IC Industry Lithography Requirements and Nikon's Plans

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ITRS Roadmap Drives the Litho Requirements

International Technology Roadmap for Semiconductors — 2001 Edition

Lithography Requirements

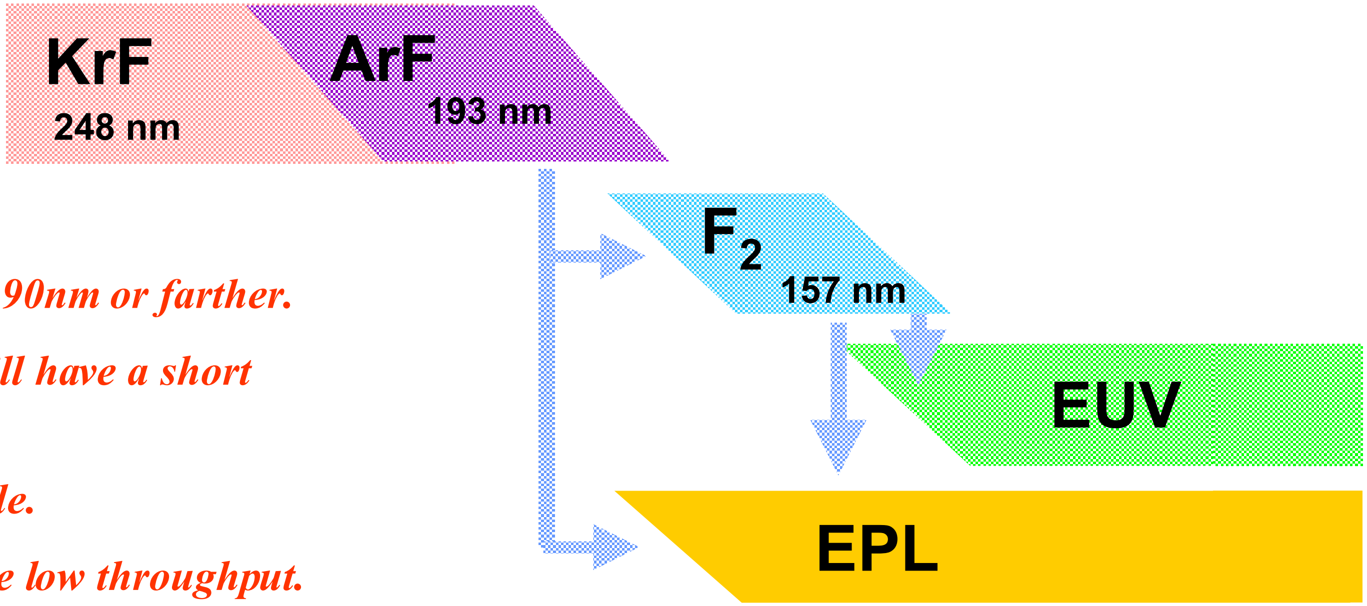
Year of Production	2001	2002	2003	2004	2005	2006	2007	2010	2013	2016
DRAM 1/2 Pitch (nm)	130	115	100	90	80	70	65	45	32	22
MPU 1/2 Pitch (nm)	150	130	107	90	80	70	65	45	32	22
MPU gate in resist (nm)	90	70	65	53	45	40	35	25	18	13
MPU gate length after etch (nm)	65	53	45	37	32	28	25	18	13	9

Current (or planned) lithography technology; an overview

- "Standard" photolithography (248 nm, KrF; 193 nm, ArF)
  - Excimer laser Illumination source and optics; mask; projection optics; mechanical stages, alignment systems, body, ancillary equipment. Optics typically fully refractive.
- Photolithography for F_2 laser sources (157 nm wavelength)
  - As above, but only CaF_2 has 157 nm transparency and is practical; optics are catadioptric
- Electron projection lithography
  - As above, but with an electron emission source and of course electron optics.
  - Mask (in Nikon's technology) scatters the illumination, rather than absorbing
- Extreme Ultraviolet Lithography (EUVL, using soft x-rays at 13.5 nm)
  - As above, but optics must be mirrors (no refractive materials) using multilayers for interference reflection. Source is not yet defined for production tools.
- Other technologies are possible, but either no longer being actively pursued (ion projection lithography, 1X x-rays), or are yet to be truly demonstrated (massively parallel, maskless projection lithography; 1X low-energy proximity electron lithography)

Nikon Lithography Roadmap *(for critical layers)*

CY	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13
DRAM(1/2pitch)	180		130			90			65			45			32
MPU(gate in resist)	140		90			53			35			25			18



ArF will be pushed below 90nm or farther.

F2 will be delayed and will have a short lifetime for critical layers.

EUV timing is questionable.

EPL will be in time despite low throughput.

EPL, ArF, F_2, EUV: what's coming and when?

- **ArF (193 nm) lithography should carry us through the 90-100 nm node.**
  - **With increasing NA, more use of phase shift masks, illumination "tricks", etc.**
  - **With increasing demands on tool and process stability, etc.**
  - **NGL will replace ArF for critical levels ONLY when cost/performance becomes superior.**
- **F_2 (157 nm) lithography has momentum, is in the mainstream of suppliers' core competence, is one prime contender for the NGL.**
  - **Nikon plans to introduce an F_2 tool in 2004.**
- **Electron Projection Lithography ("EPL") has significant attractions, represents the other NGL contender with F_2.**
  - **Nikon's "early-learning" tool ready in 2003, with a production tool in 2004.**
- **Nikon believes EUV lithography can compete, but will be later.**
  - **With R&D development steps still to be taken. (Source, thermal control, manufacturability of multilayer mirror lenses, practicality of defect-free multilayer mirror masks, etc.)**
  - **Introduction in 2007 or even later.**
- **Nikon is developing both F_2 and EPL, in parallel.**
  - **To assure maximum benefits, minimize risks.**

Details . . .

F_2 (157 nm) Status — Benefits & Risks

Benefits

- Key technologies are within the core competence of Nikon, other suppliers.
  - Projection and illumination optics, matches with the illumination source, body design, etc.
- Only the illumination power sets an intrinsic throughput limitation.
  - Available lasers already suitable; more power, smaller output bandwidth in sight.

However, there are risks

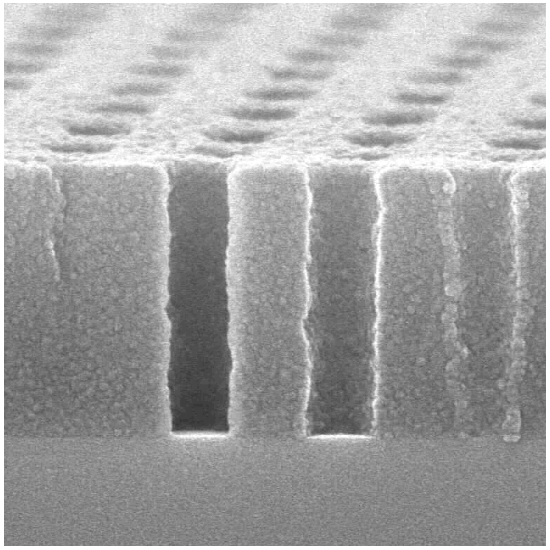
- Resists. Industry still working on resist chemistry. Single-level resists may not be possible.
- Pellicles. Hard pellicles are very fragile (and become an optical element). Soft pellicles have short lifetimes. Industry working hard to keep pellicles.
- CaF_2 availability in quantity with high quality; lens design to control intrinsic birefringence.
- Optics contamination (controlled by engineering, including materials selections)
- Phase shift masks, possible double exposure techniques, etc. increase cost of ownership.
- Tool will be introduced at less than half-wavelength features, with attendant demands on process and stability. This may also be a schedule risk for the IC fabricators.
- For the supplier, F_2 may be a one-generation technology for critical levels, leading to ROI concerns. Development will not be ready for the 100 nm generation production (2003-4).

Nikon's EPL Status— Benefits & Risks

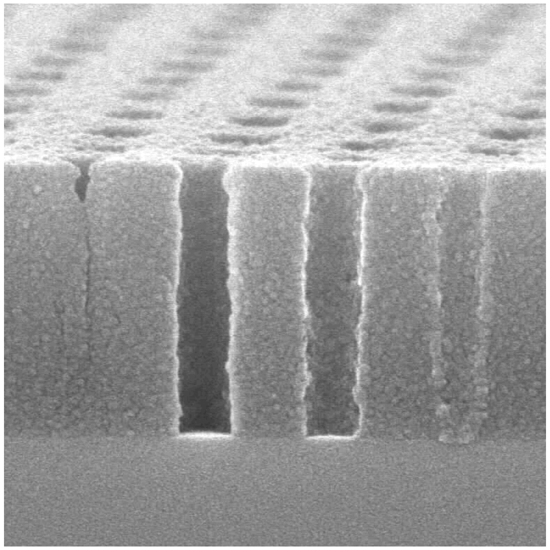
- **EPL has some fundamental attractions: essentially unlimited resolution; can use existing production resists; "huge" process margins (e.g. micron size DOFs).**
  - **EPL technology is intrinsically extendible. Even early tools can be used for sub-70 nm development (trading throughput for extended resolution).**
- **Mask technology, while based on membranes, builds on existing 1X x-ray infrastructure; no known show-stoppers.**
  - **Production cost is likely to be less than for PSMs for optical.**
  - **No "mask error enhancement factor," as with advanced optical tools.**
  - **Both full-membrane and stencil masks can be built and used in Nikon's tools.**
  - **Three Japanese suppliers plus others as developers. Hoya also for blanks. Hoya is committed.**
- **Mix/match with ArF, F_2, or even EUV, is a likely scenario, with EPL used for contacts & vias (especially with ArF, F_2); difficult images for optical technology.**
  - **Low pattern coverage means that EPL's throughput is enhanced.**

Resist resolution for 1:2 Holes/Spaces with EPL

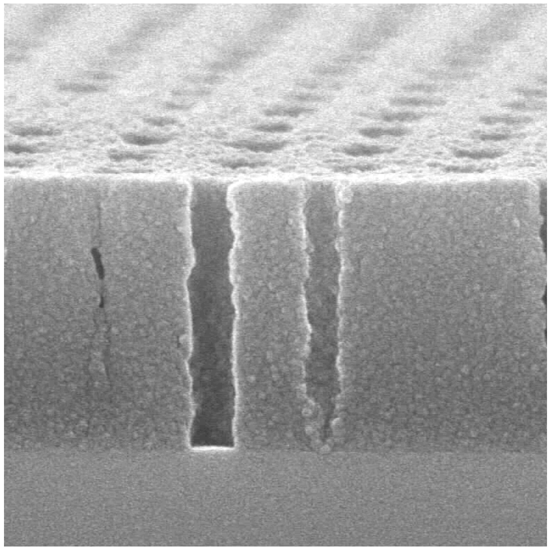
90nm



80nm



70nm



FEP-136(FUJIFILM ARCH)

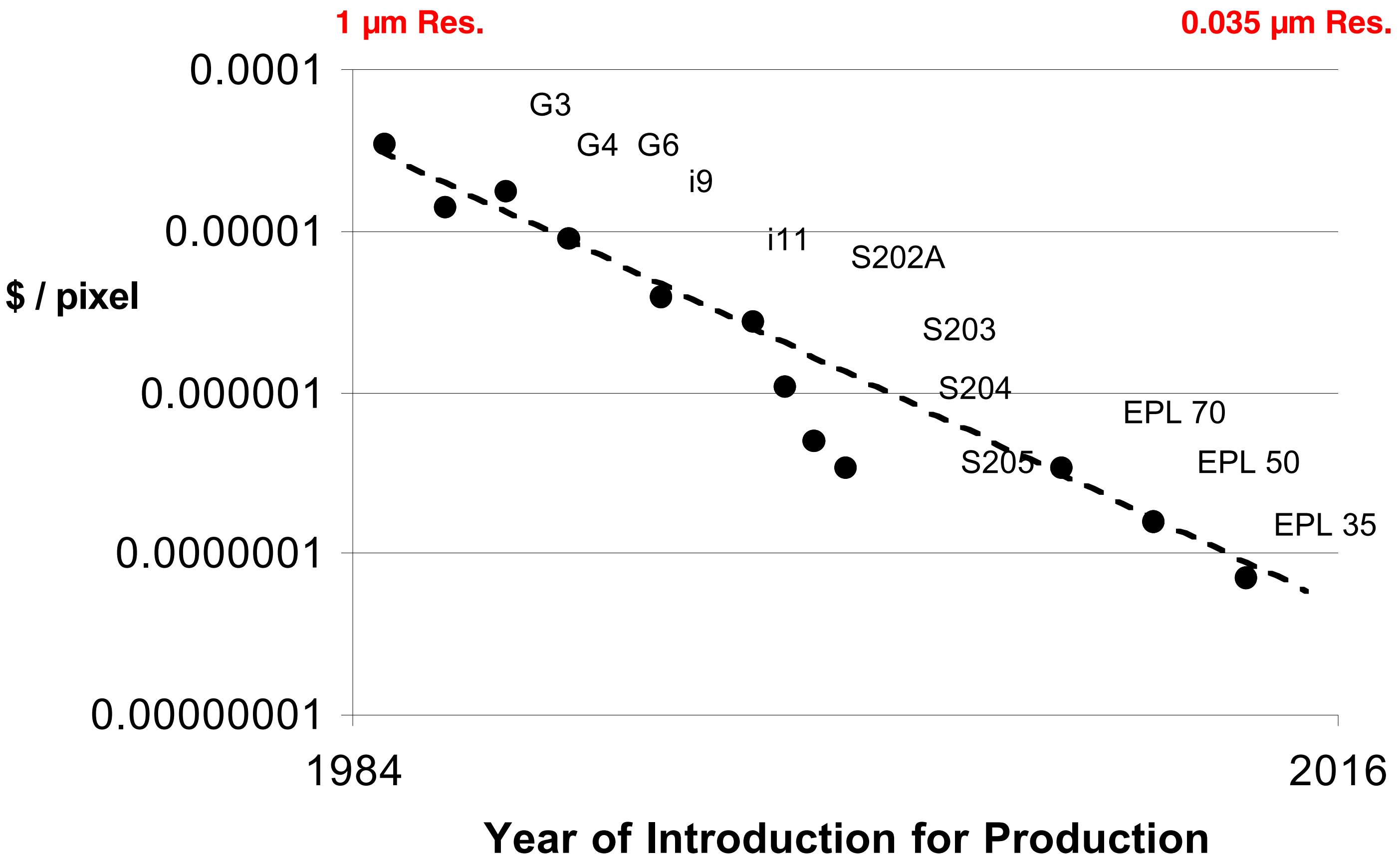
Thickness=500nm

Expose dosage=9.0μC/cm^2

Exposed with ***Nikon's EPL experimental column*** (EB Acc=100kV)

Nikon Lithography Tool Cost

(Cost per exposed pixel amortized over 5 years.
Adjusted for inflation. 3% inflation projected into future years.)



Elements of Cost of Lithography

- Tool price and throughput are key; however …
- IC yield from marginal processes play a role in technology introduction and in “technology push” for extensions of applicability. Examples:
  - ArF below 90 nm, F_2 at introduction, contact holes for all “optical” lithography below 90 nm.
  - “Exotic” lithography techniques can be costly: strong PSMs, multi-pass printing
  - Very small process margins require very high process stability; very hard.
- Thus come practical trade-offs; raw throughput not necessarily the “king”.

Summary

- **Nikon's plans are to push ArF technology as far as practical**
  - **Keep and mature existing technology for the IC industry**
- **Introduce F_2 and EPL roughly in parallel, mix and match**
- **Keep pursuing EPL at least for contacts and for lithography beyond optical capabilities**
- **Keep working on EUVL R&D through feasibility and practical production introduction**