Tin DPP Source Collector Module (SoCoMo): Status of Beta products and HVM developments

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ABSTRACT

For industrial EUV (extreme ultra-violet) lithography applications high power EUV light sources are needed at a central wavelength of 13.5 nm. Philips Extreme UV GmbH, EUVA and XTREME technologies GmbH have jointly developed tin DPP (Discharge Produced Plasma) source systems.

This paper focuses in the first part on the results achieved from the Alpha EUV sources in the field. After integration of power upgrades in the past, now the focus is on reliability and uptime of the systems.

The second part of this paper deals with the Beta SoCoMo that can be used in the first pre-production scanner tools of the lithography equipment makers. The performance will be shown in terms of power at Intermediate Focus, dose stability and product reliability but also its reachable collector lifetime, the dominant factor for Cost of Operation.

In the third part of the paper the developments for the high volume manufacturing (HVM) phase are described. The basic engineering challenges in thermal scaling of the source and in debris mitigation can be proven to be solvable in practice based on the Beta implementation and related modeling calibrated with these designs. Further efficiency improvements required for the HVM phase will also be shown based on experiments. The further HVM roadmap can thus be realized as evolutionary steps from the Beta products.

Keywords: EUV sources, gas discharge produced plasma, Tin, EUV lithography

1. INTRODUCTION

Alpha DPP (Discharge Produced Plasma) sources have been developed by Philips EUV and XTREME technologies to generate EUV (Extreme Ultra-Violet) light at 13.5 nm, within 2% bandwidth, for production of dies with 22 nm node or below. The Alpha tools (Sn and Xe based) run at several sites in the world for development of EUV scanners and materials. For the future source generations, the tin based technology has been selected due to reasons of scalability to higher power.

In the Sn-DPP source the EUV light is generated in a highly ionized Sn pinch plasma, that is produced in between 2 rotating electrode wheels that are covered with a thin Sn layer. By laser ablation on one of the electrode wheels, a tiny Sn cloud is propagating towards the opposite electrode. If this cloud reaches the second electrode, a conductive channel is created. At this moment a capacitor bank with a stored energy of up to several Joules is discharged and a high current between the electrodes of up to 20 kA, flows through the tin cloud. A highly ionized Sn pinch plasma is ignited, that generates the EUV radiation. In normal operation the source runs at several kHz repetition rate. In figure 1 the principles of the Sn-DPP source is schematically illustrated. The basics of the Sn-DPP sources are described in more detail elsewhere[1,2].

Extreme Ultraviolet (EUV) Lithography, edited by Bruno M. La Fontaine, Proc. of SPIE Vol. 7636, 763610 · © 2010 SPIE · CCC code: 0277-786X/10/$18 · doi: 10.1117/12.846545

Where Alpha Sn-DPP sources, that deliver EUV power of 70W to 170W EUV power in 2π, have shown significant improvements in lifetime and reliability, the Sn-DPP Beta development will continue with developing higher power sources to serve the EUV wafer scanner development.

In this paper we report on progress of the EUV source collector module (SoCoMo) development. During the last year, a full SoCoMo has been built as a demonstrator device for the technical performance. All components like source, foiltrap, collector, vacuum system, metrology and periphery have been integrated into an operating system. First light at the intermediate focus of this system was achieved in September 2009.

The SoCoMo was adapted to the beta-level scanner requirements. Modular setup enables the further development and later integration of single components. The feasibility of the power upgrade to HVM level using this technology has been proven in demonstration experiments. The results of the performed experiments are the basis for the HVM SoCoMo development.

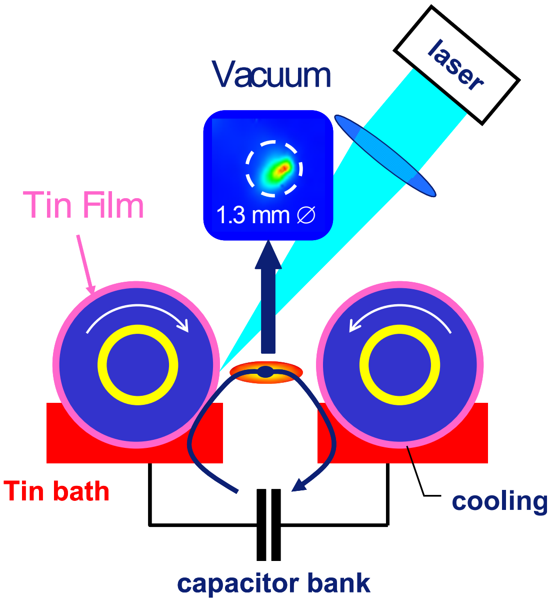

figure 1 The principle of the Sn-DPP EUV source

2. ALPHA SOURCE STATUS

Up to now, DPP sources are under operation for more than 100 billion DPP pulses, which were used for exposures as well as source testing. Alpha scanners are in the field since 2007 with tin based high power EUV sources integrated. After source upgrades in the field, a usable power at the intermediate focus (IF) of up to 8 W is available continuously. In the scanning mode > 4 wafers can be exposed per hour assuming a resist sensitivity of 5 mJ/cm².

DPP sources were delivering all the photons for all 12" wafer results presented at this conference[3,4,5,6]. During the source operation a continuous learning and improvement process took place. Along side the power increase, a structured 8D (eight disciplines) improvement approach led to an increase of the MTBI (figure 2, MTBI defined as mean number of shots between interrupts) and uptime (figure 3) of the sources. After the doubling of the MTBI number over the summer of 2009, as announced at the EUVL Symposium in Prague[7], another doubling is realized in the following quarter after all improvements were installed in the field.

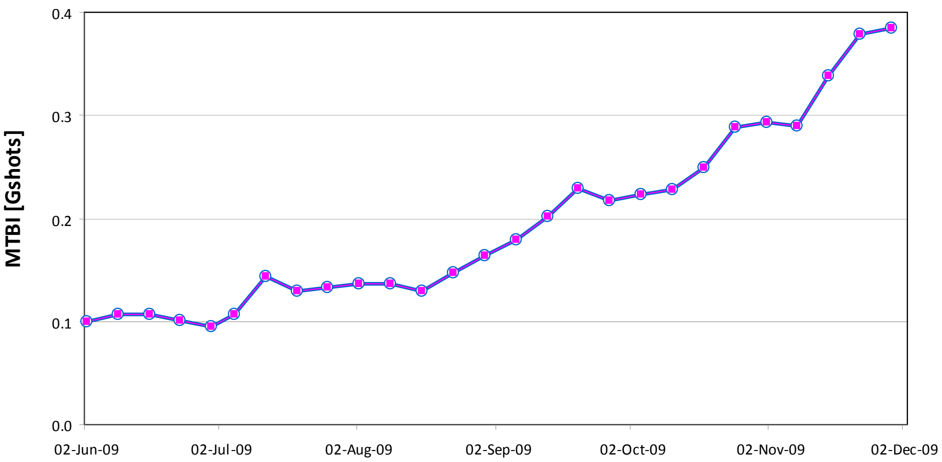

figure 2 The mean number of shots between interrupts (MTBI) could be significantly improved during 2nd half of 2009

The uptime of the two sources has been calculated according to the SEMI definitions to 73 % in average during the second half of the year 2009 (figure 3). Further substantial improvement has been achieved by the introduction of automated tin refill modules to shorten the maintenance periods. During January 2010, an ADT uptime record could be achieved resulting in a pulse number of 3 billion shots within one month.

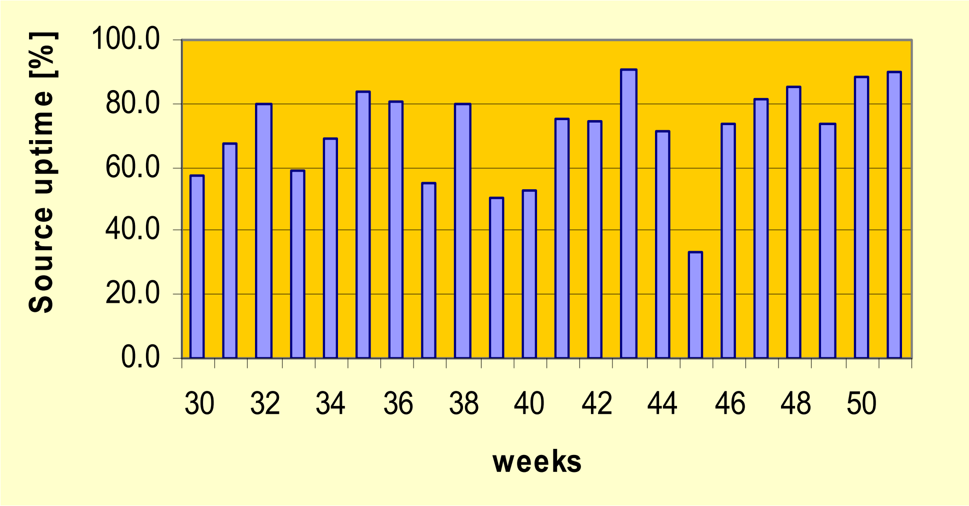

figure 3 Source uptime of the alpha demo sources during the second half of 2009

3. BETA SOURCE COLLECTOR MODULE

For the demonstration of the performance of a source collector module (SoCoMos) for scanners on beta level and for the preparation of the deliveries, a SoCoMo demonstrator based on discharge produced plasma (DPP) source technology has been worked out including all components (figure 4). The overall performance as well as the interfaces were defined and aligned with respect to the requirements of the beta-level scanner. The modular setup of the SoCoMo demonstrator allows for the integration and tests of individual components in the system for further development and performance improvements.

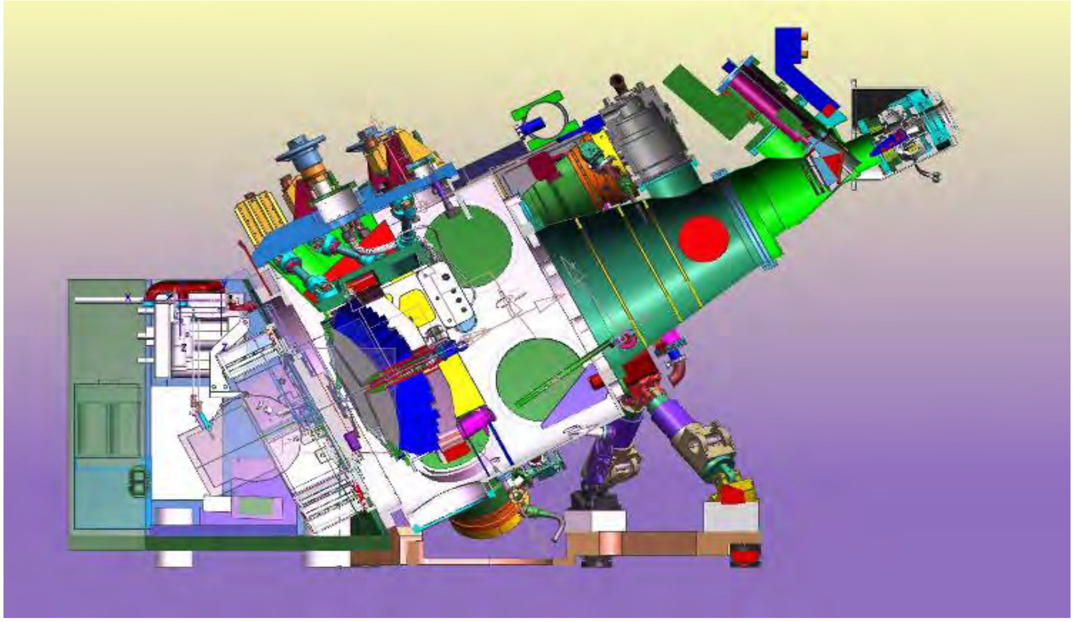

figure 4 Full source collector module architecture of the built demonstrator

During the year 2009 the system has been realized (figure 5) and first results were shown earlier[7]. The SoCoMo does not only contain the source unit, the collector, the foiltrap and the vacuum chamber, but also metrology to measure the source performance and the beam properties in front of the intermediate focus (IF), at IF position and behind in the so called farfield.

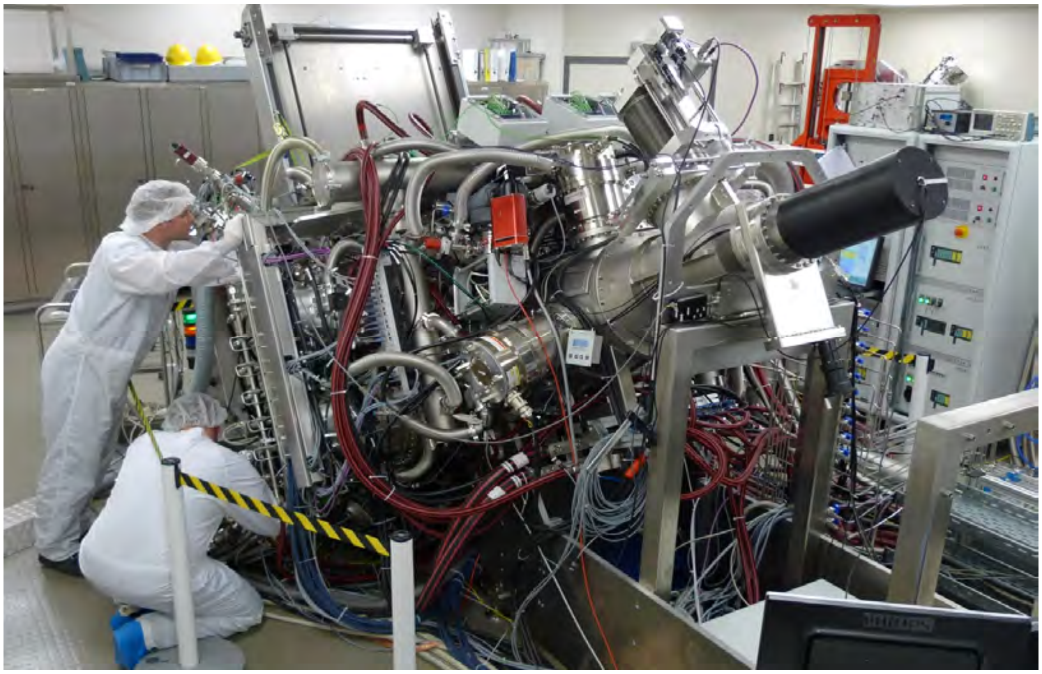

figure 5 Source Collector Module for the NXE 3100

Main modules of the SoCoMo were developed and tested in parallel. In the integration phase all modules were assembled to a full SoCoMo. The main modules are the production source, the foiltrap to protect the collector from the debris out of the source and the vacuum chamber including pump system (figure 6). The collector itself has been developed and built by Media Lario (Italy)[8].

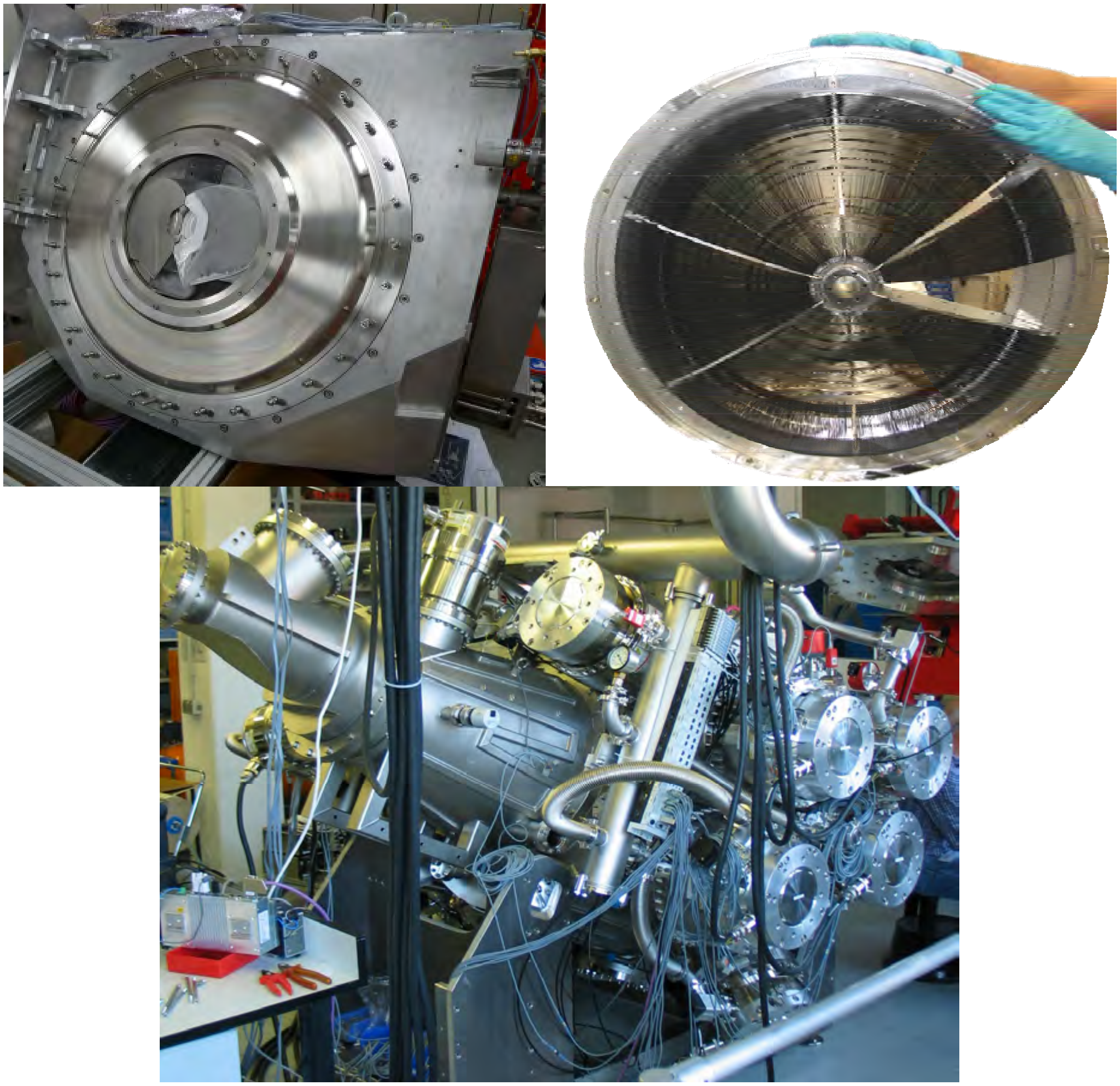

figure 6 Images of different modules like the production source (upper left), the foiltrap (upper right) and the vacuum vessel and vacuum pumps (bottom) just before integration.

The main task during the integration was, beside the mechanical work of the assembly, the alignment using special tools and metrology. For this the source performance itself was monitored by pulse to pulse energy sensors and by EUV cameras measuring the plasma size and position. In addition two screen tools are integrated to allow for the detection of the intensity distribution, one in front of the intermediate focus aperture and a second one behind this aperture. An alignment concept was worked out to achieve the best alignment of all components to each other to increase the system efficiency as much as possible.

To shorten the maintenance time, a so called swap flange has been developed and integrated. To the swap flange an adjustment tool is attached allowing the alignment of the foiltrap/collector unit with six degrees of freedom to the beam axis given by the source position and the intermediate focus aperture. The foiltrap/collector unit has been pre-aligned on a test stand using visible light. This pre-alignment allows for the maximum transmission of the foiltrap with respect to the collector.

The swap flange itself can be handled as one unit for the integration into the SoCoMo. A special handling tool enables the moving of this device (figure 7).

figure 7 Image sequence during the exchange of the swap flange containing the foiltrap and the collector optics.

The full SoCoMo system has been integrated, aligned and tested. First light in the intermediate focus has been achieved in September 2009. To save time and resources, the integration of a collector with reduced performance has been decided for the first experiments.

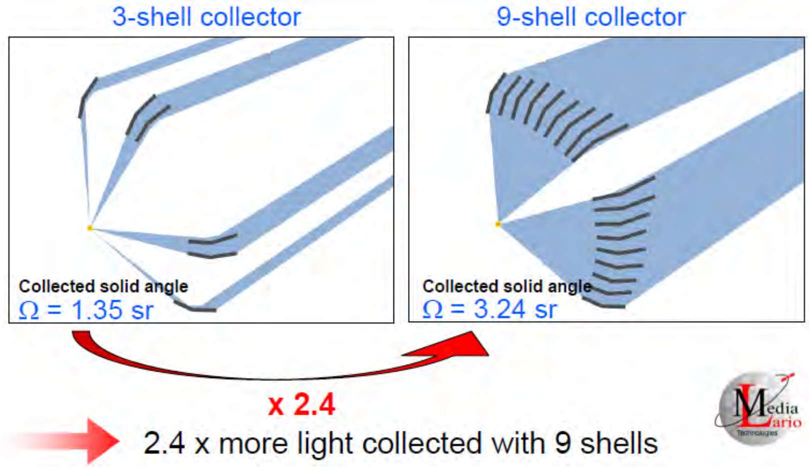

figure 8 Comparison of the 3-shell (left) collector to the full equipped 9-shell collector (right). Swap to the 9-shell collector will increase the power in the intermediate focus by a factor of 2.4 from the geometrical collection angle.

The full collector design consists of 9 shells, whereas the integrated collector was equipped with 3 shells only. With the 3-shell collector, an intermediate focus power of 14 W has been achieved. According to the collector design, the collection angle of the full 9-shell collector is a factor of 2.4 larger compared to the applied 3-shell collector (figure 8). Therefore the expected power in the intermediate focus using the full collector is 34 W assuming the same conditions (figure 9).

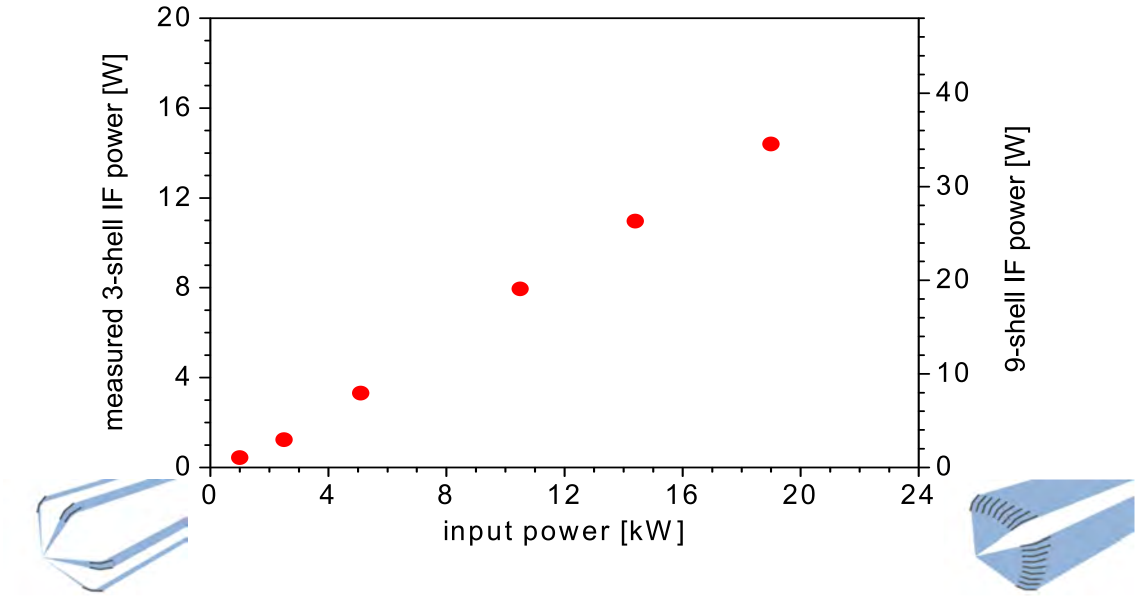

figure 9 EUV power in the intermediate focus in dependence on the electrical input power measured for the 3-shell collector (left y-axis) and extrapolated for the full 9-shell collector (right y-axis)

To enable the control of the output power of the system, a dose control algorithm was implemented into the source controller. The input signal for such algorithm was directly derived from the measured power signal behind the intermediate focus aperture. For a dose control experiment the source has been operated for 30 minutes at 100 % duty cycle with 19 W intermediate focus power (9-shell collector equivalent). A dose stability value of +/-0.3% could be demonstrated with a dose repeatability of 0.08% (3 sigma) (figure 10).

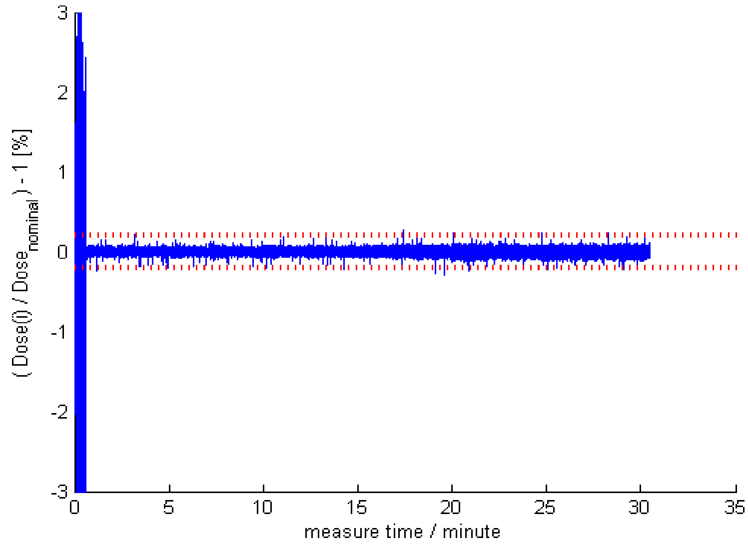

figure 10 Measured pulse to pulse energy without dose control (first 2 minutes) and with applied dose control. The red bars indicate a dose control range of +/-0.2 %.

Using the burst mode simulating real exposure conditions including wafer overhead phases and field exposures, a dose stability of +/-0.2 % could be achieved after optimization of the control algorithm. Also here a good dose stability of 0.09 % (3 sigma) could be achieved, very close to the continuous wave (cw) operation described above.

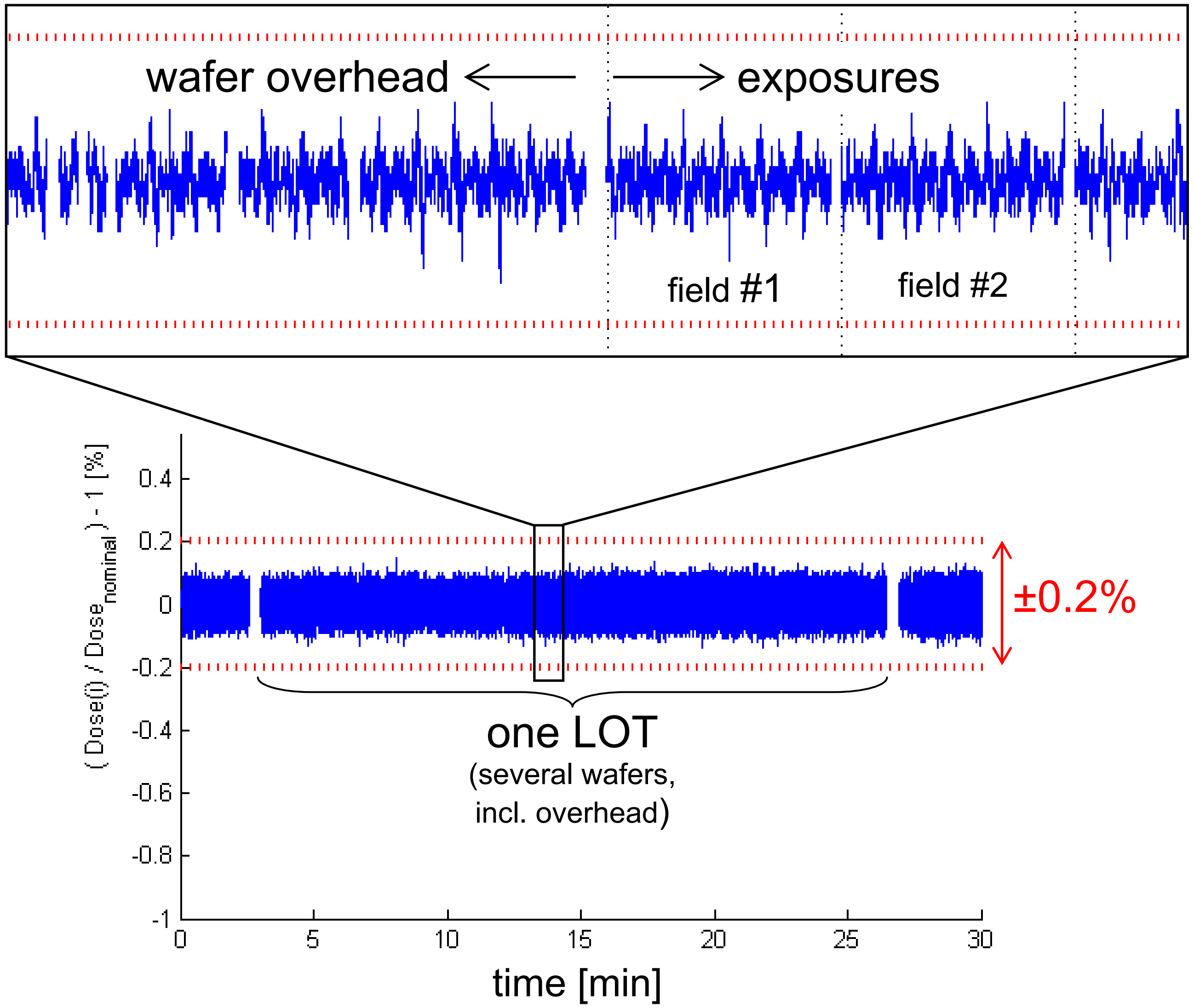

figure 11 Pulse to pulse stability and dose stability during the burst operation of the SoCoMo. In this example a real exposure scenario was simulated over 30 minutes.

4. HIGH VOLUME MANUFACTURING DEVELOPMENT

For the integration into the HVM scanner generation, an adapted source design is under preparation. The main requirements are not only the increased power performance of the SoCoMo compared to the source for the beta-level scanner, but also the angle of the optical axis to the floor. This requires re-designs also of basic source components, which do not fulfill the requirements any longer. The different angle of the beam line make also changes in the tin handling and serviceability necessary.

The current SoCoMo performance is also not yet sufficient to support the high volume manufacturing requirements. Three power scaling parameters are addressed to improve the performance of the system and to achieve the requested power level for economical HVM scanner operation. Those parameters are the output energy per pulse, the repetition frequency of the source operation and the intrinsic conversion efficiency.

a) Output energy per pulse

In demonstration experiments the output energy per pulse was varied by changing the electrically stored input energy. The output energy scaled roughly linearly with the applied input energy (figure 12). A maximum output energy of 80 mJ per pulse has been achieved without reaching any physical limitation.

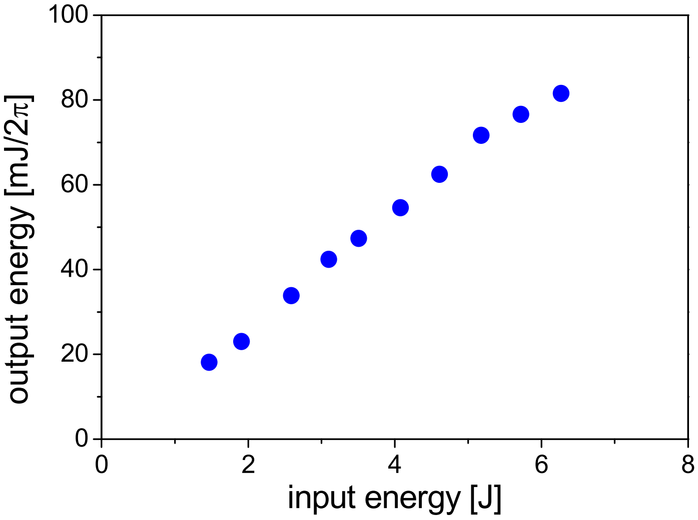

figure 12 Output energy per pulse in dependence on the stored electrical input energy

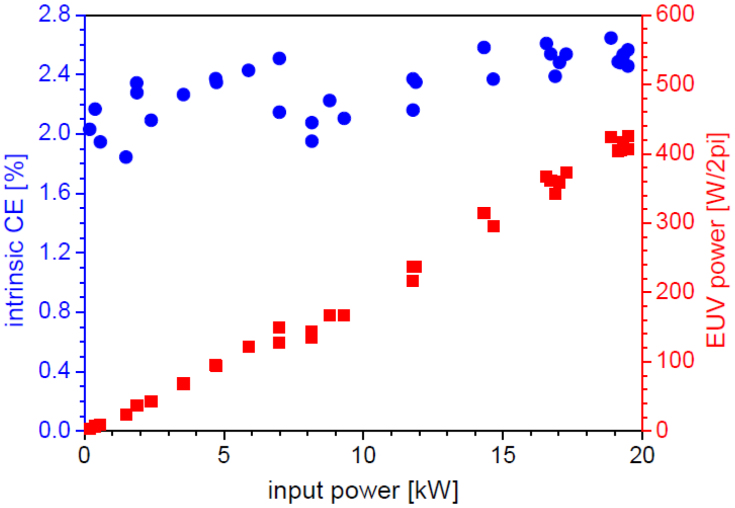

figure 13 EUV output power and intrinsic conversion efficiency in dependence of the electrical input power.

b) Repetition frequency

The repetition rate has been scaled up to 100 kHz. Also here the output power of the source is roughly linearly and no physical limit has been observed, so that the scaling to higher source power is also demonstrated to be feasible (figure 15). From the measurement on the presented Beta source (figure 13) it is clear that the intrinsic conversion efficiency (i.e. the EUV energy produced over the electrical energy put into the pinch) remains almost constant, while the output power of the source scales linearly with the electrically applied input power which is in itself related to the frequency here.

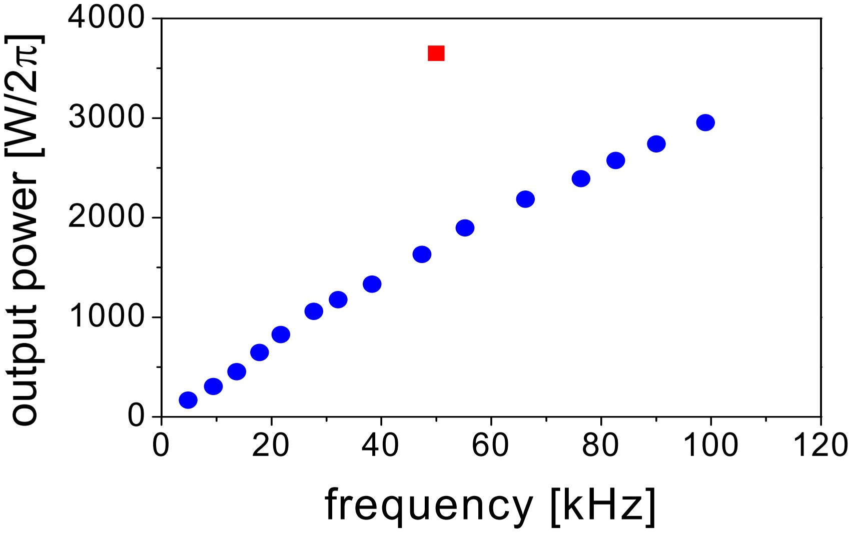

figure 14 Source output EUV power in dependence on the repetition frequency. For 50 kHz also the electrical input energy has been increased for demonstration.

c) Conversion efficiency

The conversion efficiency is a very attractive parameter for the power scaling, because here the output power can be increased without increasing the input power. That means that the output performance can be improved without additional thermal impact on components and so without further issues for the engineering of components. By mainly adapting the parameters of the igniting laser, an improvement of a factor 1.5-2.0 could be demonstrated (figure 15).

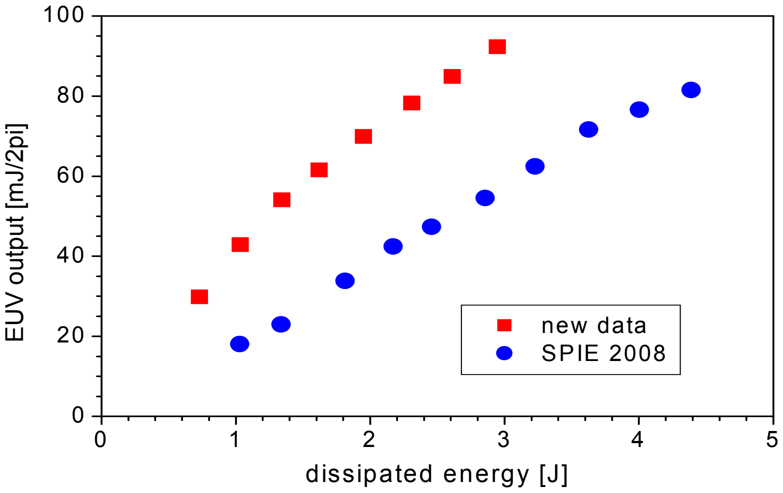

figure 15 The output pulse energy could be increased by a factor of 1.5-2.0 by optimizing the discharge parameters.

In summary, many experiments were done to demonstrate the scaling potential of our technology to IF power > 400 W (figure 16). A source output power of up to 4000 W is needed to achieve a usable power of up to 500 W at the intermediate focus. Combining the results from the experiments described above, one set of parameters could be 80 mJ pulse energy at 50 kHz repetition frequency.

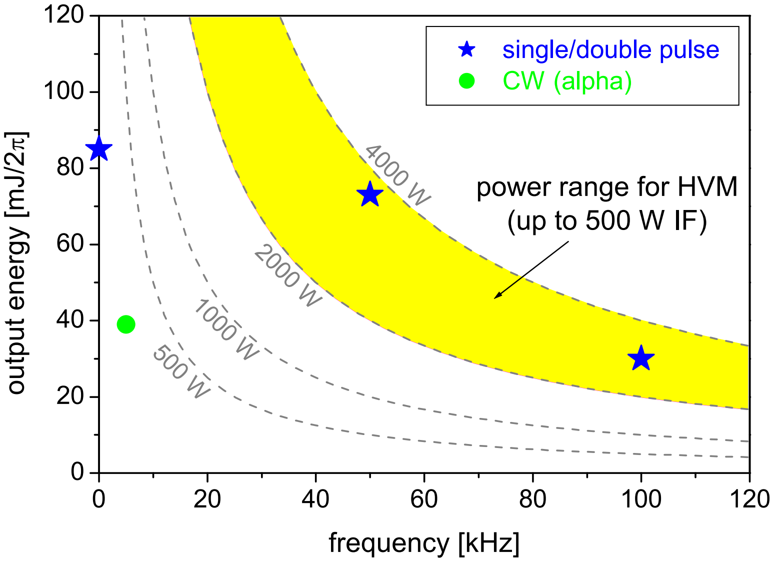

figure 16 Output power scenarios for the HVM scaling. E.g. at 80 mJ pulse energy and 50 kHz repetition frequency, an output power of 4000 W can be achieved, which is feasible for the HVM power level.

The foiltrap has been adapted to cover the full collection angle of the collector (figure 17). In another demonstration experiment, successful debris mitigation was demonstrated with collector samples exposed during several 8-hour source runs. A very low level of Tin deposition of only 0.1 nm was measured after exposure. On these samples a very low Ruthenium sputter rate of 2 nm/Gs was observed. But there is still further improvement possible by optimization of the gas flows in the foiltrap. Also the foiltrap temperatures stay well below critical limits during the tests. For the collector a 1 year lifetime is expected from the test results.

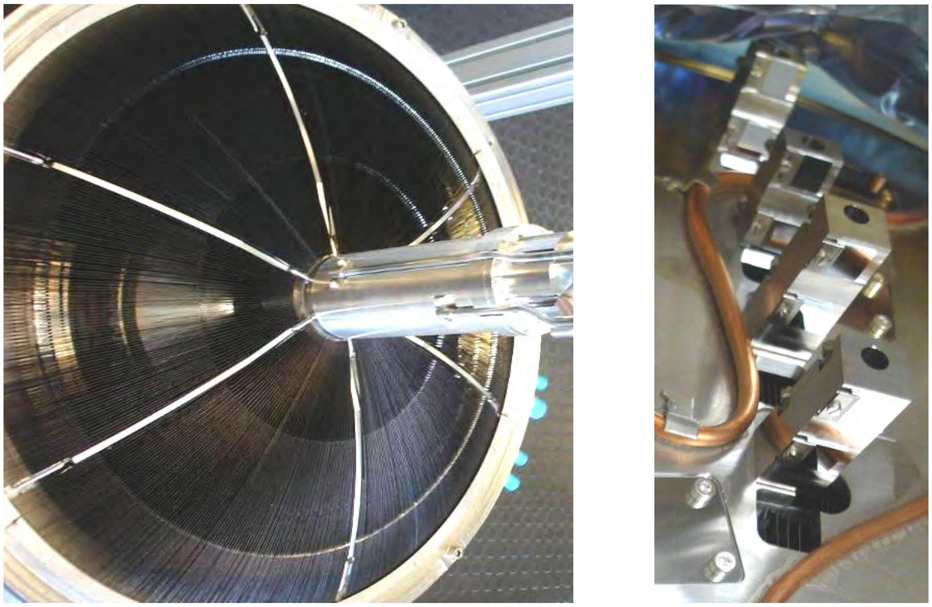

figure 17 Foiltrap from the collector side (left) and arrangement of the collector samples during the longterm tests (right).

SUMMARY

Joint development activities from XTREME technologies, Philips EUV and EUVA led to significant performance improvements of gas discharge based EUV sources. For the source technology on beta level and beyond, the tin based technology was selected due to the better scalability to the requested power level for HVM scanners. Whereas for the alpha sources in the field the uptime and reliability could be increased, a first source collector module on beta technology level has been realized in 2009. Operation of the system leads to an achievement of reliable data on source system performance. Additional sources are available in the laboratories and have been used for successful experiments for the demonstration of the power increase up to HVM level as well as the development of components with high reliability.

ACKNOWLEDGEMENTS

We gratefully acknowledge the contributions of our technology teams at XTREME technologies, Philips EUV and EUVA. Thanks for their contributions to our development partners ASML, Fraunhofer ILT, Nikon, MediaLario Technologies, USHIO and Zeiss.

The work performed at XTREME technologies GmbH and Philips Extreme UV GmbH has been partially funded by the German BMBF under contracts 13N8865 and 13N8866 and by the European Commission within the project “more Moore”. The development was integrated into the European MEDEA+ projects T405 “EUV source development” and 2T301 “EAGLE”. Part of the work is supported by EUVA, Japan.

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