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PMJ17 Best Poster

Fabrication of Cylindrical Micro-Parts Using Synchronous Rotary Scan-Projection Lithography and Chemical Etching

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ABSTRACT

Lithographical patterning on the surface of a fine pipe with a thin wall is required for fabricating three-dimensional micro-parts. For this reason, a new exposure system for printing patterns on a cylindrical pipe by synchronous rotary scan-projection exposure was developed. Using the exposure system, stent-like resist patterns with a width of 251 μm were printed on a surface of stainless-steel pipe with an outer diameter of 2 mm. The exposure time was 30 s. Next, the patterned pipe was chemically etched. As a result, a stent-like mesh pipe with a line width of 230 μm was fabricated. It was demonstrated that the new method had a potential to be applied to fabrications of stent and other cylindrical microparts.

1. Introduction

Lithography onto cylindrical pipes is required for fabricating medical micro-parts and bio-devices[1,2]. Electron or laser-beam writing methods have been researched. However, there is a problem in those methods that it takes a long time for delineating complicated patterns. To solve this problem, a new scan-projection exposure system was developed[3]. In the new system, while a reticle is moved in the horizontal direction, a cylindrical pipe is rotated synchronously. An oblong slit was placed on the reticle to replicate patterns in a narrow almost flat area of the cylindrical pipe surface. The imaging performance was kept excellent because the pipe surface was exposed almost at the same height in the oblong slit area. And, all the reticle patterns were printed on the pipe surface during the one rotation of the cylindrical pipe through the slit. Adopting this exposure scheme, the total exposure time is kept almost constant without depending on the complexity of the reticle patterns.

After printing stent-like mesh patterns on the surface of a stainless-steel (SUS304) pipe, the pipe was chemically etched in an aqueous solution of ferric chloride. The resist patterns were used as

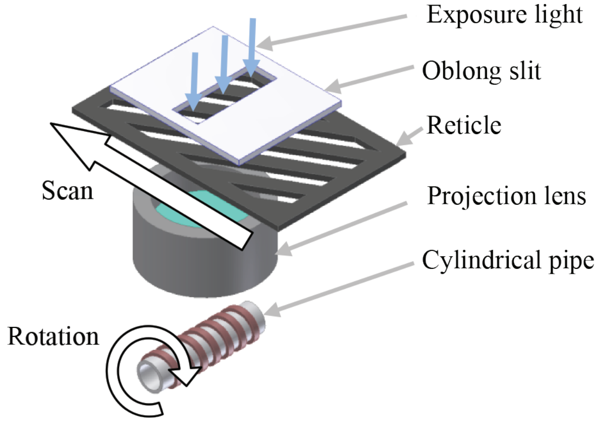

Figure 1. Synchronous rotary scan-projection lithography.

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Editorial

Can We Now Say X-Ray Lithography is Next?

Jon Haines, Micron Technology Inc.

I was Roku surfing the other day and found myself transported back to a youthful hypnotic state while watching the 1927 classic sci-fi movie *Metropolis*. It occurred to me that the original viewers of this movie must have felt a hope and wonder that early researchers experienced when reading the first semiconductor manufacturing papers. I decided to spend some time reading through old articles published around the start of *medium-scale semiconductor manufacturing*. With today's near realization of EUVL, I found the early history of x-ray lithography particularly interesting.

Not only do x-rays have low-diffraction, high-resolution, and high-depth-of-focus, they are dust-insensitive, non-reflective and non-scattering. Why then was XRL not the next heir to the throne? If you are at all familiar with EUVL, many of the challenges XRL faced will sound familiar. X-rays and ultraviolet spectrums border each other at the 10nm wavelength. The four most referenced XRL engineering challenges are mask fabrication, long exposure-time, flux-uniformity, and pattern alignment. Since there were no known efficient optics for the XRL spectrum (reflective or refractive), 1:1 transmission masks were necessary. Later, product damaging ionizing radiation was an additional challenge to be mitigated.

The early XRL mask materials and manufacture were quite expensive. Mask blanks were made of thin, low atomic weight materials transparent to x-rays such as Mylar, Be, Si, BN, SiN, polyimide or combinations thereof. The blanks were patterned with x-ray absorbing, thick, high atomic weight materials such as Au, Pl, and Ta. The notoriously brittle/thin/flexible nature of the materials combined with a high-stress-inducing manufacturing process resulted in significant distortions in the mask image. This stressed and/or flexible nature compounded with the non-adjustability of the 1:1 direct transfer resulted in near impossible overlay/matching on wafer.

Until the advent of partially-collimated synchrotrons sources, x-rays were generated with high-energy electron beam collisions and, later, high temperature plasmas. Synchrotrons were extremely expensive while other source types were thermodynamically limited to low intensity outputs. With collisions and plasma acting as point sources and the need to lessen penumbral blurring for improved resolution, more distant or collimated emitters were needed. The increased distance, low emissions, and lack of resist sensitivity resulted in very long exposure times and thus less stepped, larger exposure field sizes. The use of larger field sizes, multiplied by the large divergence of point sources, made image distortion increasingly sensitive to non-flatness in wafer and mask surfaces.

In the early days, low-resolution optical lithography seemed not long for this world. But within a few years, proximity printing using collimating reflective 1:1 lenses demonstrated OL's potential and pushed the timeline of a replacement. With the reported loss of 2.5x in resolution over contact-printing, death once again looked close for optical. Nearly every year up through the early 1990s, it was preached that OL's death was almost here and that the x-ray or electron beam would be the new king. But each time, optical slipped through death's cold-hands by the seemingly endless list of technological advancements.

XRL have been around since the early 1970s. Like EUVL, there are obvious engineering challenges, but lack of adoption/utilization appears to have more to do with the semiconductor industry's ability to engineer more economical alternatives in optical lithography. Following is a quick list of some of the most prominent of those OL engineering achievements:

Optics: reflected demagnification, refracted, refractive demagnification, 2.5X, 4X, 5X, 10X, compounded, improve tolerances/quality, improved materials, increasing NA, immersion, polarization, mono-chromatic, multilayer mirrors.

Wavelengths: 436nm, 405nm, 365nm, 248nm, 193nm, 157nm, EUV.

Light sources: higher intensity/efficiency, narrow-band, filters, arc, laser, plasma.

Apertures: DOF-improving, larger fields, off-axis, dynamic.

Mechanics: steppers, scanners, interferometer, noise damping/isolation, particle-reduction, pellicles, high-speed, auto-focus, auto-alignment, climate-control.

Masks: improved substrates, phase-shifting, attenuating, hi-transmission, variable-proximity-corrections, optical-proximity-corrections, process-matching.

Tricks: multi-focus exposures, post-exposure resist modification, double patterning, multi-patterning, pitch-multiplying.

Resist/films: flattening, thinner, etch-resistant, etch-selective, multi-layer, anti-reflective, metal, non-organic, increased-sensitivity, chemically amplified, contrast-enhancing.

There are far too many to list!

(Continues on page 6)

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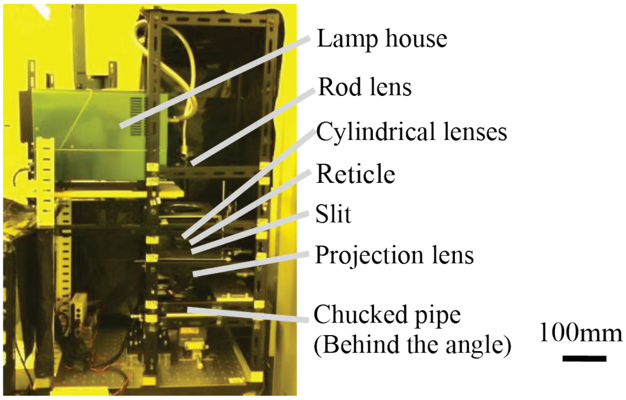

Figure 2. Developed synchronous rotary scan-projection exposure system.

etching masks. Caused by the undercut phenomena, mesh widths of etched pipes were slightly narrower than those of resist patterns. However, stent-like components were successfully fabricated by removing the resist patterns after the etching.

2. Synchronous Rotary Scan-Projection Exposure System

Figure 1 shows a schematic Figure of the synchronous rotary scan-projection lithography, and Figure 2 shows the appearance of the exposure system used for the research. The sizes of the system are 600 mm wide, 400 mm deep, and 935 mm high. As a light source, an ultra high-pressure mercury lamp (Infridge, UVB-300) with a major wavelength of 365 nm was used. A camera lens for the use of macro photography (Sigma, 50 mm F2.8 EX DG MACRO) was used as the projection lens, and the projection ratio was adjusted to approximately 1:1. F-number was set at 2.8, and the calculated numerical aperture (NA) was 0.09. Light intensity was homogenized using the rod lens and additionally inserted cylindrical lenses within ± 5% in the 12-mm long area narrowed by the oblong slit with a width of 0.8 mm.

The resolution limit R of line-and-space (L&S) patterns is roughly estimated by

$$R = k_1 \frac{\lambda}{NA}. \quad (1)$$

If $k_1 = 1$ and $\lambda = 0.365$ μm are substituted, R becomes 4.1 μm.

3. Printing of Stent-like Patterns on Stainless-steel Pipes

Stent-like patterns were printed on stainless-steel pipes with outer and inner diameters of 2.0 mm and 1.9 mm, respectively. The exposure field was 15 mm long in the pipe axial direction. The pipes were coated with a negative resist (tok, PMER N CA-3000PM) in 5 μm thick using the dip coat method[4]. Because the pipes were undercut in the etching, resist patterns should be sufficiently wider than the target width of mesh widths. For this reason reticle pattern widths of meshes should be fully wider than the aimed mesh widths. Therefore, patterns were printed using a pattern reticle with 250 μm wide meshes, as shown in Figure 3. The exposure time for rotating a pipe 360° was 30 s. Figure 4 shows stent-like patterns replicated on a stainless-steel pipe.

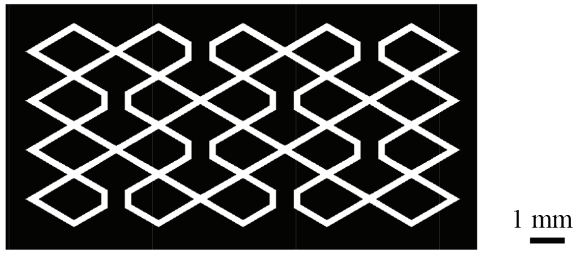

Figure 3. Reticle pattern.

The resist pattern widths were measured at 8 points in the axial direction at an interval of approximately 1.5 mm. Figure 5 shows the pattern width distribution in the axial direction. Measurement position numbers of 1-8 correspond to the axial distance of 12 mm. The position was numbered from the tip side. The widths were measured at four angles of 0°, 90°,180° and 270°, and the average widths were plotted in the Figure. The error bar shows the range of values.

Figure 6 shows the pattern width distributions in the circumferential direction. There appeared no specific distributions in both the axial and circumferential directions. The average pattern width was 251 ?m, and the deviation range was ± 30 ?m.

4. Chemicical Etching

The patterned pipe was chemically etched in an aqueous solution of ferric chloride. In order to uniformly etching the pipe, the etchant was constantly stirred using a screw shaft propeller during the etching. Figures 7 and 8 show etched results. Comparison of resist and etched mesh widths in the axial direction is shown in Figure 9. The widths were measured at four angles of 0°, 90°, 180° and 270°, and the average widths were plotted in the Figure. The line width after the etching was 230 ± 30 ?m, which was narrower than that of the resist line patterns. This line width reduction was caused by the undercut during the etching. The mean width reduction was approximately 20 ?m.

5. Conclusion

Using the synchronous rotary scan-projection exposure system, stent-like resist patterns with widths of 251 ± 30 μm were formed on the surface of the cylindrical stainless-steel (SUS304) pipes. The exposure time required for 2-mm pipe was 30 s, and this time was not dependent on the complexity of patterns. The exposure time is far shorter than that of the laser beam delineation system[5]. The patterned pipe was chemically etched in an aqueous solution of ferric chloride. As a result, a stent-like component with mesh widths of 230 ± 30 μm was successfully fabricated.

6. Acknowledgements

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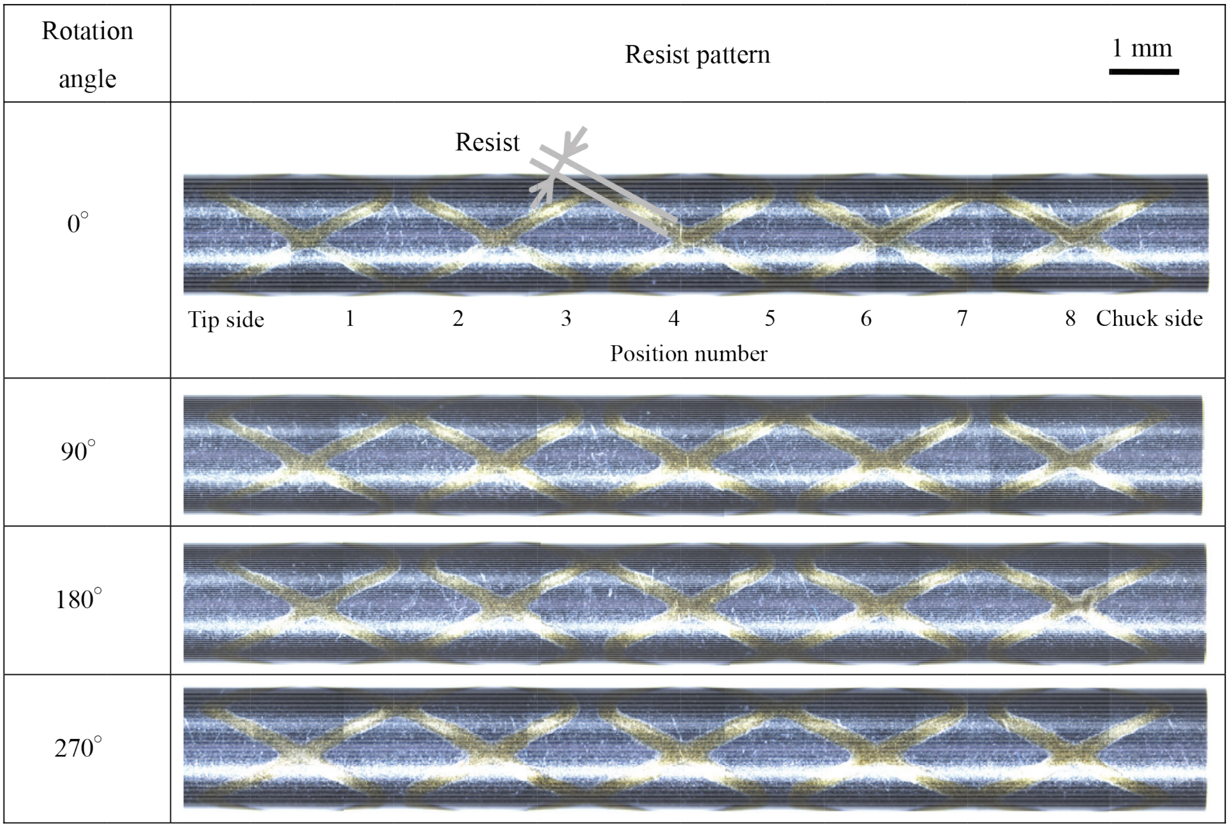


Figure 4. A stent-like resist pattern replicated on a stainless-steel pipe.

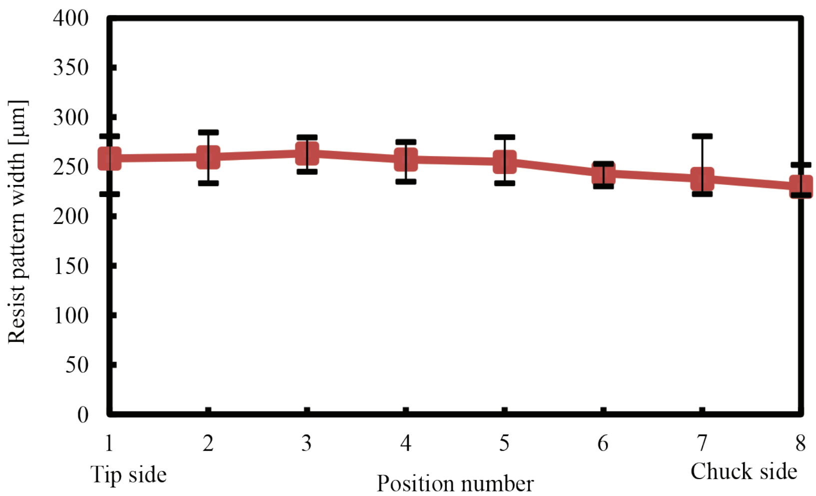


Figure 5. Resist pattern width distribution in the axial direction.

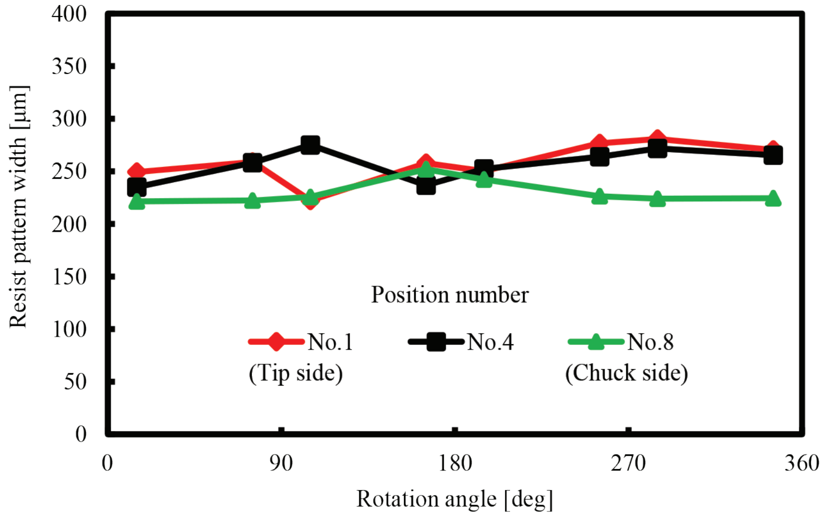


Figure 6. Resist pattern width distributions in the circumferential direction.

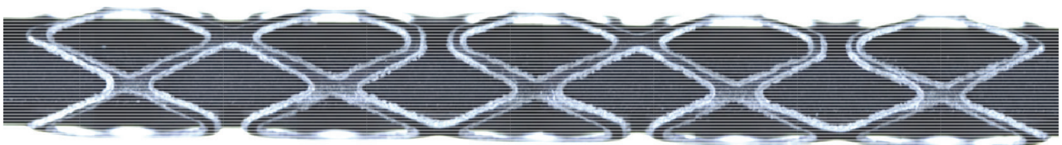
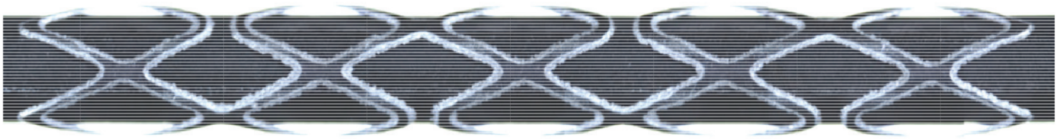
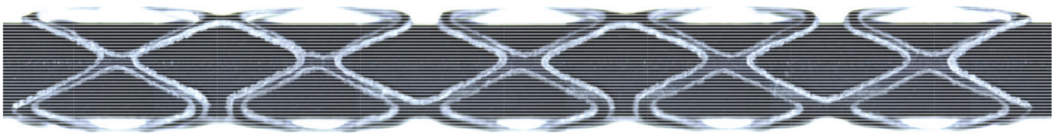
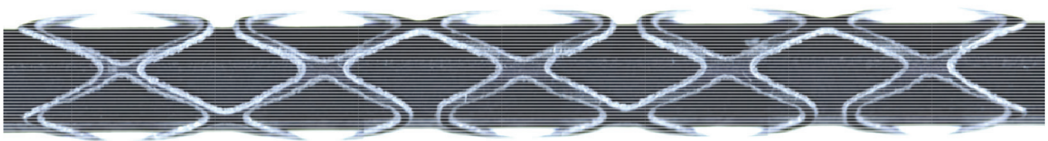
Rotation angle	Etched result (1 mm)
0°	 Tip side / Chuck side
90°	
180°	
270°	

Figure 7. Etched result.

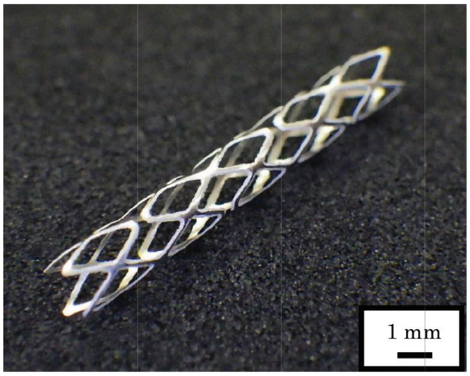


Figure 8. Bird's eye view of the etched pipe.

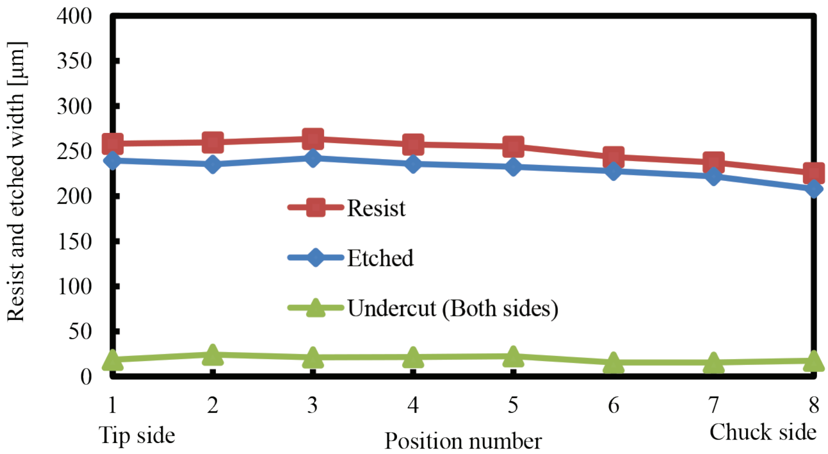


Figure 9. Comparison of resist and etched mesh widths.

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Editorial *(Continued from page 2)*

We are now told EUVL is the new prince, and that the death of the 193i OL king is drawing nigh. If EUVL is to be the next king, who is the next heir to the throne after 13.5nm is exhausted? Will it be BEUV (Beyond Extreme Ultraviolet ~6.7nm), x-ray, or will electron/ion direct write sprinkled with nanoimprint and self-assembly; who will wear the crown? If BEUV, then we will have technically left UV and reached x-rays at <10nm (Although the general public might prefer to stay with the safer sounding EUV name over x-ray death beams). Should we speculate that there would still be momentum, opportunity, and engineering solutions to keep shortening wavelengths from soft x-rays down to hard (<0.2nm)? Well yes, if more than 45 years of photolithography history has anything to say about the future. What might that future look like? I personally believe the same evolutionary path as OL. Contact-print: done; Proximity-printing: done; reflective: effectively-done; reflective-demagnification: close to done; diffractive/refractive-demagnification: working on it. We all know the rest.

So… anyone out there interested in buying a movie script titled Lithopolis? It's about a young gamma-ray lithographer living in a seemingly utopian world, but chooses to rebel by joining an underworld teenage gang who 3D print atoms.

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Industry Briefs

Globalfoundries Names Caulfield CEO

By **Rick Merritt,** EETImes

Sanjay Jha stepped down as chief executive of Globalfoundries after just four years on the job. Thomas Caulfield, an ex-IBM manager who runs GF's Fab 8 in New York, has become the new CEO. The change comes at a key inflection point for Globalfoundries. It needs to snag major customers for its fully depleted silicon-on-insulator (FD-SOI) process this year, and it will ramp its internally developed 7nm node, a potentially lucrative technology, but one about six months behind rival TSMC.

Jha leaves to pursue other opportunities, including potentially starting systems businesses at the Mubadala Investment Company in the United Arab Emirates that owns GF. The company did not provide any details of what his new role will be at Mubadala, but said the transition had been in the works for some time and declined to make executives available for interviews. Caulfield, the new CEO, is credited with getting GF's Fab 8 into volume production of 14nm process technology. It is making the Ryzen and Epyc x86 processors driving AMD's comeback as well as IBM's z-series mainframe and Power 9 processors.

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China Plans $31.5 Billion IC Industry Fund

By **Alan Patterson,** EETimes

The Chinese government is planning a new 200 billion yuan ($31.5 billion) fund aimed at renewing efforts to kickstart its domestic chip industry and offset a huge trade deficit in imported semiconductors. The state-backed China Integrated Circuit Industry Investment Fund Co. is in talks with government agencies and corporations, targeting the new financing, according to press reports, citing unidentified people familiar with the matter. Under the reported plan, the fund would begin disbursing money in the second half of 2018.

More money may not be enough to jumpstart China's semiconductor industry, according to Bill McClean, president of market research firm IC Insights. "While the Chinese have plenty of money to spend, they are lagging severely on the technology to be competitive," McClean told EE Times. The goals of the new funding effort have almost no chance of success without strong results in both funding and technology, he said. Each of those factors will have equal weight on the final outcome, he added.

The new funding effort would follow earlier footsteps of the China IC Industry Investment Fund, created three years ago to bootstrap domestic chipmakers that remain generations behind the global semiconductor industry in production capacity and process technology. The investment fund has disbursed a total of 106 billion yuan, or about 77 percent of the amount allocated for its first stage. The fund has attracted an additional 350 billion yuan from regional governments and the private sector.

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Samsung Tops Intel with EUV SRAM

By **Rick Merritt,** EETImes

Intel claimed that it maintained Moore's law scaling with a 10-nm SRAM that it described here at the International Solid-State Circuits Conference (ISSCC). However, Samsung followed by describing a smaller 256-Mbit SRAM made with extreme ultraviolet lithography and expressed confidence in EUV. Intel described 0.0312-mm2 high density and 0.0367-mm2 low-voltage SRAM bitcells made in its 10-nm process. Samsung's 6T 256-Mbit device has a 0.026-mm2 bitcell.

The Intel design shows 0.62–0.58x scaling compared to its 14-nm SRAM, maintaining Moore's law and "within 15 percent of the smallest reported 7-nm cell," said Intel's Zheng Gui, pointing to smaller 7-nm SRAMs from Samsung this year and TSMC at ISSCC 2017.

But can Samsung make its SRAM with EUV in volume? "Having real, working silicon lowered our concerns," said Taejoong Song, a vice president in design enablement, who presented the paper for Samsung.

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