An Encounter with Light Generating Devices

Eric Mesa

Hamamatsu Corporation

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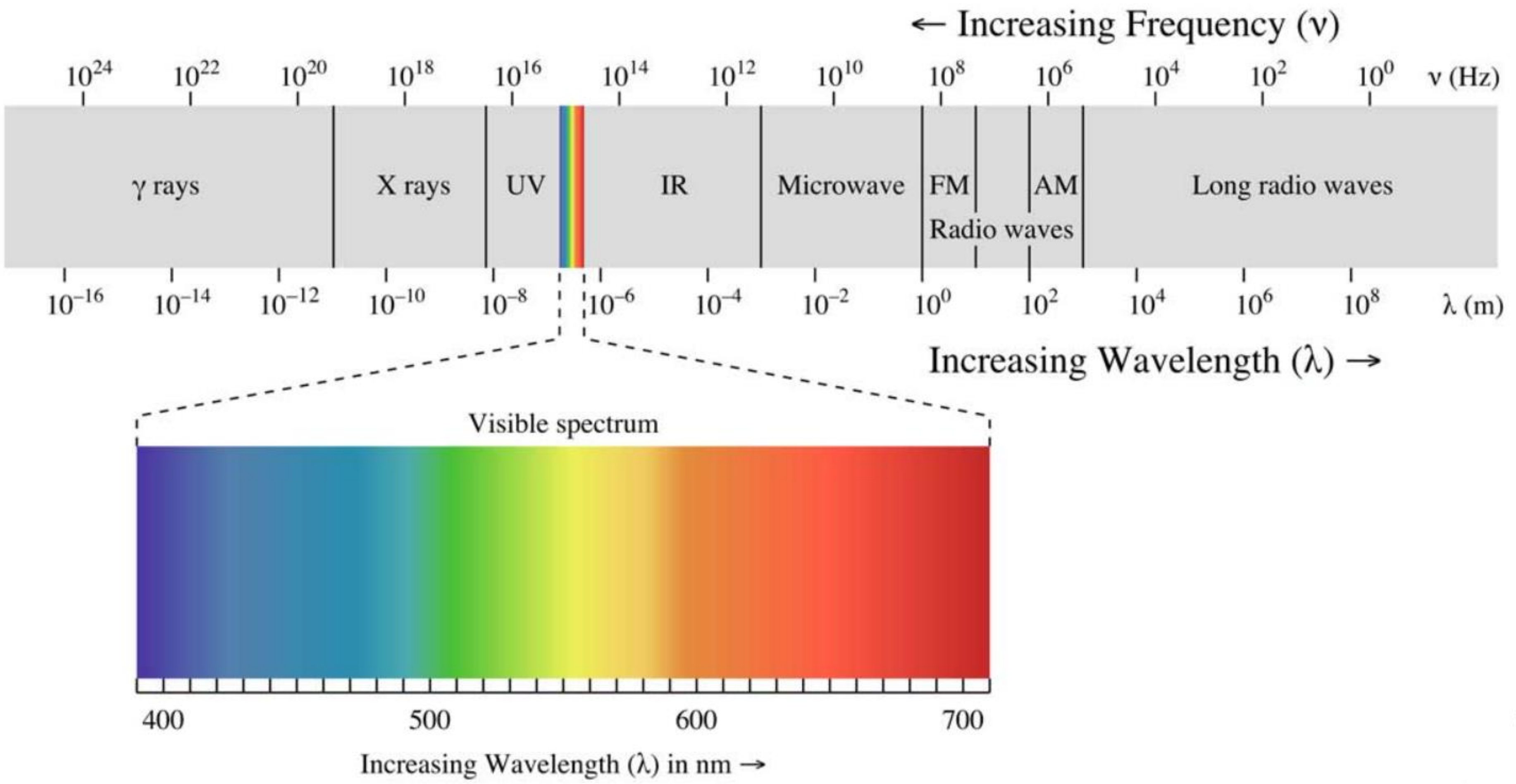
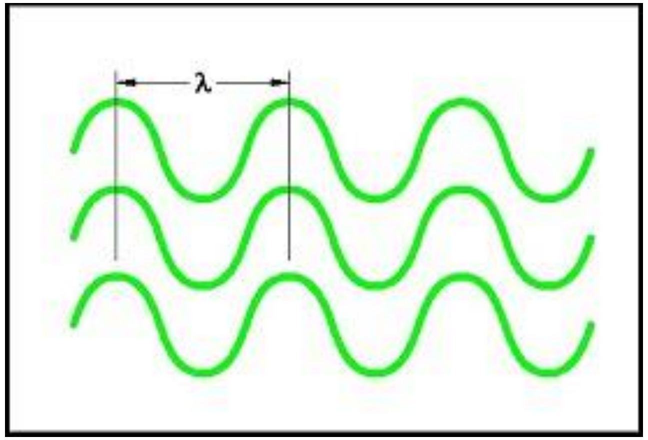
Outline

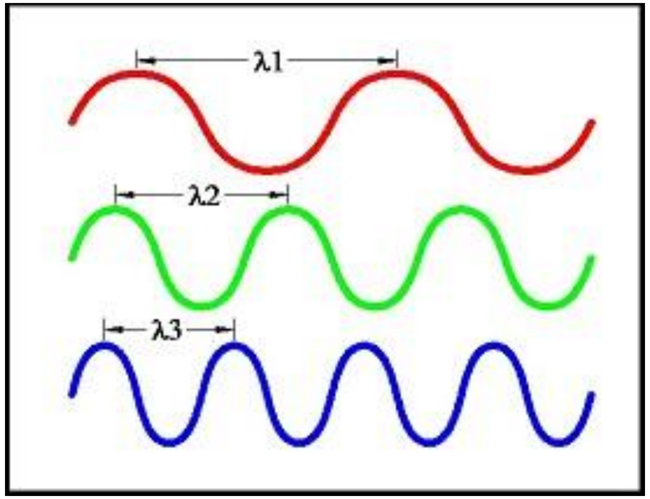
- Light Source Terminology
- Thermal/Black Body Sources
- Discharge Sources
- Specialty Sources
- Light Source Summary/Conclusion

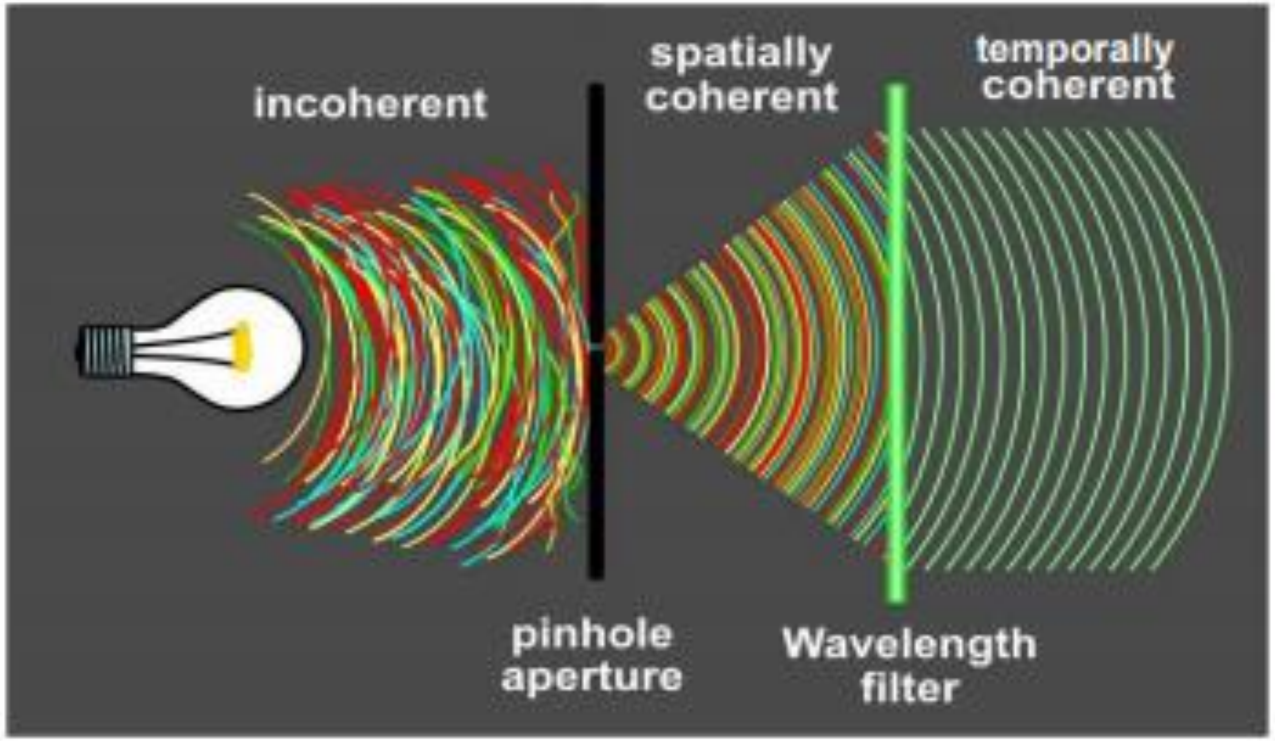
Wavelength– (λ)



Coherence (temporal, spatial)







Light Source Terminology

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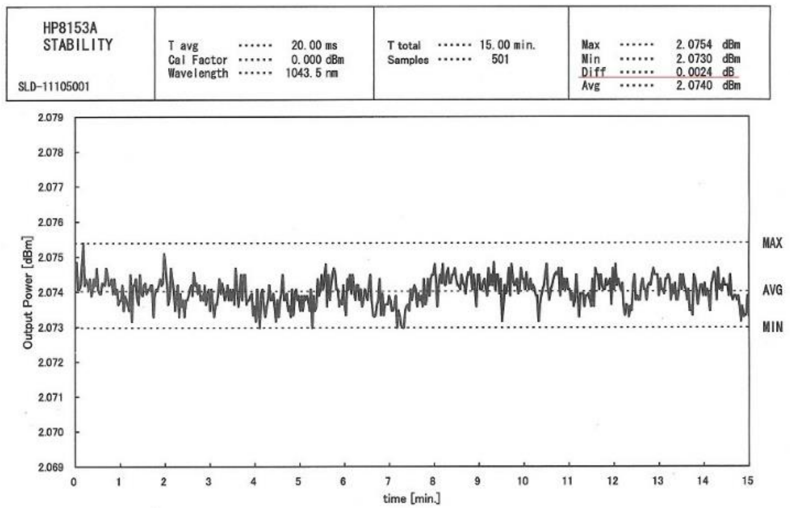
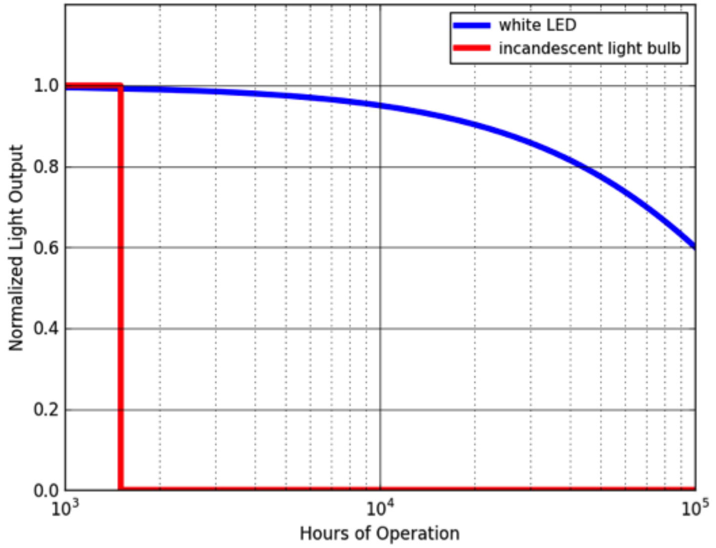
Stability

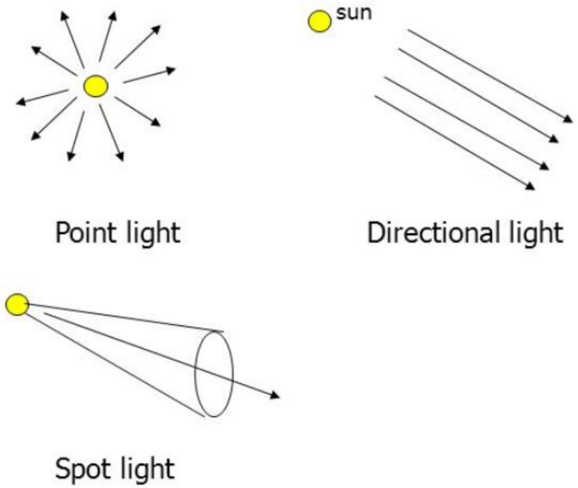


15 Minutes Stability after WarmUp

Lifetime – (h)

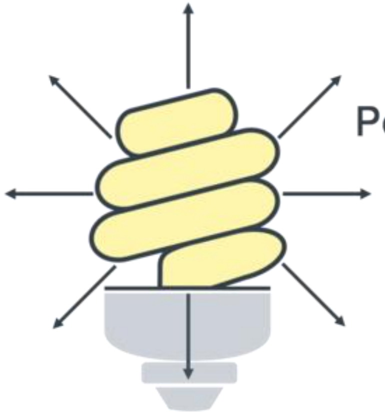


Emission

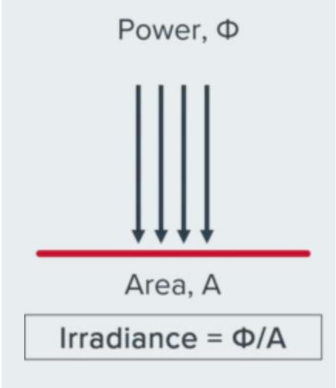


Light Source Terminology

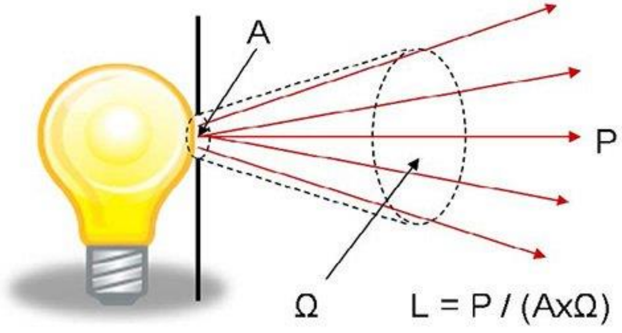
Radiant Flux/Power – (W).



Irradiance – (W/m2).

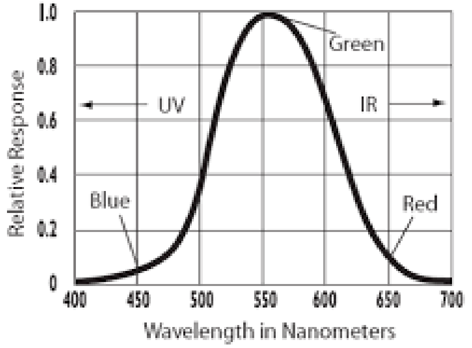


Spectral Radiance (brightness) – (W/m2-sr)



Luminous Flux – (lm)

Luminous flux = Radiant power (watts) x 683 lumens/watt x luminous efficacy



CIE phototopic response curve.

Thermal Light Sources

Thermal Light Sources – Principle of Operation

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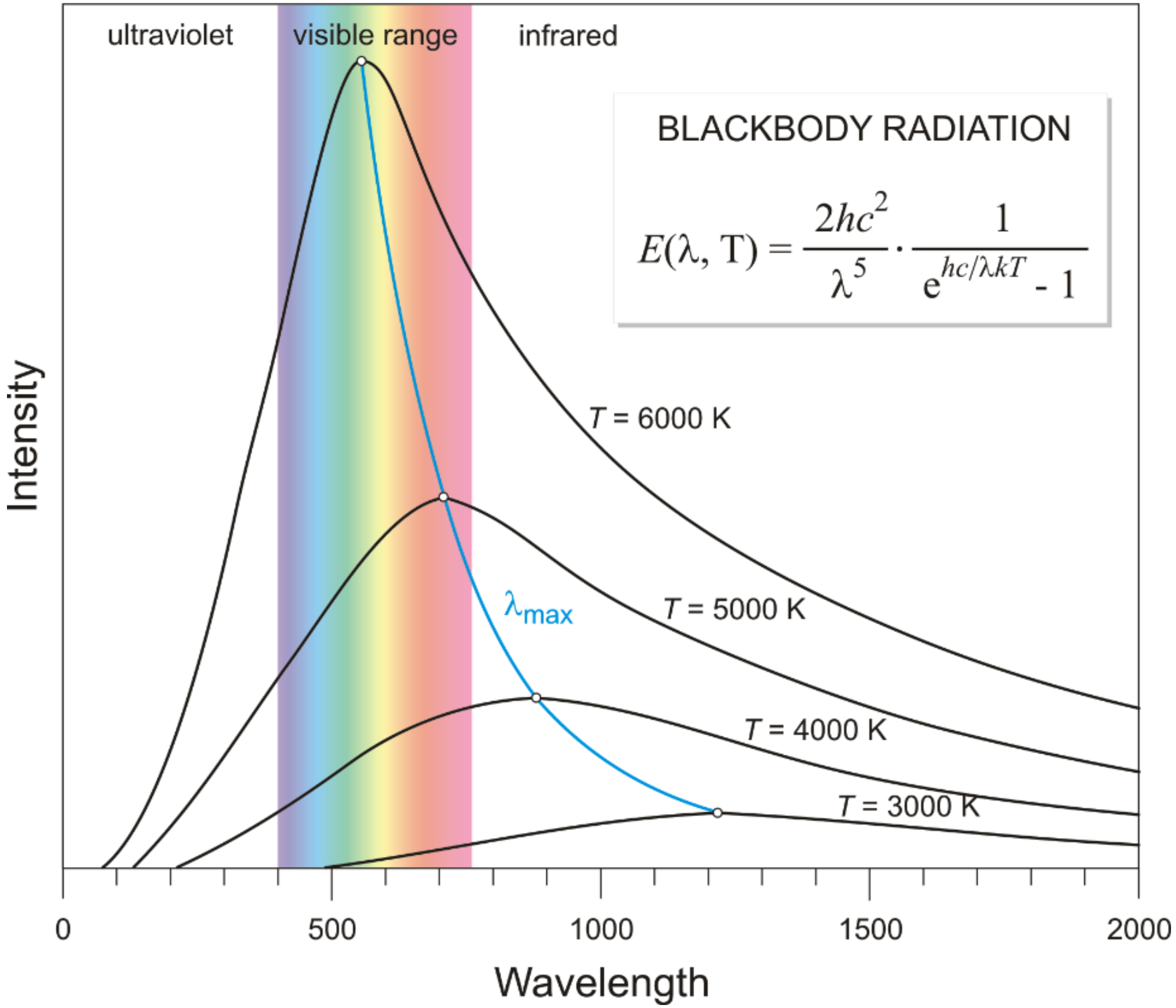
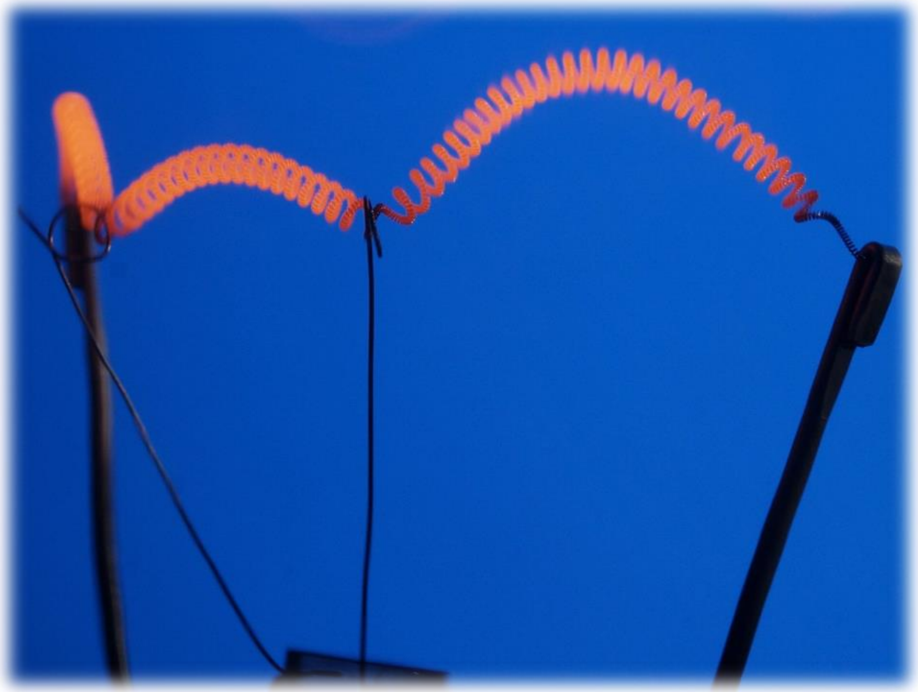
- Black body radiation from a heated filament
- Filament temperature – black body output
- No source is a perfect black body
- Temperature calibrations



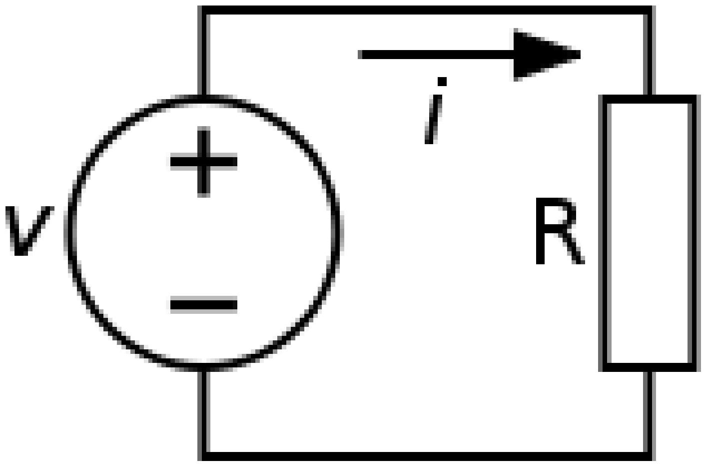
Thermal Light Sources – Optical Characteristics and Efficiency

- Smooth optical spectrum
- Incoherent light
- Low efficiency
- Low UV Output
- Typ. luminous efficiency on the order of 15 lm/W
- Lifetimes on the order of 1000s of hours
- Relatively low cost



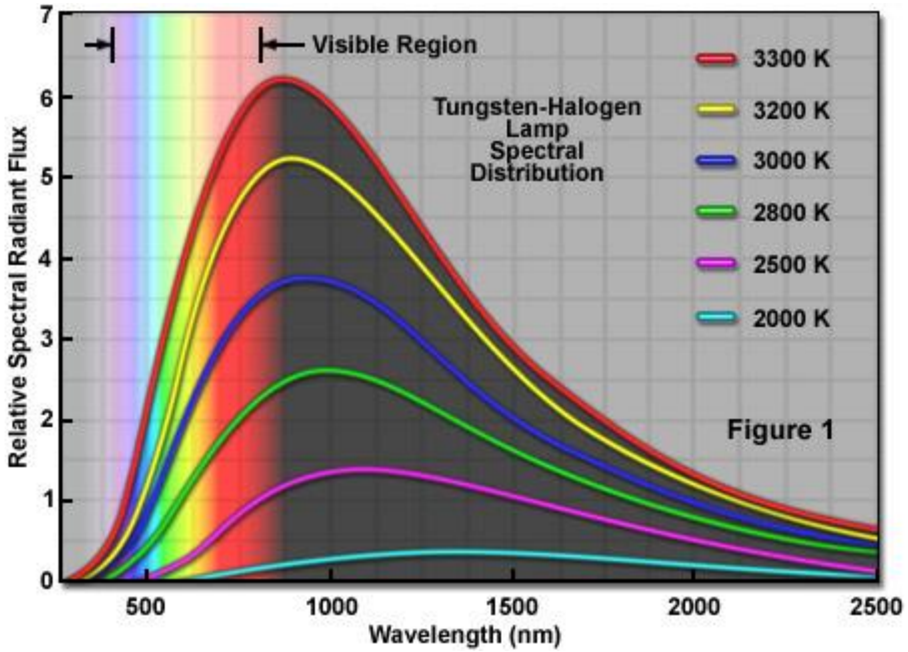
Thermal Light Sources – Electrical Characteristics

- Thermal light sources are purely resistive loads. Fairly simple for operation
- Electrical resistance increases with higher temperatures
- Resistance is lower during start-up which results in a high initial warm-up current
- Thermal light sources are not suited for fast switching or fast pulsed operation. Pulsing will degrade the filament faster



Types of Thermal Light Sources –Tungsten

- Electrically heated filaments are made from Tungsten.
- **Tungsten-Halogen**, bulb filled with a Halogen gas mixture
- Low efficiency
- Widely used for general purpose lighting, but also scientific applications in broadband spectroscopy, microscopy, and as well as general imaging



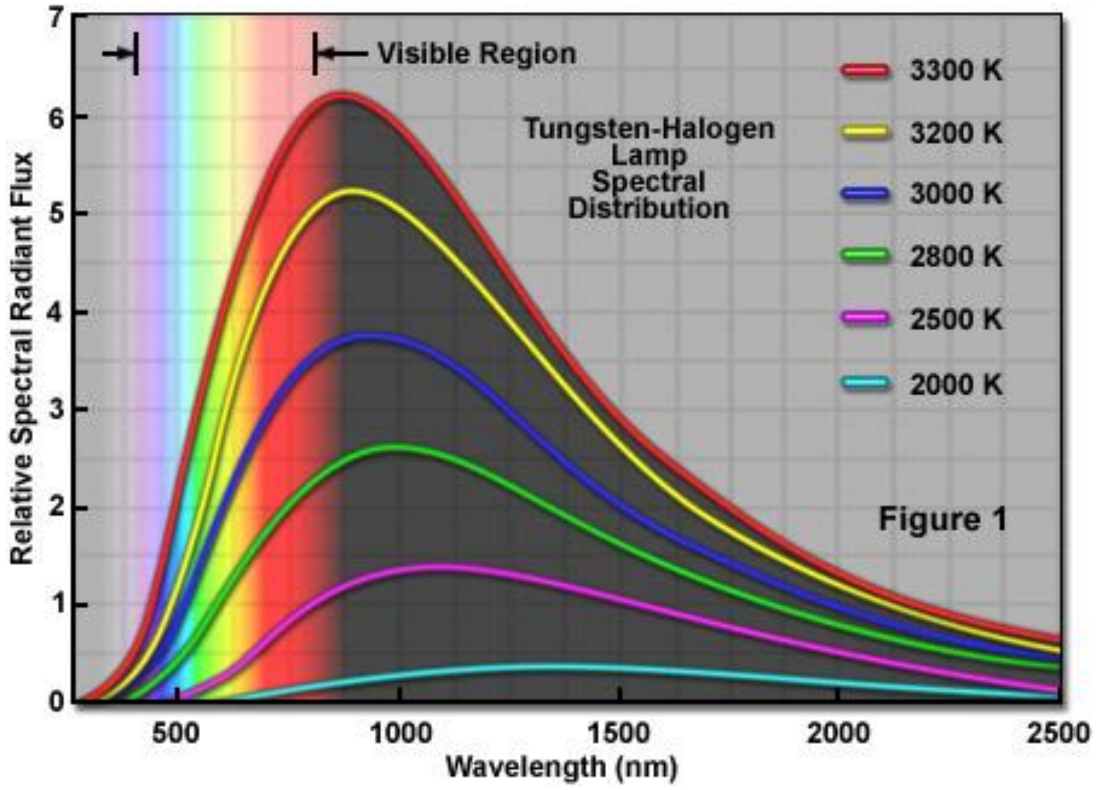
Types of Thermal Light Sources – Tungsten

Feature	Application Benefit
High Operating Temperature	➢ **More light in visible spectrum**
Resistive Load	➢ **Simple operating circuitry**
Smooth Black Body Radiation Spectrum	➢ No sharp peaks or dips
Low long term output decay (Tungsten-Halogen)	➢ Consistent output over time

Types of Thermal Light Sources – Tungsten

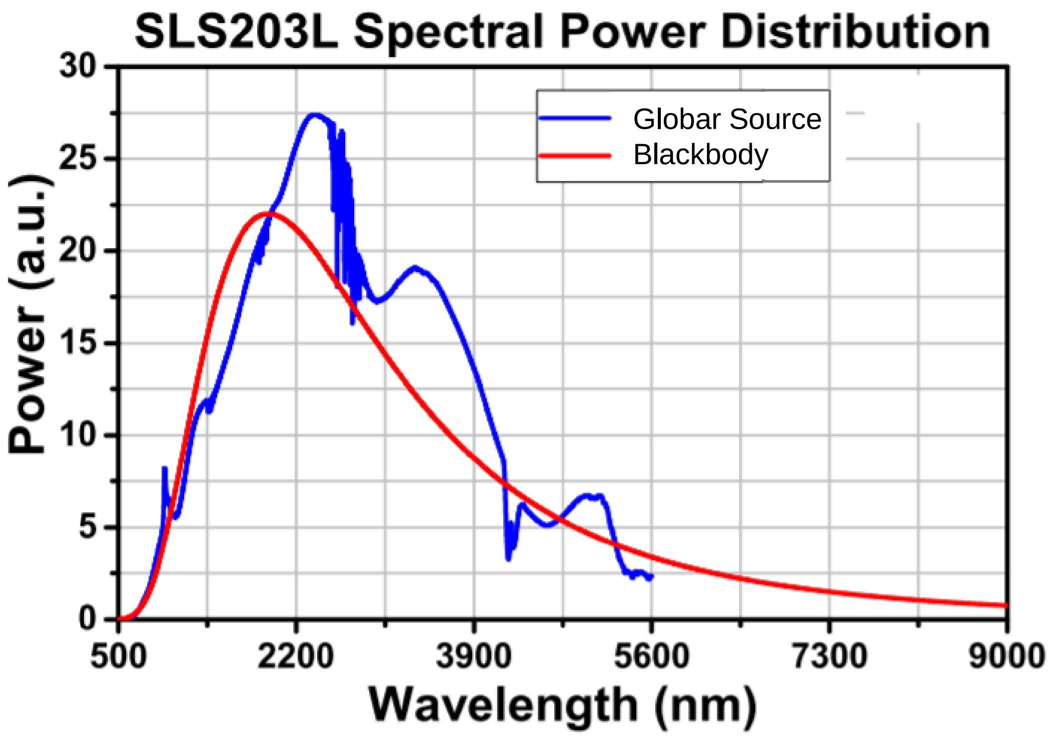
Microscope Illumination

- Default Illumination source for most teaching/research level microscopes
- High Intensity, broadband, visible light
- Good for long term experiments due to stable temporal and spatial output fluctuation



Types of Thermal Light Sources - Globar

- The **Globar** source uses a Silicon Carbide rod as a heating element, instead of Tungsten
- Lower black body temperature shifts the peak emission into IR.
- Commonly used as broadband IR source for Infrared spectroscopy



Types of Thermal Light Sources – Globar

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Feature	Application Benefit
Lower Relative Operating Temp	➢ **Peak output is in NIR**
Large relative filament size	➢ **Larger area of emission**
No pressurized bulb	➢ Safer handling
Low long term output decay	➢ Consistent output over time
Smooth Black Body Radiation Spectrum	➢ No sharp peaks or dips

Figure 2 A Silicon Carbide Globar

Types of Thermal Light Sources – Globar

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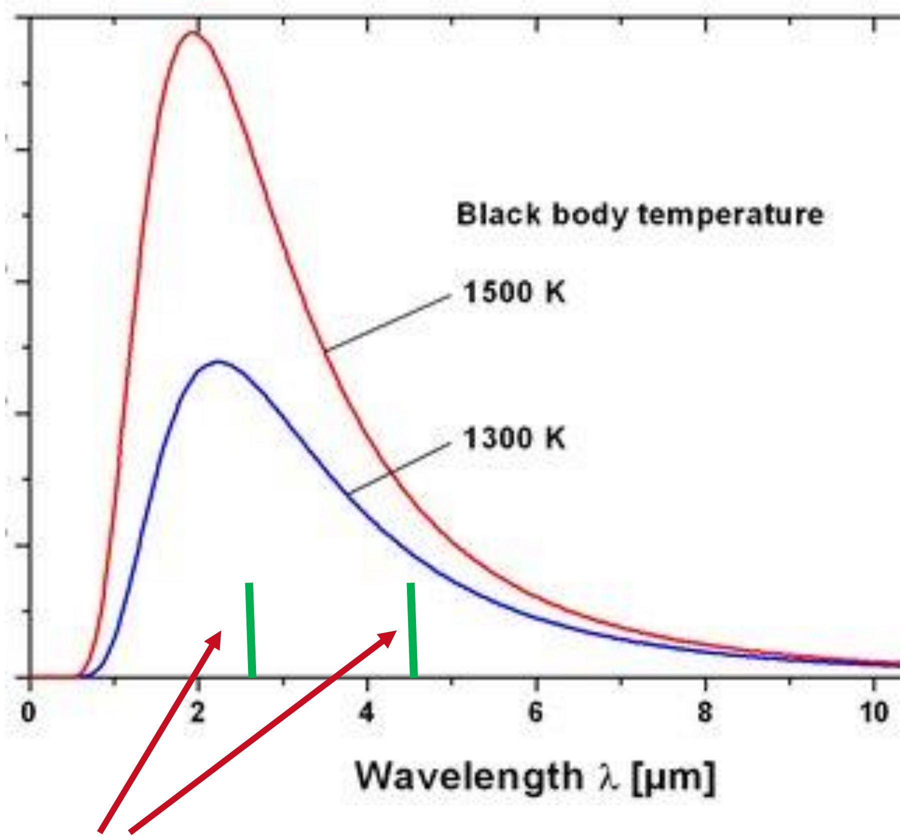
FTIR Spectroscopy

- FTIR spectroscopy identifies organic (in some cases inorganic) material by measuring absorption of IR light
- Key IR absorption bands identify the specific molecular components and structures

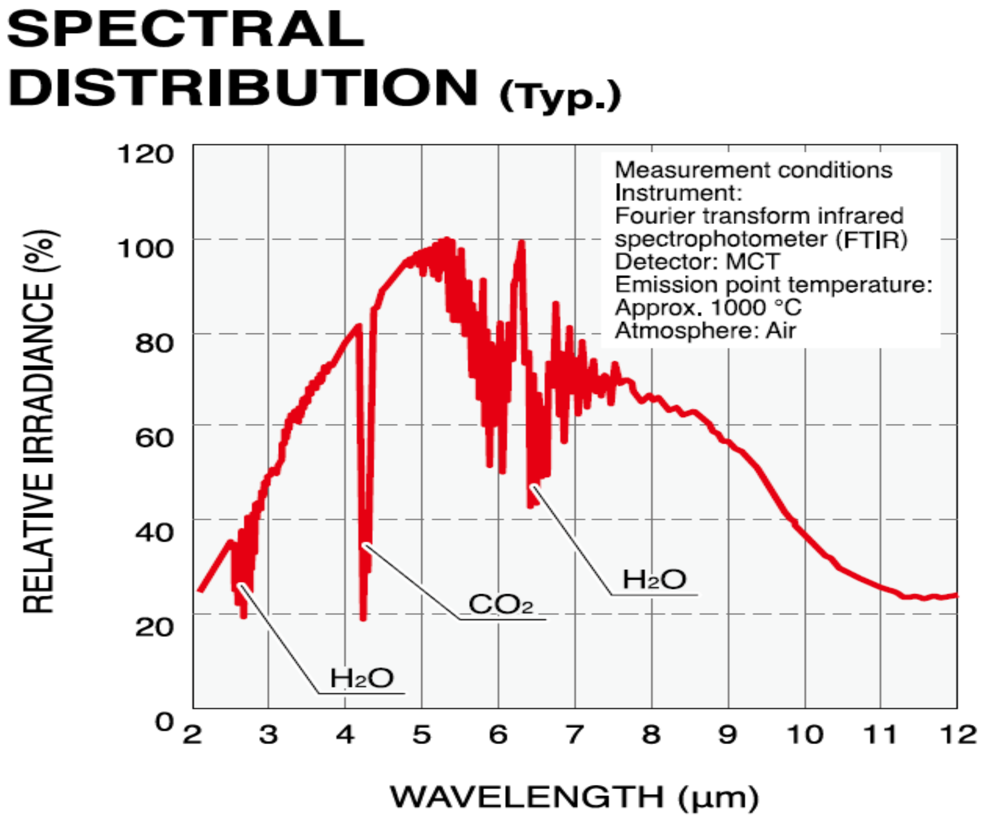
- Globars have broad, smooth, continuous spectrum which provides coverage across various absorption bands
- Information collected from multiple absorption bands provides higher measurement accuracy.



CO2 absorption bands

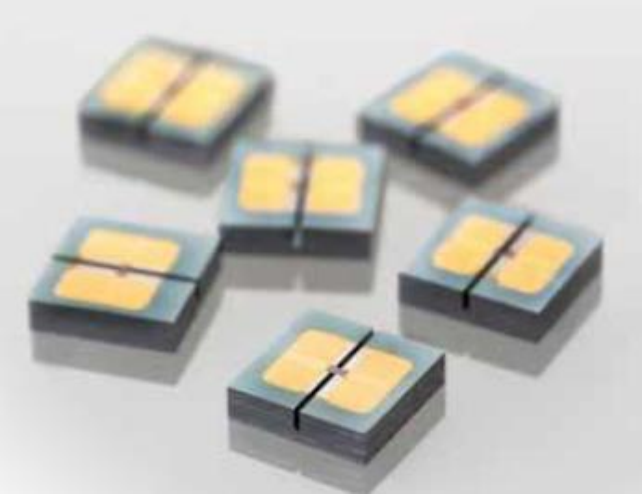
Types of Thermal Light Sources - Graphene

- Graphene emitters are a compact IR thermal light source
- Smaller, brighter
- Operates at 1200K
- Fast pulsing operation, 3kHz
- Vacuum confined filament



Types of Thermal Light Sources – Graphene

Feature	Application Benefit
Small Thermal Capacity	➢ **Fast Pulsing Operation**
Small form factor	➢ **Integration into portable systems**
Smooth Black Body Radiation Spectrum	➢ No sharp peaks or dips
Lower Relative Operating Temp	➢ Peak output is in NIR

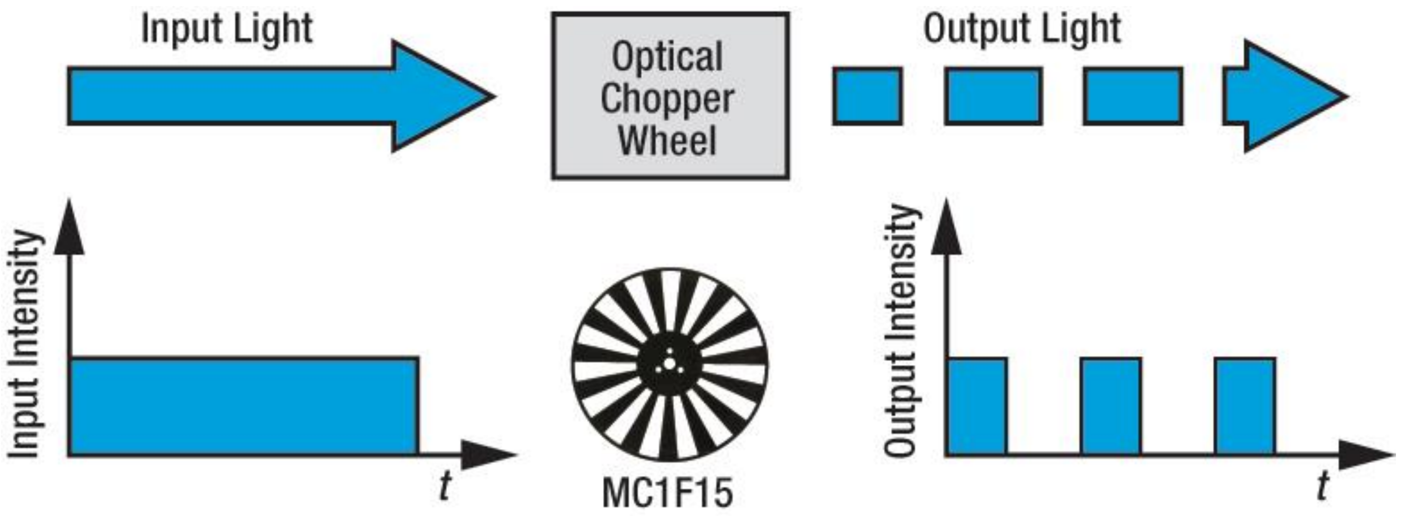


Types of Thermal Light Sources – Graphene

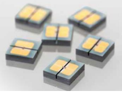
Pulsed Source

- Optical “chopping” is a technique used to increase SNR when pair with a lock-in amp
- Mechanical choppers can produce mechanical vibrations and truncated beams

- Ability to pulse the light source eliminates need for mechanical element



Thermal Light Sources – Key Takeaways

	Tungsten 	Globar 	Graphene 
Advantages	➢ **Low Cost** ➢ Smooth broadband output spectrum ➢ Low long term output decay	➢ **Long lifetime** ➢ Broad NIR Spectrum ➢ Smooth output spectrum ➢ Atmospheric operation	➢ **Compact form factor** ➢ **Fast pulsing operation** ➢ Broad NIR Spectrum
Disadvantages	➢ **High bulb pressure** ➢ Low UV output ➢ Low efficiency ➢ Cannot be pulsed	➢ **Typically requires water cooling jacket** ➢ Low UV output ➢ Low efficiency ➢ Cannot be pulsed	➢ **Low relative intensity** ➢ Small emission area ➢ Low UV output
Applications	➢ **Broadband Spectroscopy** ➢ **Calibration source** ➢ General purpose lighting	➢ **FTIR spectroscopy** ➢ Can be used as a heating element	➢ **FTIR spectroscopy**

Gas Discharge Sources

Discharge Lamps – Principle of Operation

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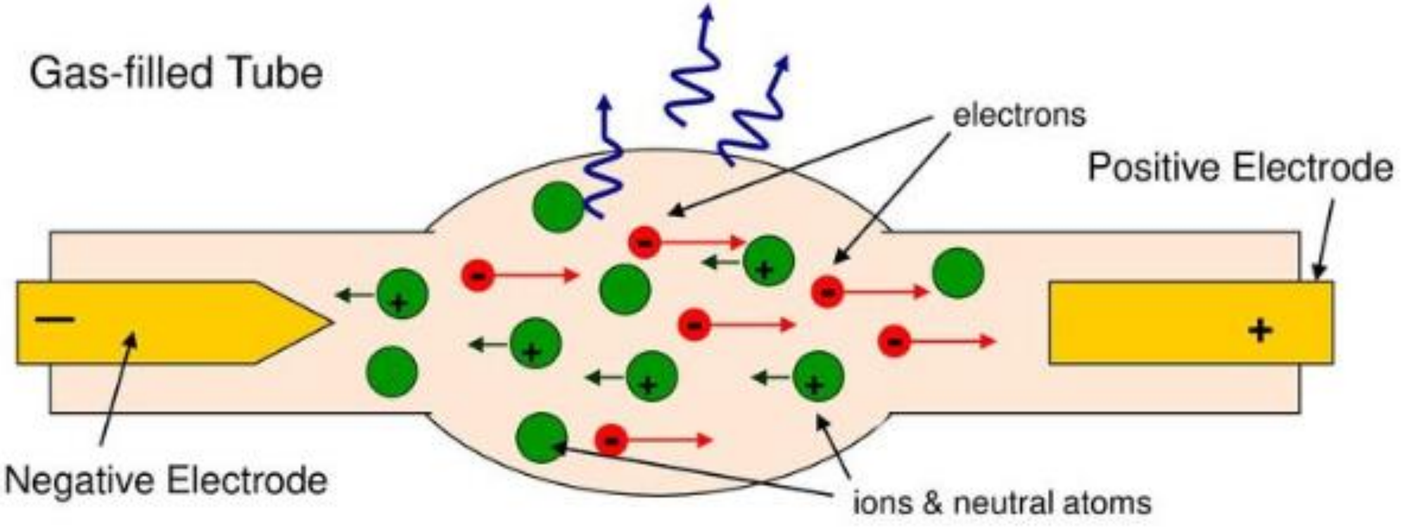
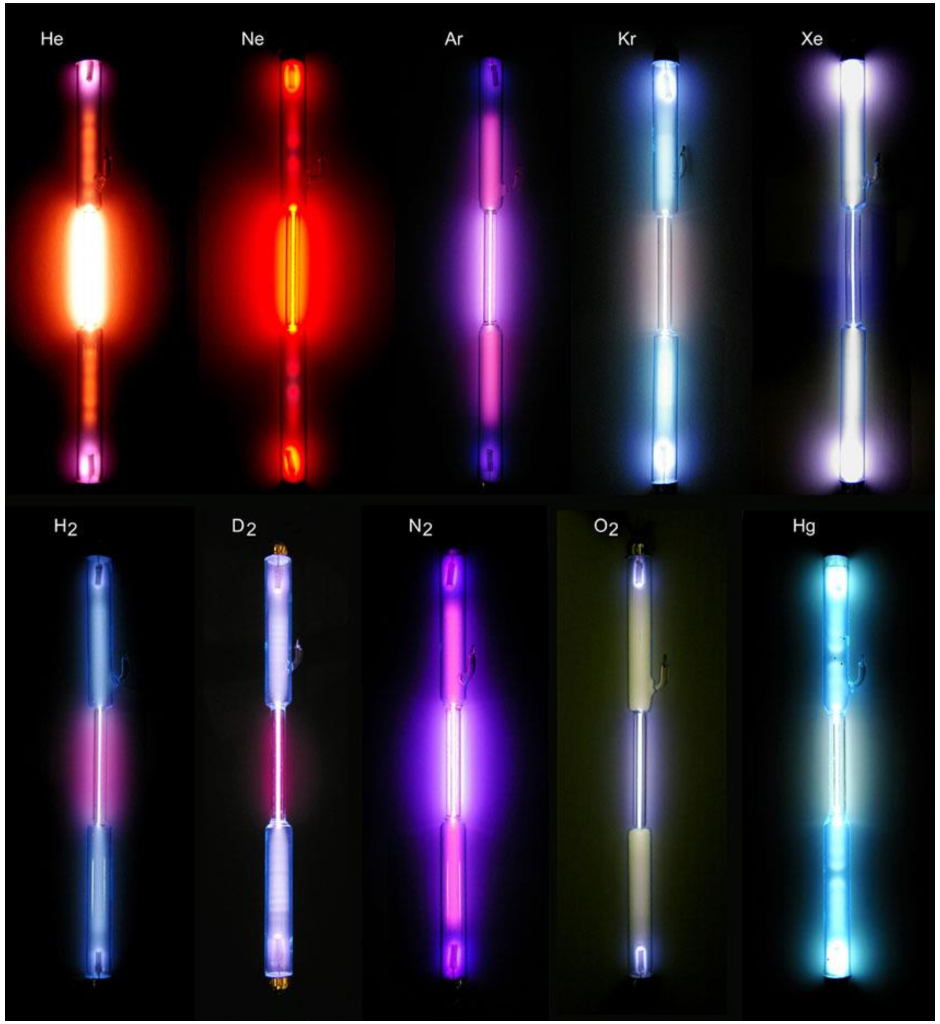
- High electric field induces ionization, gas becomes conductive
- Ionized gas particles form light emitting **plasma**
- Light is emitted by downward electronic transitions in gas atoms
- A gas atom’s orbitals differ by specific energies, and these differences determine the emitted photon energies or wavelengths.



Discharge Lamps – Optical Characteristics and Efficiency

- Luminous efficacy is higher than thermal light sources, on order of 50-150 lm/W
- Incoherent light
- Startup time can range from a few secs to mins
- Lifetime is on the order of 2000-4000 hours for deuterium and xenon lamps
- Xenon flash lamps can reach up to 1 billion flashes

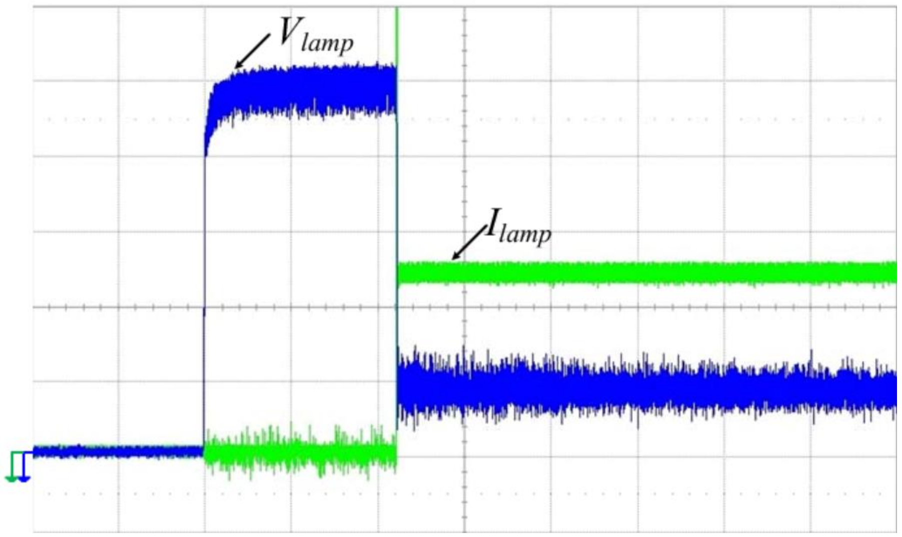


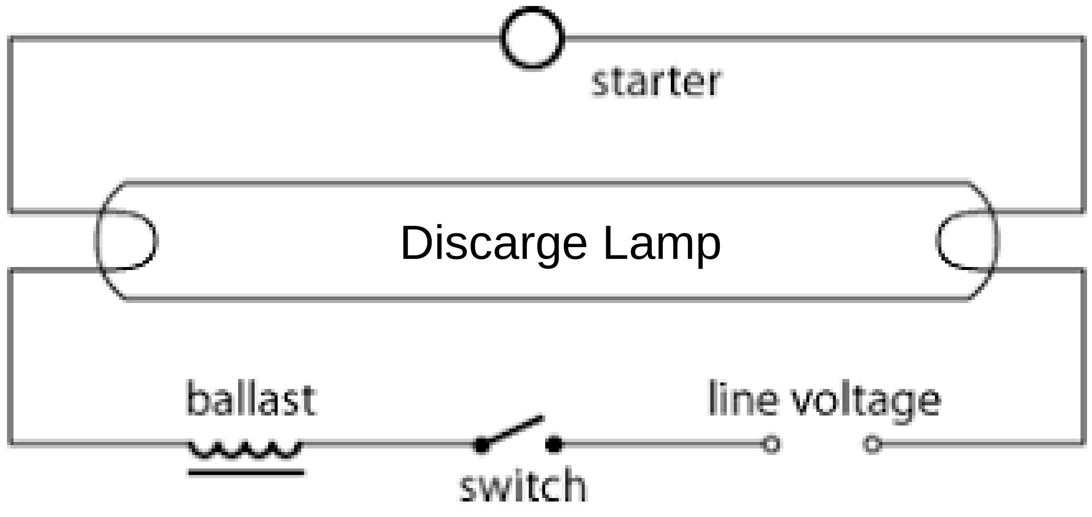
Discharge Lamps – Electrical Characteristics

- Impedance of the discharge lamp depends on the amount of ionization inside lamp

- A high trigger voltage must be used to induce the gas ionization within the lamp. This requires more complex start-up circuitry (Starter + power supply)

- Once ionization is triggered, impedance decreases and ionization is sustained by the increasing lamp current.





Types of Discharge Lamps – Deuterium Lamps

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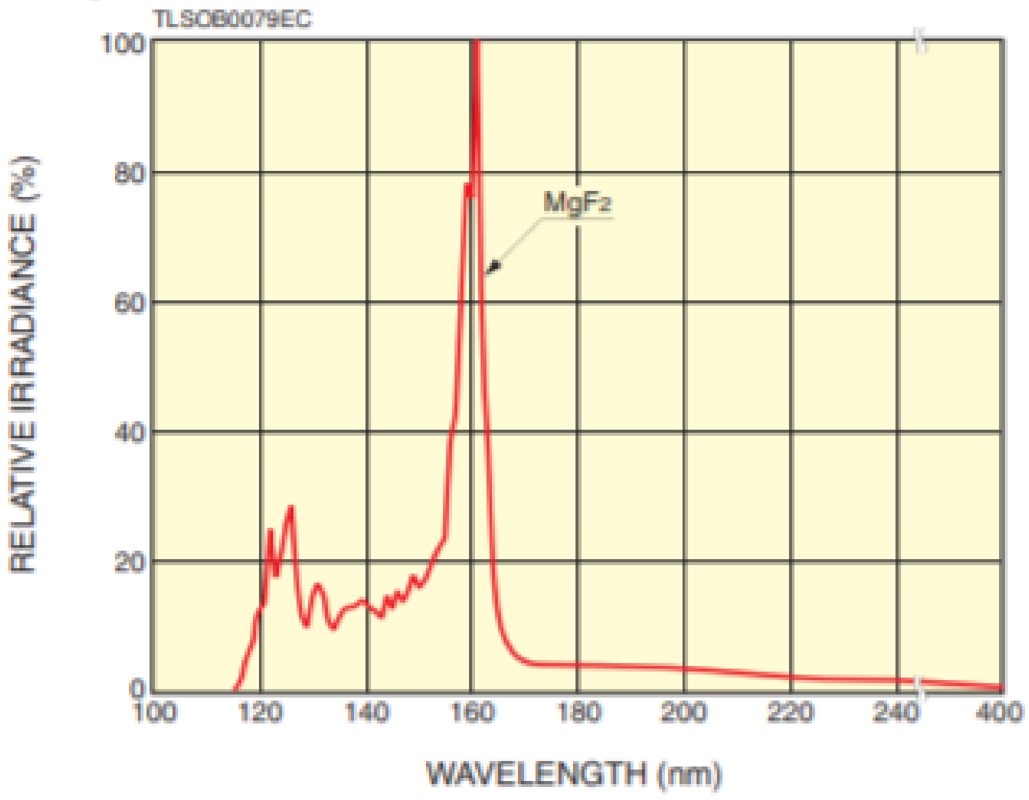
- **Deuterium Lamps** are a type of low pressure gas discharge lamp that use deuterium gas. They are UV light sources well known for their high stability (0.005% peak to peak).

■MgF2



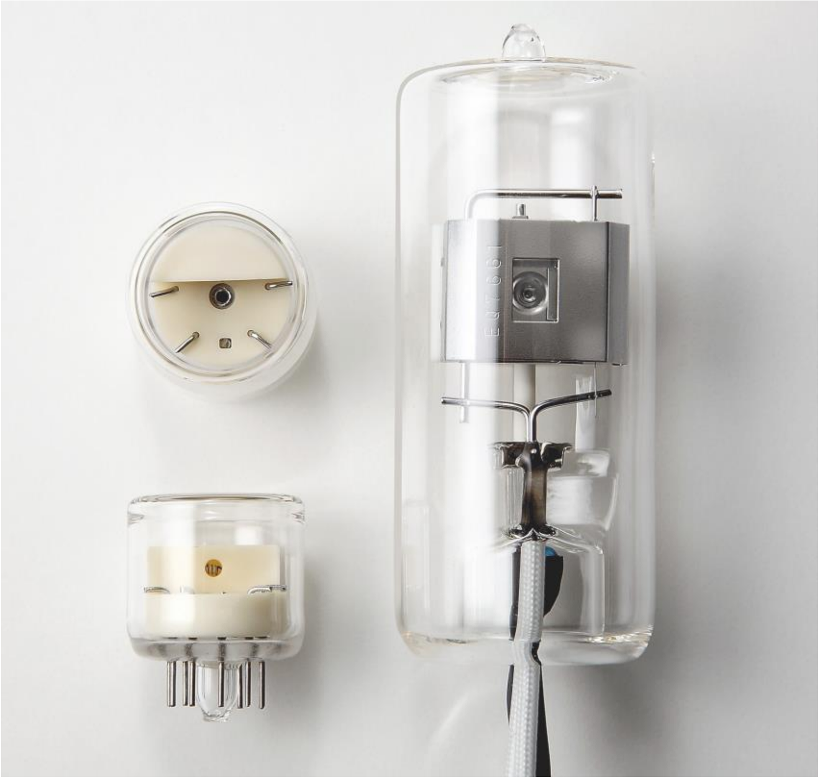
- 115nm to 400nm Emission
- 2000 ~ 4000h Lifetime
- Point light source

Types of Discharge Lamps – Deuterium Lamp

Feature	Application Benefit
High stability (0.005% peak to peak)	➢ **High accuracy measurement**
High energy UV output	➢ Ability to ionize molecules
Limited only to UV output	➢ No need to filter VIS or IR

Deuterium Lamp Applications

- High Performance Liquid Chromatography (HPLC): High intensity, High stability
- UV-VIS spectrophotometers
- Semiconductor Inspection
- Film Thickness Measurement
- Electrostatic Remover: VUV output

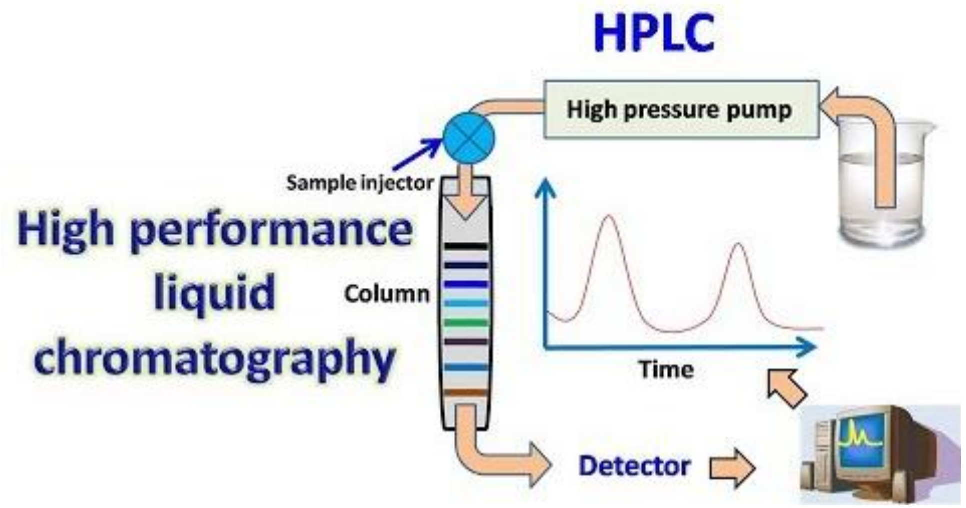


Types of Discharge Lamps – Deuterium Lamps

High Performance Liquid Chromatography

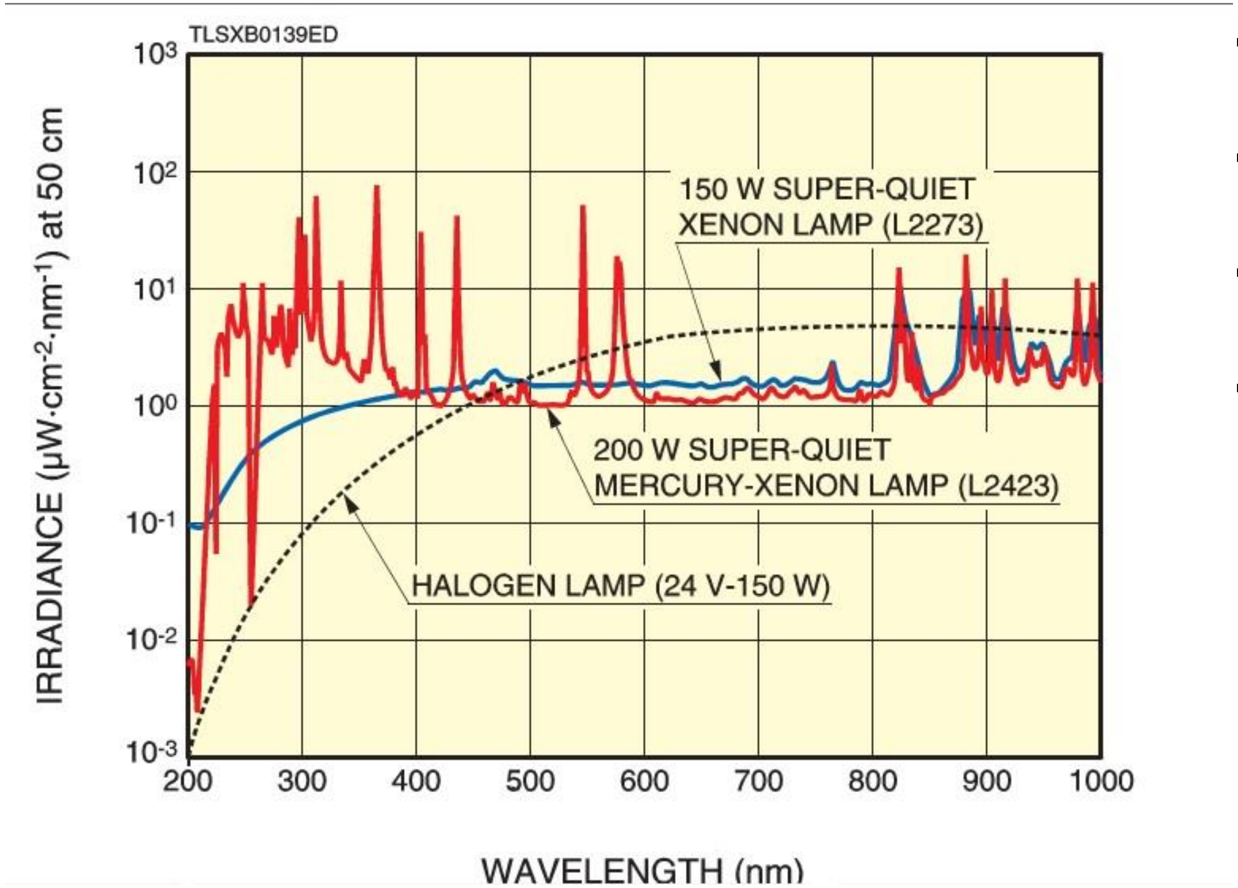
- Technique used to separate and analyze individual components of a mixture
- Usually to confirm/check purity of the mixtures

- Dealing with very small particles/sample sizes, absorption is low
- Low output variation of D2 lamps allows for high precision absorption measurement



Types of Discharge Lamps – Xenon/HgXe Lamps

- **Xenon and Mercury Xenon Lamps** are high pressure gas discharge lamps (10-20 atm) emitting multiple spectral features from UV to NIR.



- Small region of emission
- High luminance, high radiance output
- Emission Spectrum (185nm to 2000nm)
- Wide range of applications

Types of Discharge Lamps – Xenon/HgXe Lamps

Feature	Application Benefit
Distinct Xenon or Hg emission peaks	➢ High intensity at these peaks
High color temperature (6000K)	➢ Can simulate solar spectrum
Point source with high radiance	➢ Produce high intensity collimated beam
Broad UV to NIR output	➢ Various wavelengths of interaction/metrology

Types of Discharge Lamps – Xenon/HgXe Lamps

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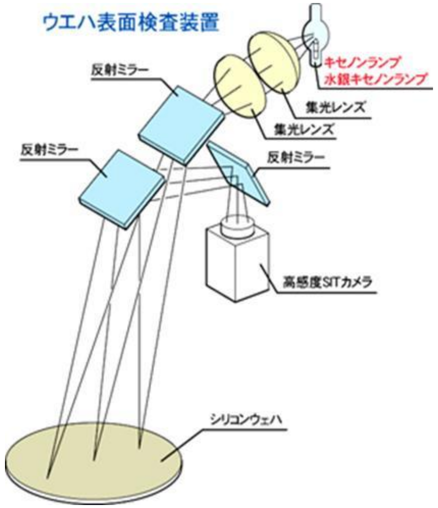
Xe/HgXe Lamp Applications

- Wafer Inspection System
- UV Curing System
- Fluorescence Spectrophotometer
- Air Pollution Analyzer



Types of Discharge Lamps – HgXe Lamps

UV Curing

- UV light initiates a photochemical reaction to cure or “dry” inks, coatings, or adhesives
- Photo chemical reactions are initiated by specific wavelengths of interaction

- UV spectral lines correspond with wavelength of interaction of many UV curable coatings.
- High intensity of Mercury-Xenon allows for short exposure/faster curing

Types of Discharge Lamps – Xenon Flash Lamps

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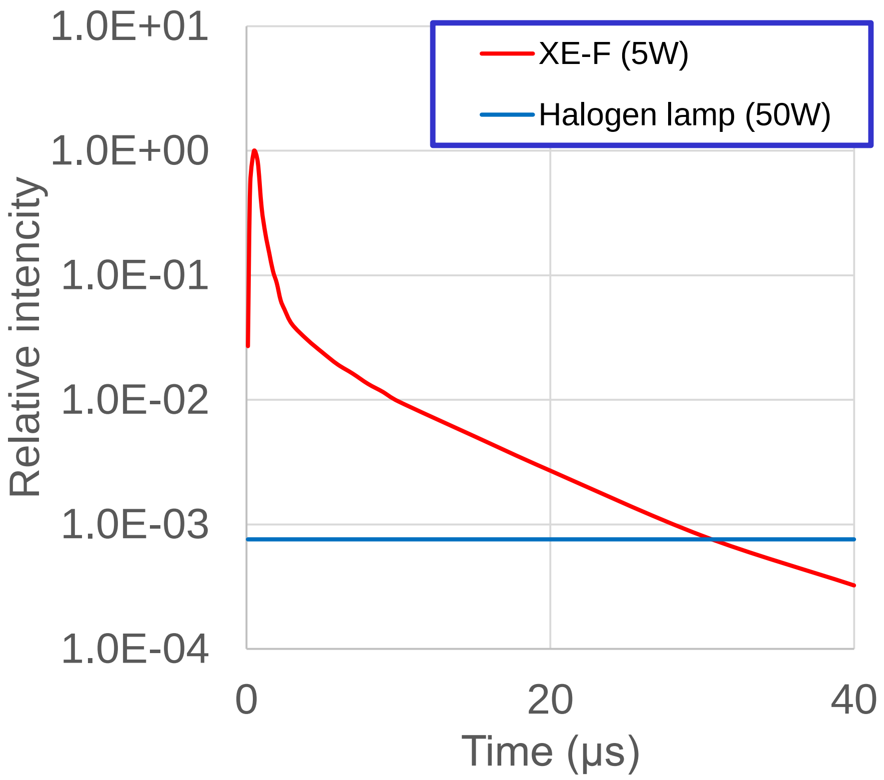
- **Xenon Flash Lamps** are xenon gas discharge lamps emitting a broad spectrum of light from UV and going into NIR.



- Short warm up time
- Pulsed, high-intensity light
- Features a small size, and low heat build-up due to pulsed operation

Types of Discharge Lamps – Xenon Flash Lamps

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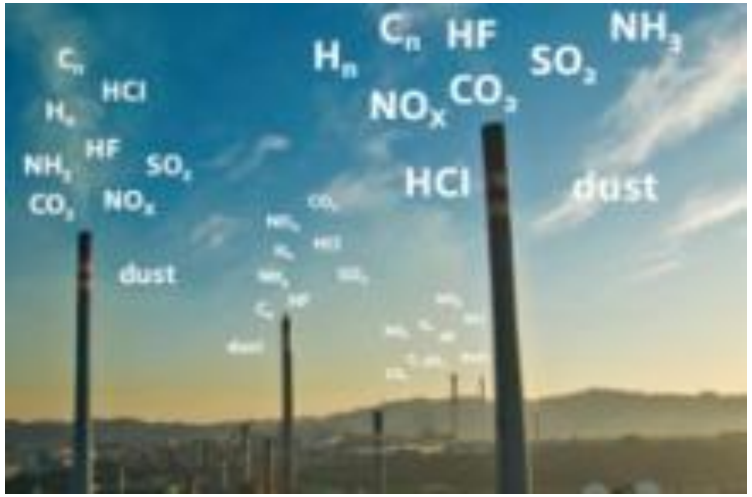
Feature	Application Benefit
High peak irradiance per pulse	➢ **Delivers many photons in short burst**
Pulsed operation	➢ Can synchronize output with exposure time
Low heat build-up	➢ Easier integration into enclosures
Short warm up time	➢ Minimize delay in taking measurements

Types of Discharge Lamps – Xenon Flash Lamps

Xenon Flash Lamp Applications

- UV-VIS Spectrophotometer
- Gas Monitoring
- Water Quality Monitoring
- Blood Analysis



Types of Discharge Lamps – Xenon Flash Lamps

Spectrophotometry Instruments

- Spectrophotometers have wide uses in chemistry and biology for reflectance and transmission measurements of samples
- Typically measurement is desired for various wavelengths of interaction
- Needs to be plug and play for in lab use

- XeF flash lamp broad spectral features provides multiple wavelengths of interaction
- Small form factor allows easy integration in to bench top units.
- Low heat simplifies design and is also non-destructive

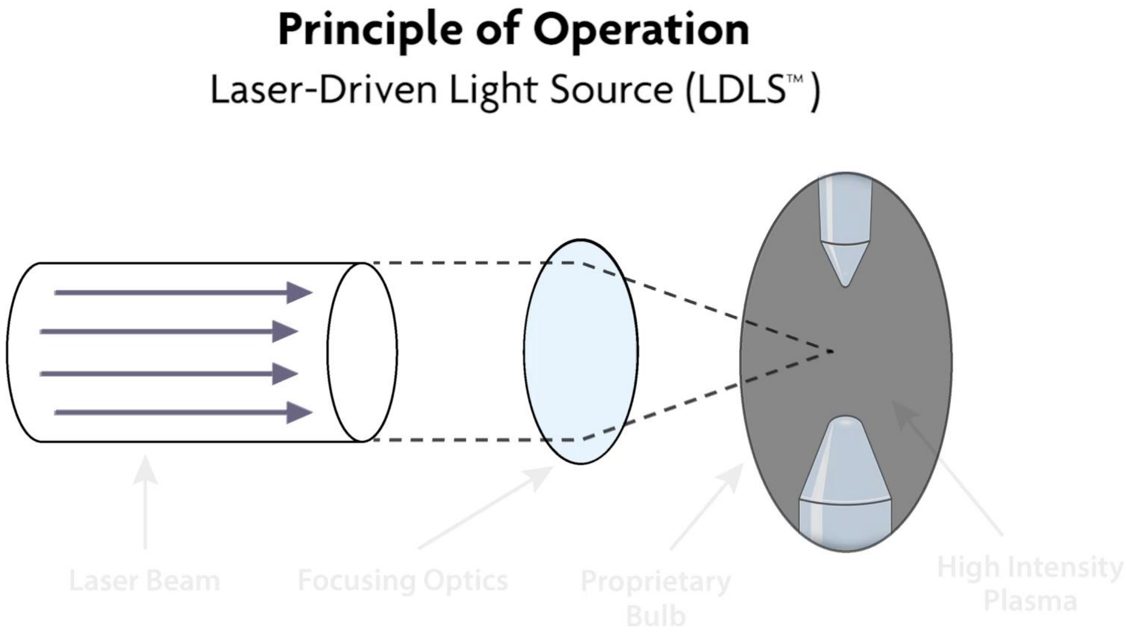
Discharge Lamps – Key Takeaways

	Deuterium Lamps 	Xe/HgXe 	Xe Flash Lamps 
Advantages	➢ **High Stability (0.005%)** ➢ Broad UV output	➢ **Broad UV to NIR Output** ➢ High stability ➢ High Color Temp (6000K)	➢ **Broad UV-NIR Output** ➢ **Pulsed output** ➢ Short warm-up time ➢ High peak irradiance ➢ Low heat generation
Disadvantages	➢ **20-30 min warm up time** ➢ Stable power source required ➢ Stability is highly depended on bulb temperature	➢ **Cathode erosion leads to long term drop in output** ➢ Several minute warm-up time ➢ High heat generation	➢ **Lower relative stability** ➢ More complex operating circuitry
Applications	➢ **HPLC** ➢ Semiconductor Inspection ➢ Film Thickness Measurement ➢ Electrostatic Removal	➢ **Wafer Inspection System** ➢ UV Curing System ➢ Fluorescence Spectrophotometer ➢ Air Pollution Analyzer	➢ **UV-VIS Spectrophotometer** ➢ Gas Monitoring ➢ Water Quality Monitoring ➢ Blood Analysis

Specialty Sources

Laser Driven Light Source

- The **Laser Driven Light Source**™ is a more recent variation of traditional pressurized xenon arc lamps. The key difference is the plasma of this specialized xenon bulb is only just initially generated by the electrodes. Then light emitting plasma is then sustained by a high power laser.



- High brightness: ~100µm diameter Xenon plasma
- Efficient coupling into small fibers or spectrometer slits
- Point source enables collimation over long distances
- Incoherent light

Laser Drive Light Source - Characteristics

- The LDLS has long lifetime due to low wear electrode wear, ~10,000 hours
- High brightness
- Efficient for small spot size illumination
- UV-VIS-NIR output
- Point Source

- Applications:
  - Semiconductor Wafer Inspection
  - Thin Film Measurement
  - Color Analysis
  - Filter/Optics Testing

Laser Driven Light Source

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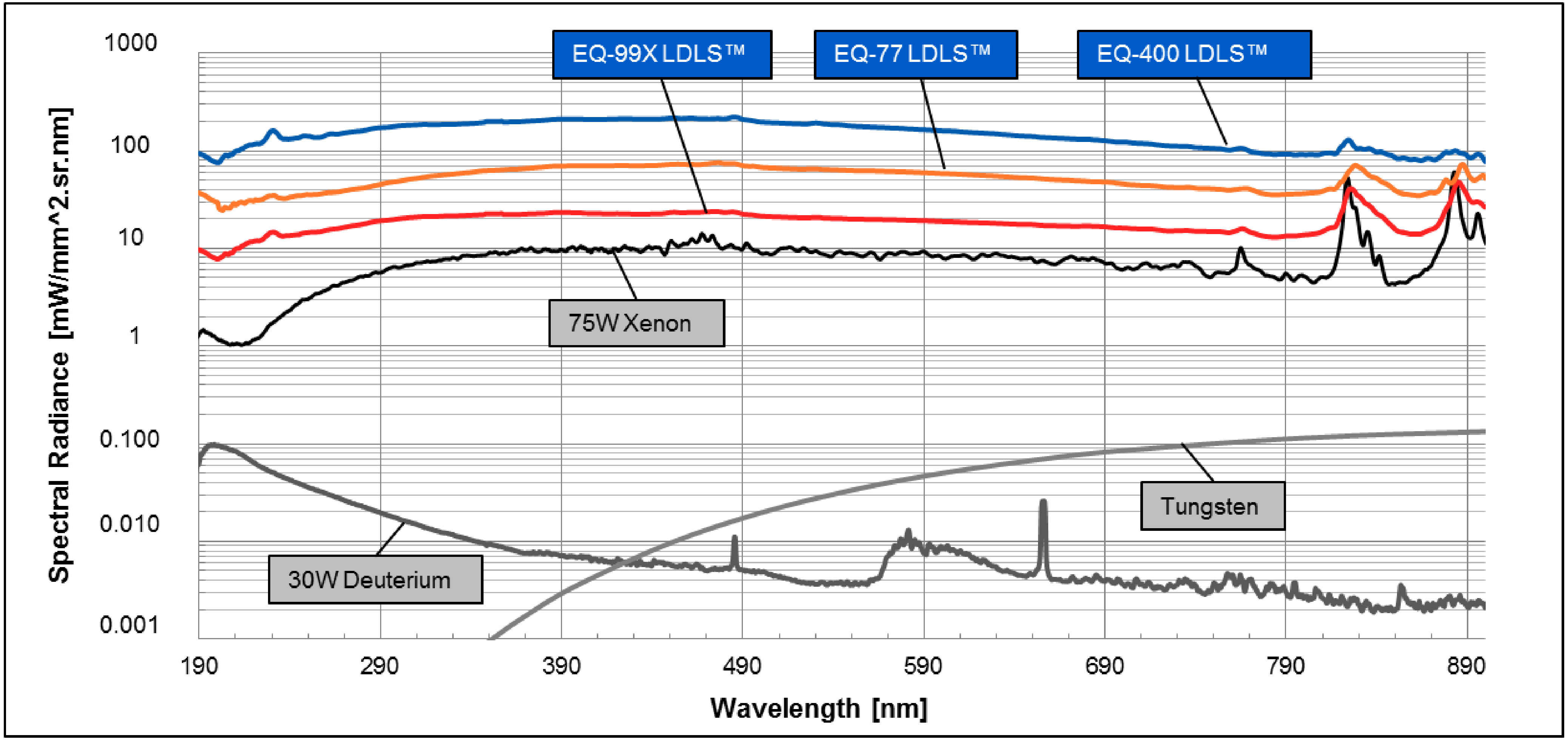
Radiance (brightness) comparison



Laser Driven Light Source

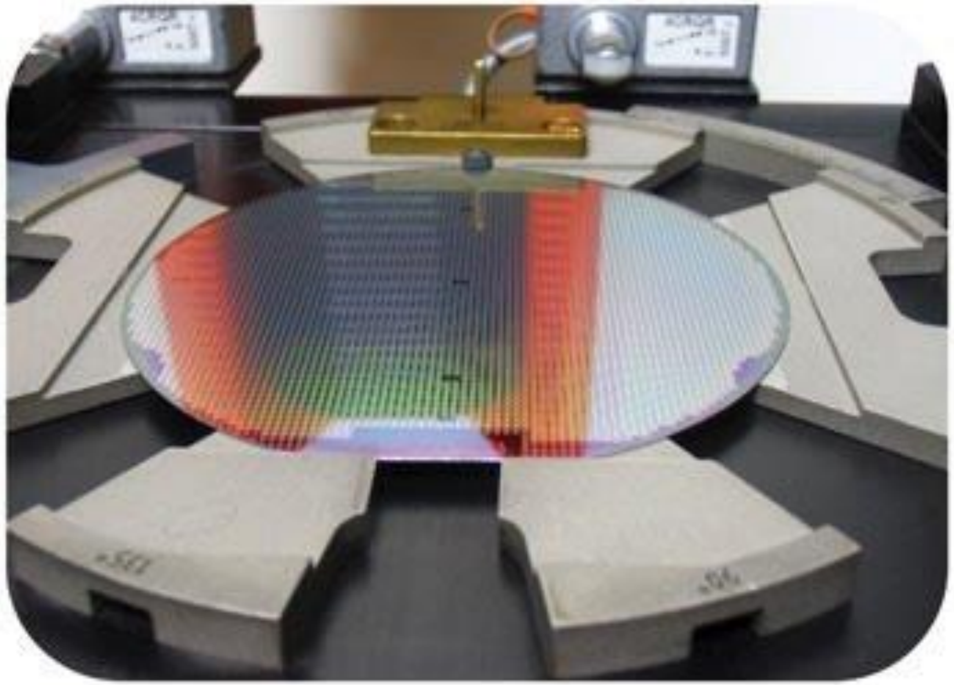
Feature	Application Benefit
High Brightness from small spot	➢ **Couple into small fiber or aperture**
Long Life	➢ **Long uptime, minimize maintenance cost**
Broad UV-VIS-NIR Output	➢ Various wavelengths of interaction/metrology
Full system	➢ Easy to integrate/use
High Relative Spatial Stability	➢ Stable/consistent light coupling

Laser Driven Light Source

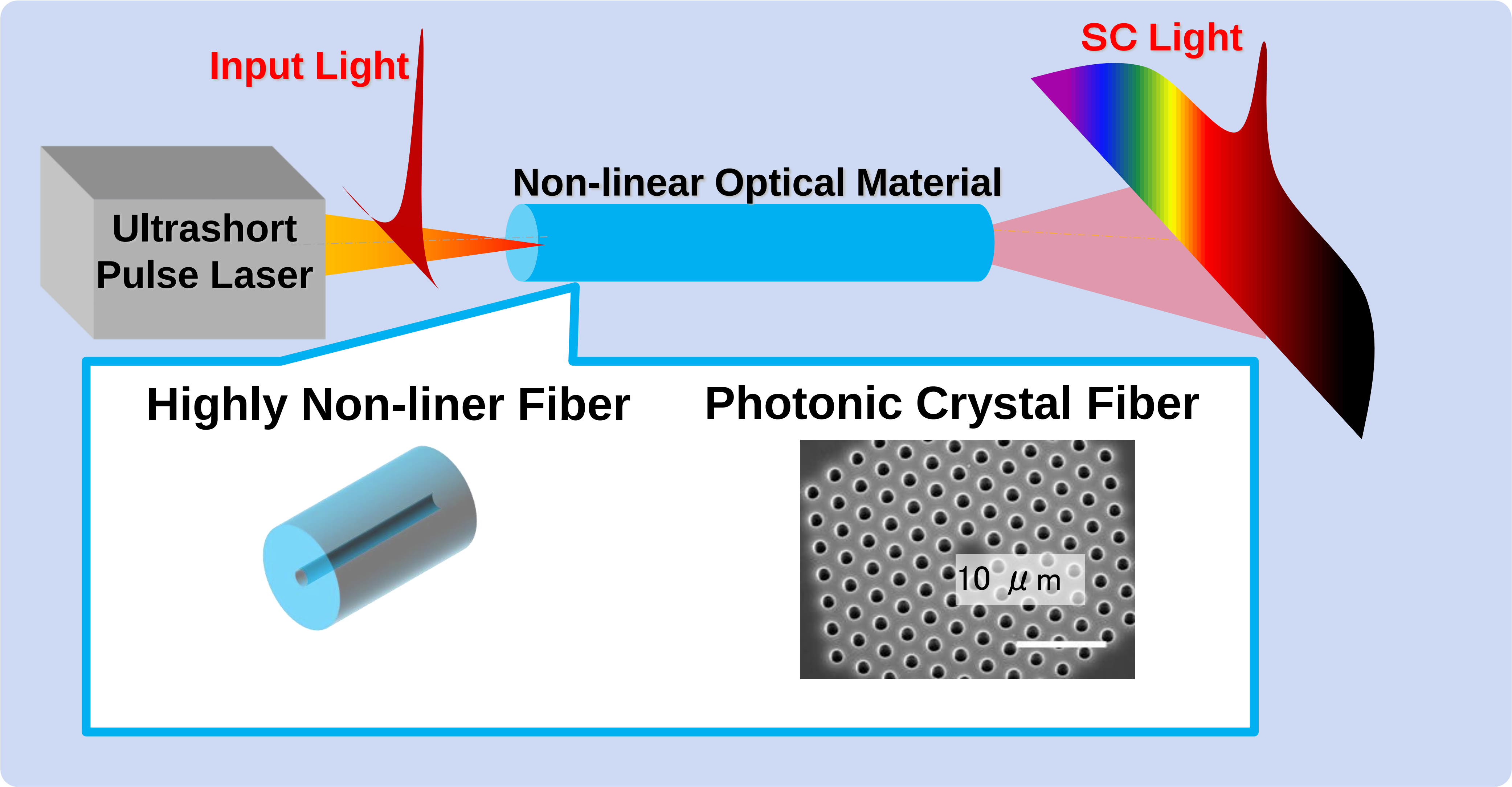
Semiconductor Inspection

- Increasing miniaturization of electronics = smaller features/small field of view for inspection
- Uptime is extremely important

- Smaller, brighter, plasma couples a lot of light into small spot
- This enables detection of small features as well as faster measurements
- Long life reduces downtime for maintenance



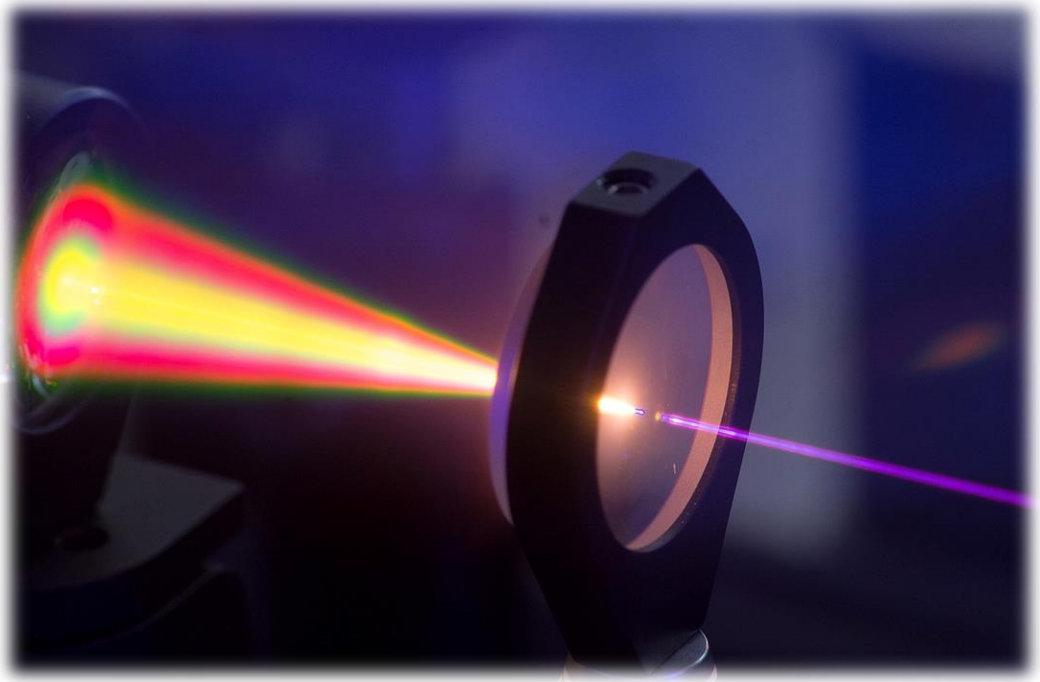
Supercontinuum Light Sources – Principle of Operation



Supercontinuum Light Sources – Principle of Operation

Supercontinuum light generation varies based on a number of factors:

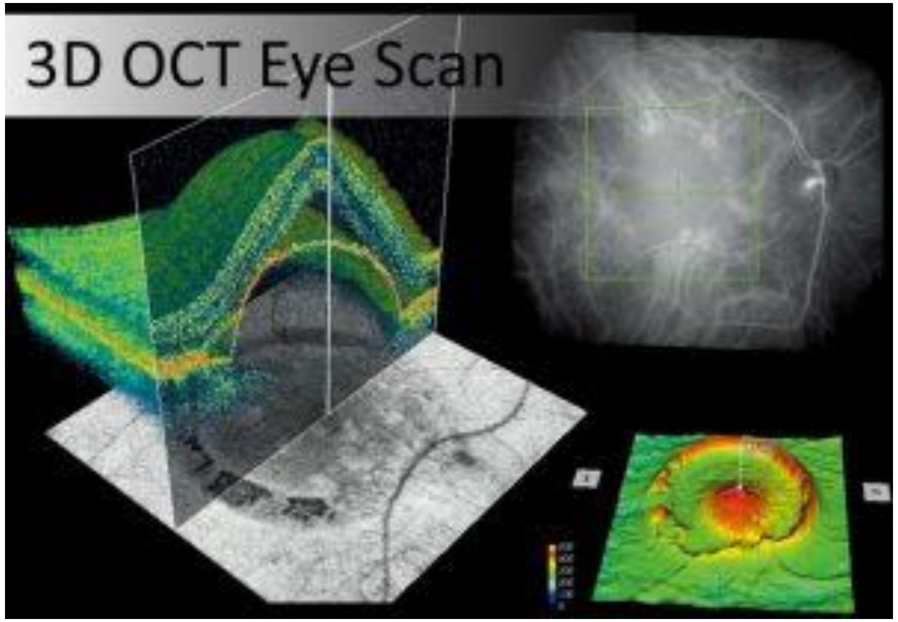
- Chromatic dispersion of fiber or nonlinear medium
- Length of fiber or nonlinear medium
- Pump source pulse duration
- Pump source peak power
- Pump source wavelength



Supercontinuum Light Sources – Characteristics

Optical Characterisitcs

- Spatial coherence is usually very high
- Low temporal coherence (broadband output)
- Spectral output range of supercontinuum generated light varies based on design. Can range anywhere from VIS into NIR.
- Applications: Optical Coherence Tomography, Fluorescence Microscopy



Supercontinuum Light Sources

Feature	Application Benefit
High Spatial Coherence/Low Temporal Coherence	➢ Advantageous interferometric properties
High Relative Stability	➢ More accurate measurement
Broadband	➢ Various wavelengths of interaction/metrology
High brightness (10um fiber)	➢ Provides broadband laser level output

Specialty Sources – Key Takeaways

	Laser Driven Light Source	Super Continuum Light Source
Advantages	➢ **High Brightness from small spot** ➢ Broadband Output ➢ Low electrode wear/long life-time ➢ High spatial stability	➢ **High Brightness, laser level output** ➢ Broadband NIR ➢ High Spatial Coherence
Disadvantages	➢ **Relatively low total radiant flux** ➢ Not compact	➢ **High Cost** ➢ Not compact
Applications	➢ **Semiconductor Inspection** ➢ Film Thickness Measurement ➢ Sensor Testing/Characterization ➢ Broadband Spectroscopy	➢ **Optical Coherence Tomography** ➢ NIR Spectroscopy

Energetiq Technology Inc

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Founded in March 2004

Wholly Owned Subsidiary of Hamamatsu - Energetiq joined Hamamatsu in October 2017

Based in Wilmington, MA 01887 USA

Upcoming Webinars:
July 14th - Extreme Ultraviolet Light Sources Supporting Next-generation Lithography

July 16th – Advances in Testing and Calibration of Modern Optical Sensors

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Laser-Driven Light Sources: LDLS™

Summary

Summary and Conclusions

- **Low Cost**
  - Thermal Sources
  - LEDs*

- **High Stability**
  - Deuterium Lamps
  - Xenon Lamps
  - LDLS
  - SC Light Sources

- **High Brightness**
  - Narrowband
    - Lasers*
    - SLDs*
  - Broadband
    - LDLS
    - SC Light Sources

- **Low Power Consumption**
  - LEDs*
  - Graphene Source

Summary and Conclusions

	Tungsten Halogen 	Globar 	Graphene 	D2 Lamp 	Xenon Flash 	Xe lamp 	LDLS 	SC 
Wavelength range (nm)	200 – 3000nm	500 – 9000nm	1000-7000nm	115-400nm	185-2500nm	185-2000nm	170-2400nm	1300-2000nm
Stability(%)	±0.3%	±0.05%	-	±.005%	±2%	±0.1%	±0.2%	±0.1%
Relative Intensity ($mW*cm^{-2}*nm^{-1}$)	20x	100x	-	1x	1000x	~10x	~100x	~10000x
Lifetime	1000h	10000h	2000h	~2000-4000h	~1 Billion Flashes	~2000-4000h	~10000h	over 3000h
Relative Cost	1x	20x	2x	10x	20x	20x	500x	500x

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Contact Us

We'd like to hear from you

- Light source selection questions
- Ideal light source characteristics
- New applications

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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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