IC Industry Lithography Requirements and Nikon’s Plans

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Nikon Precision Inc.
**ITRS Roadmap Drives the Litho Requirements**


**Lithography Requirements**

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<td>DRAM 1/2 Pitch (nm)</td>
<td>130</td>
<td>115</td>
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<td>MPU 1/2 Pitch (nm)</td>
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<td>MPU gate in resist (nm)</td>
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<td>MPU gate length after etch (nm)</td>
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<td>37</td>
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<td>28</td>
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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 F₂ laser sources (157 nm wavelength)
  - As above, but only CaF₂ 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)

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<td>MPU(gate in resist)</td>
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*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, F₂, 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.

• F₂ (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 F₂ tool in 2004.

• Electron Projection Lithography (“EPL”) has significant attractions, represents the other NGL contender with F₂.

• 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 F₂ and EPL, in parallel.
  – To assure maximum benefits, minimize risks.
**F<sub>2</sub> (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<sub>2</sub> 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<sub>2</sub> 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, F₂, or even EUV, is a likely scenario, with EPL used for contacts & vias (especially with ArF, F₂); difficult images for optical technology.
  – Low pattern coverage means that EPL’s throughput is enhanced.
Resist resolution for 1:2 Holes/Spaces with EPL

FEP-136 (FUJIFILM ARCH)
- Thickness = 500nm
- Expose dosage = 9.0 μC/cm²

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.)

Year of Introduction for Production

$ / pixel

1 µm Res. 0.035 µm Res.

1984 2016

G3 G4 G6 i9 i11 S202A

S203 S204 EPL 70

S205 EPL 50

EPL 35
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, F₂ 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 F₂ 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