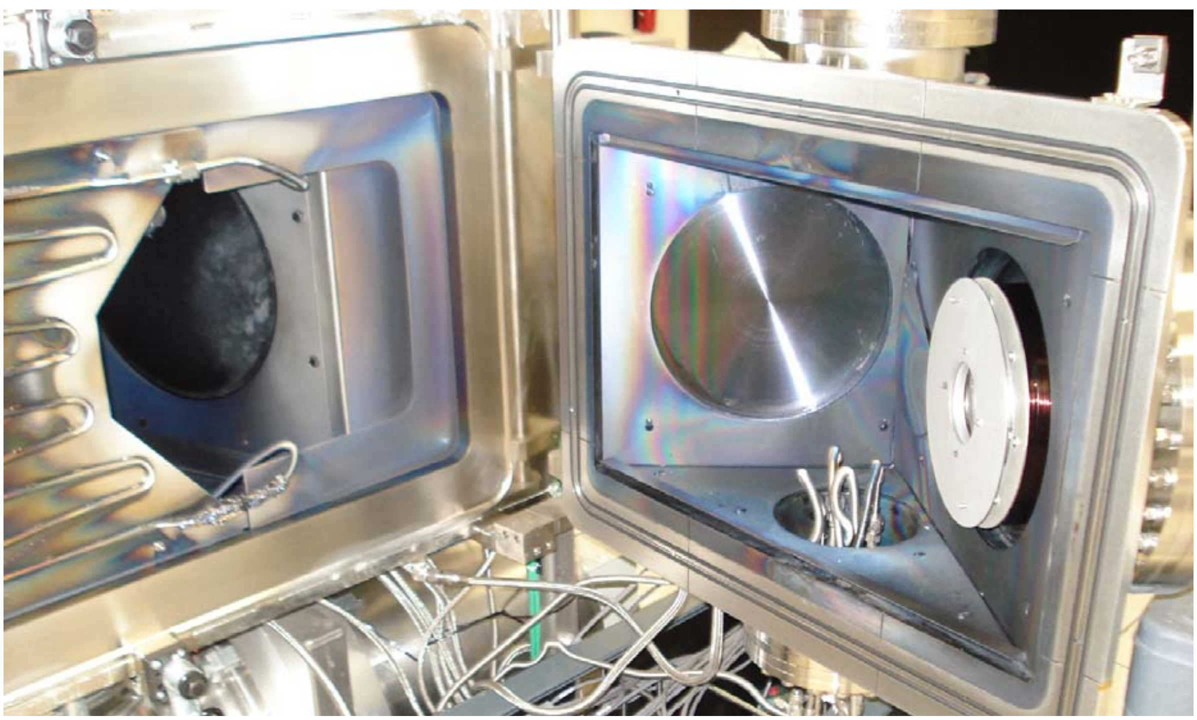

Fig.2. The source installed on the chamber.

Fig.3. Power supplies and control unit of the source during operation.

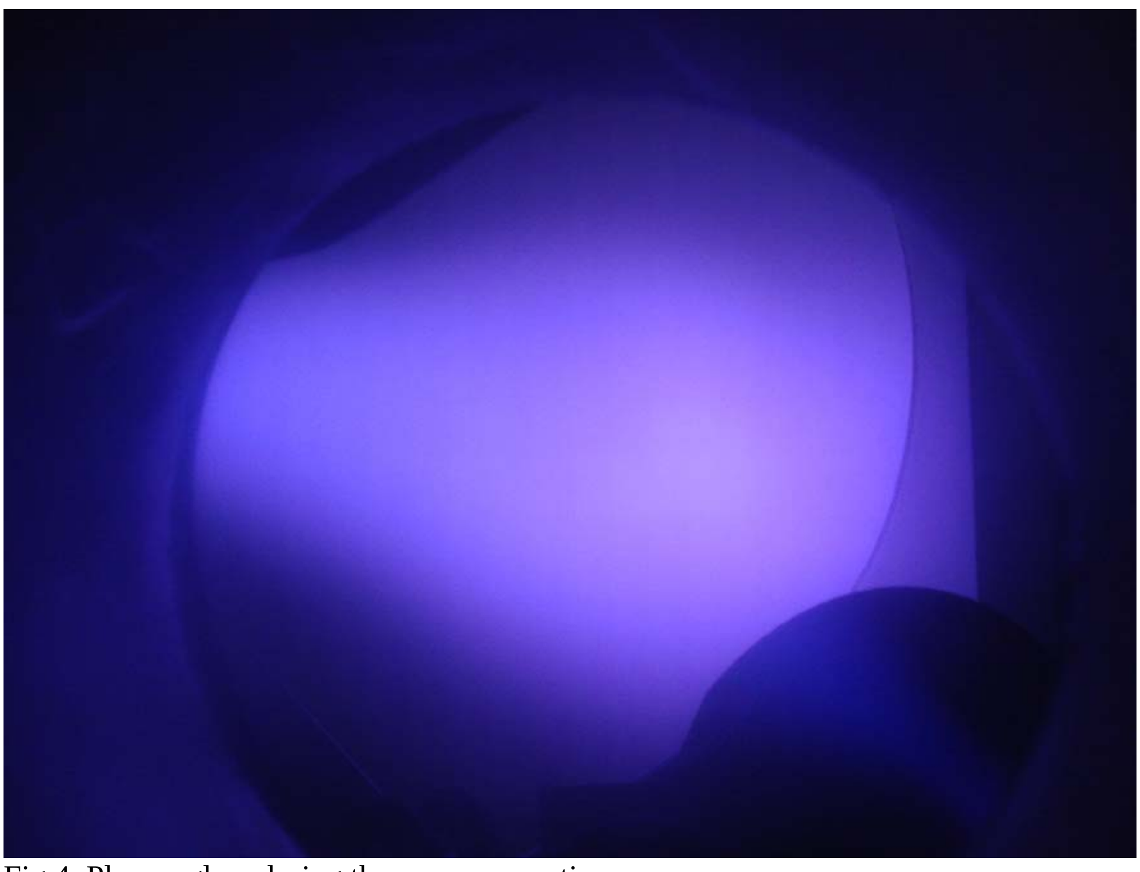
Fig.4. Plasma glow during the source operation.

3. RESULTS OF TESTING THE SOURCE

The results of testing the source, giving proof to the data cited in the Acceptance Report, are illustrated below.

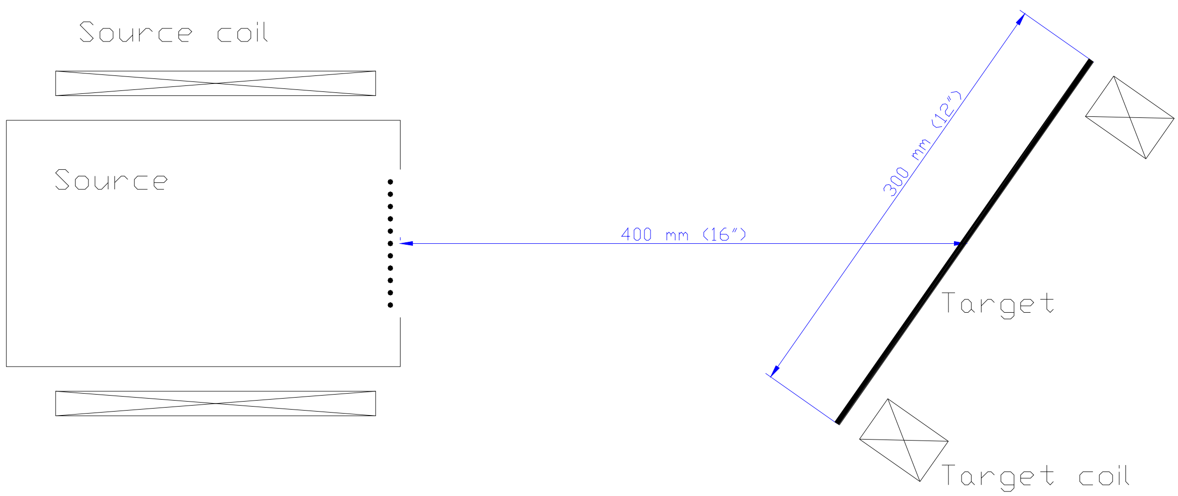

Fig.5. Relative position of the source and the target.

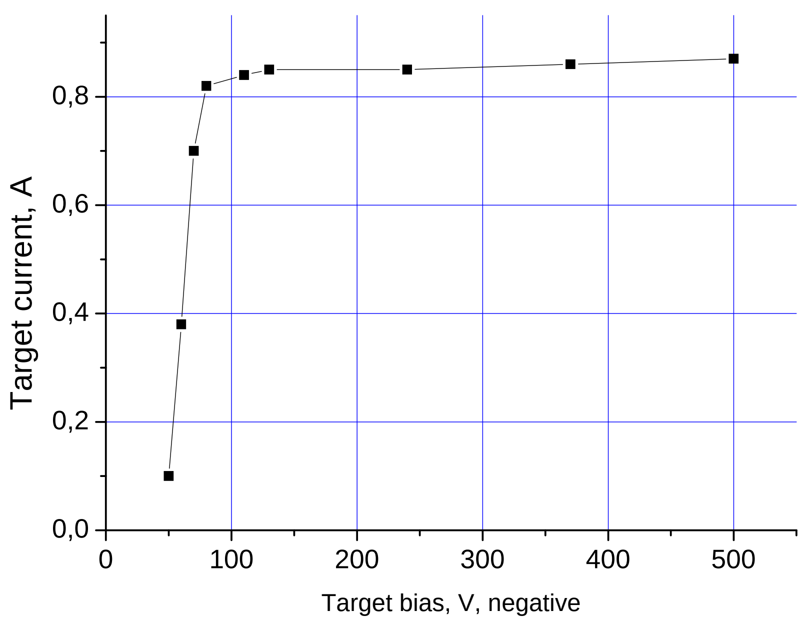

Fig.6. The dependence of the target current on the target bias voltage. Emitter current is 8 A. Plasma discharge voltage is 40 V. Gas flow rate (argon) is 40 sccm. Pressure is $2.4 \cdot 10^{-4}$ Torr. Source electromagnet current is 8 A. Target electromagnet current is 8A.

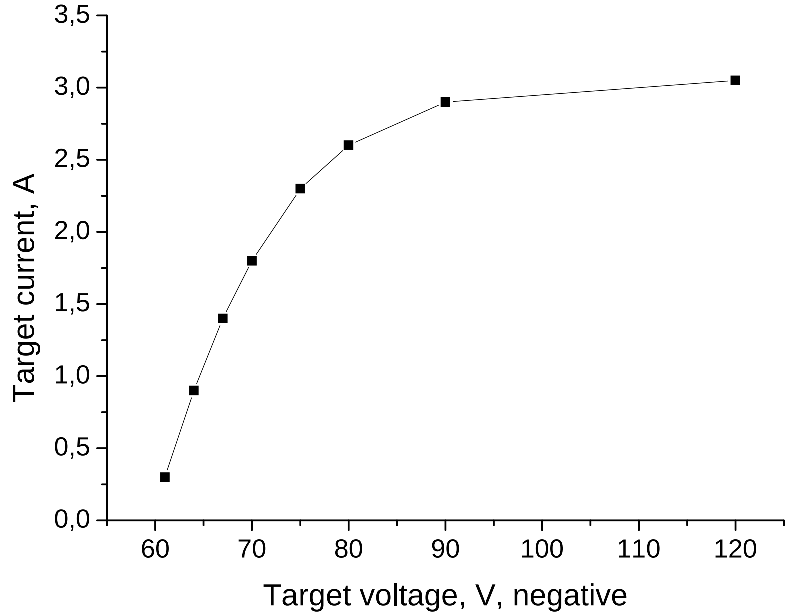

Fig. 7. The dependence of the target current on the target bias voltage. Emitter current is 35 A. Gas flow rate (argon) is 40 sccm. Pressure is $2.4 \cdot 10^{-4}$ Torr. Source electromagnet current is10 A Target electromagnet current is 10 A. Discharge current is 24 A. Discharge voltage is 40 V.

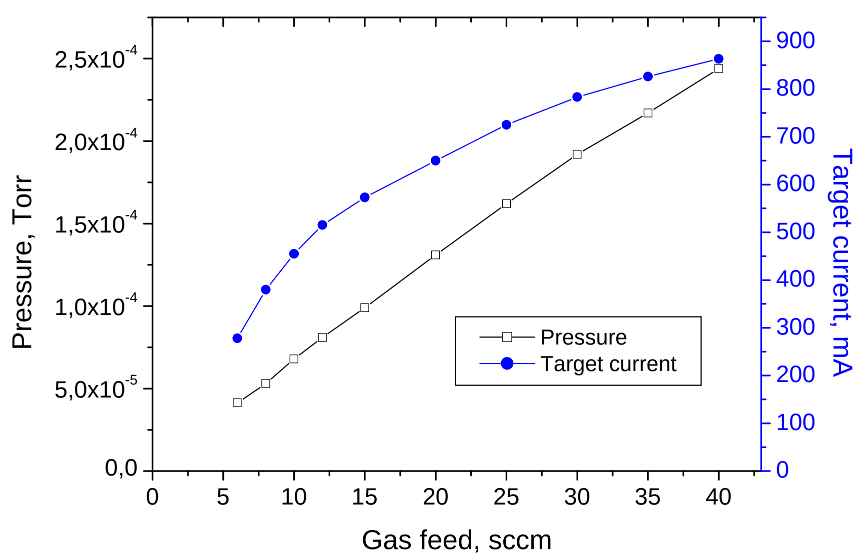

Fig. 8. Pressure dependence of the target current. Argon. Emitter current is 8 A. Discharge voltage is 40 V. Source electromagnet current is 8 A. Target electromagnet current is 8 A. Target voltage is 500 V.

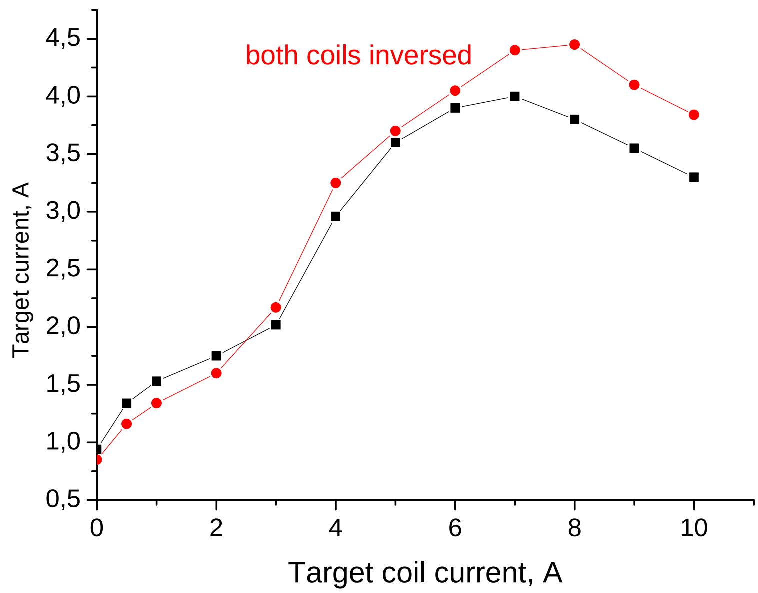

Fig.9. The dependence of the target current on the target electromagnet current. Emitter current is 37 A. Gas flow rate (argon) is 40 sccm. Pressure is $2.4 \cdot 10^{-4}$ Torr. Source electromagnet current is 8 A. Target bias voltage is –120 V.

For the highest target current, the magnetic fields of the source and the target electromagnets must be directed in the same direction. Moreover, even in this case, the target current also depends on the direction of the resulting magnetic field, due to its interaction with intrinsic magnetic field of injected electron flow.

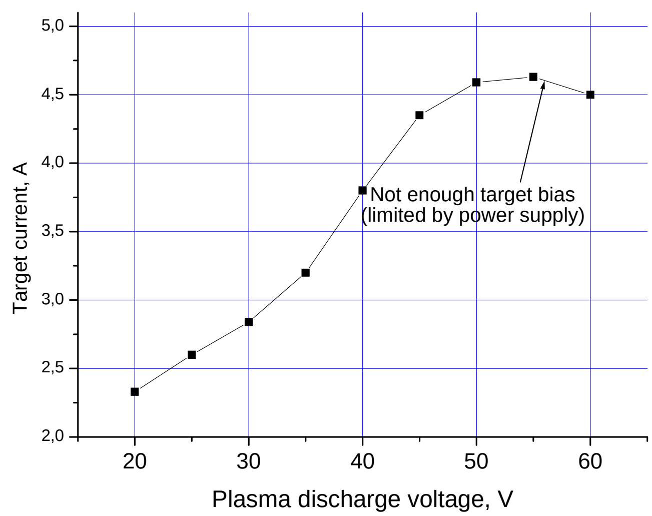

Fig. 10. The dependence of the target current on the plasma discharge voltage. Emitter current is 37 A. Gas flow rate (argon) is 40 sccm. Pressure is $2.4 \cdot 10^{-4}$ Torr. Source electromagnet current is 8 A. Target electromagnet current is 8 A. Target bias is 120 V.

The target bias voltage was limited by 120 V because of the power supply available, and, as follows from Fig.10, it was not enough with discharge voltage higher than 40 V, at which injected electrons start to reach the target reducing its current. Previously made measurements of injected electron spectra have shown that the spectrum is wide and the highest electron energy may reach 2.5-fold plasma discharge voltage-corresponding energy, obviously, due to collective acceleration effects. The curve behavior (Fig.10) allows us to assume that ion saturation current at plasma discharge voltage of 50 V reaches 5 A, which cannot be registered with the available power supply.

4. CONCLUSIONS

All the goals of the project were accomplished as is evident from the above description: a high current ion source for ultra-low energy ions has been developed up to the commercialization stage.

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