EUV Source Roadmaps—

Physics vs. Engineering

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I am frequently asked by my consulting clients and colleagues when EUV sources will be ready to support high volume manufacturing (HVM) of semiconductors. It is a difficult question to answer, partly because readiness metrics have been a moving target, or the latest performance data is not very clear. For example, how many wafers per hour will make it cost-effective to adopt EUVL over the alternatives of triple or quadruple 193 nm immersion lithography for a given product at a specified feature size for 300 mm or 450 mm wafers? Is the latest data in pulse mode and integrated, and for how long an operation?

Even if the targets are clear, there is still uncertainty because source progress has not increased as much as predicted by supplier roadmaps. Last week in a press release (see http://optics.org/news/4/1/26), ASML was quoted as saying, “40 W sources are providing good dose controls and will be used in NXE3300B to be shipped in 2013. 60 W sources have been successfully tested with no sign of performance degradation from debris.” But can we take these numbers at face value and expect sources to be ready as promised in the supplier roadmaps?

As EUV source technology has been the main reason for the delay in EUVL for HVM, it is worthwhile spending some time pondering why this is so and what we know. When I look at what I know about source technology status, my only data is what is shown at industry conferences by source suppliers or chip-makers. Most presentations are about achievements which have been significant, but not sufficient. Unfortunately, no one talks much about what is not working, except to say "We'll fix the problems and here is our roadmap."

Given the many delays in HVM-ready EUVL, we should know by now that looking at roadmaps and press releases may not be the best way to predict technology readiness. Presumably, customers who own the latest EUVL scanners get confidential updates on source readiness so they have a better idea of what needs to be fixed. But these are chip- makers and not source experts, and their information may end with predictions from roadmaps which I suspect are very close to those shown in public by source suppliers. Of course, I have no clue about what additional information source customers may have, except that all of them list EUV source as the #1 problem in their public presentations.

One of the most repeated statements I hear on this topic is, “The physics is known and it is just an engineering challenge.” In other words, it is all about figuring out how quickly solutions can be engineered. I tend to disagree with this statement, and here's why:

Let's start by defining physics and engineering. Per Webster’s dictionary, “Physics is science dealing with the properties, changes, interactions of matter and energy,” while “Engineering is concerned with putting scientific knowledge to practical uses and planning, designing, construction or management of machinery.”

In other words, something is not physically possible if the physics is not there. Even if something is possible at low repetition rates, it does not mean that physics will support power scaling without near-impossible engineering. Figuring out physics is like seeing our target in a forest. Yes, we can see it, but can we build a freeway to it for 24 x 7 traffic? Take nuclear fusion as an example: the physics is there, but we have yet to power a light bulb from a fusion reactor after more than 50 years of research. At least EUVL scanners are in the field and are printing wafers every day for process development. So how large is the remaining engineering challenge for EUV sources? Isn't finding that out the real challenge in EUVL?

This assertion that "only engineering challenges remain for source technology” is usually backed by low to very low repeatable data, e.g.,: “Yes, we have 70 W and we got this for 10 s in standalone mode at 10% duty cycle, but it means we know the physics and all we have to do is to engineer this result into a 24 x7 product that can be integrated into a scanner.”

You may remember that Xe discharge produced plasma (DPP) sources worked very well but never went beyond 5 W, once we finally figured out that collectable power would never exceed 5 W due to etendue limits (i.e., one can collect light only from a very small part of the plasma). In addition, it is not possible to mitigate all the heat that higher power produces in Xe DPP sources. So we had to use different physics by changing the fuel to tin, which was easier to engineer for power scaling using DPP and eventually source suppliers have put more focus on tin based laser produced plasma (LPP). But LPP sources utilize different physics than DPP to heat the plasma, so we had to use slightly different physics to create new systems of LPP Sn. These systems were initially based on 1 micron (m) lasers and today we are using 10 m lasers, according to results from lab physics experiments. Now the focus is on other aspects of Sn LPP to achieve HVM targets, including 1) changing of the delivery system from droplet to mist targets, and 2) pulse shaping and pre-pulsing to increase conversion efficiency. With each new twist, slightly different physics are added to the mix. So I am not sure if Sn LPP will scale up without our introducing new designs based on somewhat different physics, such as going to ion beam targets or something else.

So the question comes down to this: do we have a physics solution that we can engineer? If so, how do we assess that solution? Surprisingly, the size of the machine is not necessarily an indication – we cannot say DPP is superior to LPP because it is more compact. Synchrotrons, which are rather large machines, very reliably generate EUV photons on 24x7 time scale. In fact, their contribution to EUVL development has been so immense, I do not know where we would be without them. In addition to their size, coherence and cost have been raised as issues for these very reliable sources of EUV photons. Can we reduce the size/cost to make synchrotrons a potential source for fabs? Have we looked at them seriously enough in the light of current source technology, recent developments in technology and our future needs? Not really, in my opinion, and we need to do this for both plasma and non-plasma based sources.

In short, we have not quite figured out the physics for EUV sources that can be quickly scaled up in power and engineered to make products. Some will disagree with me that this is not so for 100 W sources, but I think I am probably right for 250 W or 1000 W EUV sources - which will be needed as we go to higher NA scanners, smaller printed features and 450 mm wafers.