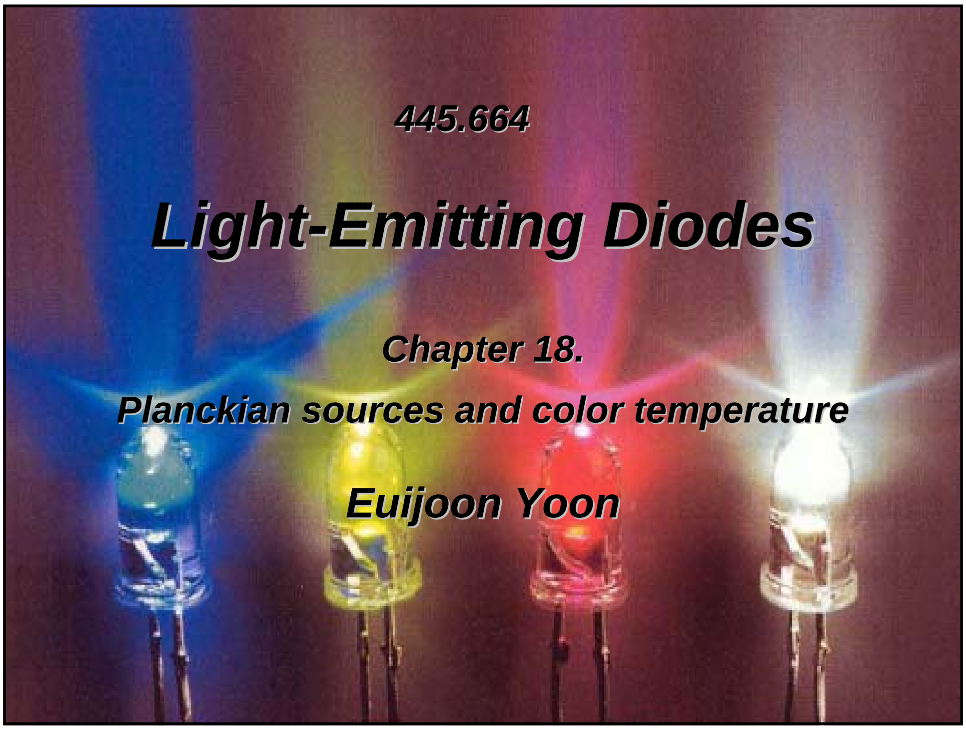

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Light-Emitting Diodes

Chapter 18.
Planckian sources and color temperature

Euijoon Yoon

Planckian source and solar spectrum

- White light is a unique color.
  - Large number of optical spectra that can be used to generate white light
  - Planckian black-body radiation spectrum forms a unique and very useful standard.
    - Spectrum with only one parameter : color temperature
    - Natural daylight closely resembles the planckian spectrum.

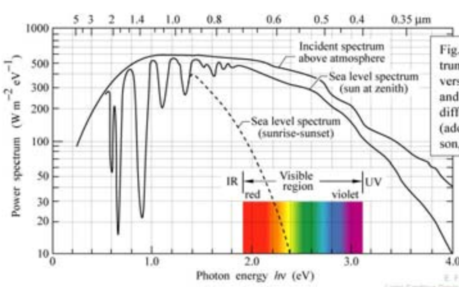


Fig. 18.1. Power spectrum of solar radiation versus photon energy and wavelength for different conditions (adopted from Jackson, 1975).

- Exact replication of the solar spectrum for white-light illumination sources would not yield an efficient source.
  - Due to the large IR and UV components of the solar spectrum

The planckian black-body radiation spectrum

- **White light usually have a broad spectrum extending over the entire visible range.**
- **It is desirable to define an independent standard for white light and the black-body radiation spectrum is used as one such standard.**
- **The black-body spectrum is given by**

$$I(\lambda) = \frac{2hc^2}{\lambda^5\left[\exp\left(\frac{hc}{\lambda kT}\right) - 1\right]}$$

- **The maximum intensity of radiation emanating from a black body with temperature T occurs at the wavelength given by Wien's law**

$$\lambda = \frac{2880\ \mu m \cdot K}{T}$$

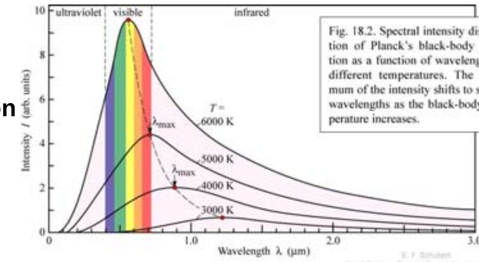
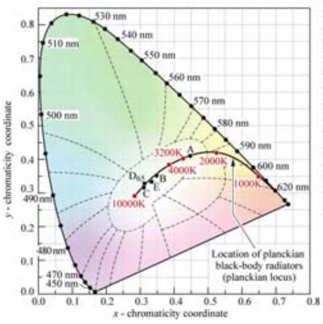


Fig. 18.2. Spectral intensity distribution of Planck's black-body radiation as a function of wavelength for different temperatures. The maximum of the intensity shifts to shorter wavelengths as the black-body temperature increases.

The location of the black-body radiation in the chromaticity diagram

- **Planckian locus**
  - **As the temperature of the black-body increases, the chromaticity location moves from the red range toward the center of the diagram.**
  - **Typical black-body temperatures in the white region of chromaticity diagram**
    - **2500 ~ 10000 K**



Illuminant A
(x, y) = (0.4476, 0.4074)
(Incandescent source, T = 2856 K)

Illuminant B
(x, y) = (0.3484, 0.3516)
(Direct sunlight, T = 4870 K)

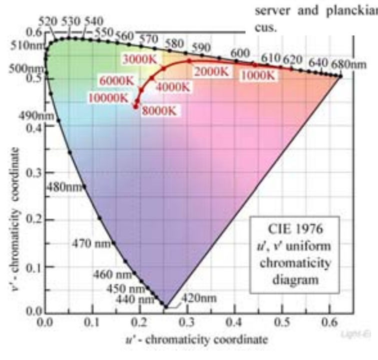
Illuminant C
(x, y) = (0.3101, 0.3162)
(Overcast source, T = 6770 K)

Illuminant D_{65}
(x, y) = (0.3128, 0.3292)
(Daylight, T = 6500 K)

Illuminant E (equal-energy point)
(x, y) = (0.3333, 0.3333)

Fig. 18.3. Chromaticity diagram showing planckian locus, the standardized white Illuminants A, B, C, D_{65}, and E, and their color temperature (after CIE, 1978).

Fig. 18.4. CIE 1976 (u', v') uniform chromaticity diagram calculated using the CIE 1931 2° standard observer and planckian locus.



Color temperature

- **Color temperature**
  - Relationship between 'color' and 'temperature' derived from Planck's black-body radiation.
  - With increasing temperatures,
    - It glows in the red, orange, yellowish white, white, and ultimately bluish white.
  - The color temperature (CT) of a white light source

    : Temperature of a planckian black-body radiator that has the same chromaticity location.
    - Unit of Kelvin
- **Correlated color temperature (CCT)**
  - For the white light source that does not fall on the planckian locus.
  - On the (u',v') uniform chromaticity diagram, the point on the planckian locus that is closet to the chromaticity location of the light source is determined. (i.e. shortest geometrical distance)
  - CCT is the temperature of the planckian black-body radiator at that point.

CCT on the (x,y) chromaticity diagram

- On the (x,y) chromaticity diagram
  - The correlated color temperature cannot be determined by using shortest distance to the planckian locus.
  - Due to the planckian locus due to the non-uniformity of the (x,y) chromaticity diagram

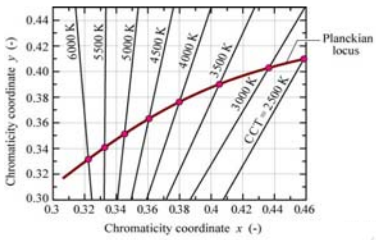


Fig. 18.5. Lines of constant correlated color temperature in the (x, y) chromaticity diagram. Whereas the correleted color temperature follows from the minimum distance to the planckian in the (u', v') diagram, this is not the case in the (x, y) diagram (after Duggal, 2004).

Light source	CCT (K)
Wax candle flame / CIE standard candle flame	1500 to 2000 / 2000
W filament household lamp: 60 W / 100 W	2800 / 2850
W filament halogen lamp	2800 to 3200
"Warm white" fluorescent tube	3000
"Cool daylight white" fluorescent tube	4300
"True daylight" color match fluorescent tube	6500
Carbon arc white flame	5000
Xenon arc (unfiltered)	6000
Summer sunlight (before 9:00 or after 15:00)	4900 to 5600
Summer sunlight (9:00 to 15:00)	5400 to 5700
Direct sun	5700 to 6500
Overcast daylight	6500 to 7200
Clear blue sky	8000 to 27000