

# ***Chronology of Lithography Milestones***

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## History of lithography as an art form

A planographic printing process that makes use of the immiscibility of grease and water. In the lithographic process, ink is applied to a grease-treated image on the flat printing surface; non-image (blank) areas, which hold moisture, repel the lithographic ink. This inked surface is then printed on paper, - *Encyclopedia Britannica*

Alois Senefelder of Munich discovered the basic principle of Lithography, "writing on stone," around 1798. Working with a highly porous stone, Senefelder sketched his design with a greasy substance, which was absorbed by the stone. He then wetted the entire surface with a mixture of gum Arabic and water (fountain solution). Only the stone areas absorbed the solution; the design area repelled it. Rolling on an ink made of soap, wax, oil and lampblack, this greasy substance coated the design but did not spread over the moist blank area. A clean impression of the design was made when a sheet of paper was pressed against the surface of the stone.

## ----- History of Photolithography for semiconductor manufacturing -----

### **1959 - GCA acquires David W. Mann. Later develops step & repeat cameras**

GCA/David W. Mann was the first firm to make a two-stage step and repeat mask reduction device (photo-repeaters) available to semiconductor manufacturers commercially. They first showed the device in the spring of 1961 and sold the first one to Clevite Corporation. Nikon optics was used for these equipment.

### **1965 - Kulick & Soffa introduces the first commercial contact aligners**

Contact printing was the work-horse technology for exposing patterns onto IC wafers into the 1970s. During the early 60s, chip makers were building equipment on their own. K&S was the first to market commercial tools. They were extremely successful and held nearly 100 percent of the (although very small) market during the 60s. In 1970, K&S teamed with Computervision Corp. and developed the first automated aligner and offered it at WESCOM Show. After selling about 50 units, K&S loses interest in the business and withdraws. Cobilt and Kasper took over the market after that.

### **1968 - Kasper Instruments was founded**

By 1973, the firm captures approximately half of the market for contact aligners. In 1973 Kasper introduced the first contact aligner to be equipped with proximity capability. Contact aligners were simple and quick to use, but the need to bring the mask and the wafer into direct contact can damage the mask or contaminate the wafer. Proximity aligner was introduced in 1973 to solve these problems. Although nearly half of all the aligners that Kasper sold from 1974 onward had this capability, Kasper aligners were only rarely used in proximity mode, (because it didn't work well) and sales declined steadily as Canon took over, and the company left the industry in 1981.

### **1969 - Nikon develops its first photo repeater**

### **1970 - The PPC-1, Japan's first mask aligner, is announced by Canon.**

### **1972 - Cobilt enters the aligner market with *Autolign* product line**

After K&S retreated, Computervision Corp. acquires Cobilt and announces the product. Autolign was successful, and Cobilt became a leading supplier. At that time, Cobilt also built wafer tracks, which later became the origin of Tokyo Electron tracks. Computervision sold Cobilt to Applied Materials for \$15M in 1981. Applied was hoping to add lithography tools to their product portfolio with this, but eventually dissolved Cobilt Division.

### **1973 - Scanning Projection Printer Invented**

Perkin Elmer (became SVG Lithography, and later acquired by ASML) introduces the Micralign projection scanner, having an NA=0.167. The company had started the R&D in 1969, under a contract with Wright Patterson Air Force Base. The combination of projection printing with positive photoresist dramatically reduced defect rate. With this tool, Perkin Elmer became the largest firm in the industry.

### **1973 - PLA-300, Japan's first contact mask aligner is introduced by Canon**

Canon later dominates the proximity aligner market since it was the first tool that actually worked in proximity mode, with a solid mask/wafer gap-setting mechanism (which Kasper tools lacked) and a good understanding of diffraction (in proximity printing, near field, or Fresnel diffraction must be taken into account) that was absent in contact printing. Some of the later products, PLA-500/600 are still actively printing chip patterns (for discrete devices, MEMS and LEDs) even today ... Still in production for more than a quarter of century after introduction, a remarkable feat.

### **1975 - IBM's Wilczynski's group demonstrates step & repeat printing**

Using an exposure wavelength of 405 nm (H-line) at an NA of 0.32, successfully printed 1 $\mu$ m features.

### **1978 - Step and Repeat System (Steppers) developed by GCA**

GCA introduces DSW 4800, the first successful wafer stepper (g-line, 10x, Zeiss 0.28NA, 10 x 10mm field size), conceptualized as a natural extension of the D.W. Mann photorepeater. This was the beginning of reduction printing. Ironically, GCA almost employed Nikon lens for this, but the final decision went to Zeiss, due to better focus uniformity. Early GCA customers included IBM, ATT, Fairchild, National Semiconductor, and Siemens, among many others. Although the actual release was in '78, the beta tool went to IBM in '77. Steppers revolutionized semiconductor patterning, but it took a while for GCA to take the market leadership position from Perkin Elmer. Steppers demonstrated much lower defect rate, significantly better overlay performance, and better yield. However, its throughput was low compared to Perkin Elmer projection aligners. It was the 256K DRAM generation that really allowed steppers to become the mainstream lithography tool.

### **1978 - Nikon prototypes Step & Repeat system, NSR-1**

This was funded by the national project, VLSI Research Program launched in 1976 by NTT and MITI. The tool was not commercialized.

### **1980 - First commercial stepper in Japan introduced, NSR-1010G by Nikon.**

Nikon knocks GCA out with its success. Nikon attracted customers by producing a higher resolution lens than GCA offered. Nikon was able to achieve 1 $\mu$ m resolution with 5 x reduction, instead of 10 x. With this, stepper was no longer a 'slow' machine. GCA struggled to match that development, but Zeiss being their sole lens supplier, it was difficult for them to reserve enough material in time. As a result, GCA was late in delivering a competitive tool. GCA stepper market share in Japan (which was about 50% of WW market at that time) had declined from 68% in 1981 to approximately 45% in 1983.

### **1980 - Concept of chemical amplified resist was proposed by IBM**

The first report was published in 1982, by H Ito and G. Wilson.

### **1980 - M. Shibuya of Nikon filed a patent of phase shift mask**

The concept was tested and proved by M. D. Levenson of IBM, independent from the work of Shibuya. Dr. Shibuya retired Nikon on 2001, and currently is a professor at Tokyo Polytechnic University.

### **1980 - Canon ships its first projection aligner, MPA-500**

Although, this was slow to take off. In 1981, Perkin Elmer still owned 60% of projection aligner market share in Japan. However, it dropped to less than 20% in 1983, and by 1986, Canon seized 90% market share in Japan.

### **1981 - Perkin Elmer announces the Micralign 500**

Although it costed more than double the price of Micralign300, Micralign500 was the first tool to hit 100wph throughput

### **1982 - Nikon established Nikon Precision Inc., in Silicon Valley**

With this foothold, Nikon started to snatch customers like IBM, ATT, Intel, RCA, Texas Instruments and AMD from GCA.

### **1984 - Nikon's first i-line stepper shipped, NSR-1010i3.**

### **1984 - The FPA-1500FA, Canon's first stepper (g-line) is shipped.**

This year, over 1,000 steppers were shipped worldwide. Close to 600 were consumed in Japan. This helped Canon take off.

### **1984 - Perkin Elmer acquires Censor, a Lichtenstein stepper manufacturer**

Perkin-Elmer spent eighteen unsuccessful months attempting to sell Censor's wafer stepper in the U.S.,

### **1984 - Philips and ASM launch ASML as a joint venture**

Although the name ASM still remains, ASM International dumped the shares in 1990, and no longer has stake in ASML.

### **1985 - ASML's first commercial stepper, PAS 2000/10 g-line.**

Cypress Semiconductor was their primary customer

### **1986 - Cymer Inc. founded**

When founded, Cymer was not yet dedicated to lithography light source. Formal entry into the market was in 1989. Cymer captures a lopsided >80% market share during the 90s and until early 00's.

### **1987 - Nikon's announces NSR-1505G4B**

The first stepper to reach sub-micron resolution (0.9 $\mu$ m)

### **1987 - ASML's first i-line stepper shipped, PAS 2500/40**

0.4NA, 0.7 $\mu$ m resolution, 70wph (on 150mm wafers)

### **1987- Komatsu ships the first KrF laser for lithography, KLE-630S**

This was used in the Nikon tool being released in the following year

### **1988 - General Signal acquires the financially troubled GCA for \$76M.**

Following this, Sematech funds GCA for developing KrF steppers. However, GCA operation was dissolved in 1993, when General Signal was unable to find a buyer. The IP's were transferred to Integrated Solutions, Inc. (ISI), which was later acquired by Ultratech in 1998.

### **1988- Cymer ships its first prototype KrF laser for lithography, CX-2LS**

This was also used in the Nikon NSR1505EX. 200Hz rep. rate, output power of 3W, FWHM=3pm.

### **1988 - Nikon's first KrF stepper shipped, NSR-1505EX**

This was an R&D tool for early learning of DUV lithography, and was not used in mass production. Resist suppliers used this tool for developing KrF resists. Had an NA= 0.42 with 0.5 $\mu$ m resolution.

### **1988 - Lambda Physik officially enters DUV light source market**

Lambda was already an established name as a manufacturer of excimer lasers (mainly Xe-CI), but for applications outside semiconductor manufacturing. Lambda later was acquired by Coherent Inc. (took two years to complete the acquisition during '03-'05), and became a Division of Coherent.

### **1990 - The FPA-2000i1, Canon's first i-line stepper, is shipped.**

### **1990 - Perkin Elmer's lithography business acquired by Silicon Valley Group**

American suppliers held 90% of litho tool market share in 1980. By this time, it plummeted to a modest 10%. GCA and Ultratech each held about 4-5%, and SVGL around 1%. They were even behind the latest comer, ASML.

### **1990 - The Micrascan, industry's first step-and-scan (scanner) tool, introduced by SVGL**

Developed by Perkin-Elmer, this tool had a resolution of 0.5 $\mu$ m. Sematech invested many dollars to help SVGL develop Micrascan. However, it only sold less than 10 units/year during '91-'94. It was only in 1997 when SVGL was able to ship the 100th Micrascan system with its 3<sup>rd</sup> generation Micrascan III

### **1991 - ASML's first KrF stepper shipped, PAS 5000/70**

0.42NA.

### **1994 - Hitachi exits stepper business**

Hitachi's stepper revenue once reached few hundred million dollars with their LD-50xx product line. However, in 1993, they sold less than 20 units, when more than 500 steppers were shipped worldwide that year. Even losing their internal customers, Hitachi quietly exits optical stepper business. Their last tool was an i-line stepper with NA=0.5. In 2005, they stepped out of EB direct write lithography as well.

### **1995 - Nikon's first step-and-scan tool shipped, NSR-S201A**

World's first fully diffraction -based scanner (since SVGL is catadioptric) with 0.25 $\mu$ m resolution. And this was actually the first production worthy KrF scanner in the industry,

### **1995 - Cymer introduces the first solid state PPM powered KrF laser**

Until then, thyatron circuit had to be used to provide the pulsed high voltage necessary for generating the light source discharge. Solid state switching allowed lasers to operate at higher repetition rates. This laser, ELS-4000F operated at 600Hz, with average output power of 6W.

### **1996 - Advantest releases its first EB direct write tool, F5120**

This tool was capable of printing 180nm patterns.

### **1996 - SVGL releases Micrascan III, its first KrF laser based DUV scanner**

NA=0.6, resolution=0.25 $\mu$ m. The earlier Micrascan models were lamp DUV systems. Because of its catadioptric design, the laser light source did not have to be line narrowed. Base price was \$7.2M. Intel, Motorola and Texas Instruments sunk a total of \$30 million into SVG stock in 1995, to speed up development of the tool. Prior to that, Sematech injected \$30M, in addition to the initial fund from IBM

earlier. This was the first Micrascan model that was close to being competitive. With Intel and IBM as their major customer, Micrascan III with following IV and V models, sold about 50 units/year, and allowed SVGL to survive for a while.

**1997 - ASML's first step and scan tool shipped, PAS 5500/500.**

Had a resolution of 0.22 $\mu$ m, with 96wph throughput (200mm), which was significantly faster than their competition.

**1997 - The FPA-4000ES1, Canon's first KrF scanning stepper shipped.**

**1997 - Canon ships the industry's first 300mm KrF stepper, FPA-3000EX3L**

**1998 - ASML develops their first ArF step-and-scan tool, PAS 5500/900.**

**1998 - Canon ships the industry's first 300mm i-line stepper, FPA-3000i5L**

**1999 - Nikon's first ArF scanner developed, NSR-S302A.**

**1999 - The FPA-5000AS1, Canon's first ArF scanning stepper shipped.**

**2000 - Gigaphoton founded as a JV of Komatsu and Ushio**

Komatsu, an early player of DUV light source business already had 2KHz KrF lasers, but was troubled with the R&D cost of ArF lasers. Ushio, the leading supplier of Mercury arc lamps for g- and i-line steppers developed a 4KHz ArF laser in 1999. Noticing that the market size is not big enough for four suppliers, two companies decided to work together and set up a 50-50% JV company, concentrating on lithography light source.

**2000 - TWINSCAN product platform introduced by ASML**

First system installed at TSMC in Oct. 2001. By this time, ASML's market share has soared to 30% from 14% in 1995.

**2001 - May, ASML acquires SVG Lithography.**

More than six months later than the initial announcement of the intent of merger. It took long due the US security concerns. ASML divests Tinsley Labs by the end of the year to mitigate the concerns. In Nov. 2001, SVGL's Micrascan line of 248nm and 193nm tools is discontinued. Although no tangible contribution is recognized from SVGL today, this acquisition enabled ASML to penetrate Intel.

**2002 - ASML achieves #1 market share**

For the first time, ASML sits in the market leader position with 47% market share. Especially, ASML was remarkably strong in Korea.

**2003 - ASML ships first 157nm tool to IMEC,**

This was a Micrascan VII from the SVGL division.

**2004 - ASML ships first commercial ArF immersion system in industry, XT:1250i.**

Announcement was made at Semicon Japan, Dec. 2003. 1250i had an NA of 0.85 and was dry/wet convertible. First shipment of this tool was in Oct. 2004 with early orders from IBM and TSMC. Prior to this, ASML installed a XT:1150 based experiment tool at IBM/Albany Nanotech for early

learning. Later, ASML announced XT:1400i with NA=0.93 before moving to hyper NA.

#### **2004 - Lambda Physik exits DUV light source market**

With less than a handful of customers in lithography market, Lambda was not able to justify the R&D burden. With this, only two suppliers of excimer lasers survived; Cymer and Gigaphoton.

#### **2005 - Nikon ships industry's first hyper NA tool, NSR-609B**

First to reach NA>1.0 (1.07), and the first immersion tool put into mass production of commercial chips.

#### **2005 - ASML announces its first hyper NA tool, XT:1700i at Semicon West**

NA=1.2, 122wph. First shipment was in Q1 '06.

#### **2006 - Nikon releases second generation immersion tool NSR-610C**

NA=1.3, 45nm resolution, 130wph. First shipment was in March 07.

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