EDITORIAL

REFLECTION ON THE LAST 17 YEARS

On February 23, at the 2004 SPIE Microlithography Symposium in Santa Clara, this editor was awarded the first Frits Zernike Award for Microlithography for fundamental achievements in the theory, practice, and extension of optical lithography. This is definitely a cherished recognition. It also prompted a nostalgic trip in lithography for me. In 1987 I published the resolution and depth of focus (DOF) scaling coefficients k_1 and k_2. Subsequently, I also laid out an extensive roadmap showing k_1 must be reduced by resolution enhancement techniques such as phase-shifting masks, optimized NA and illumination, proximity correction, managing reflections on the wafer and in the mask, and reducing mask-to-wafer vibration. I pointed out that a large field size can be realized by step and scanning a slot area taken from the circular field of a stepper projection lens. I also pointed out the advantages and challenges in immersion lithography. The exposure-defocus (E-D) tree methodology to construct a common processing window was my tool to quantify the advancement of optical lithography. With wavelength reduced to 193 nm, NA to 0.65, and k_1 to 0.35, I pointed out that the ultimate resolution of optical lithography was 0.15-μm half pitch to support a 0.7-μm DOF. The common E-D window I used was from the windows of closely packed lines and spaces, isolated lines, and isolated spaces. At that time the majority of experts considered that optical lithography would peak out at 0.12 μm using VUV free-electron laser and all-reflective projection optics. The year it went to manufacturing was supposed to be 1999. The 157-nm wavelength would come two years earlier. In my predictions, I failed to anticipate that the NA could be raised to above 0.9 while maintaining the field size. I also failed to foresee the practicality of chemical mechanical polishing to reduce the DOF requirement. Now, by factoring 193-nm immersion in water and a much lower DOF requirement, the ultimate resolution in optical lithography becomes 45-nm half pitch as reported in my article in this issue. We have carefully included the multimedia, high NA, and polarization effects in our calculation to reflect as close to reality as possible.

While on my nostalgic trip, I came across the four lithography horses that I introduced in the rump session of the IEEE Lithography Workshop, which I chaired at Marco Island in 1988. The comments are still very relevant for today. I am reproducing them here, followed with my up-to-date interpretations.*

All normal horses are supposed to have four legs. Lithography horses are no exception.

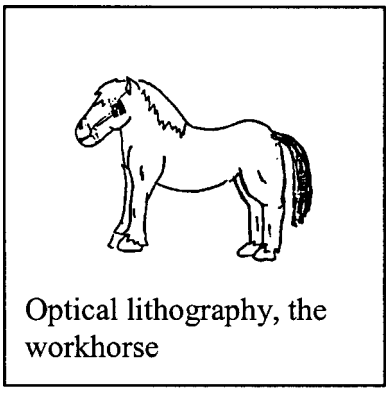
- Leg 1: Pattern generation.
- Leg 2: Proximity printing.
- Leg 3: 1x projection printing.
- Leg 4: Reduction projection printing.

Optical lithography is a workhorse.

- Workhorses are affordable.
- Workhorses populate the world.
- Workhorses advance one solid step at a time.
- They march through barriers after barriers, never seeming to want to stop.
- Workhorses are gagged with a mouthpiece. They don't blow trumpets or complain, just work and work.
- Workhorses have masks covering their eyes. They can only look straight ahead, good for work, bad for spotting political dangers.
- People suspect that due to their long existence, thus old age, these workhorses have exhausted their depth of focus.

E-beam lithography is a racehorse.

- Racehorses also have four legs.
- Racehorses run fast. They zip past in nanoseconds.
- Racehorses are not meant for throughput, unless they are put to work in parallel as in the three printing legs.
- When too many of them work too closely in parallel, they repel each other.
- When hitting particles, they tend to scatter. Unsightly proximity effects prevail.
- Racehorses are expensive. No one can really afford them but everybody wants one for prestige.
- If not properly guided by conductors, charging may occur.
- When they run poorly, the resist on the field is always blamed.



*The cartoons are credited to my son John, who was 15 when he drew them for me.

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E-beam lithography, a racehorse

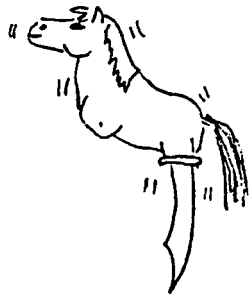
Ion-beam lithography is a baby racehorse.

- Even baby racehorses have four legs.
- Baby horses need plenty of time to grow.
- Baby horses need plenty of food to grow.
- Since they haven't acquired as much charge per mass as the mature racehorses, they work better in parallel.
- Being massive babies, they need even more conducting to prevent charging.
- Ever penetrating, they don't have a resist problem.
- Still lagging speed and field coverage, they work best at small isolated jobs such as fixing the mask for the other horses.

X-ray lithography is a one-legged horse.

- This poor thing has only the 1x proximity leg.
- Poor but expensive, the spoiled type even feeds on storage rings.
- Rare, found in only three countries in the world.
- With only one leg, the horse shakes. It cannot align accurately.
- With such inferior structure, the horse is still standing, so the support must be extremely powerful.
- Being inferior on the number of legs, this horse has a big mouth to make up for its deficiencies.
- The knife-shaped leg can carve out resists like butter.
- The single leg is often mistaken as a single layer monopolist.
- This horse says, "Who needs legs, I can fly before learning to walk."
- If it ever flies, all the other horses will get the knife, especially the workhorse.

Ion-beam lithography, a baby racehorse



X-ray lithography, a one-legged "horse"

As of today, the workhorse is still plowing along. It now has to get itself wet to extend its coverage. It may have to reduce the density of coverage and complete the job in two passes to stretch even further. Its riders better treat it friendlier to get more mileage out of the old workhorse.

The racehorse today is no longer that expensive in comparison nor is it a status symbol. However, with its repelling attitude, it will never become a workhorse. Fortunately, they are learning. Tens of thousands of them working together keeping at a safe distance from each other can become a formidable instrument, plowing out the field without having to wear any masks.

The baby racehorse has stopped growing because of its mass and enormous appetite. It remains a great helper to repair the masks of the other horses.

The one-legged horse did not fly after all the publicity and extravagance. Its claim of the same photon breed as the workhorse did not help. It is limping along to help the MEMS crowd carve out high-aspect ratio images in resist. Claiming the photon breed is irresistible. There is a modern-day short-legged infinite-appetite horse that is doing the same. Originally, its legs were supposed to be 120 nm long. It has been cut to 22 nm and possibly even shorter. There is a purse-string-friendly imprint animal that is helping the MEMS crowd as well. Whether it will become a horse depends on its ability to sustain high speed and long working hours without introducing defects while supporting precision overlay. It also depends on the imprint masks not bumping at the red brick wall.

Happy reading!

Burn J. Lin
Editor-in-Chief