



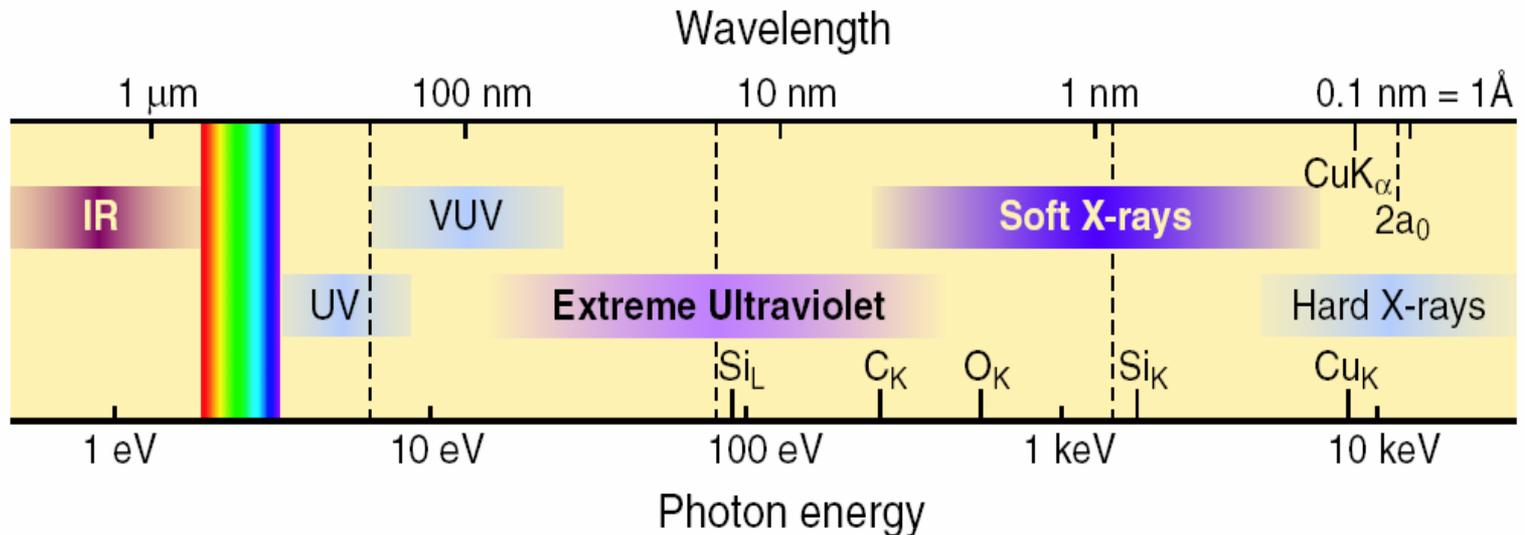
Extreme UV (EUV) lithography



OUTLINE

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Electromagnetic spectrum



- UV down to about 170 nm ($\sim 7\text{eV}$)
- EUV/soft x-ray, 2-50nm
- 47nm is the λ for the Ne-like-Ar X-ray Laser (capillary discharge laser).
- But for EUV lithography, it is at $\sim 13.5\text{nm}$ (92eV).

EUV Lithography-An Introduction

- Since the 1970s, the semiconductor industry has strived to shrink the cost and size of circuit patterns printed onto computer chips, doubling the number of transistors on a computer's central processing unit (CPU) every two years.
- The introduction of extreme ultraviolet (EUV) lithography, printing chips using 13-nm-wavelength light, opens the way to future generations of smaller, faster, and cheaper semiconductors. In this way, EUVL is one technology vying to replace the optical lithography.
- EUV lithography relies on specialized lenses made of curved mirrors with reflective coatings called multilayers to print patterns with high resolution. One special flat mirror called a mask is particularly sensitive to even the smallest imperfections.

Why EUV lithography?

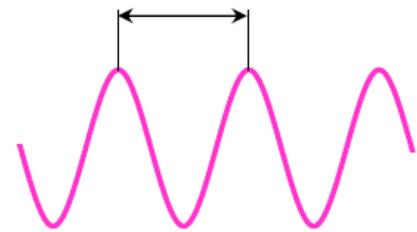
- Shorter λ gives higher resolution.
- No need of resolution enhancement techniques.
- Relax the requirement for NA.
- For EUV lithography, $\lambda=13.5\text{nm}$ where efficient “lens” (reflected mirror) exists.

$$\text{Spatial Resolution} = \frac{k\lambda}{NA}$$

EUV and SXR microscopy can potentially resolve full-field images with 10-100x smaller features than conventional visible microscopy

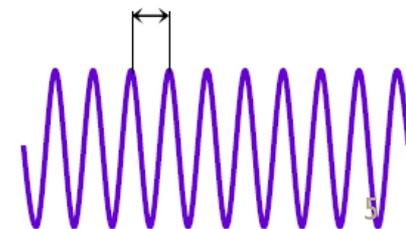
visible light

$$\lambda = 500 \text{ nm}$$



Extreme ultra-violet
and soft x-ray light

$$\lambda = 1 - 50 \text{ nm}$$



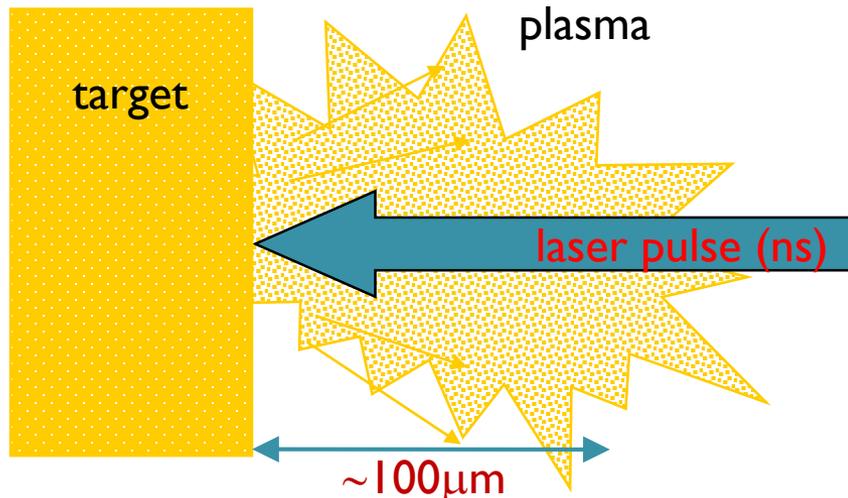
EUV An extension of Optical lithography

- Uses very short wavelength 13.5nm of light
- 13.5nm radiations absorbed by all materials
- All optics are reflective
- Uses reflective mask
- Vacuum operation
- Unique source for EUV light

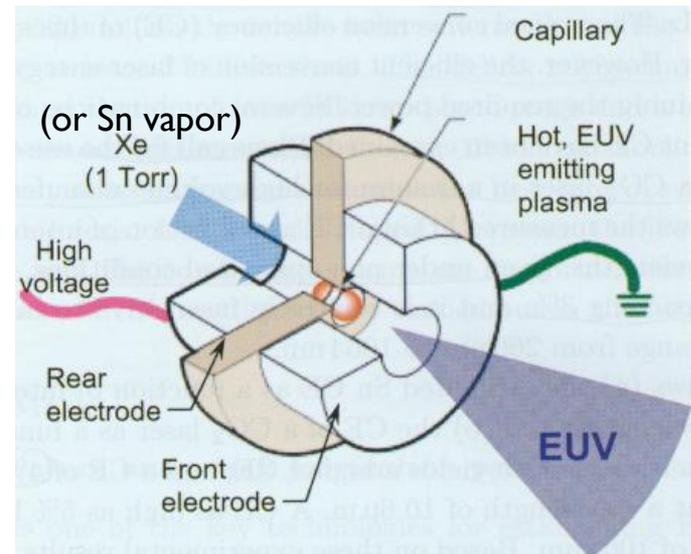
Sources of 13nm EUV

- Light sources must match the wavelengths at which Mo/Si multi-layers have high reflectivity.
- The only viable source for 13.5nm photons is a hot and dense plasma.
- Powerful plasma: temperature of up to 200,000°C, atoms ionized up to +20 state.
- Emit photons by (e - ion) recombination and de-excitation of the ions.
- Plasma must be pulsed: pulse length in pico- to nanosecond range.
- Plasma is produced by powerful pulsed laser or electric arc (discharge) of up to 60,000A peak current.

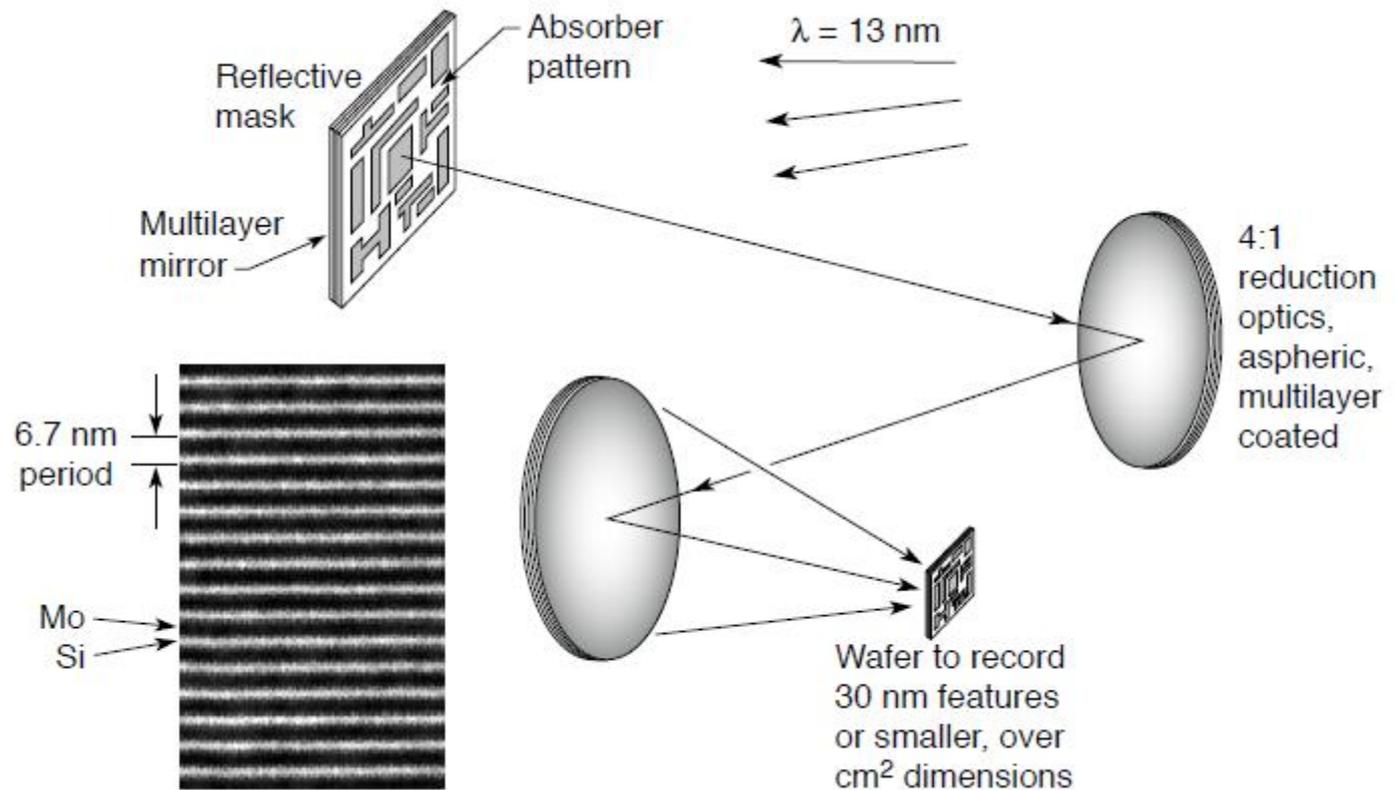
Laser Produced Plasma (LPP)



Discharge Produced Plasma (DPP)



EUV lithography :Working

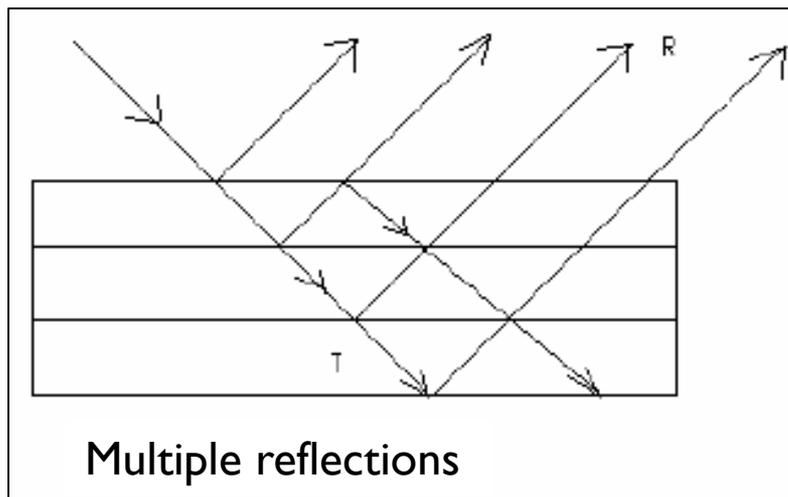


- EUV radiation is strongly absorbed in virtually all materials, even gases, so EUV imaging must be carried out in a near vacuum.
- There is no refractive lenses usable - EUVL imaging systems are entirely reflective.

- But EUV reflectivity of individual materials at near-normal incidence is very low, so distributed Bragg reflectors (period about $\lambda/2$) are used.
- The best of these function in the region between 11 and 14nm (Si/Mo material)
- EUV absorption in standard optical photo-resists is very high (low penetration depth into resist), so new resist and processing techniques will be required

Optics for EUV lithography (EUVL): Overview

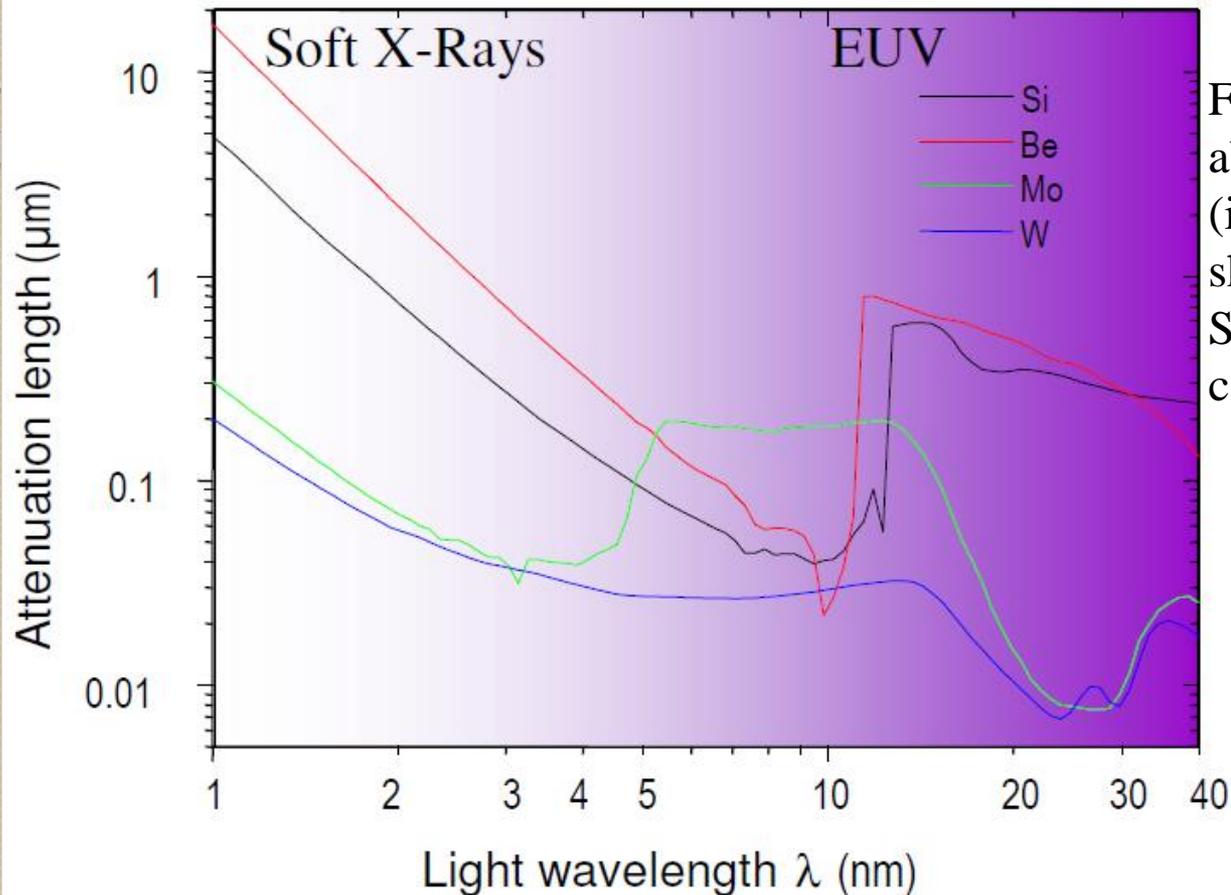
- All solids, liquids, and gasses absorb 13.5nm photons, so no longer refracting lens.
- A beam of EUV light is absorbed in 100nm of H₂O.
- Even worse, conventional optical devices will not reflect EUV light.
- EUVL uses concave and convex mirrors coated with multiple layers of molybdenum and silicon -- this coating can reflect nearly 70 percent of EUV light at 13.5nm.
- The other 30 percent is absorbed by the mirror.
- Without the coating, light would be almost totally absorbed before reaching the wafer.
- The mirror surfaces have to be nearly perfect - even small defects in coatings can destroy the shape of the optics and distort the printed pattern in resist.



If the thicknesses and compositions of all films are carefully controlled, the reflected light will constructively interfere resulting in the brightest possible reflection.

Why Si/Mo and 13.5nm?

Absorption in solids for EUV and soft x-rays



For high reflection, the absorption should be low (i.e. attenuation length should be large). So Mo, Si, Be are good candidates at ~10-15nm.

- Mo/Si ~40 layer pairs ~70% reflectance where Mo and Si are most transparent.

Schematic of EUV lithography system

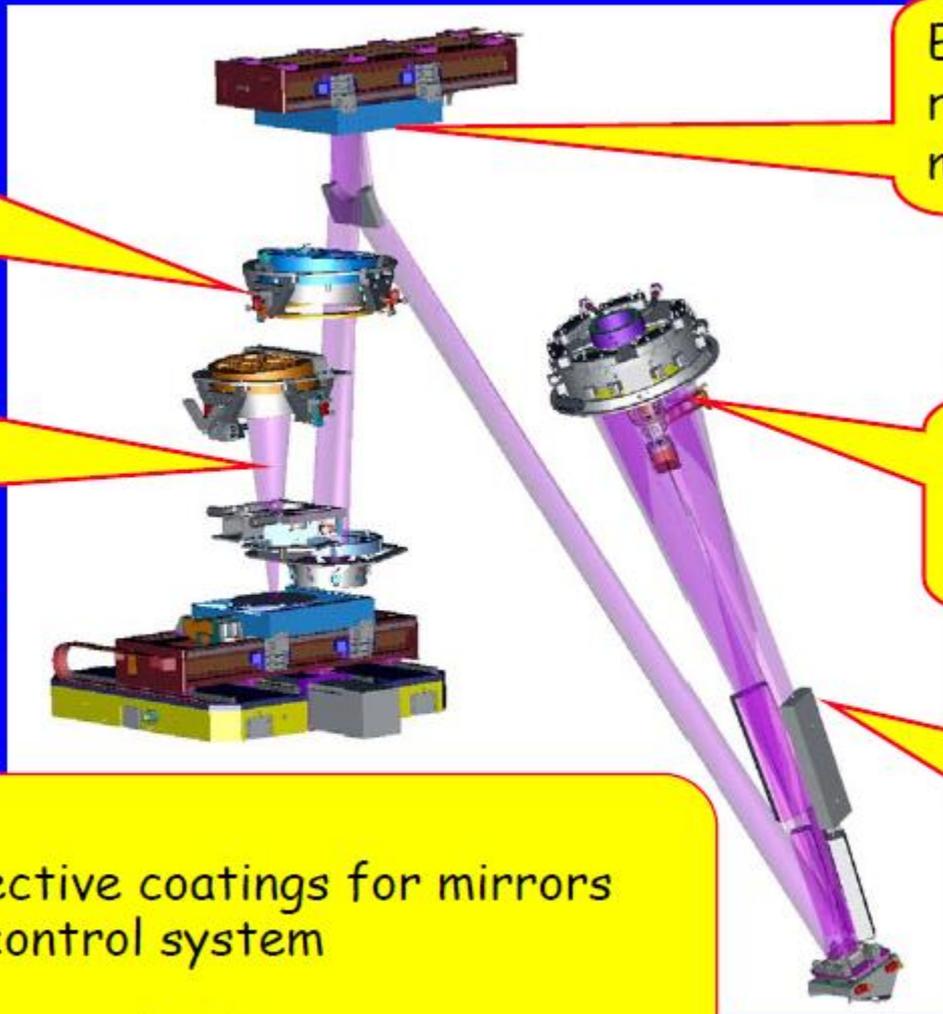
EUVL alpha-tool

Aspheric mirrors with sub-nm surface error

Robust 4X reduction EUV projection optic.

Plus:

- Multilayer reflective coatings for mirrors
- Environmental control system
- EUV resist
- Operating and control software



EUV reflective masks

A reliable source of EUV photons.

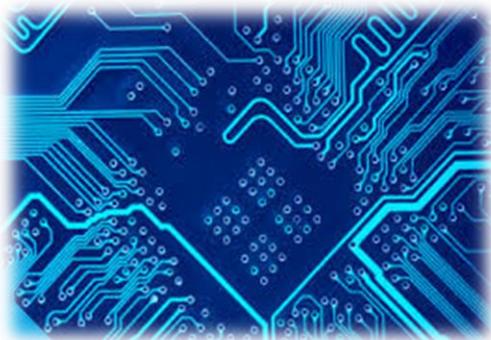
A condenser to collect and shape EUV radiation.

How is EUV different from the prior lithography technologies?

- There are multiple ways that EUV differs, mostly associated with the methods to create and transport the short wavelength light.
- Traditional lenses cannot be used with EUV as they absorb the light. A mirror with a highly specialized coating, called a multilayer mirror (MLM) must be used. Even these special mirrors still absorb about 30% of the light so it is advantageous to use as few as possible.
- Any gas in the light path, such as air or nitrogen, will also absorb the light - thus the entire light path is inside a vacuum chamber.

APPLICATIONS

- In lithography, the complex process used to create computer chips, a six-inch glass plate called a mask carries one layer of a circuit pattern—the image of which is transferred onto a silicon wafer that becomes a computer chip.
- A microprocessor made with the EUVL technology would be a hundred times more powerful than today's. (etc)



Defects

- A single undetected defect can ruin the mask and the entire process. Currently, one of the major obstacles to the commercialization of EUV lithography is the lack of mask inspection and imaging tools that can detect defects before they are printed and replicated on millions of chips.
- Contamination of lens: EUV irradiation leads to photochemical reactions that cause hydrocarbons to adsorb to the mirror and mask, reducing mirror's reflectivity.



THANKS...