Moving Forward with Moore's Law:

Throughput of EUVL Scanners

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In order to bring EUVL scanners into high volume manufacturing (HVM) of computer chips, its throughput of 10 wafers per hour (WPH) needs to increase. That brings up three questions: how much do we need to increase the current throughput for HVM insertion, what needs to be done to increase throughput, and how quickly can this increase be achieved?

Throughput of EUVL scanner for HVM Insertion

Imaging by EUVL scanner offers a higher k1 value than is available from 193 immersion (193i) based lithography. A higher k1 value results in better imaging and lower lithography process complexity, hence the attraction of EUVL as an optical projection lithography. Today, 193i scanners are used in a double pattering process to print the smallest features needed in HVM. Toward 14 nm and smaller nodes, if EUVL is not ready, chip-makers will need to use quadruple patterning with 193i scanners, combined with increased optical proximity correction (OPC) and design rules restrictions to print increasingly smaller features. This is not an attractive option for chip-makers, hence their increasing emphasis on EUVL readiness. As manufacturers evaluate available technology, switching from double pattering based 193i to EUVL, throughput is most often mentioned as the criterion for evaluation.

As printing of circuits is a sequential process, in double patterning (DP) the same wafer is exposed twice in a 193i scanner. Between the two exposures, there are many additional processing steps to enable the DP process. Hence, we need less than 50% throughput from an EUVL scanner (as compared to 193i scanners) to achieve a given feature size. In the case of quadruple pattering, an EUVL scanner needs less than 25% throughput to compare with an immersion scanner due to the four exposures. After accounting for the additional processes of deposition, etch, ash and metrology, the equivalent throughput of an EUVL scanner may become less than 40% and 20% to compete with double and quadruple patterning, respectively. Thus, to match the throughput of a 200 WPH 193i scanner for DP process , we need less than 80 WPH and 40 WPH from an EUVL scanner. This is an important point, as it’s often said in press that an EUVL scanner must reach the throughput of a 193i scanner to be considered equal. (Cost of Ownership wise, the Lithography team of the

International Technology Roadmap for Semiconductors (ITRS) has already shown that EUVL is more cost-effective than 193i DP for next generation lithography (NGL) [1]).

How to Increase EUVL Scanner Throughput

Of course, EUVL scanners still need to boost their throughput numbers from the current 10 WPH. For economic reasons, it's best to have throughput as high as possible from an EUVL scanner. Although much focus is placed on sources for improving throughput, other things can be done to increase the productivity of an EUVL scanner.

To better understand the challenge, let's start with a model that estimates throughput of an EUVL scanner for 1) a given source power, 2) scanner parameters, and 3) reflection/transmission efficiency of various components [2]. EUVL scanners are not very efficient in transferring photons from source to wafer. Hence, in addition to increasing the number of photons available to the scanner, we can also work to increase its transmission. It is important to note the relationship of scanner throughput to scanner's overhead time and resist sensitivity. [2] For example, for 50 W of source power at intermediate focus (IF), 20 mJ resist will allow 30 WPH while 10 mJ resist will allow 55 WPH. For a 10 mJ resist at 80 WPH, we need 115 W of power for 18 s overhead time, while for the 10 s overhead time we need only 50 W of power! [2]

There are additional factors that can help increase throughput. By decreasing the resist sensitivity to out-of-band radiation, the need for spectral purity filters may be eliminated. Reflection of mask as well as effective reflection of optics can be increased as well. Optical throughput of the NXE3300B is supposed to be 50% more than the NXE3100 [3] so there is already progress in increasing scanner throughput.

EUV sources are a difficult challenge due to the inherent complexity of reliable and repeatable generation of high temperature plasma of 40 eV for a production environment. Current EUV source conversion efficiency (CE) is only 2 % (i.e., 2% of input energy is converted into EUV photons). Of these photons, only about 10% can be collected due to the limitations of collector optics, debris mitigation and spectral purity filters. We need improvement in each of these areas to enable higher power and increased throughput. CE of 5.5 % has been demonstrated recently, larger collectors are being developed and debris mitigation techniques will continue to improve – all allowing more photons to reach the wafer.

How Higher Scanner Throughput can be Achieved Quickly

There is no magic bullet, so lots of innovative solutions are needed to lessen various loss factors to reach 100 W of source power. Beyond that, we may need different approaches to key source components such as fuel delivery. In meetings at the 2012 International Workshop on EUV and Soft X-Ray Sources (Dublin, Ireland, October 8-11), the largest annual gathering of EUV source experts, we can expect discussion on some of these key topics in EUV source development. The workshop will include:

- Several papers on how to increase CE of sources for both EUV and beyond BEUV (6.x nm) LPP sources
- New designs to allow higher power DPP sources
- Data on the latest SPF of up to 80% transmission, improved collector optics, and other topics

I look forward to seeing the latest results from the industry's source experts and will report them on this site.

In summary, I expect a rather slow but steady increase in EUV source power, and I'm still on record as predicting enough throughput by 2014 to allow adoption of EUVL scanners for HVM by leading chip-makers.

References:

1. Lithography Chapter, International Technology Roadmap for Semiconductors (2009).

2. Chapter 3, "EUV Source Technology," in EUV Lithography, Vivek Bakshi (Editor), SPIE Press 2008, for discussion of a general throughput model for an EUVL scanner.

3. Rudy Peters, ASML presentation at the 2011 EUVL Symposium.