Stationary flow of dense magnetized plasma with multiply charged ions as a source of EUV radiation [[1]](#footnote-1)\*)

DOI: 10.34854/ICPAF.2023.50.2023.1.1.153

Abramov I.S., Gospodchikov E.D., Shalashov A.G.

Institute of Applied Physics RAS, Nizhny Novgorod, Russia, abramov@ipfran.ru

Extreme ultraviolet (EUV) lithography is an advanced technology for chip manufacturing, providing the ability to move to chips with nodes less than 7 nm [1]. For exposure in this technology, EUV radiation is used in narrow spectral bands (13.5 nm ±1%, 11.2 nm ±1%, etc.), corresponding to the peaks of the reflection coefficients of multilayer mirrors. For its generation, line radiation of high multiplicity ions is used.

In operating EUV lithographs, the necessary radiation is generated by a plasma with multiply charged ions, which is produced during the evaporation of a tin droplet by pulsed laser radiation [2]. Such sources generate radiation with a power of 250 W in the range of 13.5 nm ±1%, which, in general, is enough for high-volume chip manufacturing [3]. Nevertheless, in order for the performance of EUV lithography to be as good as that of previous generation lithographs, the development of sources with higher power is required [1, 2]. Also, studies of photoresist chemistry show that a significant decrease in the edge roughness of the exposed lines is possible when using higher power radiation in exposure, which is important for moving towards smaller nodes [4].

As a source of high-power EUV radiation, it was proposed at the IAP RAS, to use a magnetized plasma flow of an electron-cyclotron resonant (ECR) discharge supported by gyrotron radiation; corresponding experimental and theoretical studies are underway [5–8]. In the ECR discharge, due to the efficient power deposition into the electronic component, favorable conditions are created for the generation of multiply charged ions and excitation of their lines by electron impact. Gyrotrons have a higher average power than lasers used in existing EUV radiation sources [9]. At the same time, the radiation of modern subterahertz gyrotrons is capable of propagating in a rather dense plasma (up to 1016 cm–3), allowing one to count on the generation of high-power EUV radiation by a compact plasma formation (dimensions of the order of 1 mm), that is good for focusing [3].

In this paper, we present a fluid model of a stationary flow of a dense magnetized plasma with multiply charged ions, taking into account successive ionization by electron impact, the momentum balance of electrons and ions, heat transfer from a localized source (ECR zone) due to nonlinear electron heat conduction, and energy losses due to ionization and line emission of ions. Simulation of tin and xenon plasma flows is performed. A search is made for flow regimes that are optimal for the generation of the target EUV radiation.

The work was supported by the Russian Science Foundation (grant no. 23-22-00270).

References

1. Fu Nan et al., J. Microelectron. Manuf., 2019, 2, 19020202.
2. Mayer P. et al., Proc. of SPIE, 2021, 11609, 1160918.
3. Bakshi V. (ed.), *EUV Sources for lithography*, Bellingham, WA: SPIE Press, 2006, 1057 p.
4. Luo Yandong, Gupta P., Proc. SPIE, 2018, 10588, 105880O.
5. Golubev S.V. et al., Tech. Phys. Lett., 1994, 20, 135-137.
6. Vodopyanov A.V. et al., JETP Lett., 2008, 88, 95-98.
7. Chkhalo N.I. et al., J. Micro/Nanolithogr. MEMS, and MOEMS, 2012, 11, 021123.
8. Abramov I.S. et al., Phys. Plasmas, 2017, 24, 073511.
9. Thumm. M., J. Infrared Millim. Terahertz Waves, 2020, 41, 1-140.
1. \*) [abstracts of this report in Russian](http://www.fpl.gpi.ru/Zvenigorod/L/Lt/ru/FG-Abramov.docx) [↑](#footnote-ref-1)