Extreme Ultraviolet Light Sources Supporting Next-Generation Lithography

Sam Gunnell
EUV Product Manager

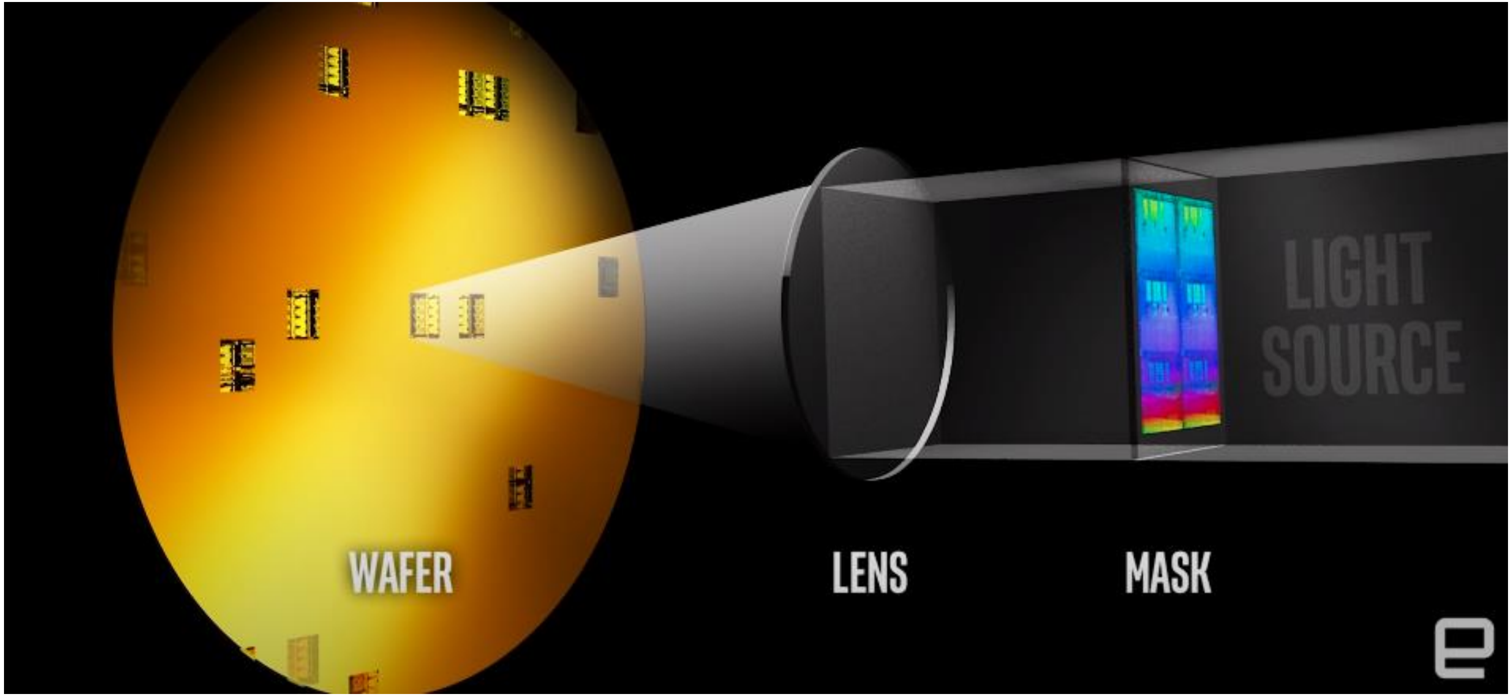
Overview

- Introduction
  - What is Photolithography?
  - Moore's Law
  - Current State
  - Why EUV?
- Key challenges
  - EUV Mask
  - EUV Photoresist
- EUV Sources for Research & Metrology
- Applications for EQ-10 Electrodeless Z-Pinch EUV Source

What is Photolithography?

Photolithography is a process used in semiconductor device fabrication to pattern an integrated circuit onto a silicon wafer. It uses light to transfer a geometric pattern from a photomask to a photosensitive chemical photoresist on the substrate.

A series of chemical treatments then either etches the exposure pattern into the material or enables deposition of a new material in the desired pattern upon the material underneath the photoresist.



Source: Engadget, 2020

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Moore’s Law…

…States that transistor density of an integrated circuit doubles approximately every 24 months

…Represents an observation on the continuous improvement of production methods, particularly photolithography

Resolution Enhancements Drive Moore's Law

$$CD = k_1 \times \frac{\lambda}{NA}$$

CD … critical dimension

k_1… process factor

λ … wavelength

NA … numerical aperture

Current state of Photolithography

Source: Zeiss, 2020

- 193nm exposure wavelength
- ArF laser source
- Transmissive mask
- Transmissive projection optics

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193nm Lithography at the Limit

The current state of the art has reached its physical limits. The structures on a chip are now many times smaller than the wavelength of light used to make them, and any more progress will require a big change.

Why EUV?

…Extreme Ultraviolet Lithography reduces the exposure wavelength from 193nm to 13.5nm, resulting in smaller critical dimensions in fewer process steps

$$\downarrow CD = k_1 \times \frac{\lambda \downarrow}{NA}$$

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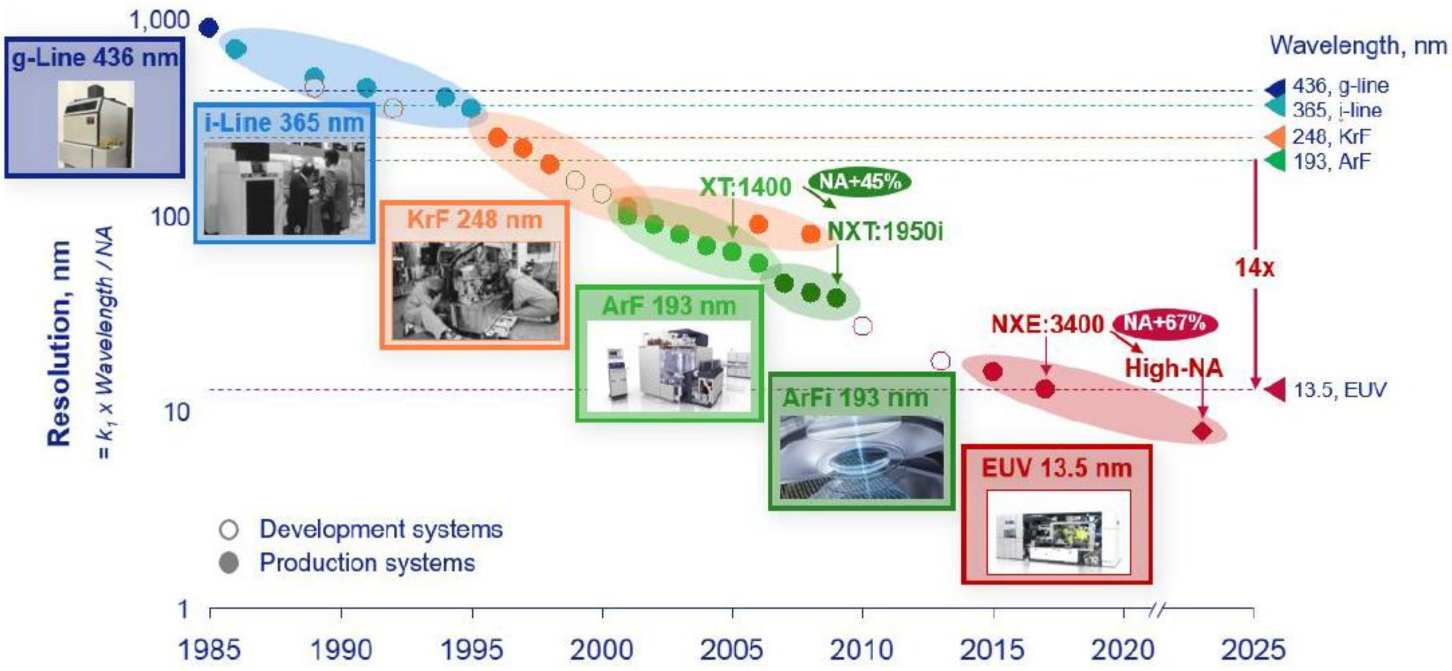
Lithography Timeline



Source: Zeiss, 2018

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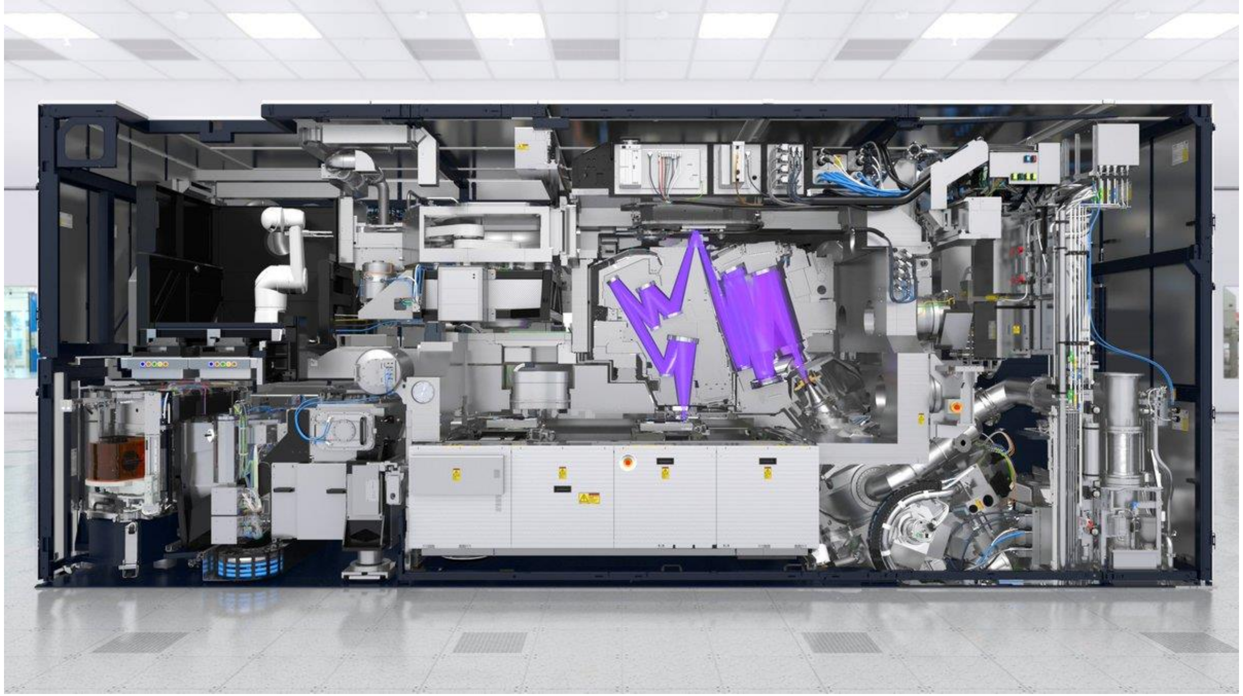
14x Wavelength Reduction…

…Introduces significant challenges

- Light-material interactions
- Defect control and metrology

The EUV Scanner



Source: ASML, Public, 2018

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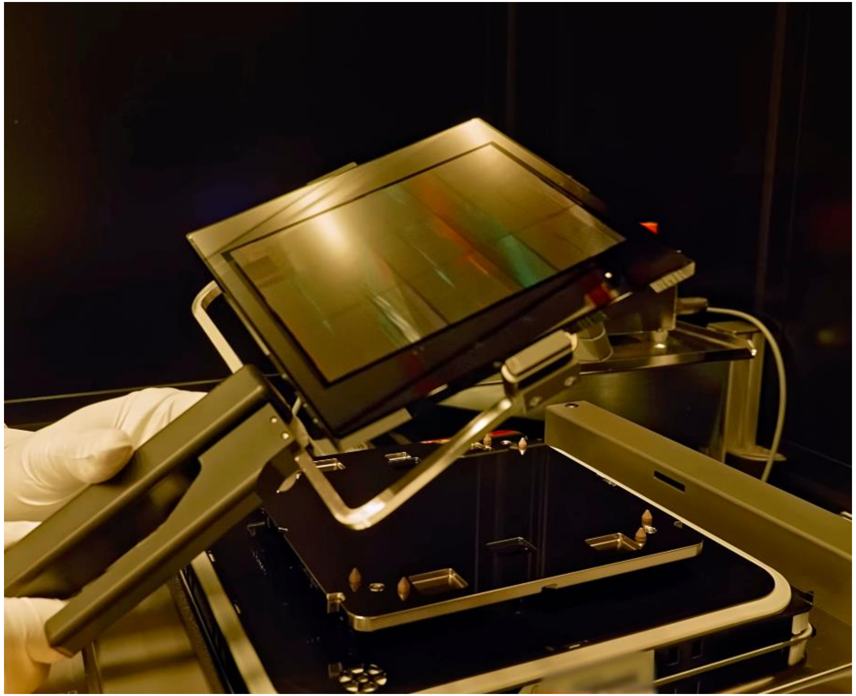
Key Challenge: EUV Mask



Source: Engadget, 2020

- The EUV Mask is a patterned multilayer mirror
- The mask must be perfect to ensure defects are not transferred to the wafer, affecting yields
- Multiple inspection steps required throughout the manufacture and lifetime of the mask
- **Only EUV inspection can “see” all defects**

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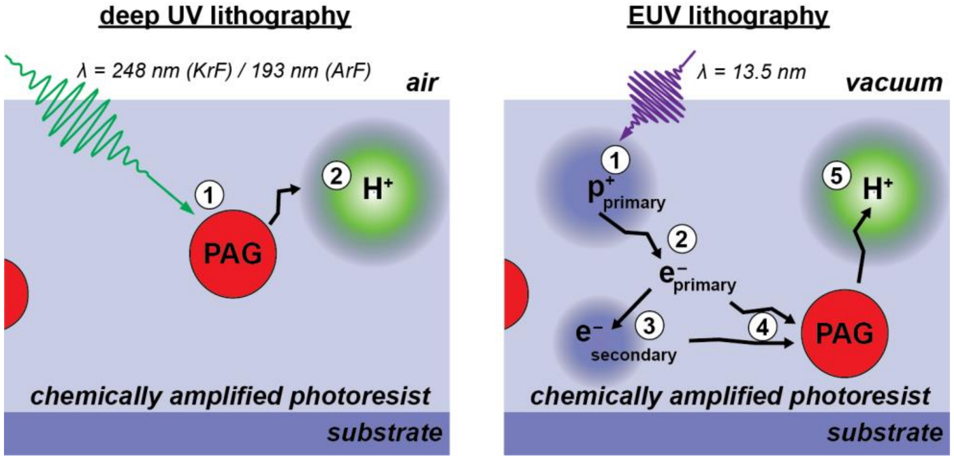
Key Challenge: EUV Photoresist

- Photoacid Generation in EUV lithography is significantly different from DUV
- New chemistries required
- **Candidate resists must be studied under EUV illumination before use in manufacturing**



Source: AMOLF, 2018

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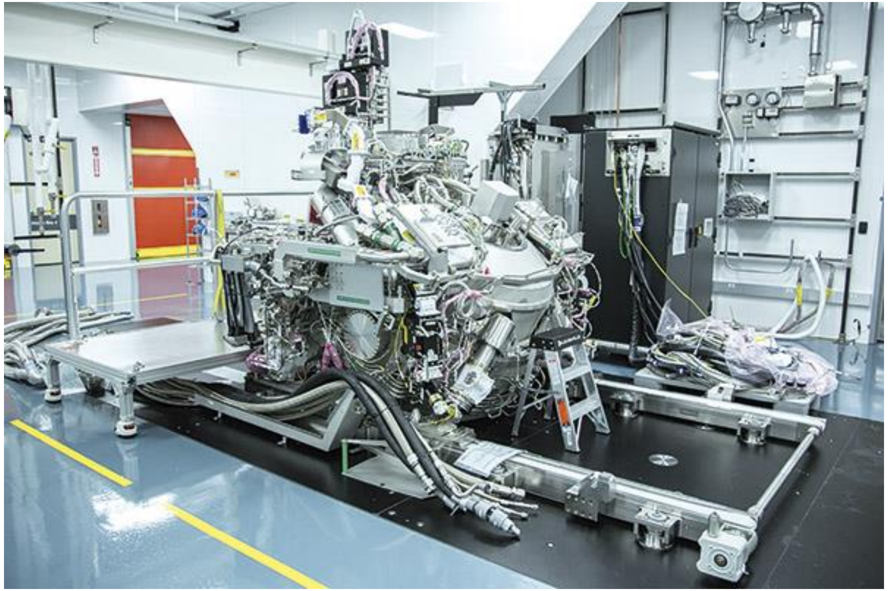
EUVL HVM Roadmap

Requires access to EUV photons for fundamental research and metrology/inspection

Why not use the scanner source?



Source: ASML, 2018

- Massive footprint
- Driven by >20kW CO2 laser
- Prohibitively expensive to own and operate
- 250W EUV at intermediate focus
- **Not suitable for research or metrology applications**

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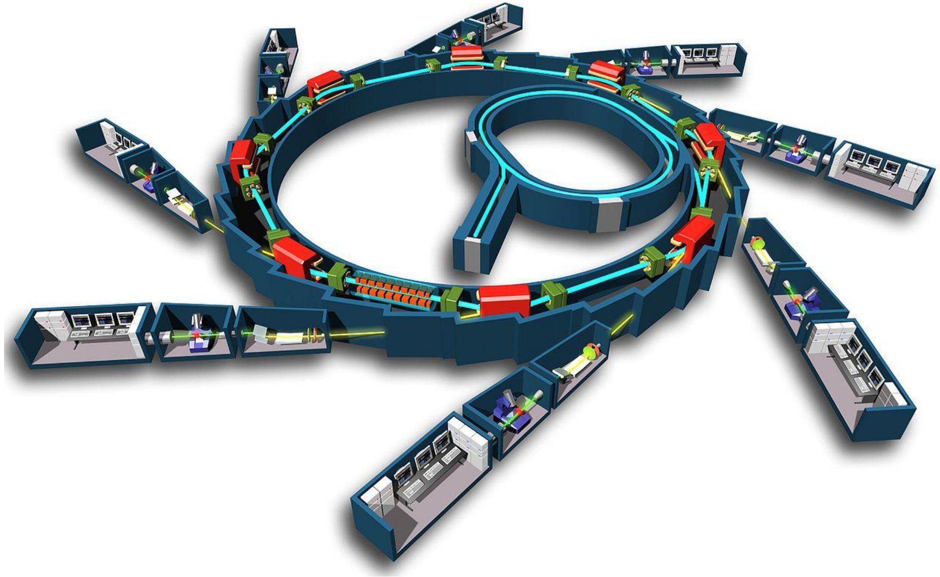
Alternative sources

Researchers and toolmakers need reliable, cost-effective, accessible sources of EUV photons

Synchrotron Radiation

- Used for fundamental research, especially for resist patterning studies and metrology development
- Many examples of industry collaboration with government labs and academic institutions
- Limited number of synchrotron facilities
- Limited number of beamlines dedicated to EUV research topics



Source: Synchrotron Soleil, 2005

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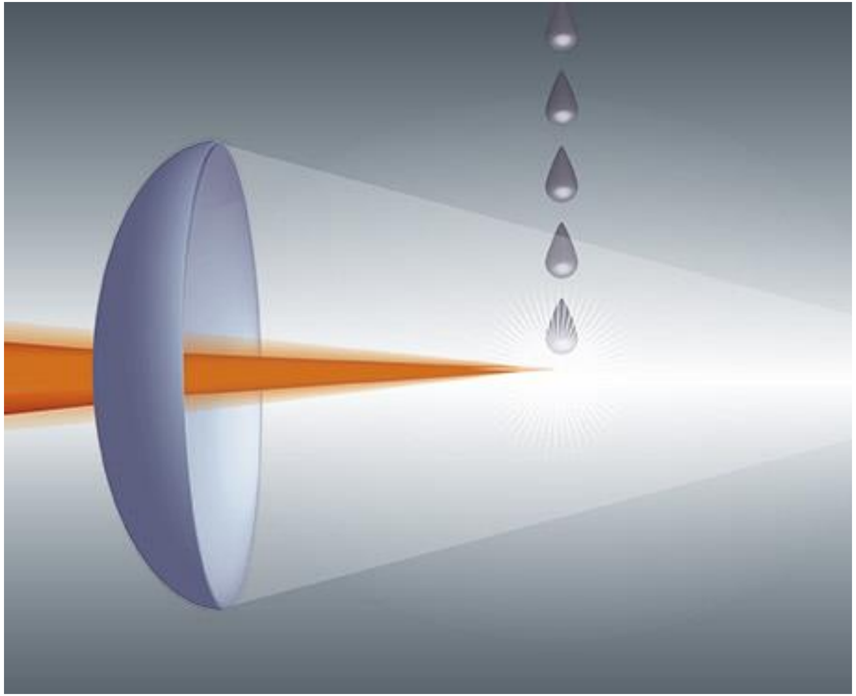
Laser Produced Plasma Sources (LPP)



Source: Bits & Chips, 2017

- Same concept as scanner source, but on smaller scale
- High brightness (~100W/mm^2 sr) required for high-throughput patterned mask inspection in the fab
- Complex debris mitigation strategies required
- High cost of ownership for materials research and certain mask inspection applications during mask manufacturing process

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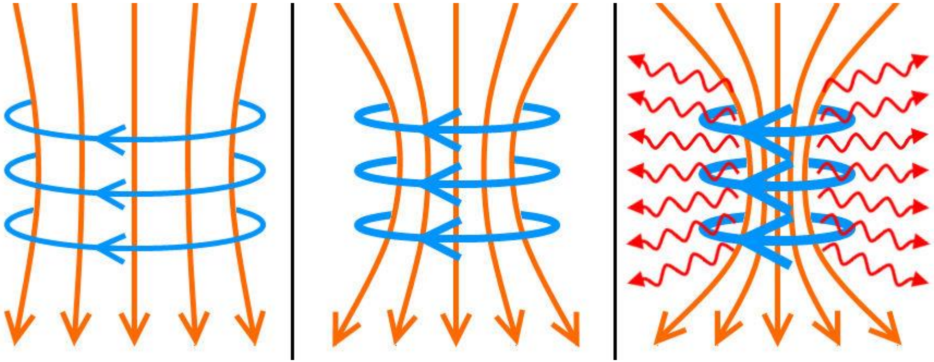
Discharge Produced Plasma Sources (DPP)

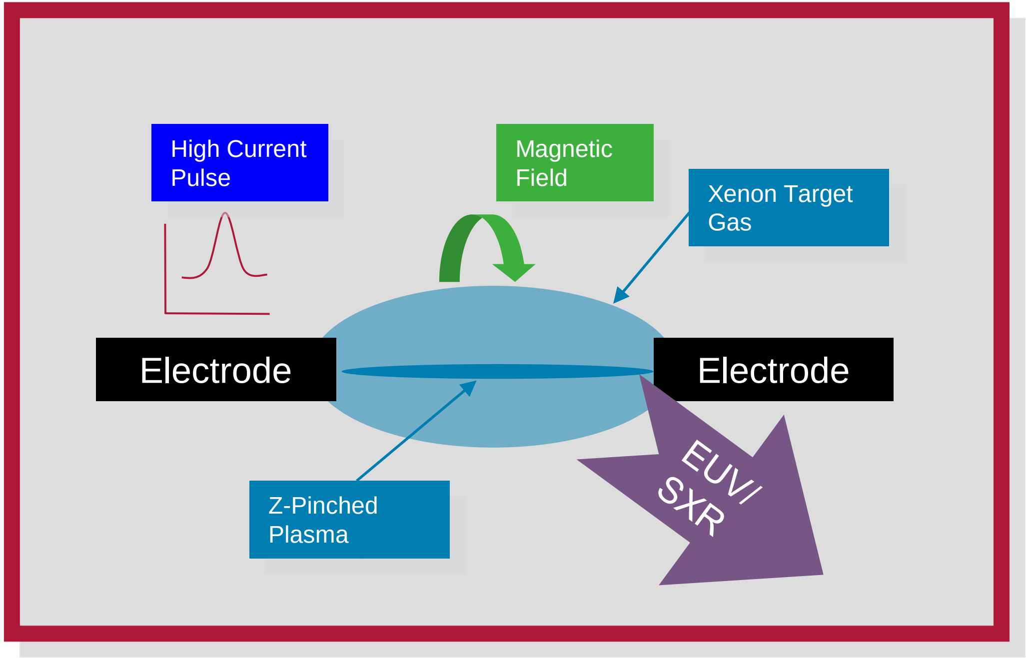
EUV-emitting Z-pinch generated by electrical discharge in a target gas (Typically Xenon)

Z-pinch: uses an electrical current in the plasma to generate a magnetic field that compresses it



Source: Everythingiselectric.com, 2015

Electrode-based DPP



- EUV generation in Xenon gas by high current discharge across electrodes
- Suitable for materials applications such as photoresist R&D
- Electrodes experience high current densities and are in direct contact with plasma
- Debris, stability, and spatial variation of the EUV emitting area are not suitable for metrology applications in production environments

EQ-10 Electrodeless Z-Pinch EUV™ Source

- Unique inductive electrodeless DPP EUV source
- Pulse-to-pulse stability, spatial stability, and brightness suitable for certain metrology applications
- Ease of use and reliability suitable for photoresist R&D at Tier 1 semiconductor companies
- 13.5nm ±1% EUV Operation (Xenon)
  - Up to 20W into 2π steradians
  - Brightness 8W/mm^2 sr
  - Source size <500um diameter FWHM
  - Frequency up to 2.5 kHz

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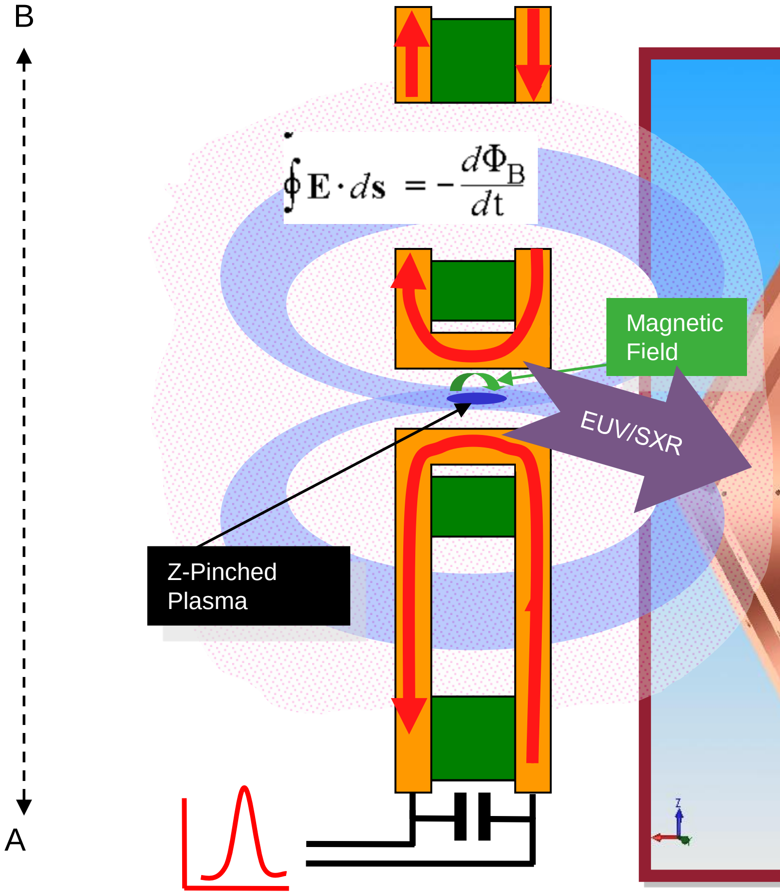
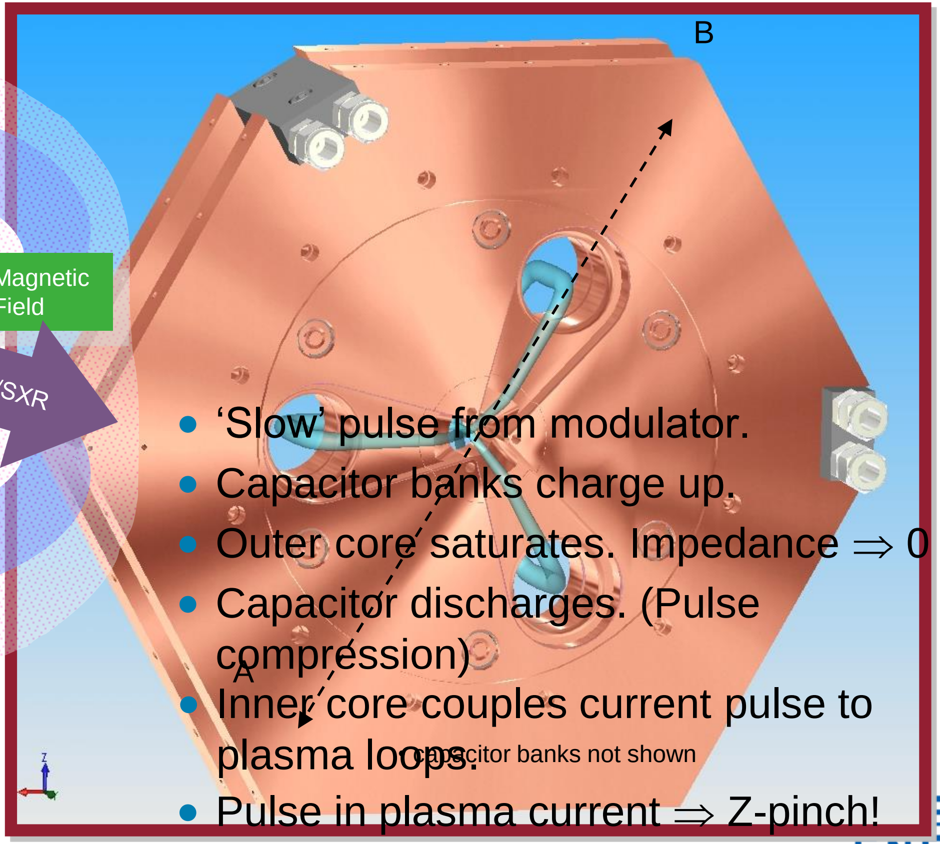
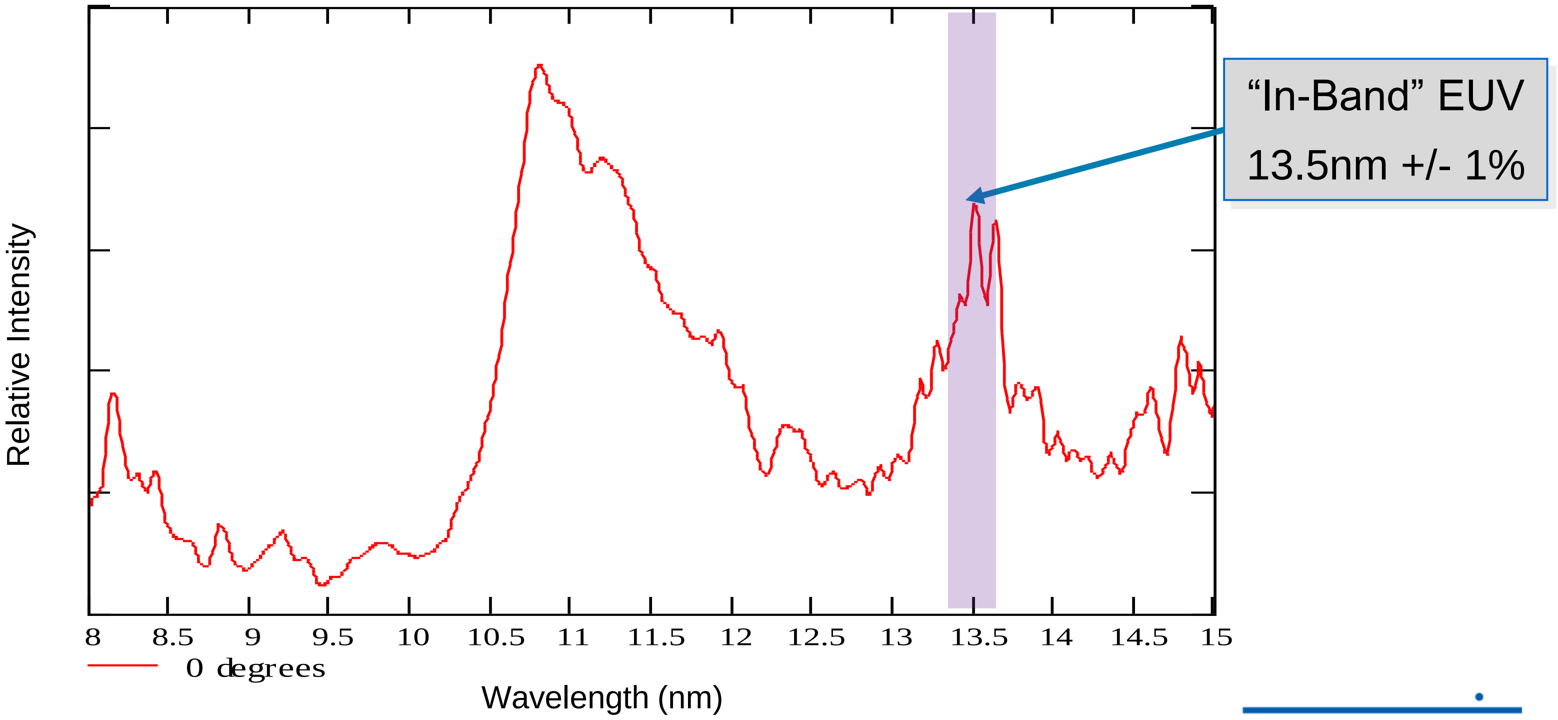
Principle of Operation





- ‘Slow’ pulse from modulator.
- Capacitor banks charge up.
- Outer core saturates. Impedance $\Rightarrow$ 0
- Capacitor discharges. (Pulse compression)
- Inner core couples current pulse to plasma loops.
- Pulse in plasma current $\Rightarrow$ Z-pinch!

Typical Spectrum



1.2kHz 325V, 80mTorr Xe, corrected for Zr/polyimide filter, on-axis

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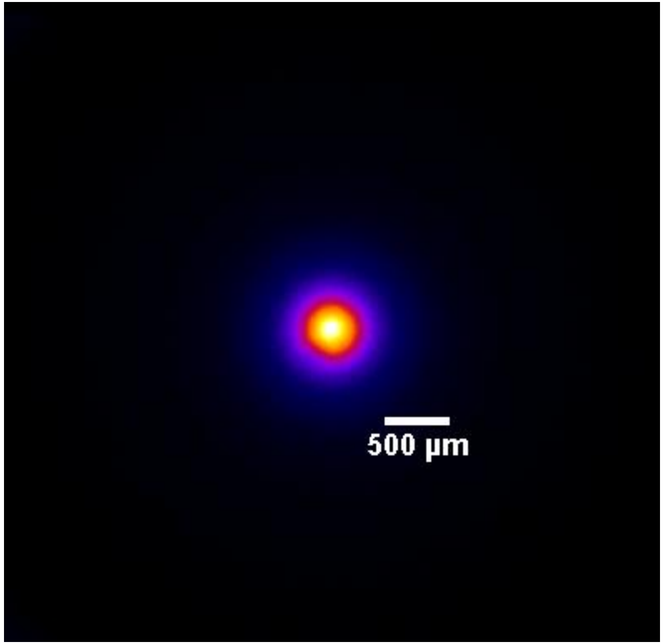
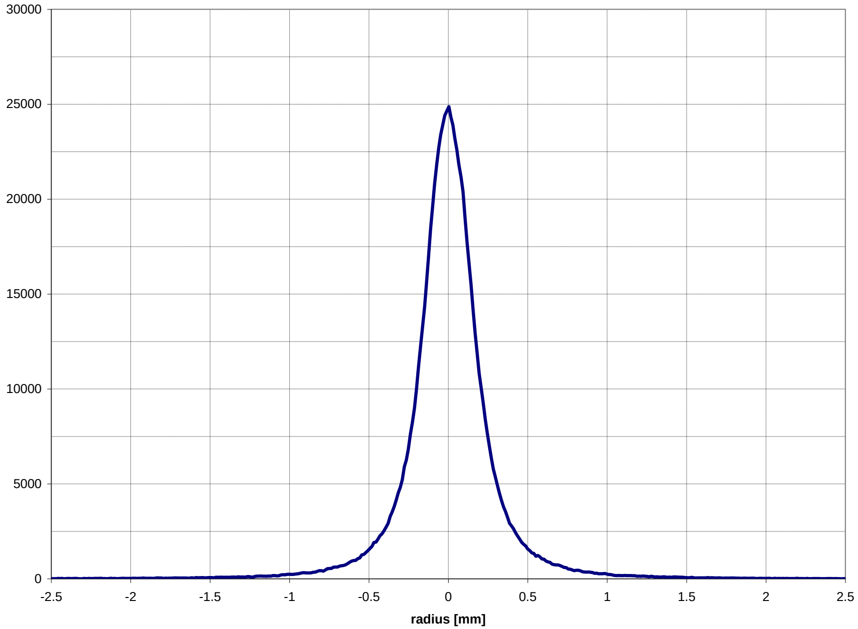
EQ-10 in-band EUV Plasma Image





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Applications

- Metrology
  - Actinic Mask Blank Inspection
  - Aerial Imaging for Patterned Mask Qualification
- Materials
  - Photoresist

Actinic Mask Blank Inspection

- Essential tool for EUV HVM infrastructure
- Enables high-sensitivity detection of printable defects inside Mo/Si multilayer

Aerial Imaging for Patterned Mask Qualification

- EQ-10 allows emulation of scanner conditions for qualifying patterned masks
- Masks can be optimized and repaired before use in scanner

Photoresist R&D Example

- Customized beamline and wafer chamber
- Reliable source of EUV photons for photoresist exposure and outgassing studies
- Exposure times depend on beamline, optics and resist under study
- Example system:
  – 20 mJ resist exposure time of ~30 seconds
    i.e. 40 mJ/min

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Open Frame Resist Exposure Tool

EQ-10HP Remote Source

Motorized Rotary Feedthrough / Wafer Holder

Interchangeable 45 degree mirror

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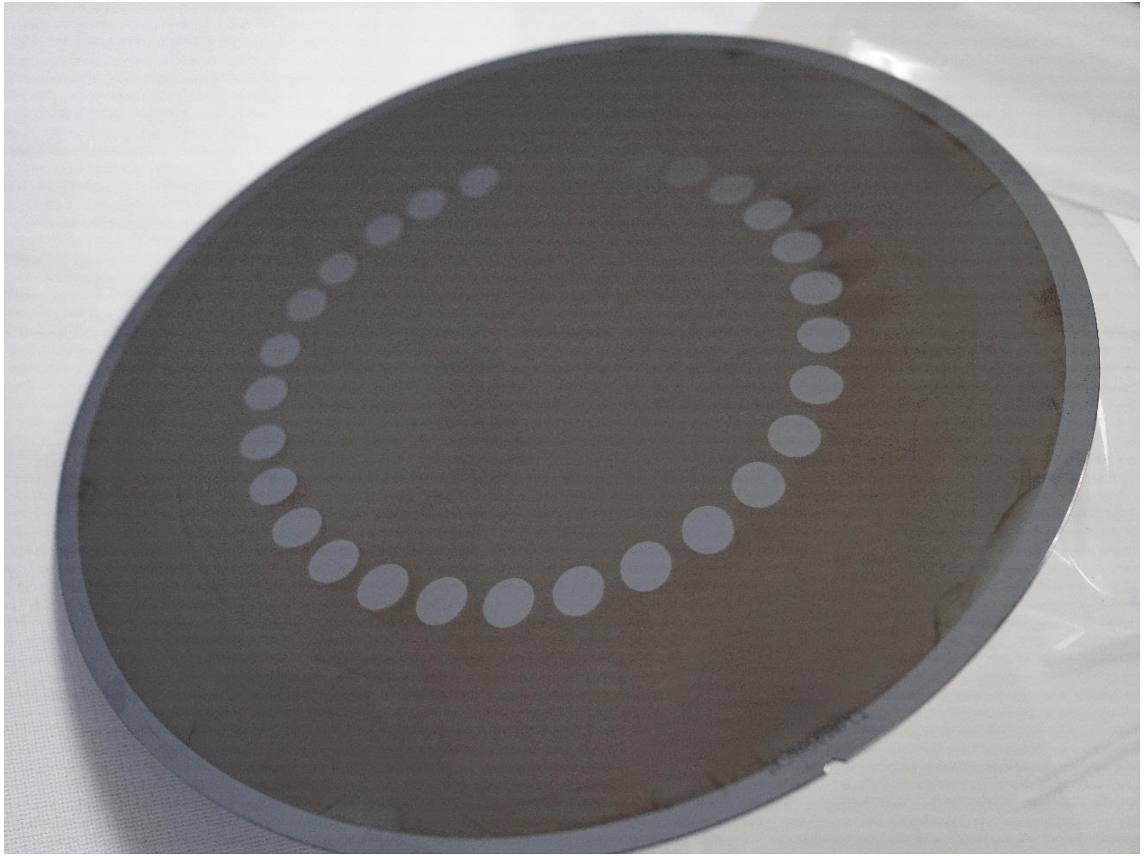
Exposed Wafer



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Comparison of Alternative Sources

	EQ-10 (electrodeless)	DPP (electrodes)	LPP
Brightness	✓	✓	✓✓✓
Cleanliness	✓✓	✓	✓
Stability	✓✓	✓	✓✓
Reliability	✓✓✓	✓✓	✓✓✓
Cost	$$$	$$	$$$$
Applications	Mask Blank Inspection Patterned Mask Qualification Materials R&D	Metrology Research Materials R&D	Patterned Mask Inspection

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Summary

- EUV Lithography has entered high volume manufacturing for certain layers, but 193nm multi-patterning is still the primary production method
- Researchers and metrologists continue to need cost-effective sources of EUV photons to address EUV HVM roadmap and infrastructure requirements
- Each type of EUV source has its own advantages and disadvantages: there is no one-size-fits all solution
- The market for alternative EUV light sources is small, but rich with unique and highly differentiated technologies
- The Energetiq EQ-10 Electrodeless Z-Pinch EUV Source is a reliable and stable source of photons for EUV metrology and infrastructure development
- >30 systems sold and large installed base with consistent operation over 15 years

Thank you!

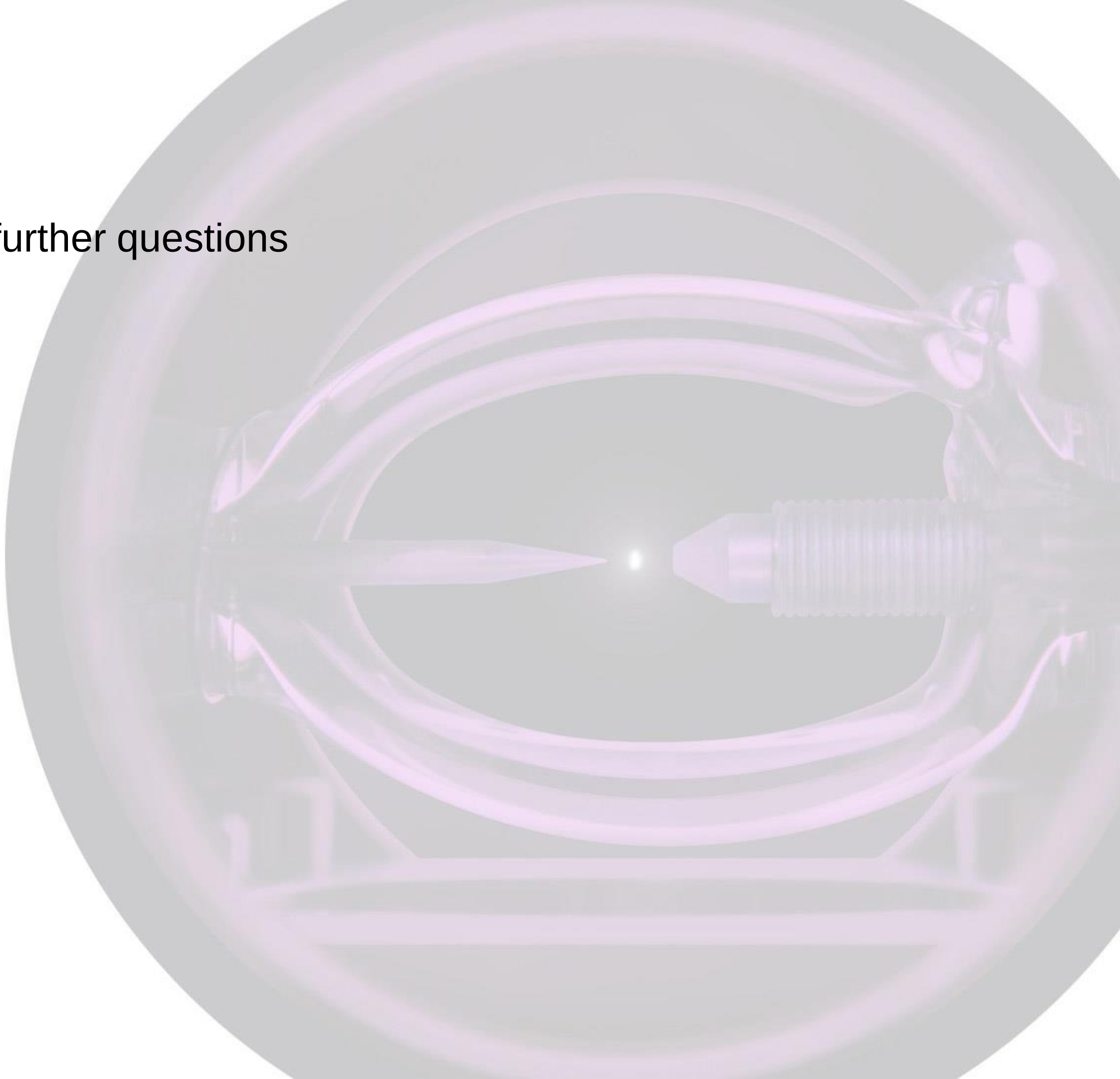
And please feel free to reach out with further questions

Contact Information:

Sam Gunnell

EUV Product Manager

sgunnell@energetiq.com



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2	Emerging Applications - LiDAR & Flow Cytometry	2	2-Jun-20	4-Jun-20
3	Understanding Spectrometer	2	9-Jun-20	11-Jun-20
1 Weeks Break				
4	Specialty Products – Introduction to Light Sources & X-Ray	2	23-Jun-20	25-Jun-20
5	Introduction to Image Sensors	2	30-Jun-20	02-Jul-20
1 Weeks Break				
6	Specialty Products – Laser Driven Light Sources	2	14-Jul-20	16-Jul-20
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