Acceleration Complex for Extreme Ultraviolet Nanolithography Based on a Free-Electron Laser with Kilowatt-Scale Average Radiation Power

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Abstract—The project of an acceleration complex is described that is based on a 0.7-GeV superconducting linear accelerator for the free-electron laser used for extreme ultraviolet lithography at a 13.5-nm wavelength with a 0.5-kW average power of laser radiation, as well as for examination of materials using X-ray and vacuum-ultraviolet radiations.

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INTRODUCTION

The project is aimed at creating an acceleration complex based on the 0.7-GeV superconducting linear accelerator for the free-electron laser (FEL) used for extreme ultraviolet lithography (EUVL) at the 13.5 nm wavelength with an average laser-radiation power of 0.5 kW [1–3]. It is also oriented toward conducting examination of materials using the coherent X-ray and vacuum-ultraviolet radiations. In the context of implementation of the project, it is suggested that the following be carried out.

1. Development of a conceptual design for the 0.7-GeV superconducting linear accelerator that provides coherent laser radiation at a 13.5-nm wavelength with an average power of 0.6 kW for EUVL.

2. Development of a conceptual design for EUVL with resolutions of 22 and 16 nm (and below) using one FEL-radiation source operating at a 13.5-nm wavelength and with an average kilowatt-scale power simultaneously for several scanners.

3. Implementation of electron acceleration to an energy of 0.9 GeV. The development of proposals on medical and biological research in the “water window” at 2.4–4.6 nm (at the third harmonic of FEL radiation), in particular aimed at carrying out time-of-flight analysis with femtosecond resolution and reconstructing the three-dimensional image of biological macromolecules on the basis of diffraction scattering or electron microscopy [4].

4. Development of proposals on investigations of magnetic materials at a wavelength of around 1.5 nm (at the fifth harmonic of FEL radiation), in particular based on magnetic-resonance scattering [5] or time-of-flight analysis of magnetic scattering of FEL radiation [6].

5. Implementation of technology related to the creation of the International Linear Collider.

EXTREME ULTRAVIOLET LITHOGRAPHY AND RADIATION SOURCES FOR IT

For implementation of EUVL at a 13.5-nm wavelength, two types of radiation sources are actively being developed at present: one is based on the laser-produced plasma (LPP) [7]; the other is being created on the basis of the discharge-produced plasma (DPP) [7]. The presently achieved level of the average power of the laser radiation source at the 13.5-nm wavelength for EUVL is ~75 W [7]. The exposure power of extreme ultraviolet (EUV) radiation reaches approximately 20 W, which provides a throughput of 15 semiconductor wafers per hour (w/h) with a diameter of 300 mm [7]. With the 200-W average power achieved in the source, a throughput of 125 w/h with 27-nm resolution is planned in ASML nanoscanners [8]. The basic design parameters of NXE platforms for EUVL and an LPP source from Cymer Co. are given in Table 1. One of the factors is throughput characterized by the number

† Deceased.
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of semiconductor wafers processed per hour with a certain diameter for the specified chip size. This factor (with the given power of the radiation source) depends on the performance of the technological cycle of wafer passage through the lithography facility determined by the construction peculiarities of its platform. The main concept of the scanner based on the TWINSCAN platform [8] (see Table 1) is the availability of two identical tables for semiconductor wafers and the implementation of parallel processes: exposure of one wafer and simultaneous metrological preparation and coordinate fixation of another wafer.

The growth of throughput of production of semiconductor wafers in the NXE scanner will be provided basically by an increase in CO$_2$ laser power and efficiency of conversion of CO$_2$ laser radiation to EUV radiation. Within the ASML roadmap, the planned maximal power of the LPP source is considered at the level of 0.5 kW [8].

ACCELERATION COMPLEX BASED ON A FREE-ELECTRON LASER FOR EUVL

In the context of the given project, we plan to provide generation of FEL radiation at a 13.5 nm wavelength with 0.5-kW average power and 34-GW pulse power (Table 2). Generating radiation at an electron energy of 1.25 GeV with an average radiation power of 1.75 kW is also discussed. FEL radiation possesses properties identical to those of optical laser radiation: high spatial coherence and small angular divergence caused by diffraction. The role of FEL active medium is played by an electron beam with an electron energy of 0.7 GeV and an average power of around 70 kW. In this case the length of the acceleration complex is approximately 110 m. Applying FEL radiation at the 13.5-nm wavelength with an average power of around 0.5 kW allows one to implement EUVL with high (industrial) throughput and to provide resolution of 22 or 16 nm or lower.

The conceptual design of an acceleration complex for EUVL is based on the technology that was implemented for the free-electron laser in Hamburg (FLASH) at DESY [9]. At present, the ultraviolet radiation at the 13.5-nm wavelength with a pulse power of several gigawatts is generated at FLASH. The base for FLASH is the superconducting linear accelerator of L-band type for electron energy of 1 GeV (Fig. 1). It is designed for operation at a pulse current of 10 mA, with a micropulse duration of 800 μs and micropulse repetition rate of 10 Hz.

The analysis carried out in [10] indicates that the technology implemented at FLASH has a good chance of increasing the electron-beam average power and the efficiency of electron-energy conversion to