Pis'ma v ZhETF, vol. 123, iss. 5, pp. 378 – 379

VLS grating for X-Ray optics as fabricated by e-beam nanolithography with optically confirmed exponential line-density variation

A. I. Arzhanov[+*], *V. V. Shulga*[+], *A. S. Shelkovnikov*[+], *K. E. Aleksashin*[+], *A. Yu. Neliubov*[+], *A. O. Kolesnikov*[+], *M. D. Logachev*[+], *A. N. Shatokhin*[+], *E. A. Vishnyakov*[+], *E. N. Ragozin*[+], *A. V. Naumov*[+*1)]

[+]*P. N. Lebedev Physical Institute of the Russian Academy of Sciences, 119991 Moscow, Russia*

[*]*Moscow Pedagogical State University (MPGU), 119435 Moscow, Russia*

Submitted 25 January 2026
Resubmitted 27 January 2026
Accepted 28 January 2026

We report the development of a large-area plane Varied Line-Space grating with line density varying exponentially along the grating surface roughly from 160 to 560 mm^{-1}. The grating was produced using e-beam lithography with original square-stamp beam profile and is intended for an innovative high-resolution single-component grazing-incidence monochromator, in which wavelength scanning is achieved simply by linear movement of the grating along its surface. For a grating width of 60 mm, the first-order operating spectral range is 9–20 nm. Optical measurements of the line density-vs-coordinate dependence reveal perfect match between the fabricated and intended by the design density dependences.

DOI: 10.7868/S3034576626030108

This article describes the development, manufacturing process, and quality assessment of a large-area flat diffraction grating with variable line spacing (VLS) designed for use in an innovative single-element grazing-incidence X-ray monochromator. The line density of the diffraction grating varies exponentially from ~ 160 to ~ 560 lines per millimeter along its entire length (60 mm), allowing wavelength scanning by simple linear movement of the grating without shifting the entrance or exit slit. This configuration provides a constant deflection angle and fixed positions of the source and detector, making the monochromator particularly convenient for practical application in X-ray optics.

The grating was fabricated using electron beam lithography on a modified ZBA-21 system with a square electron beam stamp of a variable size (200 nm to 6.2 μm). This approach significantly increases recording productivity while maintaining nanometer placement accuracy and minimizing stitching errors across a large exposure field of 60×10 mm. The electron beam lithography method allows for the precise implementation of a specified exponential linear density distribution, overcoming the limitations inherent in mechanical ruling, holographic recording, and interference lithography methods.

The quality of the fabricated VLS diffraction grating was analyzed using atomic force microscopy (AFM), scanning electron microscopy (SEM), and optical diffraction measurements (see Fig. 1). AFM analysis confirmed the excellent accuracy of the grating line profile and extremely low surface roughness, while SEM images demonstrated the high uniformity of the grating structure and smooth stitching between exposure fields. Optical diffraction experiments using He–Ne laser radiation confirmed that the experimentally measured change in linear line density corresponds exactly to the theoretical design.

The results show that stamped electron beam nanolithography is an effective and reliable tool for manufacturing large-area aperiodic diffractive optical elements. The developed VLS grating fully meets the design requirements for high-resolution soft X-ray monochromators and opens up new possibilities for next-generation X-ray optical devices and related applications.

Funding. A. O. Kolesnikov, M. D. Logachev, A. N. Shatokhin, E. A. Vishnyakov, and E. N. Ragozin acknowledge the support from the Russian Science Foundation under Grant # 25-12-00314 "Development and research of new optical elements for the soft X-ray spectrum region (5–25 nm)", https://rscf.ru/project/25-12-00314/.

The work of A. I. Arzhanov, V. V. Shulga, A. S. Shelkovnikov, K. E. Aleksashin, A. Yu. Neliubov,

1)e-mail: a_v_naumov@mail.ru

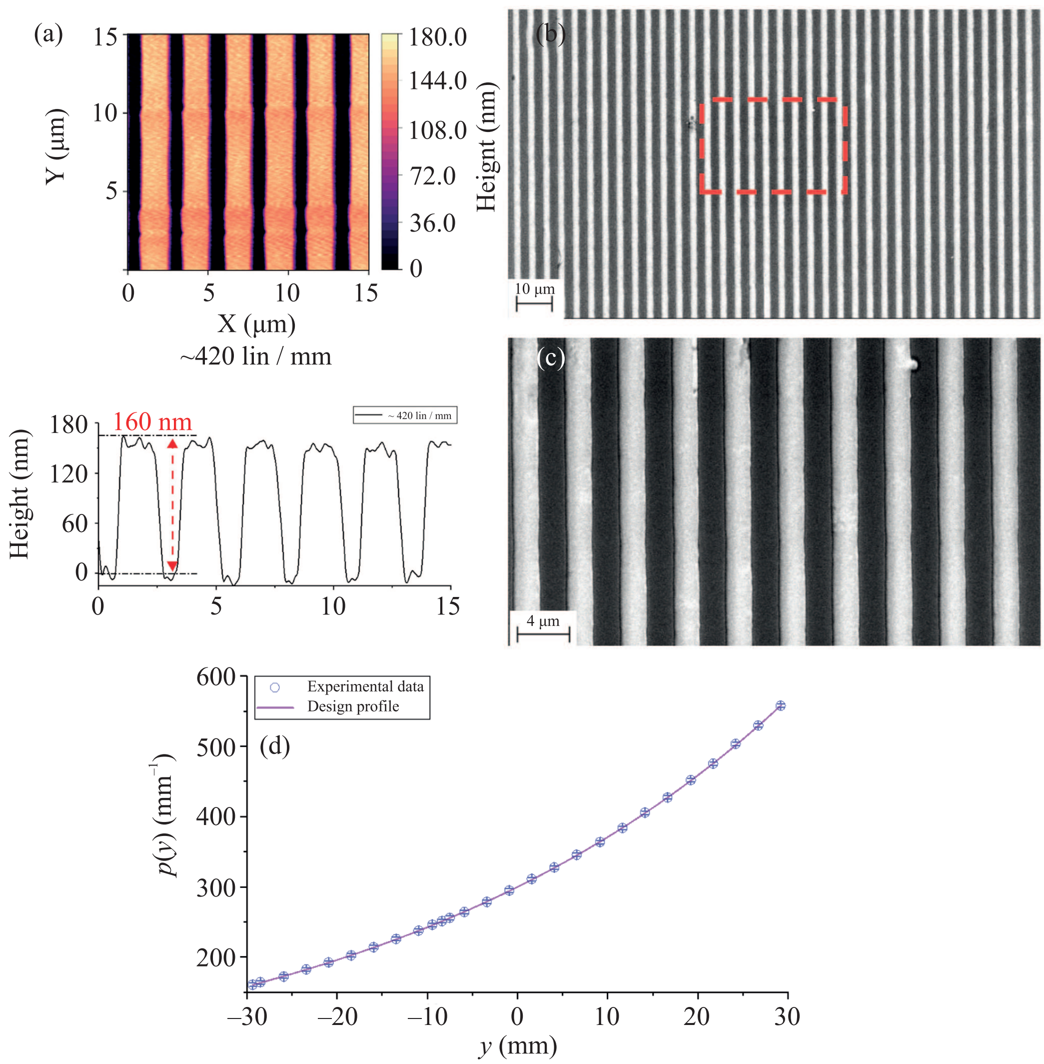

Fig. 1. (Color online) Properties of fabricated VLS grating. (a) – Atomic force microscope measurements of the grating profile in the area with line density $\sim$420 lin/mm. (b), (c) – Scanning electron microscope images of the grating that shows fine homogeneity and lack of "stitching" artefacts, or other major defects. (d) – The results of optical measurements performed to evaluate the match between the actual distribution of lines density of the grating with the one intended by the design

A. V. Naumov was performed within the framework of the State Assignment for the P. N. Lebedev Physical Institute (development of e-beam lithography).

Regarding the development of nanostructure characterization methods, A. I. Arzhanov, A. Yu. Neliubov, A. V. Naumov acknowledge also the support within State Assignment of the Moscow Pedagogical State University from the of Ministry of Education of The Russian Federation "Photonic Technologies in Science and Education: Materials, Methods, and Tools for Ultra-High-Sensitivity Optical Sensing and Microscopy".

Conflict of interest. The authors of this work declare that they have no conflicts of interest.