Trends in the Cost of Photolithography Development and an Outlook for the Future

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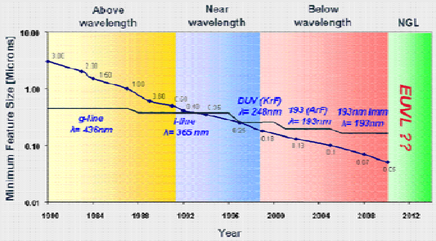
Evolution of Technology

- In support of Moore's law and the drive to economically support production of each technology node optical lithography has been pushed to limits once thought impossible.
- However, each technical advance in lithography introduced greater complexities to early process development and engineering support.
  - The advancement of lithography to imaging features near the wavelength of the illuminator required:
    - a move from I-line (λ=365nm) radiation produced with a lamp to a DUV (λ=248nm) laser source
    - the introduction of assist features on the reticles to enhance imaging (optical proximity correction -OPC).
  - As imaged feature sizes become smaller than the wavelength of the source:
    - lithography technology transitioned from steppers to scanners,
    - light sources from DUV illumination at λ=248nm to λ=193nm
    - from simple reticle OPC to more advance resolution enhancement technique (RET).
    - multi layer resist processes and dual exposure techniques were introduced.



NGL Business Challenges

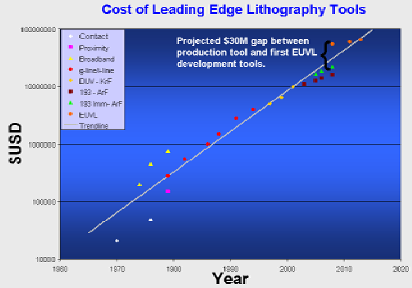
- The general feeling in lithography community today is that optical technology is now approaching its imaging limits.
- EUVL is gaining support as the successor to optical lithography. However, tool suppliers will have to face tough business challenges, as follows:
  - [illegible]
  - [illegible]
  - [illegible]
  - [illegible]
  - [illegible]
  - The introduction of EUVL into production is [illegible]

NGL - EUVL Development

- Although there are similarities between EUVL and traditional lithography there are also significant differences with many technical challenges.
  - As the radiation is absorbed by the transparent material of the lenses, EUVL optics will be fully reflective and manufactured with multilayer mirrors.
  - Tight film deposition uniformity for high reflectivity and better mounting strategies to maintain low wave front errors are required to meet the mirror specifications.
  - Specifications of the mirror surfaces require defect free multilayer mirrors and reticles to reduce scattering of the light.
  - With a high susceptibility to contamination, all optical components, including reticles, may have a relatively short lifetimes. This could require backup optics to be readily available to avoid extensive delays in development and insure manufacturing capacity.
  - There are significant power and debris issues with the light sources at EUVL wavelengths.
  - Due to the high absorption of EUVL radiation in air, the EUVL exposure process has to be conducted in a vacuum. This will very likely increase downtime from planned and unplanned maintenance events.

Traditional Cost of Advance Lithography

- The expense of developing advanced lithography processes has and very likely will always increase.
  - The primary drivers are the cost of exposure tools, tracks, reticles, and the number of wafers exposed per product.
  - The invest required by each of these drivers has increased significantly over time and in today's leading edge fabs lithography can account for 30 percent or more of the total cost of processing a semiconductor wafer.
- The cost of exposure tools alone remains one of the major investments of any semiconductor fab and the price of advanced imaging tools continues to escalate.
  - In early 1970 the cost of a leading-edge litho tool was approximately $250,000.00.
  - By mid 1990 the cost had increased to approximately $5 million.
  - Today, the cost of a leading-edge tool exceeds $20 million.
  - Costs of future tool generations are projected to exceed $50 million.



EUVL Related Cost at a Factory

- To develop insight into the investment required to support the introduction of EUVL an estimation of process cost was calculated using a per wafer based cost of ownership model described by [illegible] et. al:

$$c_w = p_w + \frac{m_0}{m_e} + \frac{e_0 + d \cdot e_m}{d \cdot t_t \cdot u_t \cdot 365 \cdot 24}$$

Where,

c_w = Cost to expose one wafer
p_w = Process cost per wafer including track, metrology, inspection
m_0 = Cost of reticle
m_e = Exposures per mask (lifetime)
e_0 = Cost of exposure system
d = Depreciation of exposure system in years
e_m = Annual maintenance cost of exposure tool
t_t = Wafer throughput in wafers/hour
u_t = Utilization of exposure system

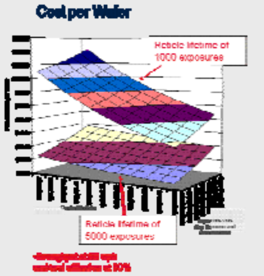
- This model was selected as it reflects processing cost per wafer and it is easily adapted to cost modeling of both production and development environments. It should be noted that the input to this model is based on assumptions and invest estimations that have many unpredictable factors.

Assumptions

The following assumptions are applied to calculate CoO of early EUVL process.

1. Process cost will remain constant at $7.50 per wafer.
2. The lifetime of an EUVL reticle is assumed to be at least 5,000 exposures.
3. Depreciation is taken over 5 years.
4. Annual maintenance will be 10% of exposure tool price tag.
5. Tool utilization percentage is a simple ratio of exposure time over a possible available time of 8760 hours. As it is difficult to predict the available operating time, the utilization number will take into account planned and unplanned maintenance and baseline monitoring of the exposure tool and track.

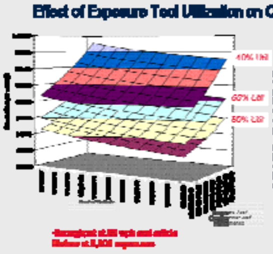
Influence of EUVL Exposure Tool and Reticle Costs on Cost per Wafer



-throughput at [illegible] wph and tool utilization at 80%

Historically the primary drivers of increased wafer processing costs of lithography have been the capital expense of exposure tools, product reticles and reticle lifetime.
A comparison of the reticle cost, lifetime and exposure tool expense is shown in this graph. The trends indicate that the capital expense of the EUVL exposure tool and the price of the product reticle have a constant influence on the processing cost per wafer.
However the reticle lifetime, in terms of the number of exposures per reticle, will have a significant impact on the overall process cost.

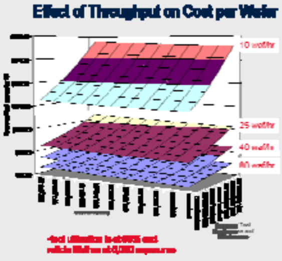
Effect of Exposure Tool Utilization on Cost per Wafer



-throughput at [illegible] wph and reticle lifetime at 5,000 exposures

Due to the absorption of EUVL radiation in air the exposure tool will operate in a vacuum. This requirement will likely negatively impact the tool availability and utilization. The overall influence of utilization on processing cost per wafer is shown here.
In general it is always beneficial to increase tool utilization, however with EUVL the cost per wafer exposed does not go below $30.00 even at 80% utilization and at 60 wph.

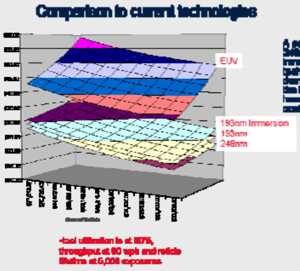
Effect of Throughput on Cost per Wafer



-tool utilization is at 80% and reticle lifetime at 5,000 exposures

Of all the parameters modeled wafer throughput demonstrates the most significant impact on processing cost per wafer. The EUVL [illegible] Even if the throughput reaches the 60 wph the cost of exposing a single wafer with EUVL will remain above $30.00.

Comparison to current technologies



-tool utilization is at 80%, throughput at 60 wph and reticle lifetime at 5,000 exposures

A comparison on EUVL with 248nm, 193nm and 193nm immersion lithography technologies clearly demonstrates the impact of the introduction of EUVL will have on wafer processing cost.

Summary

- Higher CoO values for EUVL will be driven primarily by four factors:
  1. Limited lifetime of the reticles. Without the ability to distribute cost per reticle over a high number of exposures the processing cost per wafer will be unsustainable.
  2. Lower throughputs. Due to uncertainty with the source it is difficult to predict what throughput is attainable. However even at 60 wph the wafer cost from EUVL will still be twice as high as that of 193nm immersion technology. EUVL could be used for large-scale production only if it were able to achieve throughputs higher the 60 wph.
  3. Utilization. Overall tool utilization will suffer due to the source maintenance, in-situ optics cleaning, and dealing with the vacuum requirements.
  4. Exposure tool costs. EUVL tools will incorporate newer optics technology, a significantly different source, require vacuum environment and precision stages to meet product requirements.

Conclusion

- EUVL has gained considerable momentum as the replacement for optical lithography.
- But introduction into manufacturing will be gated by when the technology makes financial sense.
- With projected tool and reticle costs associated with EUVL it should fit well with high volume manufacturing, however:
  - EUVL will not be cost effective for low volume manufacturing, reticle cost are too high.
  - EUVL may not be affordable for production of commodity products, such as DRAMs, processing cost per wafer can not be supported.
- For EUVL to come it must be affordable to more than just microprocessor manufacturers.

Never stop thinking

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