Tungsten Filament Lamps as Absolute Radiometric Reference Sources

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Quartz Tungsten Halogen (QTH) Lamps

- Widely used as transfer standards of spectral irradiance
- FEL & DXW type lamps most common
- Planckian radiators with a few corrections
Spectral Irradiance of QTH Lamp

- Modified Planck’s radiation law

\[ B(T) \text{ is a geometrical factor of the measurement, slightly affected by } T \text{ due to thermal expansion} \]

- \( \varepsilon_W(\lambda, T) \) is the spectral emissivity of tungsten

- \( \varepsilon_\Delta(\lambda, T) \) is a residual correction due to other minor contributing factors


Fig. Spectra of an FEL lamp whose \( T \) (2500 – 3050 K) is modified by changing the lamp current.
Emissivity of Tungsten

- Measured extensively in the 50’s by De Vos and Larrabee.
- De Vos data available in analytical form $\lambda = 340 – 2600$ nm, $T = 1600 – 2800$ K. Numerically down to 230 nm!
- Simple to combine with Planck’s law
- Larrabee data considered more accurate (scattering) but $\lambda = 350 – 800$ nm and $T = 1600 – 2400$ K are limited. Non-continuities when extrapolating.

Fig. Spectral emissivities of sheet tungsten according to De Vos (Dashed lines, 1954) and Larrabee (solid lines, 1959).
Residual correction

• Planck’s law modified with tungsten emissivity was fitted to a temperature-varied 1-kW FEL-lamp.
• With the presented residual correction, a common solution was found.
• Lamp model with two free parameters, \( B \) (geometry) and \( T \) (temperature).
• Tests with Aalto and NPL data on DXW and FEL type lamps indicate <1% interpolation/extrapolation uncertainty for \( \lambda = 340 – 850 \) nm.

Fig. Residual correction needed for Planck’s law with FEL and DXW type lamps after correcting for tungsten emissivity of de Vos. [Ojanen et al, Appl. Opt. 2010]
Simple Spectral Irradiance Scales

\[ E(\lambda, T) = B(T)\varepsilon_w(\lambda, T)\varepsilon(\lambda) \frac{2hc^2}{\lambda^5 \left[ \exp\left(\frac{hc}{\lambda kT}\right) - 1 \right]} \]

- Two unknowns \( B \) and \( T \) may be obtained
  - With two filter radiometer
  - Illuminance and color temperature
  - Illuminance and electrical measurements
  - Other combination

- Not strictly traceable and accuracy limited (~3%) but may give valuable info for end users
QTH Lamp as Absolute Reference Source

• Temperature of the filament can be obtained from published values of resistivity and hot/cold resistance measurements of filament

• In theory, the geometrical factor can be calculated. However, one intensity measurement is more accurate.

• Corrections for
  – Filament shape (light recycling factor)
  – Quartz glass transmittance
  – Filling gas absorption
  – Tungsten material???
Light recycling

- Filament is not sheet metal as in emissivity measurements.
- Coiled structure enhances the emissivity by
  \[ \varepsilon_{LRC} = \frac{\varepsilon_W}{1 - \xi(1 - \varepsilon_W)} \]
- For FEL’s we estimate \( \xi = 0.5 \pm 0.1 \)
- Appears as a temperature change of 17 – 20 K.
Bulb Transmittance

- Light from the filament passes through one glass surface and ~1 cm of filling gas.
- We measured three FEL lamps (new, old, broken) for bulb transmittance.
- Absorption of filling gas not seen.
- Glass absorbs heavily. Changes when the lamp ages.
- Introduces a temperature change of $5 - 15$ K.
Transmittance as Function of Temperature

• Theoretically the filling gas absorption could change as a function of temperature.
• A halogen lamp was measured for transmittance in on and off states using PLACOS.
• Lamp burn increases absorption in UV, no effect in visible.
Electrical measurements

- Temperature can be obtained from cold resistance and hot dynamic resistance measurements as
  \[ T = \frac{R(T)}{[0.0063 \text{ K}^{-1} R(295 \text{ K})] + 393 \text{ K}}. \]
- \( R(T) \) measured as lamp voltage / driving current
- 4-wire measurement for \( R(293 \text{ K}) \)
- The uncertainty is 4% / 19 K

Fig. Our resistivity values calculated from measured spectra are in good agreement with other groups.
Summary

• Simple modest-uncertainty spectral irradiance scales may be obtained by modeling incandescent lamps
• In addition to tungsten emissivity
  – Light recycling and bulb transmittance change the temperature of the lamp by 23 – 36 K (in the $T$ range 2770 – 3080 K)
  – Filling gas does not absorb
  – Increased temperature increases absorption in UV, but no effect in visible
• Residual correction of $\pm2.5\%$ still needed. Tungsten properties probably differ from those tabulated.
• Lamp temperature may be obtained from electrical measurements with reasonable uncertainty
Further Reading