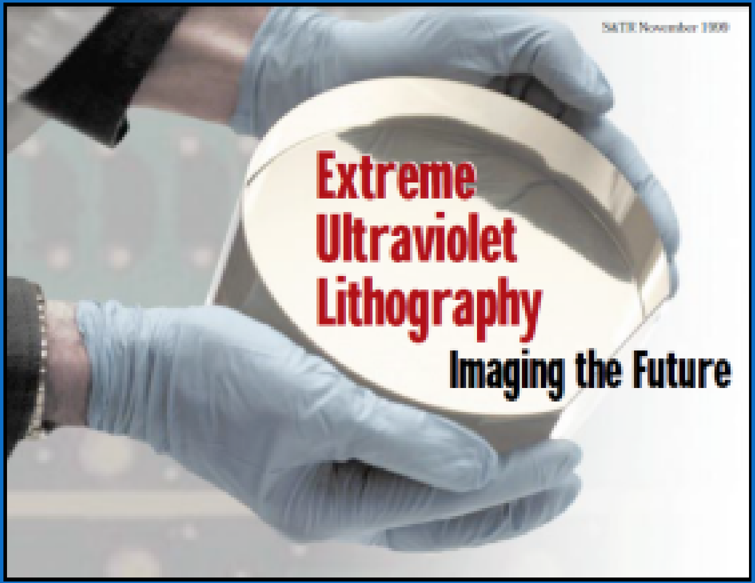
Deep and Extreme UV Lithography

The Successor to Optical Lithography



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Optical lithography at shorter Wavelength

Why We needed Deep UV?

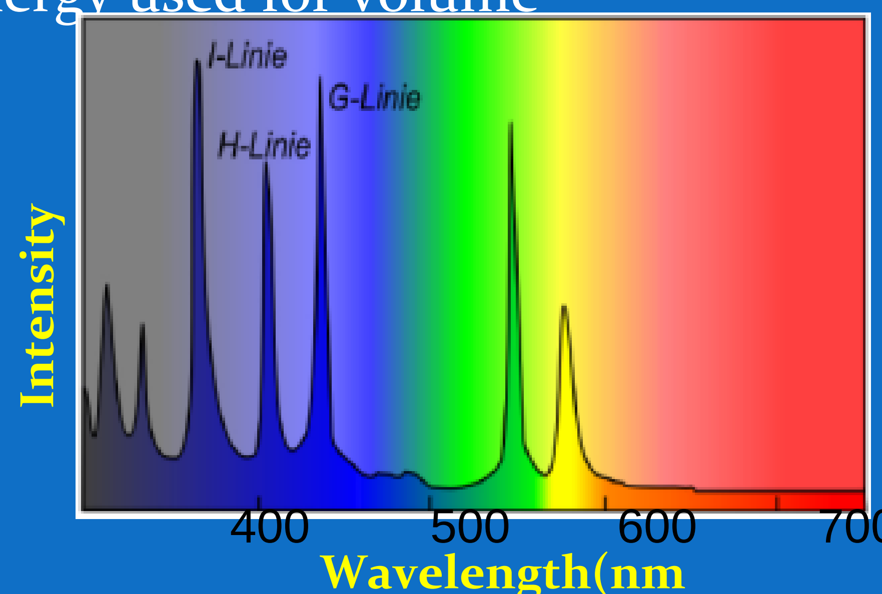
- Mercury Lamps were used earlier as illumination source.
- As mask features shrink, shorter wavelengths became the choice.
- Small mask features made mercury lamp unsuitable because of not possessing enough photon energy used for volume

Light sources

Source	λ	Resolution
• Hg lamp (g-line)	436 nm	400 nm
• Hg lamp (i-line)	365 nm	350 nm
• KrF	248 nm	150 nm
• ArF	193 nm	80 nm
• F_2	157 nm	research

increasing cost ↓

Extreme UV, x-ray lithography research topics.
Difficulties lie in sources, and materials for optics and masks.



Spectrum of an Hg-Lamp

Excimer Lasers as a savior

- Pulsed gas discharge lasers which produce light output in the ultraviolet region of the spectrum.
- These met both requirements of high photon energy and shorter wavelength.
- DUV Lithography started with KrF excimer laser.
- As time passed we moved to ArF then F_2 then to Ar_2 which used wavelength of 157nm.

Wavelength	Active Gases	Relative Power
157 nm	Molecular Fluorine(F_2)	10
193nm	Argon Fluoride(ArF)	60
248nm	Krypton Fluoride(KrF)	100
308nm	Xenon chloride(XeCl)	50
351nm	Xenon Fluoride	45

Excimer lasers and their relative power

For Optical Lithography at 157nm and smaller

- At shorter λ absorption of photons is more.

- 3 critical Things:
  - Material of Optical Lens.
  - Transparent and radiation durable pellicle for masks.
  - Photoresists.

- Material of optical lens:

  we moved from fused silica to CaF crystal.

Pellicle :

- Due to absorptive nature at 157nm. Not applicable.
- Which will lead to distorted image at substrate.

Photoresists:

- Absorptive nature creates the same problem with this.

So Question arose whether to stick with 157nm or to move to shorter wavelength like 13nm?

- EUV could play a key role in several generations of IC ahead from 32nm to 22nm or below.
- With major players like Intel driving the field wavelength optical lithography went to EUV.

Advantages

- **Large field size.**
  ICs with many photonic integrated devices can be prototyped, for complex circuits, testing many devices or large parameter sweeps.

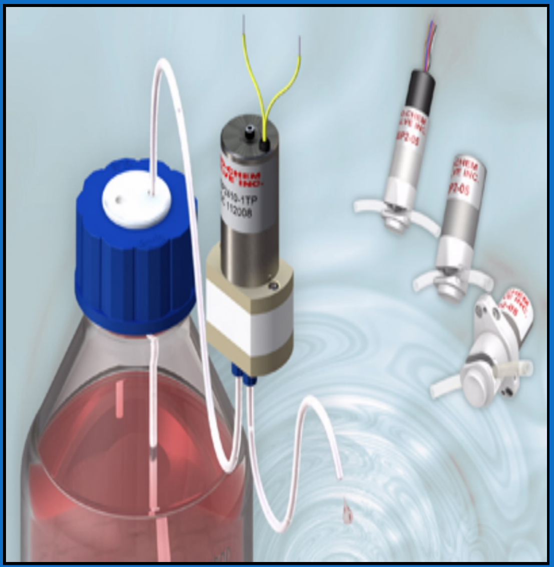
- **Large amount of chips.**
  With DUV lithography, fabricating 200 or 1000 chips is as easy as fabricating one (or rather: easier).

- **Capable of handling complexity.**
  CMOS technology is built to handle complexity.

- **Volume manufacturing compatible technology.**
  Using the same technology in research and in manufacturing saves costs and time in bringing research to the market

Applications

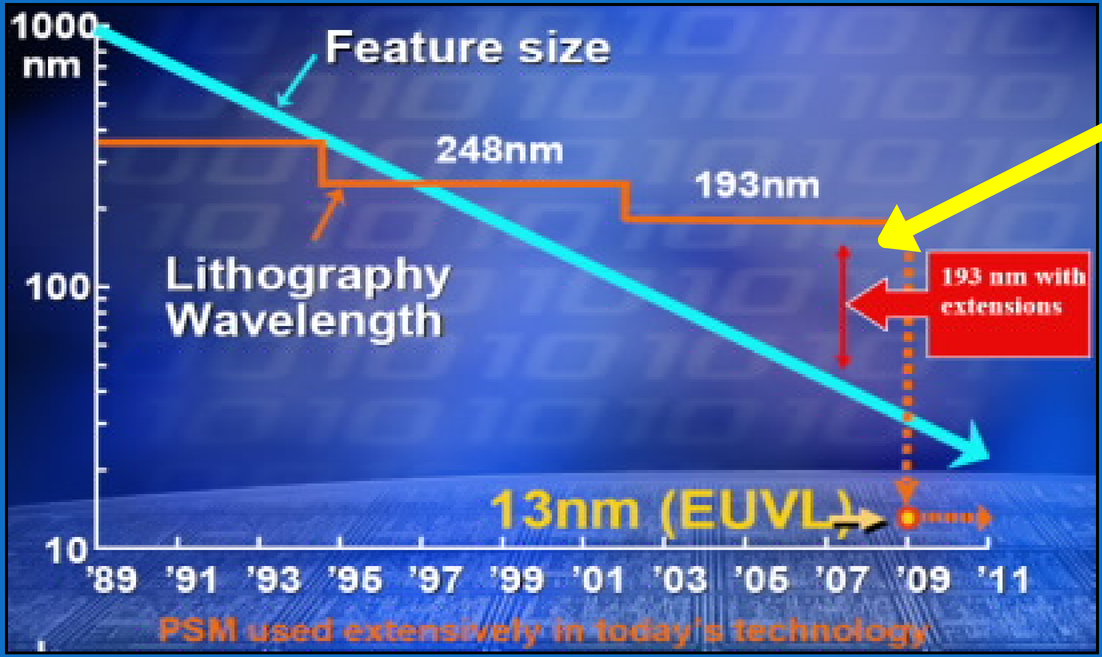
- Micro pumps :
  - Used to precisely control very small fluid flows. e.g in chromatography, to apply insulin doses, in DNA recognition micro devices and to control specific chemical reactions.



- 193nm used to fabricate minimum feature size (180-32) nm

Why we need EUVL?

- **Minimum lithographic feature size =** $\frac{k_1 * \lambda}{NA}$
- **k1**: "Process complexity factor" – includes "tricks" like phase-shift masks
- **λ**: Exposure wavelength
- **NA**: Numerical aperture of the lens – maximum of 1 in air, a little higher in immersion lithography (Higher NA means smaller depth of focus, though)

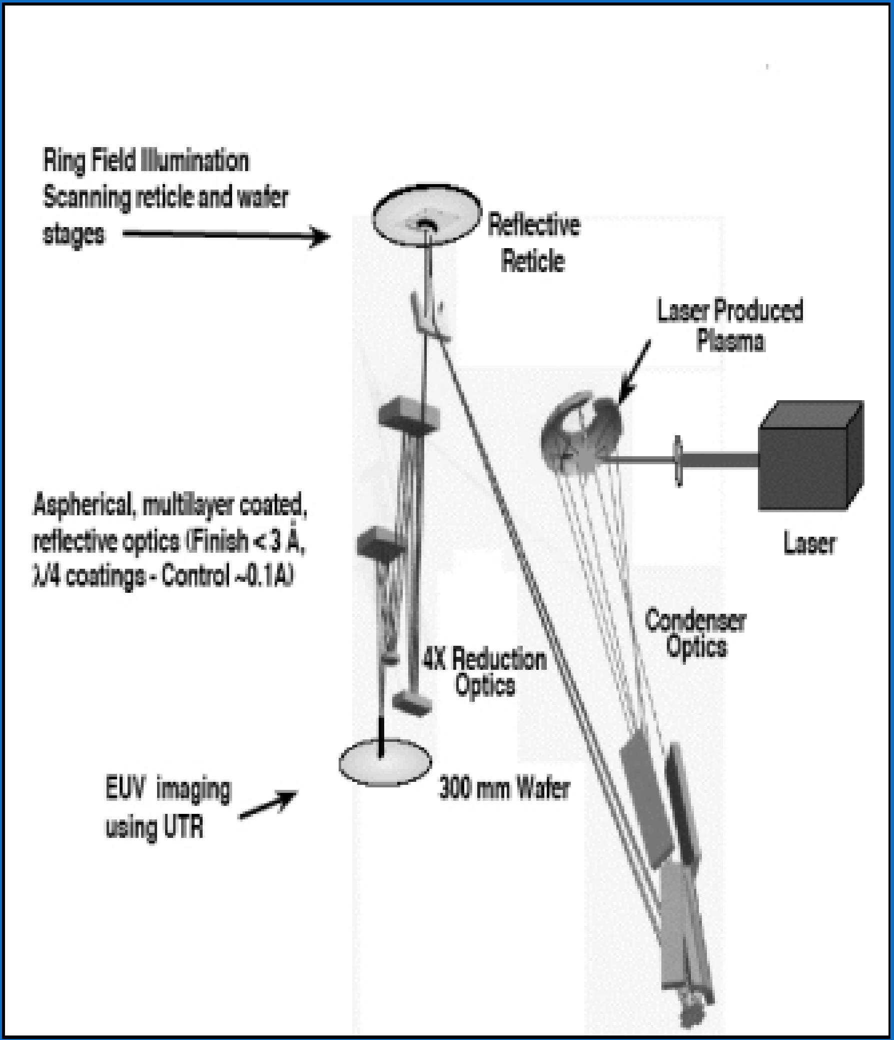


There are only so many "tricks" to increase this gap, and they are very expensive … we MUST go to a shorter wavelength!

ftp://download.intel.com/research/silicon/EUV_Press_Foils_080204.pdf

Next Generation Lithography : EUV

- Uses very short 13.5 nm wavelength.
- Also called Soft X-ray. Still considered Optical lithography .
- Reflective optics is used (all materials absorb on refractive optics!) for focusing as well as mask.
- Uses reduction optics (4 X)
- Step and scan printing
- Optical tricks like : off axis illumination (OAI), phase shift masks and OPC apply.



Technology for EUV

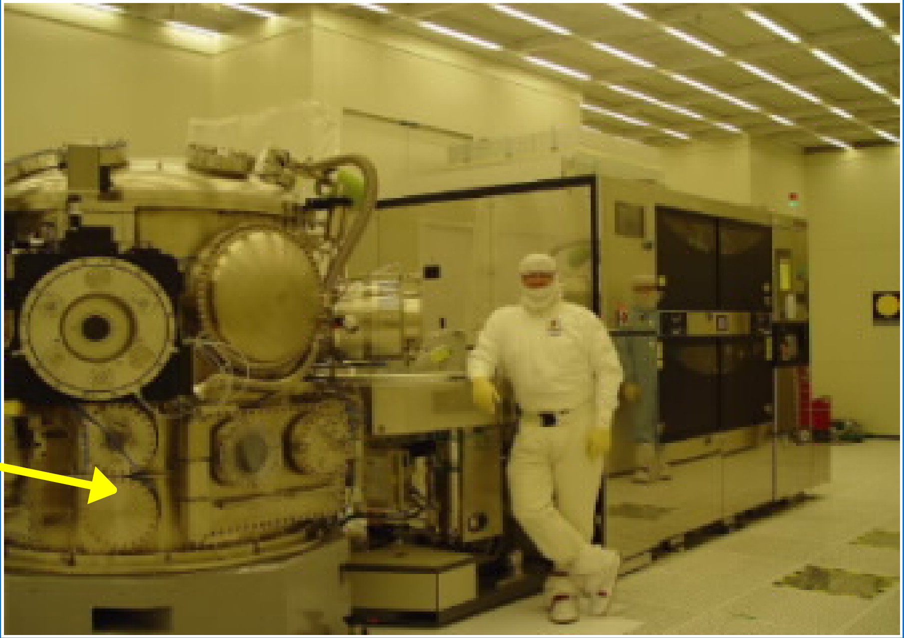
All solids, liquids, and gasses absorb 13.5nm – so system is under vacuum

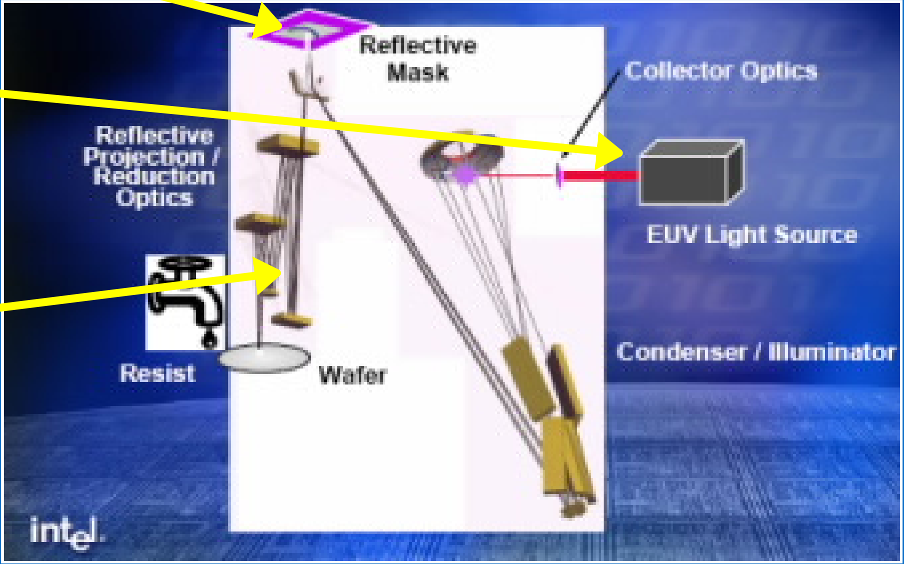
Mask must be reflective and exceptionally defect-free

13.5nm photons generated by plasma source

All-reflective optics

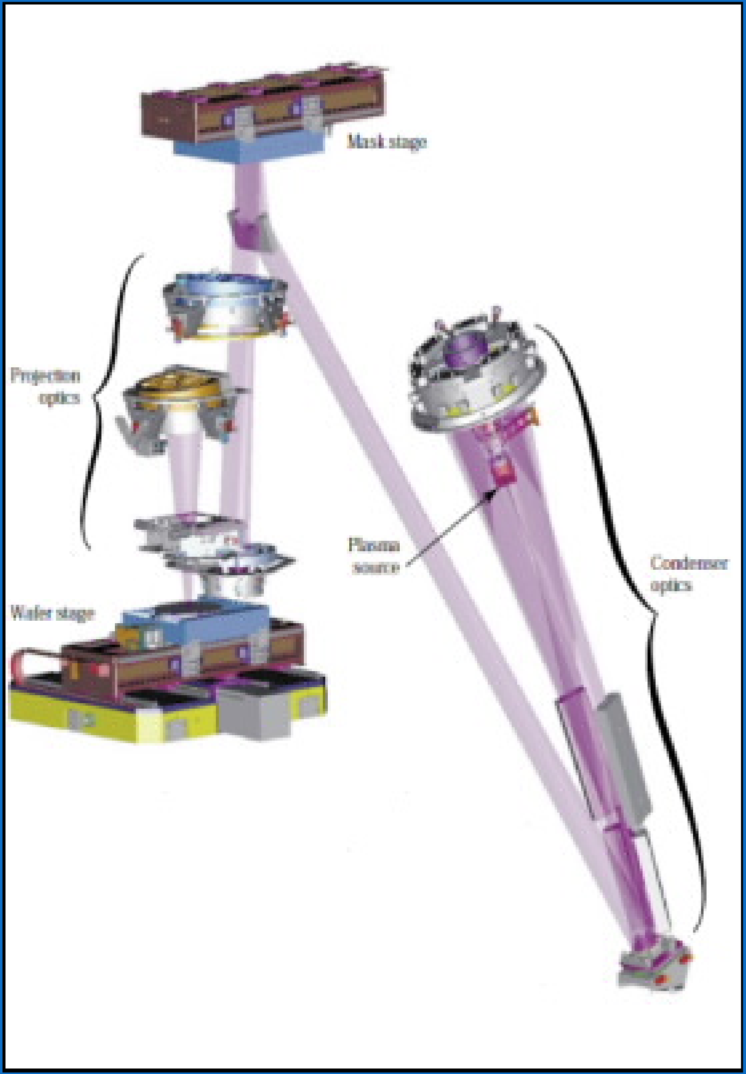
(all lens materials are opaque)





How EUVL works

- A laser is directed as a jet of xenon gas. When laser hits the Xenon gas it heats up and creates a plasma.
- Once is created , electron begins to come off and radiates light at 13nm.
- Light travels to condenser and is directed to the mask.
- Pattern on the mask is reflected on to the series of four to six curved mirrors , reducing the size of the image and focusing the image onto the silicon wafer.



EUVL SYSTEM COMPLETELY DIAGNOZED

EUV Radiation Source

- Generated by 2 methods:

  1) Plasma (Viable for industrial use).

  2) Synchrotron source(owned by National government).

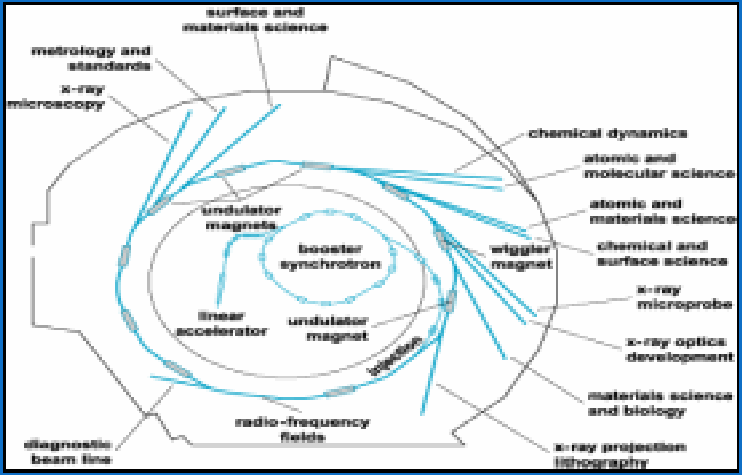
  Powerful plasma required :

  1) Laser produced Plasma(LPP).

     LPP uses a high-power CO_2 laser to ionize tin droplets.

  2) Discharge produced Plasma(DPP).

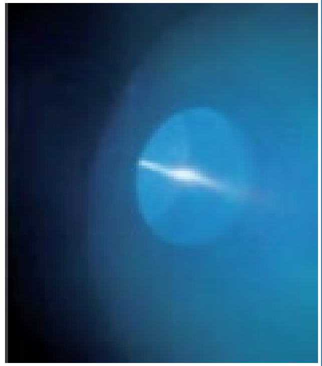
     High pulsed current to heat up and ionize tin



Synchroton

Issues Needing Review: 1) Output Power of EUV source.

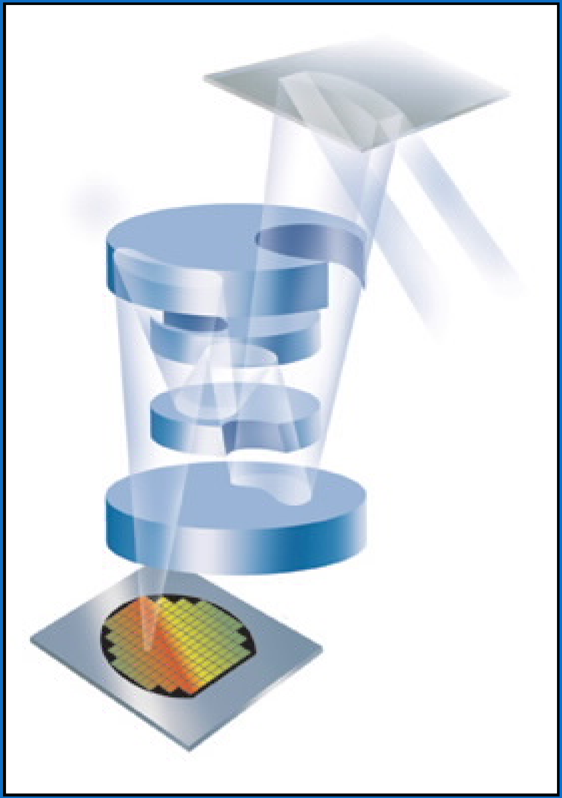
2) Lifetime of Collector optics due to contamination caused by debris generated in source.



Plasma discharge used to produce extreme ultraviolet light

EUV Optics

- Key Component is:
  - Multilayer reflective mirror (UV reflectivity of any single material at near normal incidence is very low) .
  - This multilayer thin film coatings know as distributed Bragg Reflectors.



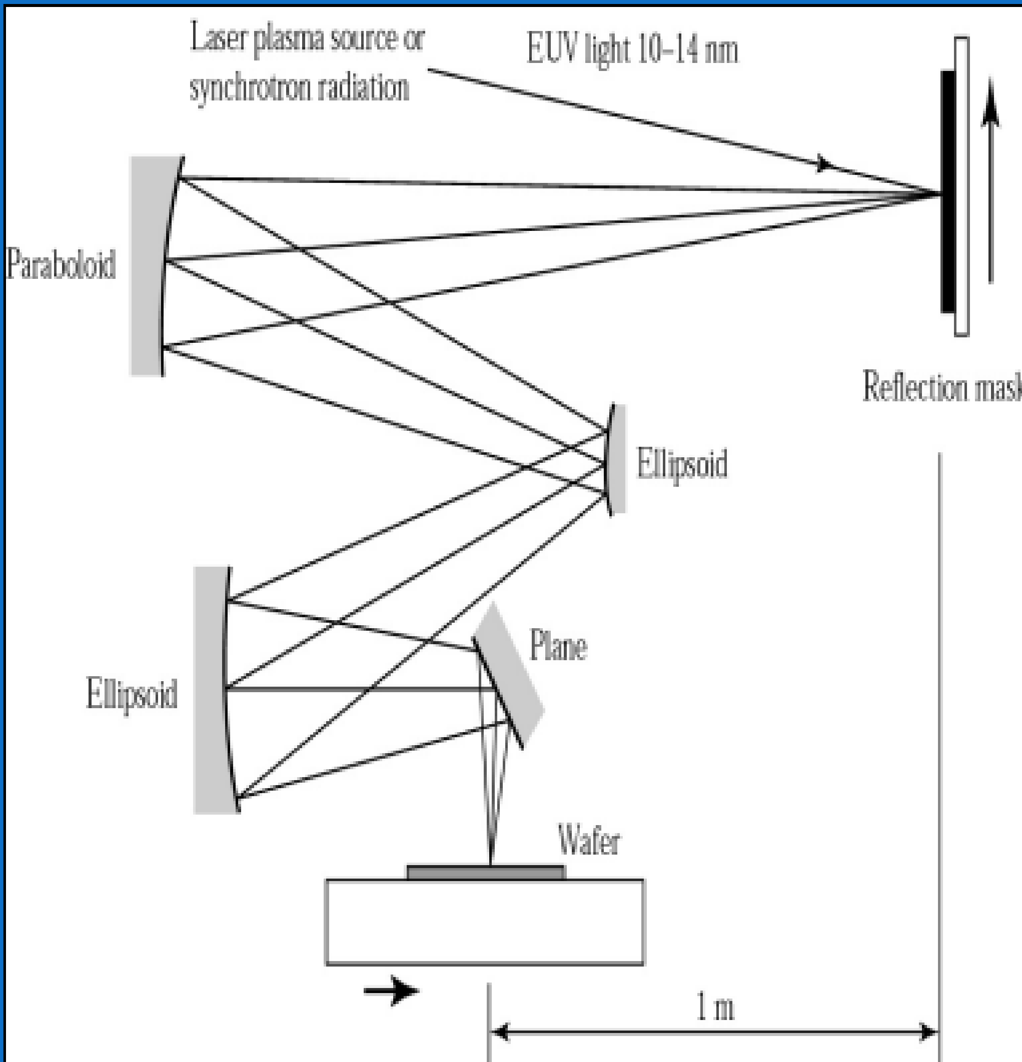
•50 or more alternating Mo/Si layers give the mirror its reflectivity

• Mo (2.76nm) – Si (4.14nm) thick.

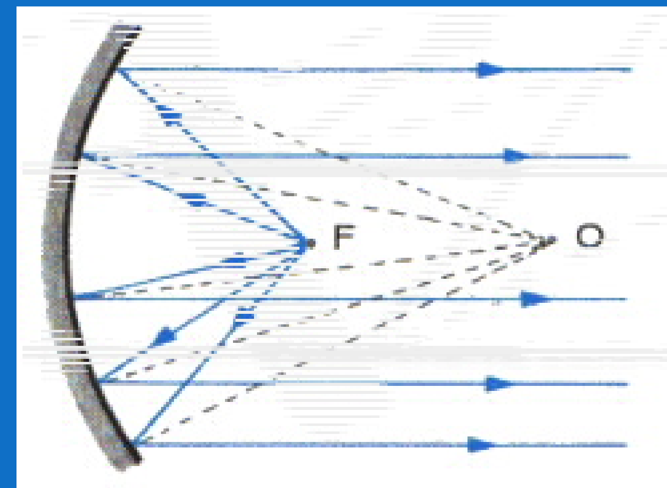
•Net reflectance: ~70%

Issues Needing Review: 1) Contamination control
2) Life time under EUV irradiation

OPTICS DIAGNOZED



How Various reflectors help in getting 4:1 reduction

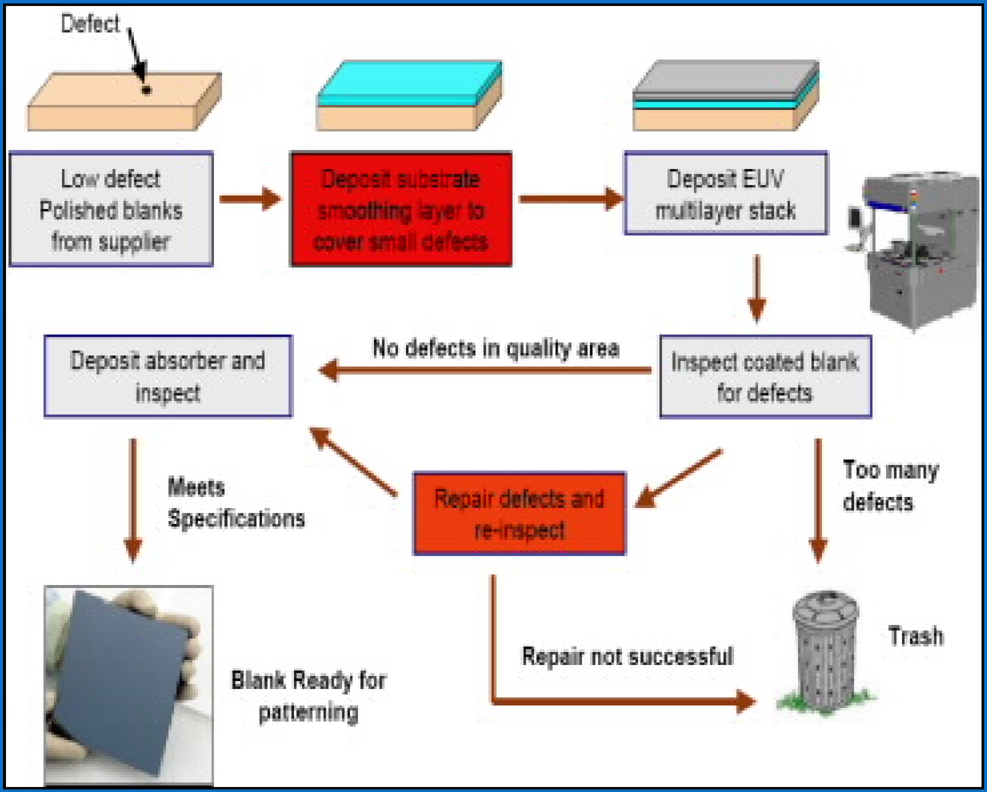


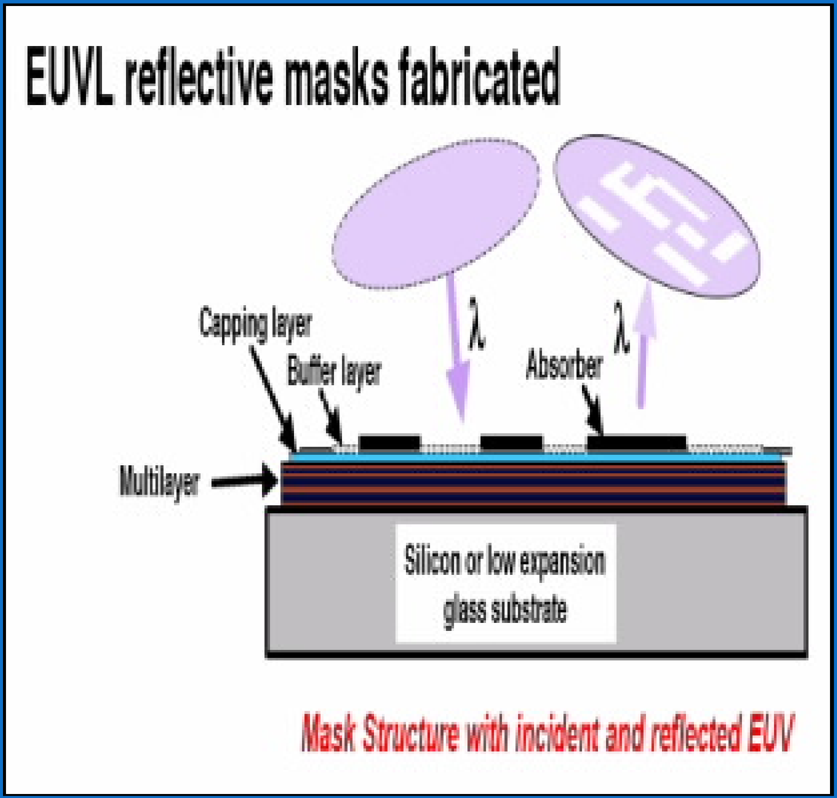
Paraboloid reflector

Ellipsoidal reflector

EUV Masks

Making of EUV mask involves : 1) Making of Mask blank.
2) Patterning of Absorber Layer.





ftp://download.intel.com/research/library/IR-TR-2003-39-ChuckGwynPhotomaskJapan0503.pdf

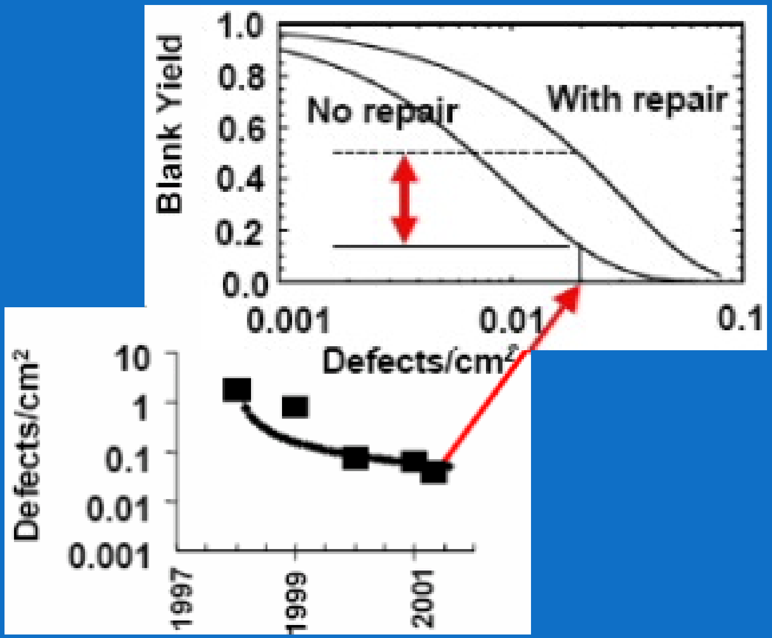
- The substrate should be Low Thermal Expansion material. With flatness of 50nm and free from defects.
- Al, Cr, Ta, and W used as absorber layer.

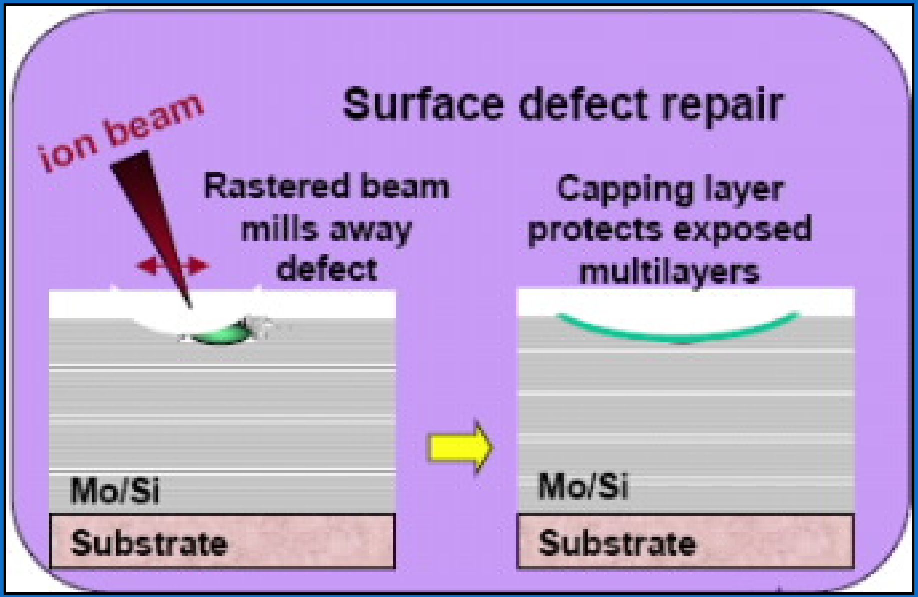
Patterning of Absorber Layer:

2 methods are used 1) Electron Beam Lithography.

2) Reactive Ion Etching(RIE).

All defects in final absorber pattern must be completely repaired.





EUV Resists

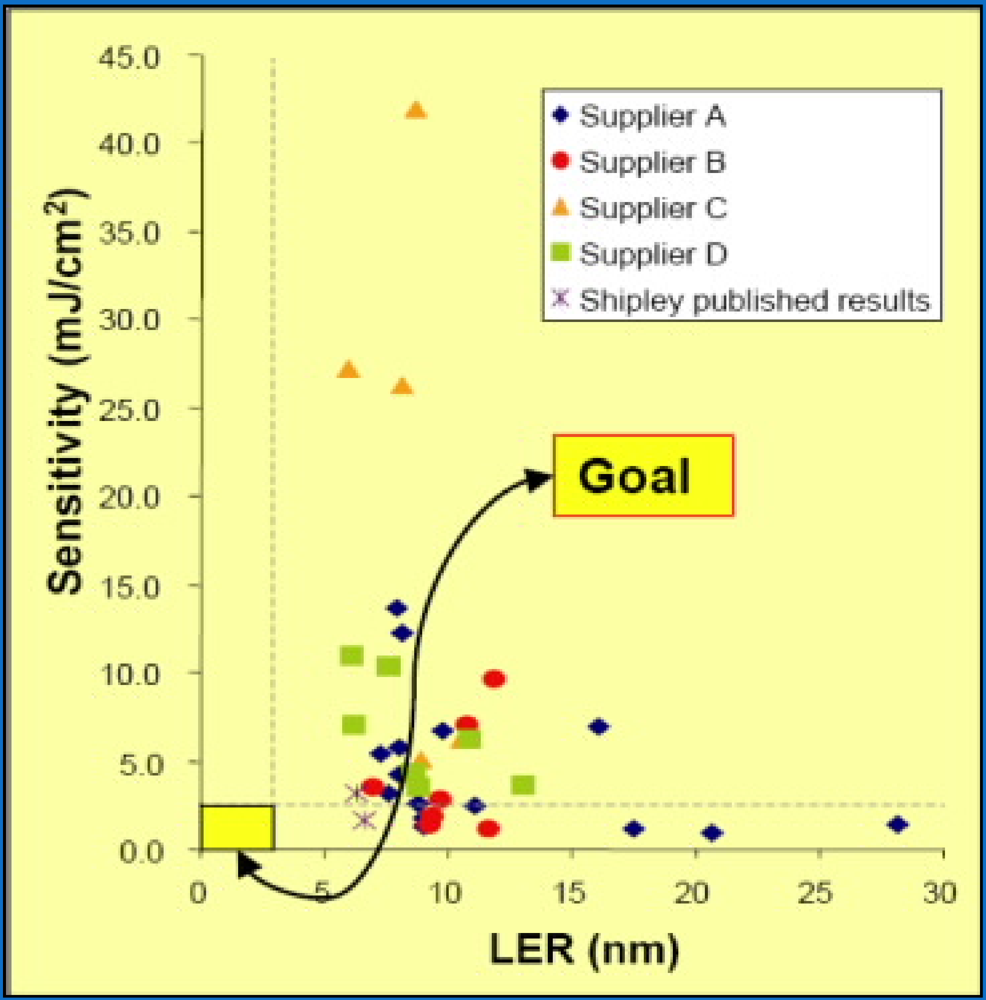
- Much Like as in DUV.
  - Sensitivity is higher.(bcz power level of EUV source).
  - Resolution Capability is More.
  - Low Line Edge Roughness.
- EUV source power of 115W, resist sensitivity of 3mJcm $^{-2}$ is necessary to give throughput of 100 wafers per hour. Only Possible with CA resistes.
- Higher the sensitivity higher LER becomes.
- 35nm and 40nm line/space seen but with unacceptable LER.

Various Issues that need review:

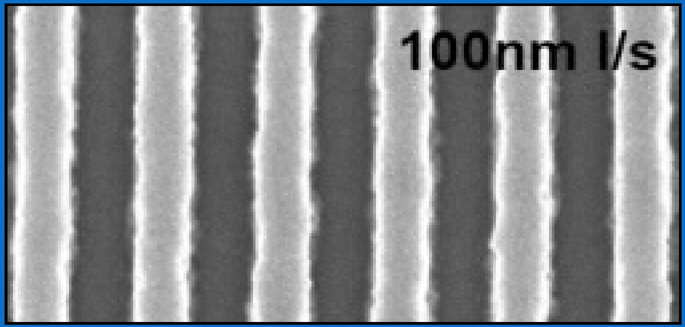
LER. (2.5nm) (CA is not able to provide this).

Gaseous Molecules Released.(contaminate mirror surface)

EUV Resists analyzed

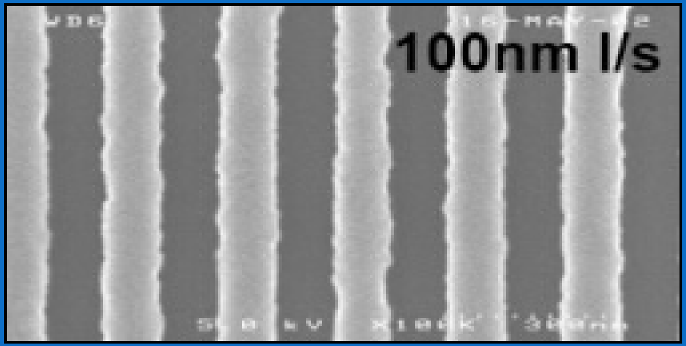


Best Positive Resist



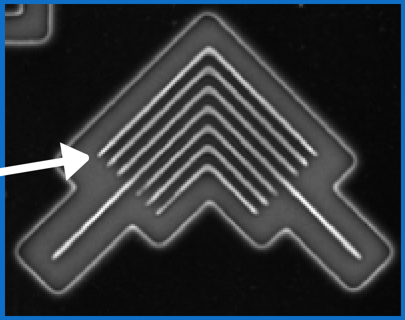
$2.3 mJ/cm^2$ LER=7.2nm

Best Negative Resist



$3.2 mJ/cm^2$ LER=7.6nm

39nm 3:1
(space:line)



ftp://download.intel.com/research/library/IR-TR-2003-39-ChuckGwynPhotomaskJapan0503.pdf

Advantages of EUVL

- EUVL technology achieves good depth of focus and linearity for both dense and isolated lines with low NA systems without OPC.

- The robust **4X** masks are patterned using standard mask writing and repair tools and similar inspection methods can be used as for conventional optical masks.

- The low thermal expansion substrates provide good critical dimension control and image placement.

Applications

- It's a Key to powerful microprocessors.

  The more transistors can be etched onto the silicon wafer.

  More transistors MEANS:

  More powerful, faster microprocessor.

  Intel Pentium 4 processor, which has 42 million transistors, is faster than the Pentium 3, which has 28 million transistors.

Conclusion

- **Will 193nm ever die?**
- In 2003, EUV was “the only viable solution” for the 45nm node
- Now Intel wants EUV for the 32nm node, but it may be pushed back more:
- A lot of work remains: increase output power of 13.5nm source, increase NA of reflective lenses, increase lifetime of collector optics (decrease cost of ownership)
- ‘From the physics of the process, 10nm structure sizes are possible, although it might still require optical tricks to achieve this with EUV. ‘
- Whether or not the physical properties of silicon chips will continue to decrease to this size is another issue, but using 13.5nm light, structure sizes of 10nm are possible, with estimates suggesting structure sizes
- will reach these levels around 2015.’

References

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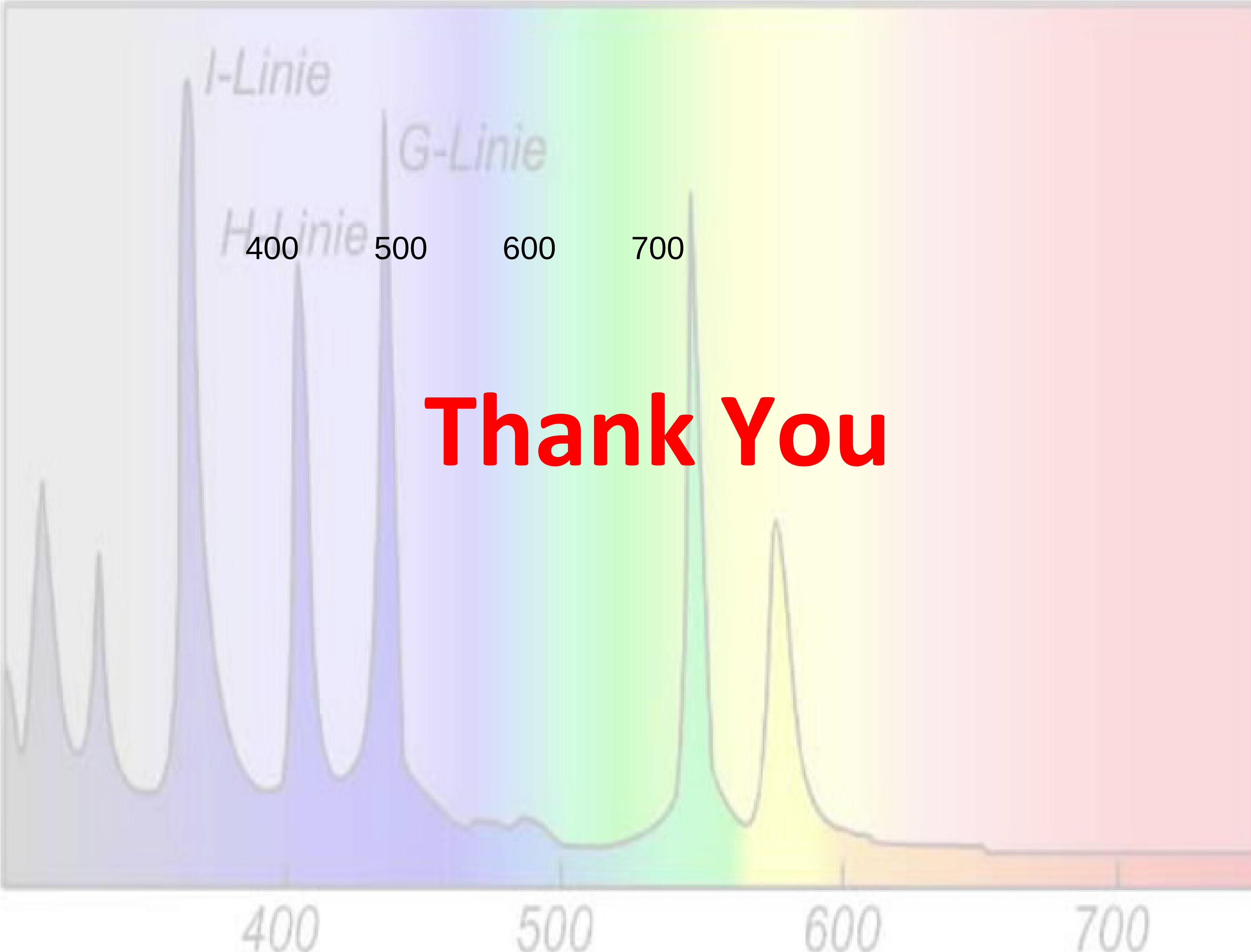
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