2011 SPIE Advanced Lithography – EUVL Conference Review

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Monday, March 7, 2011

Sure Sign of Spring

One of the sure signs of spring for me is when I have the annual SPIE Advanced Lithography (AL) conference in my figurative rear-view mirror. Having returned exhausted to Austin after a week of meetings at SPIE, I filled up a coffee mug one morning and walked around my ranch with my dog to look for signs of the season. At my place, one or two bushes and a cedar elm tree are the first to bud out, a sure sign of spring. But you have to know where to look for them in the vast jungle of trees and shrubs showing few signs of life.

Evaluating lithography technology, which is what we do at SPIE AL, is not much different – we need to look for the early buds that appear before all the woods begin turning green. For me, the early buds of EUVL were obvious at SPIE AL: ASML's shipment of NXE:3100 beta EUVL scanners, the growing number (eight or ten so far) of orders for production-level EUVL scanners, patterning performance demonstrated at 22 nm and below, and the doubling of enrollment in my EUVL short course. To me, these are signs that EUVL is about to come into full bloom.

NXE:3100 tools have been (or are scheduled to be) delivered to leading-edge chipmakers and the IMEC consortium. IMEC expects their upgrade from ASML's EUV alpha demo tool (ADT) to NXE:3100 scanners to increase throughput 20X. Although the trade press reported some concern about installed NXE:3100 throughput being as low as 6 WPH, slow ramp-up is par for the course with new technology. It takes at least a year to fix the bugs and meet the specs for cutting-edge tools, and EUVL equipment is no exception. I expect 35-40 wafers WPH in 2011 from NXE:3100 scanners, sufficient to satisfy process development needs.

ASML showed that 22 nm patterning capabilities and 18 nm resolution capabilities have been demonstrated for NXE:3100 with off-axis illumination. Flare is now < 5%. Line edge roughness (LER) is being studied in depth and there are new ways of reducing it and dealing with the unrealistic LER targets of the International Technology Roadmap for Semiconductors (ITRS). LER may remain a fundamental issue, but all we want is to have working devices while we look for ways to avoid performance limitation from LER. For example, the Rayleigh resolution criterion still holds, but we still have found ways to keep resolving finer and finer features.

Both discharge-produced plasma (DPP) and laser-produced plasma (LPP) source technologies continue to contribute to NXE:3100, with current exposure power levels in the 10-20 W range. I expect this will double to about 40W in 2011, but in my opinion 100W targets will not be met before 2012, despite supplier roadmaps that promise them this year. So we can expect 100 W sources at about the same time HVM-level NXE: 3300 tools start to ship – a good thing, since 100W can support 80 WPH throughput, which some experts consider a must for HVM.

(For figures showing the latest litho performance data, please visit the following link.)

Fresh Ideas Come from Where?

I will be first to point out what has delayed EUVL and caused some people to have some very genuine concerns about the technology, and that's EUV light source. EUVL imaging and mask metrology are not very efficient and require lots of photons. So where are we going to get more of them to satisfy next generations of EUVL tools? I believe the answer is that they need to be developed by a focused industry supported R&D effort, and I'll elaborate on this below.

Not long ago, I heard a story of a little boy who went to the grocery store with his dad to get milk. Having grown up in the city, he thought that fresh milk was made in the back of the store by guys who then packaged it nicely in cartons. Well, we grownups know that producing milk is a tedious process involving cows and occasionally a bull – and if you've ever been on a farm, you know it's not the cleanest place and sometimes you end up stepping in something you wish you'd noticed first. Technology innovation and development isn't much different. It starts with fresh ideas (generation of milk) followed by development of commercial products (refrigerated cartons for you to purchase), and in between we may step on mushy ground.

I believe that the current version of source technology can go from 100 to 150W. But to even get to 100W and deliver 24x7 sources, we will need a little more innovation – and to get past 150W and develop 250W sources, we will need fresh ideas for many of the source components. But the fly in the buttermilk, as we say on the farm, has been the lack of research papers at SPIE AL and elsewhere on how we're going to do this. The work of university researchers like Ahmed Hassanein of Purdue, who has consistently shown how to increase conversion efficiency (CE) and reduce debris in EUV sources, has gone largely unfunded. Ahmed told me at the conference that this is his last year of EUVL research. Other people with very bright and credible ideas for sources have come and gone for lack of funding to develop and bring their ideas to products. With very few exceptions, source research, the very lifeline of EUVL, has essentially been stopped.

So coming back to my story, ending source research at universities and national labs is like closing down the farms while expecting grocery stores to be fully stocked with fresh milk every day! (Fortunately there are some exceptions, such as the research results shown by Hakaru Mizoguchi of Gigaphoton. In order to solve the scaling and debris issue, Mizoguchi-san went back to the drawing board with a 10 Hz source at a university to learn how to get 3.6 % CE and eliminate most of debris. The results are expected to become part of his commercial tool this year.)

DPP has done very well so far and can be found in ADT and NXE:3100, but not a single research paper showed how this technology will be scaled beyond 100W. I am not alone in my concern. I have seen designs from the ISAN Institute showing how to scale DPP, but who is turning these and other ideas into products that will give that 250W of exposure power needed for future manufacturing? We need to invest in some farms (university and national lab R&D) to keep the milk (innovation) flowing for EUVL.

Next is my favorite rant about mask metrology tools, for which sources need higher brightness and not higher power. The EMI consortium has funded Carl Zeiss to build an AIMS tool. Zeiss knows well how to design and build EUVL optics and an optical system and can team with ASML to build excellent AIMS metrology tool, but it does not have a source of required brightness to complete the job. Mask blank and patterned mask inspection tools will need sources of even higher brightness – and if sources of sufficient brightness are not there, the future of this and other mask metrology tools looks a bit cloudy to me. So far, the Energetiq Technology source has been the main force behind metrology tool development and is the workhorse of the industry. But this is only 8W/mm^2 sr, although I believe it can be scaled up in brightness to the required 25 W/mm^2 sr. But the supplier has no plans to do this without external investment, and who is making sure that happens? Cymer, Gigaphoton and Ushio most probably can build sources to support AIMS and other mask metrology tools, but they are not in this business. NanoUV (special design DPP), Adlyte (Sn LPP) and Bruker /AIXUV (Sn LPP) have shown proof of principal and want to develop these sources as commercial products, but who is investing and making sure we have sources from these suppliers in time to support the mask metrology infrastructure? In short, EMI funding is not going toward efforts to make sure that the most critical element of the technology is ready in time. I have seen in presentations for several years that source development is being left to the supplier community. Well, this critical technology has to be driven by a consortium, or we're not going to end up where we want to be. Sn LPP is already a proven technology, but no commercial sources are available for metrology. Maybe Japan's new EIDEC consortium will focus their efforts on this need.

Optical Scaling and the Art of Barn Maintenance

Right before leaving for SPIE AL, I had to make a critical decision affecting my personal bottom line. The roof on my barn had started leaking after a good 50+ years of service, and my stopgap solution - a new, transparent tarp that set me back more than $500 -- bit the dust after just one season, allowing the elements to damage my stuff and hurting my bottom line instead of preserving it. I didn't understand the "physics" or expected performance of my non-conventional chosen technology, and so I decided to implement the conventional solution of a new roof, eat the cost, and wait for time to tell whether it's a better option for my bottom line.

My experience is not so different from the fancy patchwork the industry has been performing on current optical litho tools, to extend 193 nm based lithography, in an effort to protect the bottom line for chip-makers, only to find that this approach has become too costly. In my opinion, and history will bear me out, some experts have committed a perfect blunder by saying EUVL is not an optical lithography, even though it utilizes the same 4X mask projection and *all* current knowledge of optical lithography applies directly to it. Can we say this for other non-optical litho options?

For example, consider the findings of Toshiba, which is considering EUVL, EUVL double patterning, and quadruple 193 nm patterning to go to 16 nm and below. Toshiba reported that on the basis of process quality, timing and cost of ownership, EUVL is the best option. Do we know enough about the physics of other non-optical Litho options to be able to predict with confidence what issues each will face in mass producing computer chips and memory for bulk sale at low prices? I say it's better to invest in EUVL

(and all signs are that leading chipmakers are doing this), because it's a familiar optical lithography technology with known risks that can take us to the end of the roadmap per Moore's Law. Doing otherwise is very risky, and as I have been known to be say before, "In this business you do not get a second chance."

You Bet Your Lotus

This review would not be complete without a few words about my two-year-old wager with litho guru Chris Mack. Back in 2009, Chris bet me his Lotus that there would be zero EUVL papers at the 2011 SPIE AL conference, which would have doomed my prediction of EUVL in HVM by 2014. I obviously won that part of the bet, but still have to wait three years or so for EUVL HVM before I can climb into a Lotus without having to take out a second mortgage on my farm. In the meantime, I'll keep the personalized "EUVL" license plates on my Suburban while I ask my colleagues to help me search the Lotus website (www.lotuscars.com) for after-market accessories.

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