Recombination Processes of Multi-Charge Ions of a Laser Plasma

Shukhrat Sultanov Davlyatovich
Docent of Fergana Polytechnic Institute, Uzbekistan

Abror Tojiboev Kakhorovich
Senior Lecturer, Fergana Polytechnic Institute, Uzbekistan

ABSTRACT

The presence of an obstacle on the path of laser plasma expansion in vacuum leads to an increase in the ion charge multiplicity, an expansion of the energy spectrum, and an increase in the total number of ions. The peculiarities of the interaction with a solid-state obstacle are largely associated with the appearance of a shock wave in it, which affects the course of recombination processes. It is shown that it is possible to control the parameters of a recombining laser plasma by changing the expansion dynamics at later stages using solid-state obstacles.

KEYWORDS: *vacuum, laser plasma, ion, stage, process, recombination, pulse.*

Introduction. Controlling the physical processes of ionization, recombination, and acceleration of multiply charged ions (MLI) of a laser plasma is important both in the elemental analysis of the composition of matter and in the creation of an active medium for lasers operating in the UV region of the radiation spectrum.

Recombination at the stage of hydrodynamic plasma expansion after the end of the laser pulse makes a significant contribution to the formation of the energy spectra of ions with different charge multiplicities [1-2]. Plasma formed by this time does not necessarily contain the entire set of ions then observed. By changing the conditions of the recombination process, it is possible to influence all aspects of the dynamics and kinetics of the expansion of a multiply charged plasma [3-4].

Objectives. In this paper, we consider the effect of obstacles on the path of laser plasma expansion, on the main characteristics of multiply charged ions flying into vacuum[1-10].

Methodology. The experiment used the method of time-of-flight laser mass spectrometry. Radiation from a neodymium laser with an energy of ~ 50 J and a pulse duration of 50 ns provided the maximum radiation density on the target surface of ~ 10^{12} W/cm^2. A flat screen made of pure aluminum (Al), placed at a distance l to the target, was used as an obstacle. This distance could be smoothly varied within $2 \leq l \leq 30$ mm along the axis of the time-of-flight analyzer. Aluminum was also chosen as a target. To ensure the reliability of the results under the same conditions, the experiment was repeated several times. At the same time, good repeatability of the obtained data was observed[11-18].

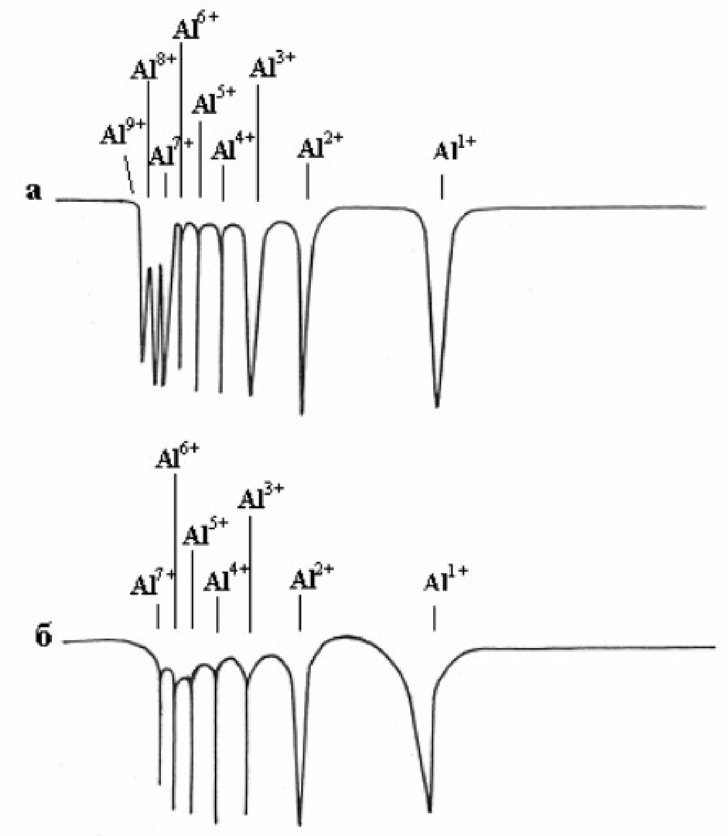

Figure 1. Charge spectra of multiply charged Al ions obtained at

$q = 3 \cdot 10^{11}$ W/cm^2;

a - in the presence of a solid-state obstacle Al on the path of plasma expansion (the distance between the target and the obstacle is 12 mm);

b - with free expansion of plasma.

The experimentally recorded maximum multiplicity of the MLI charge AL at a laser power density = 3 10^{11} W/cm^2 was $z_{max} = 7$ (Fig. 1.b.). In the presence of an obstacle (l = 12 mm) on the path of the plasma expansion into vacuum, the value of z_{max} of Al ions increased by 2, i.e. $z_{max} = 9$ (Fig. 1.a.). To obtain the same zmax in the absence of an obstacle, it was necessary to increase the power density to $q = 8 \cdot 10^{11}$ W/cm^2. The dependence of the maximum ion charge on the distance between the target and the obstacle was established.

To compare the z_{max} formed in plasma and recorded at a distance, their average z_{av} values were calculated. By solving the equation of stationary plasma flow for a certain characteristic point of the plasma, the Jouguet point, for the conditions of our experiment, it was possible to calculate the following plasma parameters: electron temperature $T_e = 80$ eV, $z_{max} = 9$, ion concentration $N = 1.2 \cdot 10^{19}$ cm^{-3}, ion velocity $v = 5.1 \cdot 10^6$ m/s. From a comparison of the experimentally obtained at a distance from the target and the calculated zav, it can be seen that during expansion into vacuum the MLI undergoes recombination losses; in the presence of an obstacle, these losses are less than in its absence[19-25].

Recombination losses also affected the dynamics of the formation of energy spectra. With a free expansion into a vacuum of an ISM, the maximum ion energy is $E_{max} \leq 3$ keV; for the case with an obstacle, it increased to about 5 keV. Judging from the energy spectra, in the presence of an obstacle, the electron temperature was significantly higher.

The study of the dependence of the number of ions of a certain multiplicity NZ on the multiplicity of the ion z has shown that in the case of an obstacle, the number of ions of each charge is greater than without it. In this case, each curve can be approximated by the dependences $N_Z = kz^{-1.7}$ and $N_Z = kz^{-1.5}$, respectively.

Thus, the presence of an obstacle on the path of plasma expansion into vacuum leads to an increase in the ion charge multiplicity, an expansion of the energy spectrum, and an increase in the total number of ions.

The features of the interaction of an expanding laser plasma with a solid-state obstacle are in many respects shining with the appearance of a shock wave in it, which affects the course of recombination processes [4, 5]. It is known that a supersonic flow arises at the stage of inertial expansion of a laser plasma. It is known that a supersonic flow arises at the stage of inertial expansion of a laser plasma. The estimation of the parameters of the expanding aluminum plasma under the conditions of this experiment corresponds to the Mach number M = 3.2-4.6, and the collision of the plasma with an obstacle leads to the appearance of a strong shock wave. The supersonic flow approaching the obstacle can be considered quasi-stationary; therefore, the shock wave front will be almost stationary and a standing wave is formed.

The features of the structure of the shock front in plasma are associated with the slowed-down nature of the energy exchange between ions and electrons. At the same time, electrons have high mobility, due to which the electronic thermal conductivity is many times higher than the thermal conductivity of ions. In the vicinity of the shock front, an increase in the electron and ion temperatures occurs, and in the shock wave, the electron temperature does not have a discontinuity, in contrast to the ion temperature. Electronic thermal conductivity promotes the transfer of heat from dense plasma layers farther from the shock to the front ones, where the electron temperature is lower. The electron temperature rises before the jump and a heating layer is formed. In this layer, the electron temperature is higher than the ionic one.

Changes in the electron temperature and electron density of the plasma in the shock wave affect the course of recombination processes occurring in plasma regions that have not yet experienced shock compression. Heat-conducting heating extends to areas close to the target. The recombination process of any type is very sensitive to temperature; the recombination rate decreases with increasing temperature.

We explain the observed increase in the maximum charge of the plasma relative to its free expansion by a significant decrease in the rate of triple recombination due to an increase in the temperature of electrons in the shock wave. It is also necessary to take into account the heat-conducting heating of electrons, which prevents the recombination of especially highly charged ions during inertial expansion.

Conclusion. The experiments performed indicate the possibility of controlling the parameters of the recombining laser plasma by changing the expansion dynamics at later stages using solid-state obstacles.

REFERENCES

1. Тожибоев А.К., Султонов Ш.Д. Измерение, регистрация и обработка результатов основных характеристик гелиотехнических установок // Universum: технические науки : электрон. научн. журн. 2021. 11(92).

2. Эргашев С. Ф. и др. Автоматизированная система управления водными ресурсами на основе элементов компьютерной автоматики. – 2020.стр.11-15.
3. Умурзакова Г. М. и др. Радиационные дефекты в полупроводниковых соединениях //Актуальная наука. – 2019. – №. 11. – С. 23-25.
4. Сайитов Ш. С. и др. Новая конструкция для пайки терминала системы подогрева заднего стекла автомобиля //Актуальная наука. – 2019. – №. 9. – С. 22-27.
5. Умурзакова Г. М., Тожибоев А. К. Действие излучений на полупроводниковые материалы //Актуальная наука. – 2019. – №. 11. – С. 26-28.
6. Mamasadikov, Yu and Mamasadikova, Z Yu (2020) "Optoelectronic device for remote control of hydrocarbon concentration in air," Scientific-technical journal: Vol. 3 : Iss. 6.
7. Тожибоев А. К., Хакимов М. Ф. Расчет оптических потерь и основные характеристики приемника параболоцилиндрической установки со стационарным концентратором //Экономика и социум. – 2020. – №. 7. – С. 410-418.
8. Kuchkarov A. A. et al. Adjustment of facets of flat and focusing heliostats, concentrators, and Fresnel mirror concentrating systems //Applied Solar Energy. – 2015. – Т. 51. – №. 2. – С. 151.
9. Хакимов М. Ф., Тожибоев А. К., Сайитов Ш. С. Способы повышения энергетической эффективности автоматизированной солнечной установки //Актуальная наука. – 2019. – №. 11. – С. 29-33.
10. MechaUz: Modernization of Mechatronics and Robotics for Bachelor degree in Uzbekistan through Innovative Ideas and Digital Technology 609564-EPP-1-2019-1-EL-EPPKA2-CBHE-JP.
11. Тожибоев А. К., Немадалиева Ф. М. Комбинированные солнечные установки для теплоснабжения технологических процессов промышленных предприятий. результаты разработки и испытаний //Современные технологии в нефтегазовом деле-2018. – 2018. – С. 253-256.
12. Kuchkarov A. A. et al. Calculation of optical-geometrical characteristics of parabolic-cylindrical mirror concentrating systems //European science review. – 2017. – №. 1-2. – С. 201-203.
13. Эргашев С. Ф., Тожибоев А. К. Расчёт установленной и расчётной мощности бытовых электроприборов для инвертора с ограниченной выходной мощностью //Инженерные решения. – 2019. – №. 1. – С. 11-16.
14. Ergashev S. F., Axmadaliyevich K. A., Yusupjonovna M. U. Optoelectronic device for remote temperature control of sanitary units //EPRA International Journal of Multidisciplinary Research. – 2021. – Т. 7. – №. 6. – С. 211-215.
15. Тожибоев А.К., Мирзаев С.А. Применение комбинированной солнечной установки при сушке сельскохозяйственных продуктов // Universum: технические науки : электрон. научн. журн. 2021. 10(91).
16. Klychev S. I., Abdurakhmanov A. A., Kuchkarov A. A. Optical-geometric parameters of a linear Fresnel mirror with flat facets //Applied Solar Energy. – 2014. – Т. 50. – №. 3. – С. 168-170.
17. Kuchkarov A. A. et al. Calculation of thermal and exergy efficiency of solar power units with linear radiation concentrators //Applied Solar Energy. – 2020. – Т. 56. – С. 42-46.
18. Kuchkarov A. A. et al. Optical energy characteristics of the optimal module of a solar composite parabolic-cylindrical plant //Applied Solar Energy. – 2018. – Т. 54. – №. 4. – С. 293-296.
19. Mamadalievich, Madraximov Mamadali, and Abdulkhaev Zokhidjon Erkinjonovich. "Principles of Operation and Account of Hydraulic Taran." *JournalNX*: 1-4.

20. АБДУЛҲАЕВ, Зоҳиджон, and Мамадали МАДРАХИМОВ. "Гидротурбиналар ва Насосларда Кавитация Ҳодисаси, Оқибатлари ва Уларни Бартараф Этиш Усуллари." *Ўзбекгидроэнергетика" илмий-техник журнали* 4, no. 8 (2020): 19-20.
21. Akbarov R. Y., Kuchkarov A. A. Modeling and Calculation of Optical-Geometric Characteristics of a Solar Concentrator with Flat Fresnel Mirrors //Applied Solar Energy. – 2018. – Т. 54. – №. 3. – С. 183-188.
22. Abbasov E. S., Abdukarimov B. A., Abdurazaqov A. M. Use of passive solar heaters in combination with local small boilers in building heating systems //Scientific-technical journal. – 2021. – Т. 3. – №. 3. – С. 32-35.
23. Мадрахимов, М. М., and З. Э. Абдулҳаев. "Насос агрегатини ишга туширишда босимли сув узатгичлардаги ўтиш жараёнларини ҳисоблаш усуллари." *Фарғона Политехника Институти Илмий–Техника Журнали* 23, no. 3 (2019): 56-60.
24. Bekzod A. Relevance of use of solar energy and optimization of operating parameters of new solar heaters for effective use of solar energy //IJAR. – 2020. – Т. 6. – №. 6. – С. 16-20.
25. Abdukarimov B., Abbosov Y. S., O'tbosarov S. R. Hydrodynamic Analysis of Air Solar Collectors //Int. J. Adv. Res. Sci. Eng. Technol. – 2020. – Т. 7. – №. 5. – С. 1354513549.
26. Abdulkhaev, Zokhidjon, Mamadali Madraximov, Axmadullo Abdurazaqov, and Mardon Shoyev. "Heat Calculations of Water Cooling Tower." *Uzbekistan Journal of Engineering and Technology* (2021).
27. Abdukarimov B. A. Abbosov Yo. S., Mullayev II Optimization of operating parameters of flat solar air heaters //Vestnik nauki i obrazovaniya. Nauchno-metodicheskiy jurnal. – 2019. – №. 19/73.
28. Усаров, М. К., and Г. И. Маматисаев. "Свободные колебания коробчатой конструкции здания." *Проблемы механики.* 5-6 (2009): 31.
29. Абдукаримов Б. А. и др. Способы снижения аэродинамического сопротивления калориферов в системе воздушного отопления ткацких производств и вопросы расчета их тепловых характеристик //Достижения науки и образования. – 2019. – №. 2 (43).
30. M.M.Madraximov, Z.E.Abdulxayev, E.M.Yunusaliev, A.A.Akramov. "Suyuqlik Va Gaz Mexanikasi Fanidan Masalalar To'plami" Oliy o'quv yurtlari talabalari uchun o'quv qo'llanma. - Farg'ona: 2020-yil, 232 bet.
31. Кучкаров А. А., Абдурахманов А. А., Рахимов Р. Х. Расчет оптимальных размеров отражающих элементов крупногабаритных составных фацетных концентраторов //Computational nanotechnology. – 2019. – №. 3. – С. 100-103.
32. Malikov, Z. M., and M. E. Madaliev. "Numerical Simulation of Two-Phase Flow in a Centrifugal Separator." *Fluid Dynamics* 55, no. 8 (2020): 1012-1028.
33. Muratovich, D. S. (2016). Study of functioning of reservoirs in the form of cylindrical shells. *European science review*, (9-10).
34. Кучкаров А. А., Абдумуминов А. А., Абдурахманов А. Разработка конструкции составной линейной Френелевской зеркальной концентрирующей системы //Гелиотехника. – 2020. – Т. 56. – №. 1. – С. 43-52.
35. Abdulkhaev, Zokhidjon Erkinjonovich, Mamadali Mamadaliyevich Madraximov, Salimjon Azamdjanovich Rahmankulov, and Abdusalom Mutalipovich Sattorov. "INCREASING THE EFFICIENCY OF SOLAR COLLECTORS INSTALLED IN THE BUILDING." In *" ONLINE-CONFERENCES" PLATFORM*, pp. 174-177. 2021.