PROPOSAL FOR AN ACCELERATOR COMPLEX FOR EXTREME ULTRAVIOLET NANOLITHOGRAPHY USING KW-SCALE FEL LIGHT SOURCE

E.Syresin , M. Yurkov, Y. Budagov, N. Balalykin, I. Lensky, A. Olshevsky, A. Sumbaev,
G. Shirkov, G.Trubnikov, Joint Institute for Nuclear Research, Dubna, Russia.

Abstract

The project is aimed at construction of accelerator complex, based on a 0.7 GeV superconducting linear accelerator, for applications in nanoindustry, mainly for extreme ultraviolet lithography using kW-scale Free Electron Laser (FEL) light source. The project involves construction of a 0.7 GeV superconducting linear accelerator to produce coherent FEL radiation for extreme ultraviolet nanolithography at a wavelength of 13.5 nm and an average radiation power of 0.5 kW. The application of kW-scale FEL source permits realizing EUV lithography with 22 nm, 16 nm resolutions and beyond. The project for construction of an accelerator complex for EUV lithography is based on the technology realized on FEL FLASH (Free Electron Laser in Hamburg) facility at DESY (Hamburg).

INTRODUCTION

The project is aimed at construction of accelerator complex, based on a 0.7 GeV superconducting linear accelerator, for applications in nanoindustry, mainly for extreme ultraviolet lithography using kW-scale Free Electron Laser (FEL) light source. The project involves the following activities.

Construction of a 0.7 GeV superconducting linear accelerator to produce coherent FEL radiation for extreme ultraviolet nanolithography at a wavelength of 13.5 nm and an average radiation power of 0.7 kW.

Construction of a dedicated channel for extreme ultraviolet lithography with a few nanoscanners operating simultaneously in a processing line with 22 nm, 16 nm and beyond using FEL radiation at a wavelength 13.5 nm.

Medico-biological investigations using radiation with wavelengths ranging from 2.4 nm to 4.6 nm (3rd harmonic FEL) .

Research in magnetic materials using radiation with a wavelength of about 1.5 nm (5rd harmonic FEL).

Realization of the superconducting RF linear accelerator technology for the International Linear Collider.

.

EXTRIME ULTRAVIOLET LITHOGRAPHY

The development of the next generation lithography was started since the middle of 1990s. A target goal was to follow Moore's law in the reduction of a feature size by a factor of two in two years. During last two decades the progress in the feature size reduction has been provided by reducing the wavelength of lasers used. The conventional lasers operate at wave length of 193 nm. Immersion and photoresist technologies aiming to get feature size below λ/4 limit reached their boundaries as well.

The ASML TWINSCAN NXE platform [1] (Fig.1) is the industry first production platform for extreme ultraviolet lithography (EUVL) based on the laser source LPP [2] at wave length of 13.5 nm. The resolution of NXE:3100 corresponds to 27 nm (Table 1). The resolution of NXE: 33000B is 22 nm with conventional illumination and 18 nm with of-axis illumination.

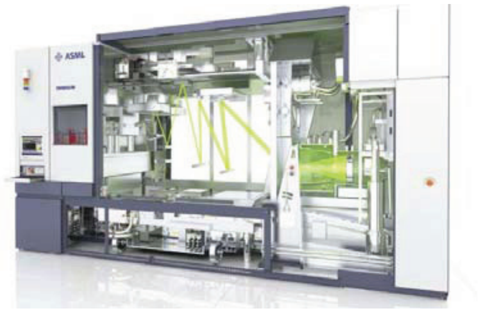

Figure 1: ASML TWINSCAN NXE industry platform for EUVL with LLP at radiation wavelength of 13.5 nm.

Table 1. Parameters of SML EUV platform.

Parameter	NXE:3100	NXE: 33000B
NA	0.25	0.32
Resolution, nm	<27	<22 (18nm off-axis illumination)
Exposition field, mm	26×33	
Illumination sigma	0.8	0.2-0.9
Overlay, nm	4.5	3.5
Productivity, wph	>60	>125

The power of LPP sources now corresponds to 75 W [2]. The exposition power is equal to 20 W that provides production rate of 15 wafers per hour (wph) at their diameter of 300 mm. It is planed to increase the production rate up to 125 wph at the LPP power of 200 W. The LPP micropulse radiation energy corresponds to 2 mJ, micropulse repetition frequency is equal to 50 kHz, the number of micropulses is 2×10^4 per macropulse. The time duration of the macropulse is equal to 400 ms, the macropulse repetition frequency corresponds to 2 Hz, the macropulse energy is about 40 J.

EUV LITHOGRAPHY BASED ON FEL

The project for construction of an accelerator complex for EUV lithography is based on the technology realized on FEL FLASH (Free Electron Laser in Hamburg) facility at DESY (Hamburg) [3]. FLASH has produced several GW powers for EUV radiation with a wavelength of 13.5 nm, a target goal for the next generation lithography. The driving engine of FLASH facility is an L-band superconducting accelerator [3]. It is designed to operate in a pulsed mode with a pulse duration of 800 microsecond and repetition rate of 10 Hz [3]. The maximum accelerated macropulse current is 10 mA. The present analysis [4] (Fig.2-Fig.4) shows that this technology holds great potential for increasing the average power of a linear accelerator and the efficiency of conversion of electron kinetic energy into light.

Table 2. Parameters of accelerator complex for EUVL.

Acceleration complex	FLASH	EUVL-0.68	EUVL-1.25
Electron energy, GeV	0.68 (1)	0.68	1.25
FEL length	250	110	180
Macropulse frequency, Hz	10	40	10
Macropulse time duration, ms	0.8	0.14	0.8
Number of pulses per macropulse	7200	1400	8000
Micropulse frequency, MHz	9	10	10
Micropulse radiation energy, nJ	1.4	8.5	22
Macropulse radiation energy, J	10	12	176
Peak radiation power, GW	5.6	34	88
Average radiation power, kW	0.1	0.5	1.75
Number of scanners		8	10

Thus, it will be possible to construct a free electron laser facility [5-7] operating at a wavelength of 13.5 nm, an average power of up to 0.5 kW and an electron energy of 0.7 GeV (Table 2). The simulations [4] are performed at the peak current of 2.5 kA and the bunch charge of 1nC. The undulator length corresponds to 30 m, it's period is equal to 2.73 cm for a facility at 0.68 GeV and 3.5 cm for EUVL-1.25. The micropulse radiation time corresponds to 250 fs. The diameter of radiation spot at undulator exit is 0.3 mm for EUVL-0.68 and 0.2 mm for EUVL-1.25.

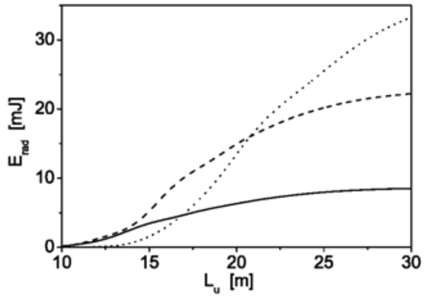

Figure 2: Dependence of radiation energy on undulator length at differen electron energies. Solid, dashed, and dotted lines correspond to the energy of driving electron beam 0.68, 1.25, and 2.5 GeV, respectively.

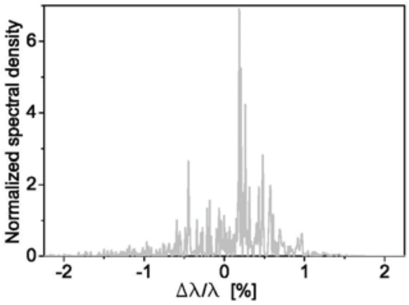

Figure 3: Normalized spectral density distribution of radiation.

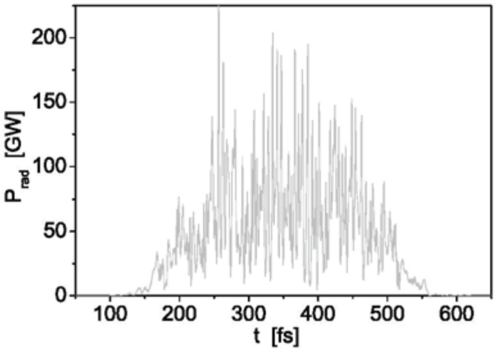

Figure 4: Dependence of peak radiation power on time at electron enrgy 1.25 GeV

Using a powerful FEL source allows this approach to be redefined as ‘single source for multiple tools’. The powerful kW-scale FEL radiation can be distributed between EUV lithography ‘multiple tools’ operated at an average power about 60 W due to multilayer mirrors installed at the entrance of each lithography scanner and FEL time structure (Fig.5).

For powerful FEL radiation at its small angle spread and little spot size there are some peculiarities of the first defocusing SiC mirror installed at a distance of 10 m after the undulator exit. The elliptical spot sizes corresponds to 5 mm and 0.35 mm at 3^0 incident angle of the FEL radiation to the SiC mirror surface. The mirror absorbed power corresponds to 50W and absorbed macropulse radiation energy is 1J at the average FEL power of 0.5 kW and reflection efficiency of 90%.

Table.3 EUVL on basis of FEL and NXE:3100 LPP radiation.

Parameter	LPP	EUVL 0.68
Number of multilayer elements	11	
Coefficient of reflection	0.62	
Micropulse radiation energy, mJ	2 1 scan.	8.5 8 scan.
Radiation energy density, mJ/cm^2	10	
Exposition energy of chip bend	5.2	
Energy of chip exposition, mJ	83	
Wafer energy exposition, J	6	
Scanning speed, mm/ms	0.2	0.1
Average radiation power, W	100	480
Wafer average power exposition, W	0.5	0.3
Number of micropulses for band exposition	520	1250
Time of bend exposition, ms	10	0.125
Number of micropulses for chip exposition	8300	20000
Time of chip exposition, ms	160	320
Time of wafer exposition, s	14	22
Time of wafer reloading, s	22	22
Production wafer rate, w/h	100 1 scan.	640 8 scan.

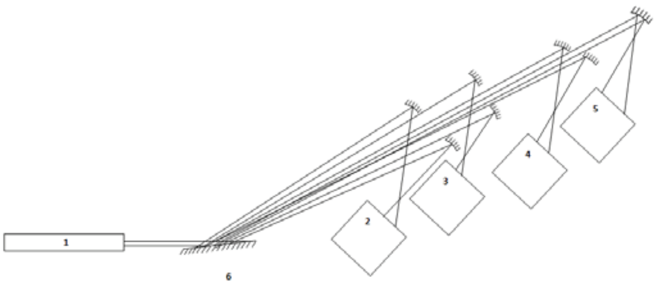

Figure 5: Distribution of FEL radiation between lithography scaners, 1- FEL, 2-5 – lithography scanners, 6 – first mirror.

The FEL radiation is divided on the 8 simultaneously operated scanners (Table 3). The FEL spot after defocusing mirror has a diameter of 50 cm which is divided on 8 concentric rings of equaled square by a special multilayer mirror system (Fig.5). The radiation from each concentric ring is pick-upped by the corresponding scanner. In each scanner a system consisted of 4 multilayer mirrors transforms the radiation ring in a bend with a size of 26×2 mm, which is exposited on chip by the 6 multilayer mirror objectives. The analogical optic for transformation of the ring in a bend is realized in NXE: 3100 platform [1] with LPP source. The full chip exposition at its size of 26×33 mm is produced at its motion across the EUV radiation flax**.** The radiation energy required for chip production corresponds to 16 J at wafer radiation energy density of 10 mJ/cm^2 and efficiency of EUV light transportation to the wafer of 0.5% (for 11 multilayer elements of NXE Platform). The bend exposition is produced at FEL macropulse time of 0.14s. The chip is scanned 20 ms between macropulses by FEL radiation. The chip and wafer expositions correspond to 320 ms and 22 s, correspondently. The EUVL scanner production rate is 80 wph, when the wafer exposition time is comparable with its loading time in scanner. The project production rate of full FEL EUVL complex with 8 scanners corresponds to 640 wph.

REFERENCES

[1] TWINSCAN NXE:3100 & NXE:3300B, ASML Product Catalog (2010) 8.

[2] D.C. Brandt, N.R. Farrar, Solid State Technology, v. 52, №9 (2009) 10.

[3] T.Aberg et al, Conceptual design report, DESY, TESLA-FEL 95-03, Hamburg, 1995.

[4] E.Saldin et al., FEL’09, (2009).

[5] V.S. Anchutkin et al., In proc. “Nanophysics and nanoelectronics”, Nishnij Novgorod, v.1, (2010) 209.

[6] O.Brovko et al., Applied physics, 3 (2010) 46.

[7] O.Brovko et al., IPAC10, (2010).