Picking the Winning NGL Technology

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Predicting the Next Generation Lithography (NGL) Technology is a big business

For the last several years, near the spring meeting of SPIE Advanced Lithography, I have been contacted by investment firms and venture capitalists who want to know the future of EUVL. Will it get to high volume manufacturing (HVM), and if so, when? Will certain suppliers deliver their tools, or will they be delayed? I have quickly learned that they are bankers, not lithographers -- they're interested in "yes" or "no" answers, without the details. Last year, one large investment firms asked me to review a report on prospects for an EUVL scanner. I did not agree with some things in the report and chose not to comment. I was surprised to see their final published document, with conclusions opposite to those they sent me! This got me more interested in how to best predict the outcome of a given NGL technology, and I would like to devote this blog to that topic – and offer my predictions about the future of EUVL.

Clarke's Law

Broadly speaking, there's a 50% chance that a given technology will succeed, so it's not impressive if somebody calls it right.   For me, it is more important to know how the prognosticator came to their conclusion, and understand the validity of their logic and data, so that we can apply their reasoning to the problem at hand. An often-quoted maxim for predicting the success of a technology is Clarke's First Law: "When a distinguished but elderly scientist states that something is possible, he is almost certainly right. When he states that something is impossible, he is very probably wrong." I find this law not very helpful, as it essentially states that if an expert says yes, then it's so; but if the expert says no, it's probably yes. In short, if an elderly and distinguished scientist takes a position on something, it will probably happen! So if something isn't going to occur, no venerable scientist will be talking about it. Following this logic, we can say that EUVL will be a winner because senior experts are definitely talking about it. However, I think we need to put a lot more thought into the issue.

Technology Selection in Semiconductor Business

The semiconductor business is driven by “Moore’s Law,” which defines the specs and timelines for various technology nodes. In this industry, you need “the right technology at the right time” and one is tempted to add “at the right cost” to the equation. I remember not so many years ago some expert declaring the semiconductor business doomed because fabs were going to cost billions of dollars. Today’s new fabs do cost billions, but the industry did not end – only the business model changed. For example, we have seen the emergence of fabless companies and foundries such as TSMC. I believe the cost of a next-generation scanner is not as important as its performance, especially throughput. So if EUVL does not make it, it won’t be because the scanner costs $100 M, but because it cannot produce 100 WPH.

Products, not Technology

People invest in technology development, but most consumers don’t buy technology – they buy products. So if no one can pursue a technology and develop it into products, that technology is doomed. I have seen this happen to technologies coming out of universities where technology transfer many times does not materialize. A few years ago, I spent a week evaluating a Sn LPP-based EUV source from a university. It ran fine all day without interruption (a big achievement at that time for LPP), but no one bought the technology or the components to develop it into a product! So technology by itself will not bring success; product engineering, service organization and investment must support it.

For a new lithography scanner technology to succeed as a product there is an additional requirement: the infrastructure has to be ready for resist, mask, mask inspection, and CD metrology. If a key component is missing – such as the lack of defect inspection metrology for EUVL masks, which the industry is now realizing – it can delay the introduction of EUVL itself.

Keep the Goal in Mind

Technology is a means to achieve a goal, not a goal in itself. For EUVL, the goal is to print 100+ WPH at 22 nm or below. So if LER specs or mask defect specs are not met for that node, there will be some other way to meet the productivity goal. At the same time, if another technology can function better and sooner than EUVL without prohibitive cost, then that technology will beat EUVL to the 22 nm node.

Difficult Challenge vs. Showstopper

Every leading technology has a list of known technical challenges. The physics of a new technology is typically well understood and its limits are recognized, but it is the engineering issues that will decide what will make good products to run 24 x 7 in a fab. So we need to look at each challenge on the list and decide if it is a difficult challenge (lots of efforts and innovation can produce a timely solution) or a showstopper (no amount of effort will deliver a timely solution). I believe this distinction is where the fate of a new technology is decided in the semiconductor industry. In order to make this decision, an independent assessment is needed and enough data must be available. (To achieve this, programs like Flying Circus are very helpful.) It also must be noted that engineering feasibility, and not necessarily physics, will decide which category the new technology falls into.

Some years ago, the discussion was focused on xenon or tin as fuel for EUV sources. Eventually it was discovered that the xenon option was limited by its low conversion efficiency (no amount of work could create a source that could give enough photons). Although physics said the xenon-based EUV sources could support EUVL scanners, engineering could not – making low conversion efficiency a showstopper. For a long time, delivery of tin was considered a “potential showstopper” (one colleague told me that tin is so corrosive you could never make a container to deliver it), but after a year or two of work it was discovered that this was just a “difficult challenge,” and a solution could be engineered.

In general, lower temperature problems are easier to solve than higher temperature challenges. I think that the tin delivery problem was overcome because it was an engineering problem at lower temperature. The tin debris issue is an engineering challenge at higher temperature, making it much more difficult to address. Thermal mitigation for high temperature plasma is another difficult challenge, but it has been addressed for Sn DPP at lower power. If solutions can be engineered for higher power (a much larger thermal load), Sn DPP can succeed. An additional issue for plasma-based machines is stability, which plagues nuclear fusion. Luckily we do not have that issue for plasma-based sources since stability is few percentage or better today. For some time the EUVL industry looked at LPP sources based on Li fuel excited by Excimer lasers. But the Excimer laser had low laser light to EUV conversion efficiency along with poor wall-plug efficiency, which together constituted a showstopper due to very large utility requirements. However, delivering photons with Sn and CO2 lasers is still possible. So to know if something is a difficult challenge or a showstopper, we probably need to gather data and see whether a solution can be engineered to meet the given technical goal.

There are some other indicators that I have found helpful. If we look at the demise of 157 nm lithography and high index immersion lithography, it is clear that if the leading challenge to a scanner technology's success is a material issue, it's a bad sign and we have probably found a showstopper. Defectivity is another topic that gets attention. Although the defectivity issue has been handled well for immersion lithography, will this be true for contact lithography? I think the answer lies in the difference between the physics of defect generation for both technologies. Throughput is another important consideration; if the critical challenge is related to throughput, we may be looking at a showstopper. Throughput is an issue for e-beam lithography and will be for EUVL if not enough photons are available to expose the resist. Xenon sources cannot deliver enough photons for high-power applications, but they work for low-power EUVL applications, and even offer an advantage over tin sources due to simplicity of design.

Recently, a distinguished lithographer criticized EUVL on grounds that it will take too much power to run a scanner due to the low wall-plug to EUV light efficiency and low collection efficiencies of EUV sources. Although I was first to point out the potential for utility requirements to become a showstopper for Excimer lasers in EUVL applications, I am not sure if this is true for CO2 lasers. The conversion efficiency of CW to pulsed form is still low for CO2 lasers, and I will need to consult experts to find out what efficiency limits the physics can support, and what solutions can be engineered. The collection ability of EUV sources and the resulting utility requirements for scanners are important topics that need careful review, but I'll discuss them in future blogs.

Technology Test Kit

In short, to predict the success of an NGL technology, we need to look at its technical challenges and ask these questions:

- Can the technology meet its goal (for example, printing 100 WPH at 22 nm resolution) and can we have tools by the deadlines expressed in the industry roadmap (ITRS)?
- Are the technology challenges difficult, or are they showstoppers?
- Is infrastructure ready to support the technology?
- Does the technology address a single node?
- Are suppliers ready to invest (or already investing) in developing the technology?

For EUVL the answer is yes to all these questions, except that the jury is still out on when high-power sources will be ready for production-level scanners. So I'm eagerly looking forward to SPIE for the latest information on this topic.

I would like to close by sharing some fun and perceptive technology poems written by my colleague, Kurt Kimmel. I think his poems are amazing, giving excellent insight into technical problems and bring a much needed sense of humor to industry discussions that many times are too serious. Enjoy!

Is EUV for me?

An ode to the plight of the EUV photon

By Kurt R. Kimmel

EUV, EUV
Dare I be? EUV?

If my source be xenon, my siblings will be few
But if she be tin, prodigiously it will spew.

Now lithium would be great,
but what might others think of my mental state?

Flying into two pi – what path to take?
These dark chambers are hot enough to bake!

The way to the dance I cannot tell…
Behind a wall but the concentric circles do compel

The tube bumps me heartily in the side,
So many brothers crashing, but through it I slide.

A new trial looms
like a blossom it blooms

So many crash its hard petals
but I survive and fly through this kettle.

They warned of the final test to separate the large from the best.
I skim the SPF but lightly – the test not so frightly.

Seven more tests to reach the dance,
but now ‘tis clear I have a chance!

The trials of crashing are harder too,
but Bragg I will, “I made it through!”

Even with a dark mask about,
I find a hole and passed through in then out.

Finally, the dance I see:
will my partner be 1K, 2D, or KRS XE?

Resolution, LER, or speed?
Will I fulfill the need?

Oh, I probably shouldn’t care
– I’m probably just flare!

EUV= Especially Unwarranted Verse

By Kurt R. Kimmel

To be or not to be defect-free, must I look actinically?
Inspecting masks is so expensive, can I make a print?
    Inspecting the wafer might just be sufficient.
Or can I turn and say
    "I'll plan to miss that defect in the way."
Perhaps I'll just take another day to think
    But do I have the time before this technology will sink?