Extendability of LPP EUV source technology in kW average power and 6.x nm wavelength operation

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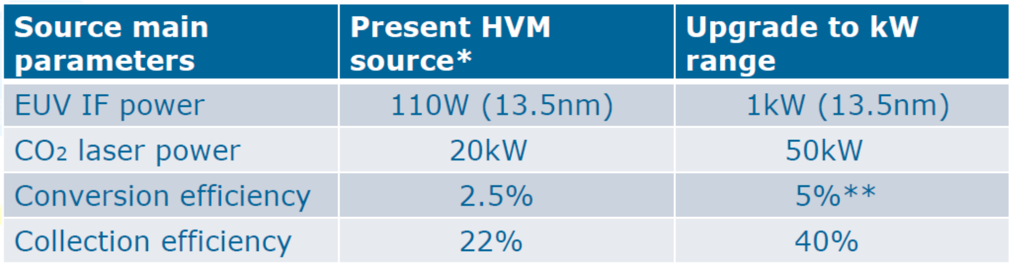
The basic architecture of EUV HVM light source technology is established after one decade of intensive international research and development. It is characterized by nanosecond CO2 laser irradiation of dispersed tin (Sn) mist from 10 μm diameter liquid droplet. Full ionization is beneficial for efficient recovery of injected Sn particles by magnetic field supported by hydrogen cleaning of a large collector mirror. Present performance is reported as 50W at the intermediate focus (IF) by 40% duty, which is 20W as average power. It is expected to be operated at 250W in 2015, after solving various engineering issues for stable long time operation.

It is suggested as the average output power is desirable to be 1kW in matured phase of EUV lithography at 13.5nm. It is necessary to consider on component technologies of the EUV HVM source technology to find critical improvement toward this goal. Table 1 summarizes relevant parameters in the present (110W) and final (1kW) EUV HVM sources. Present CO2 lasers are operated with less than 20kW, by typically 10ns pulse length at 100 kHz. It is possible to operate at 50kW by two laser beams by slightly increased repetition rate without any serious overload in the laser system. Conversion efficiency is possible to be increased as more than 5% by better conditioning of the tin mist by picosecond solid state laser pre-pulse. Significant effort is necessary to improve the collection efficiency from present 22% to 40%. This involves almost all engineering efforts to avoid higher thermal instability and EMI interference, together with full recovery of injected Sn particles. EUV light transmission is to be improved by higher vacuum level, and by less physical obstacles inside the chamber.

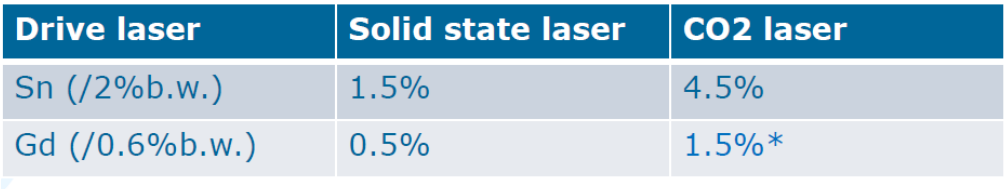
Working wavelength of the next generation of EUV lithography is expected to be shorter as 6.x nm, because higher reflectivity multilayer mirror such as La/B4C is suggested to be possible at this wavelength. Candidate radiating atoms are gadolinium (Gd) and/or terbium (Tb) based on the physical rule of unresolved transition arrays (UTA) of highly ionized atoms. The usable band width of mirrors is narrower as 0.6% compared to 2% of Mo/Si multilayers at 13.5nm. Physical properties of radiating phenomena are quite similar between Sn and Gd/Tb, but the effective conversion efficiency (CE) is limited due to the available mirror band width. Table 2 summarizes relevant parameters of the CEs.

It is reviewed in this talk on the fundamentals of the various properties of the dynamics of EUV HVM light sources toward 1kW at 13.5nm and further extension to 6.x nm wavelength.



Source main parameters	Present HVM source*	Upgrade to kW range
EUV IF power	110W (13.5nm)	1kW (13.5nm)
CO_2 laser power	20kW	50kW
Conversion efficiency	2.5%	5%**
Collection efficiency	22%	40%

Table 1: Main source parameters at 13.5nm : Present HVM source* is shown by parameters of laser drivers, conversion efficiency and collection efficiency of generated EUV power to the intermediate focus. This is from I.V.Fomenkov et.at JM3 11 (2), 021110 (April-June). Conversion efficiency is shown to be 5%** by picosecond solid state laser pre-pulse by Gigaphoton in July, 2012. Intensive engineering effort is required to achieve 40% collection efficiency.



Drive laser	Solid state laser	CO2 laser
Sn (/2%b.w.)	1.5%	4.5%
Gd (/0.6%b.w.)	0.5%	1.5%*

Table 2: Comparison of CEs: Typical conversion efficiencies are shown by laser wavelength and radiating species. Narrower mirror bandwidth results in lower CE. Optimization of CO2 laser irradiation is still under research to achieve more than 1.5% CE by Gd *.