Strategy to realize the EUV-FEL high power light source
- Present status on the EUV-FEL R&D activities -

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Abstract

It is important to develop the high power EUV light source up to 1 kW to realize the beyond 5nm node, which is expected to be in production at 2023-24. To this end, an energy recovery linac(ERL)-based free electron laser(FEL) must be a most promising candidate, so that our group has done some feasibility studies from the view point of accelerator technology. However, this kind of design studies by academia would not be enough to realize the EUV-FEL light source for semiconductor industry. It is required to conduct the R&D on the design of such practical accelerators in collaboration with equipment suppliers and end users. Furthermore, because the properties of the FEL light are somewhat different from these of an ordinal LPP light source, feasibility studies for EUV light optics, multi-layer-mirrors, masks, and resist materials, and so on, will be required. Thus, it is important to make a collaborative work between source group, tool and material suppliers, and end users to realize the EUV Lithography total system by means of EUV-FEL light source.

Present Status and Future Development on EUV Lithography

Present Status

- The technologies on EUV Lithography system based on LPP light source are progressing, now.
- The system based on ~100 W LPP light source is starting point of the production phase, and the ~200 W LPP light source is the stage of a development phase.

Future Development

- It is expected that the systems based on ~500 W EUV light source will be necessary to realize the production less than 7nm node, and that these on ~1kW source will be necessary to realize the production less than 5nm node, too.
- It is important to develop new type light source to realize higher power than ~1kW, and also the other technologies which are related on EUV lithography such as multi-layer-mirrors, masks, and resist materials, and so on, because the properties of the FEL light are somewhat different from these of an ordinal LPP light source.

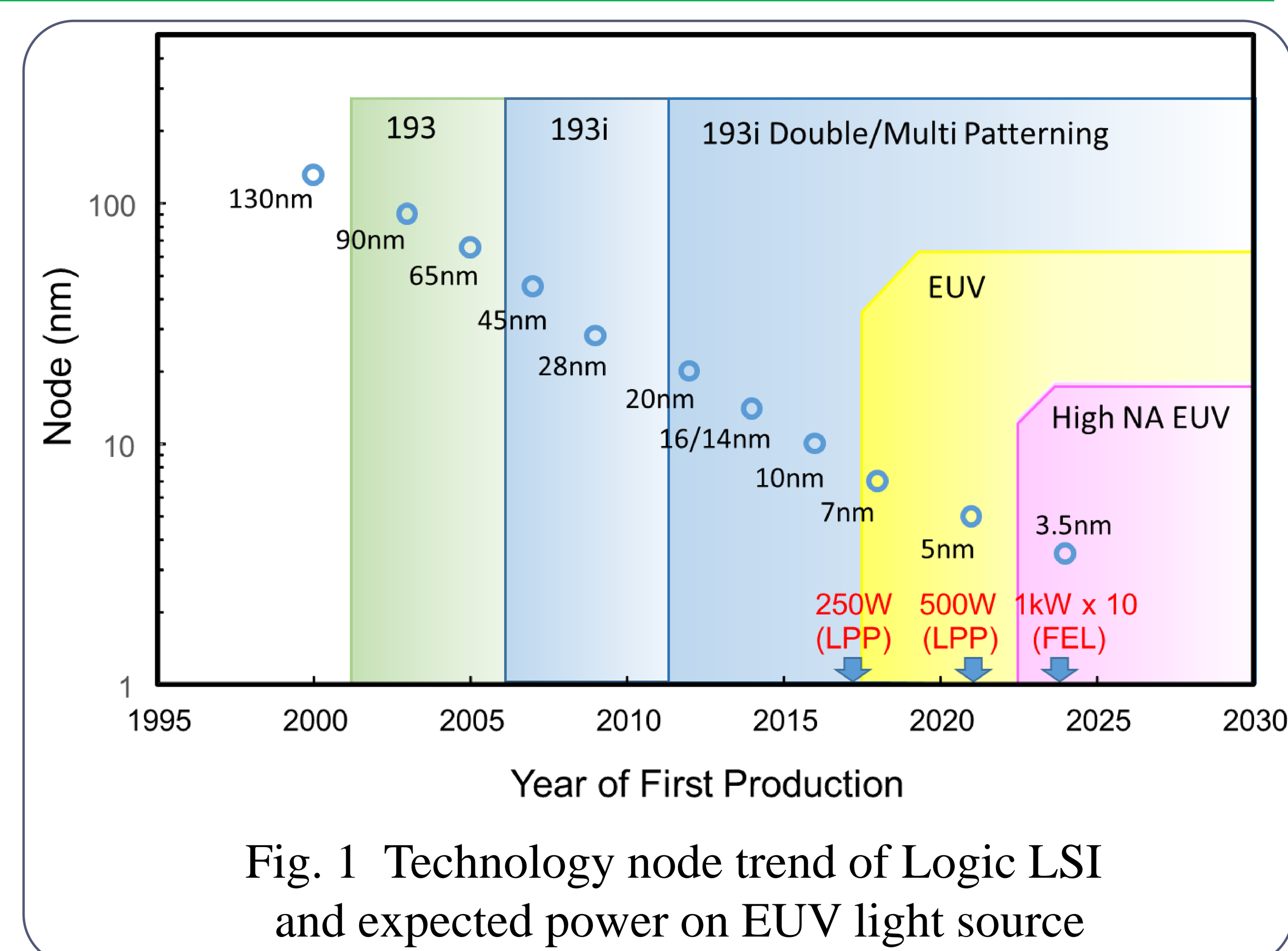

Fig. 1 Technology node trend of Logic LSI and expected power on EUV light source

Design study on high power EUV-FEL light source

Design concept

- High energy accelerator technologies bring us 10 kW class high power EUV light source based on Free Electron Laser (FEL).

Key technologies

- Super conducting accelerator technologies with Energy Recovery Linac (ERL) (800MeV, 20 mA)
- High power FEL technologies (~30 kW)
- Accelerator elements, systems and operation skill, which are developed in cERL at KEK

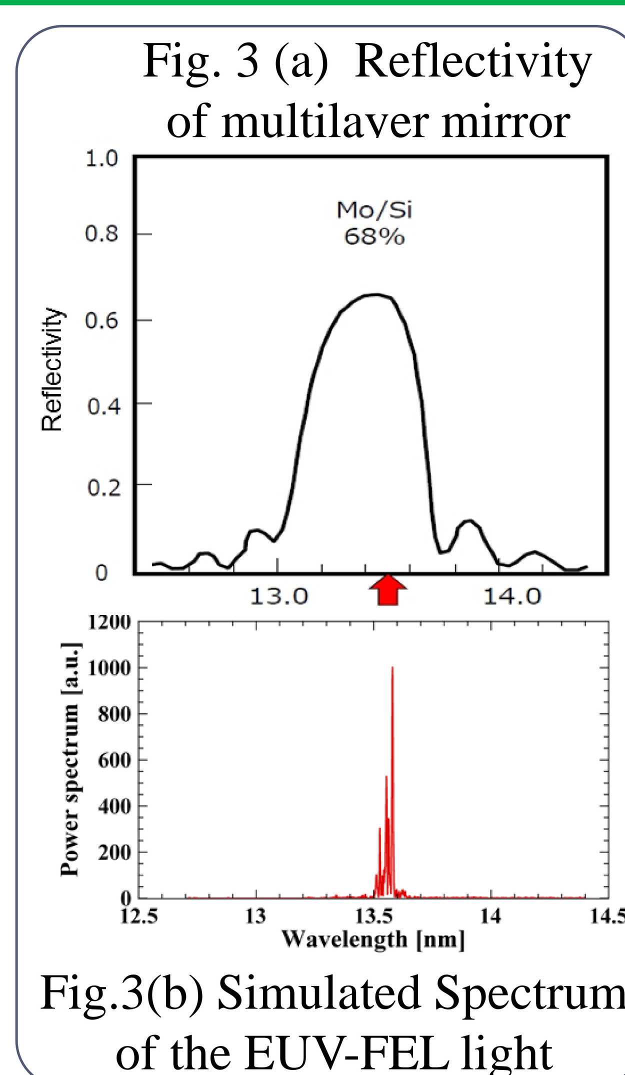

Fig. 3 (a) Reflectivity of multilayer mirror

Fig.3(b) Simulated Spectrum of the EUV-FEL light

Achieved values in cERL and Design values at the EUV-FEL

Items	Achieved values in cERL	Design Values at the EUV-FEL
Energy for injector (MeV)	2.9-6	10.5
Energy of Accelerator(MeV)	20	800
Charge /bunch (pC)	0.7-5	60
Repetition rate (MHz)	162.5-1300	162.5
Average Current (mA)	1.0	9.75
Emitance for electron beam (mm mrad)	0.3-1	0.6
Gradient of the accelerated energy (MV/m)	8.6	12.5
Wavelength of EUV-FEL (nm)	/	13.5
Average power of EUV-FEL (kW)	/	Higher than 10 kW

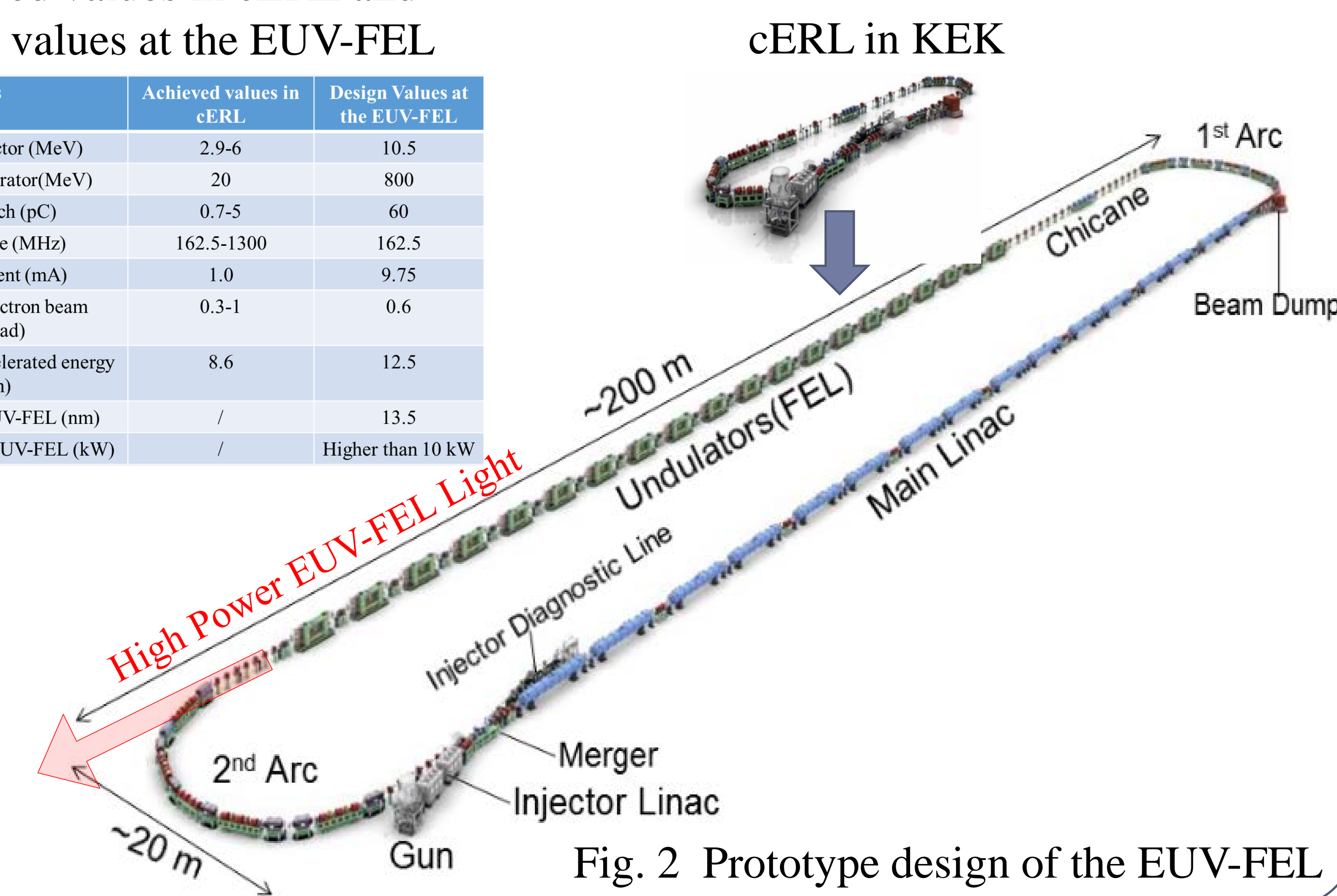

Fig. 2 Prototype design of the EUV-FEL

Further development for HVM light source

The much smaller EUV-FEL light source is required to install in Fab.

- Double loop scheme as shown in Fig. 4.
- Higher field gradient of the super conducting cavity (SC)

  (Power consumption of the cryogenic systems) ∝ (field gradient)^2/Q

  It is important to develop much higher Q materials for SC.

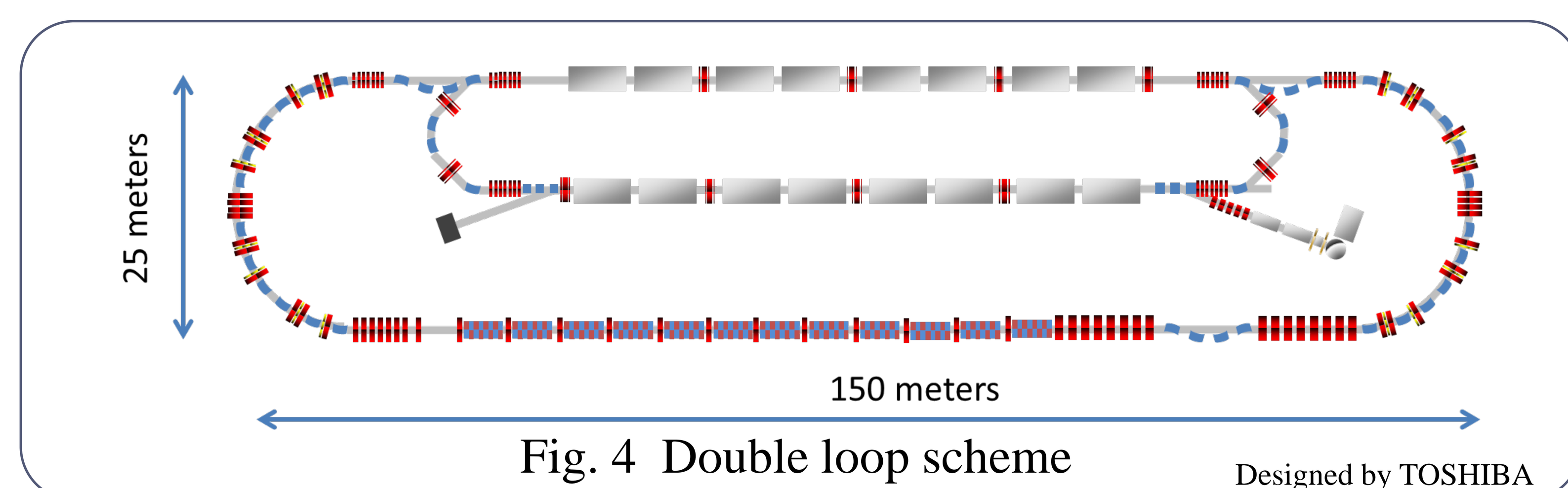

Fig. 4 Double loop scheme

Designed by TOSHIBA

Summary

- In order to keep the milestone shown in Fig.1, it is important to push forward the construction of the prototype EUV-FEL light source (Fig. 3) to develop the related items such as multi-layer-mirrors and so on as soon as possible.
- It is important to develop the light source and the related lithography integration should be done simultaneously in order to minimize the development resources and time. To this end, source group, tool and material venders, and end users should have collaborative works from the early stage.
- At the beginning of the collaboration, the "EUV-FEL Light Source Study Group for Industrialization" has been established since last year (2015) as shown in Fig. 5.
- Figure 6 is the expected image of LSI Fab using EUV-FEL light source.

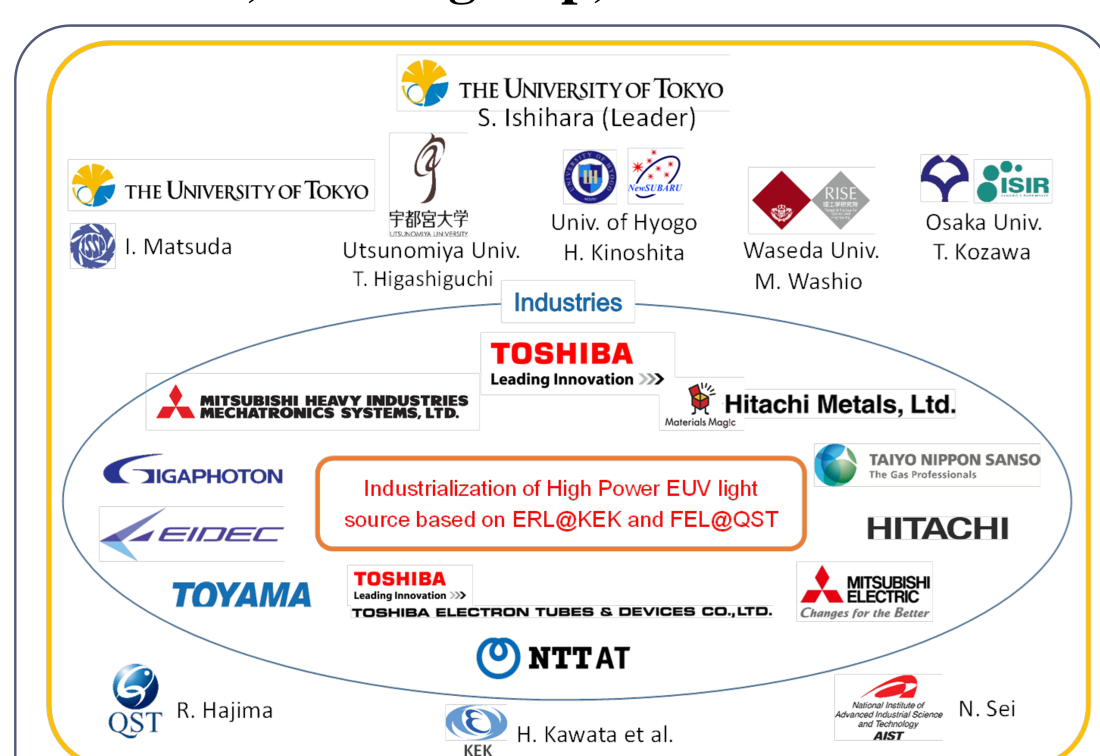

Fig. 5 "EUV-FEL Light Source Study Group for Industrialization"

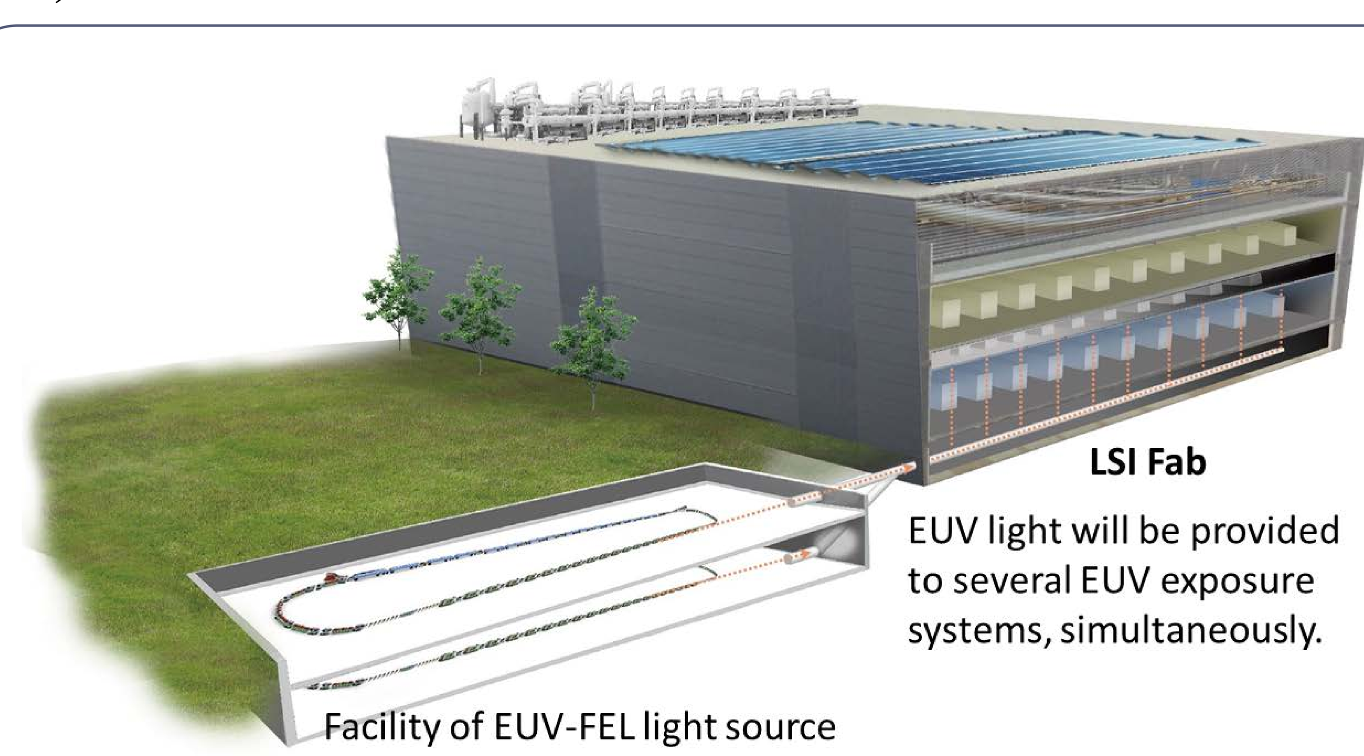

Fig. 6 Schematic view of the EUV-FEL light source in a LSI Fab