4. Experimental Apparatus

4.1 Parts

LEOI-63 blackbody experimental apparatus is composed of grating monochromator, receiver unit, scanning system, electronic amplifier, A/D acquisition unit, Bromine-Tungsten light source with adjustable voltage regulator, computer*, and printer*. This apparatus integrates optics, precision mechanics, electronics, and computer technology in one system.

*Note: Computer and printer are optional parts.

4.2 Structure of Main Unit

As shown in Figure 2, the main unit of the apparatus consists of grating monochromators, slit, receiver unit, optical system, and grating driving mechanism.

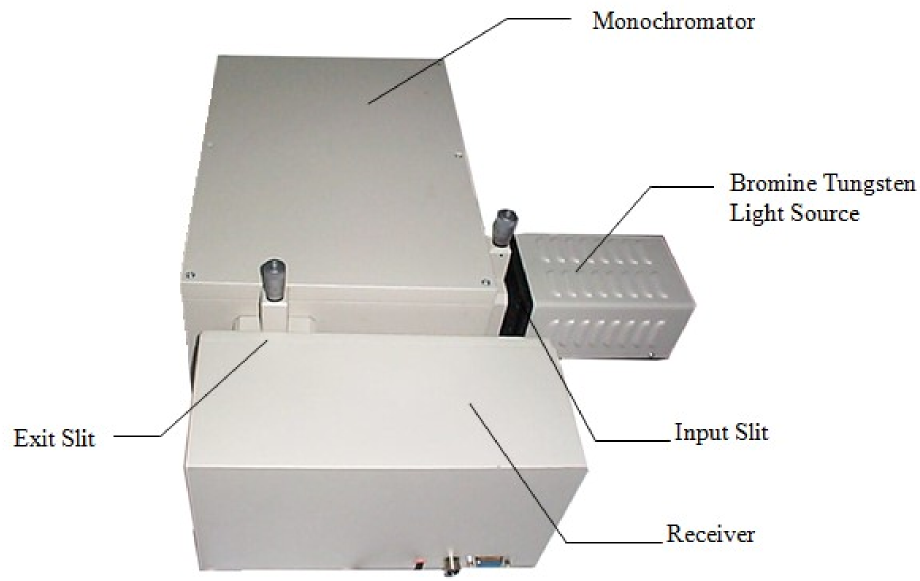


Figure 2 Description of experimental apparatus

4.2.1 Slit

Slit is straight with width continuously adjustable from 0 ~ 2.5 mm. The slit opens up when turning the knob clockwise and vice versa. One turn corresponds to a change of 0.5 mm in slit width. To extend the lifetime of the slit, do not open the slit up to exceed the 2.5 mm maximum width. If not in use, the slit width should be maintained at 0.1 to 0.5 mm.

4.2.2 Optical System

The optical system adopts a C-T model, as shown in Figure 3.

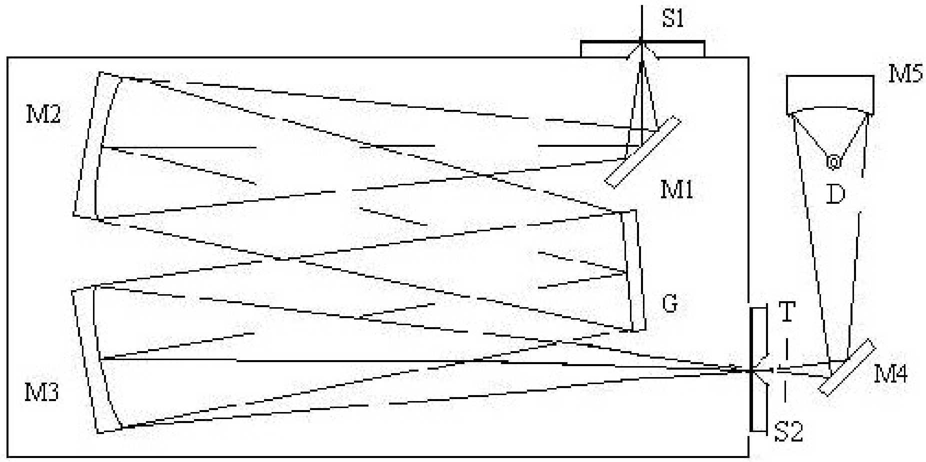


Figure 3 Schematic of optical system

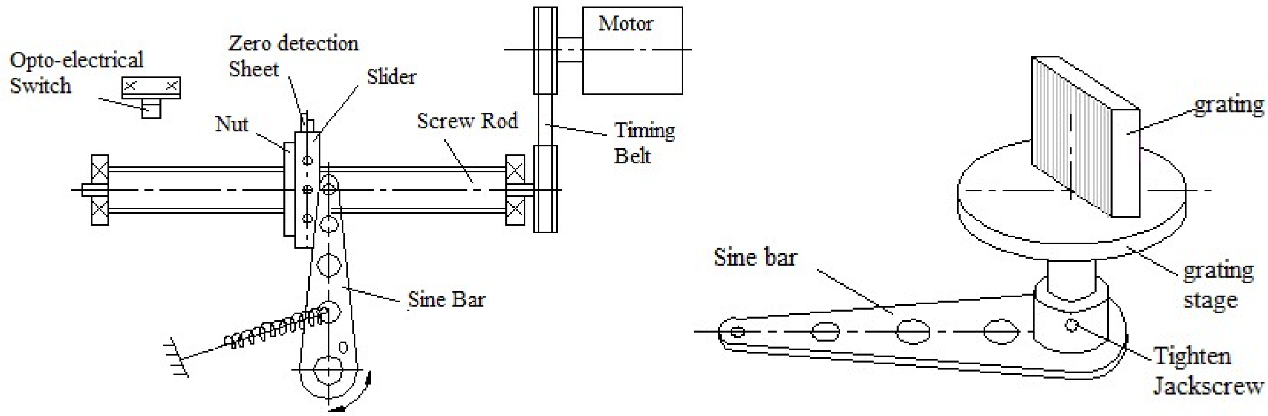
M1: Reflective Mirror, M2: Collimated Mirror, M3: Objective Mirror， M4: Reflective Mirror, M5: Deep Ellipsodial Mirror, G: Plane Diffractive Grating, S1: Input Slit, S2: Exit Slit, T: Chopper, D: Opto-electrical Receiver.

Both input and exit slits are straight with width continuously adjustable from 0 to 2.5 mm. Light from light source enters the system through input slit S1, which is located at the focal plane of reflective collimated mirror M2. The light beam is collimated by M2 and then the collimated beam is incident on plane grating G. The parallel light beam diffracted by G is imaged on exit slit S2 by objective mirror M3. It is focused to opto-electrical receiver D by M4 and M5.

M2 & M3	Focal length = 302.5 mm
Grating G	300 lines/mm, blazed wavelength = 1400 nm
Spectral range of filters	1st: 800 ~ 1000 nm 2nd: 1000 ~ 1600 nm 3rd: 1600 ~ 2500 nm

4.2.3 Mechanical Driving Mechanism

As shown in Figure 4 (a), a Sine mechanism is used to perform wavelength scanning. A lead screw is driven by a stepping motor and a nut moves along the axial direction of the lead screw. A Sine bar connected with grating stage is pulled by a spring against the slider attached to the nut. The Sine bar can also rotate around the center of grating stage, as shown in Figure 4 (b). As a result, the grating can rotate continuously and monochromatic light of various wavelengths can be scanned to exit from exit slit.



(a) (b)

Figure 4 Schematic of scanning mechanism (a) and grating rotation stage (b)

4.3 Bromine-Tungsten Light Source

Because a standard blackbody is very costly, a Bromine-Tungsten lamp with voltage regulator is used as the light source in this experiment. The filament of a Bromine-Tungsten lamp is made of Tungsten whose melting point is 3665 K and hence it is a refractory metal.

A Tungsten filament lamp is a selective radiation body whose emission spectrum is continuous. The total radiant of a Tungsten lamp can be expressed by following equation:

$$R_T = \varepsilon_T \delta T^4 \tag{7}$$

where ε_T is the emissivity coefficient of the Tungsten lamp at temperature *T*. By definition, it is the ratio of intensity radiated by a Tungsten filament to that radiated by a perfect blackbody at the same temperature.

$$\varepsilon_T = \frac{R_T}{E_T} \quad \text{or} \quad \varepsilon_T = (1 - e^{-BT}) \tag{8}$$

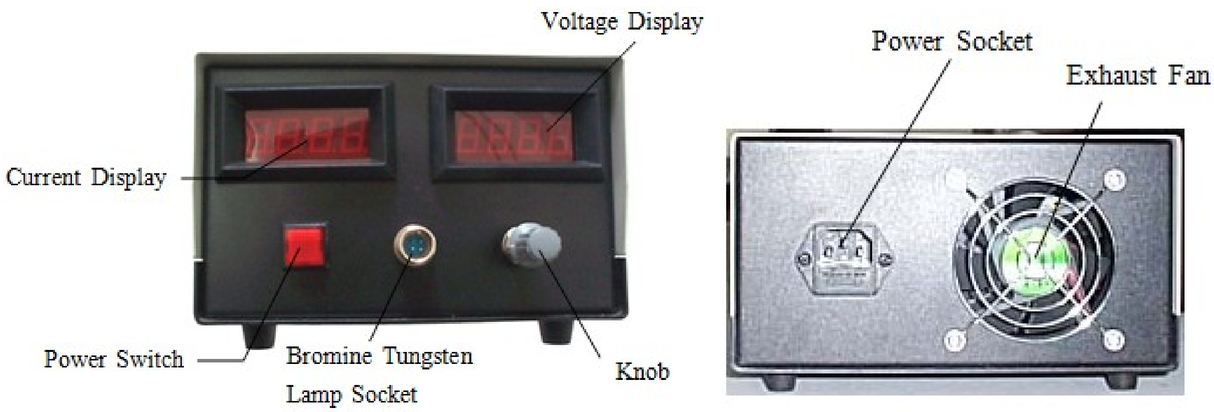
where *B* is a constant (1.47×10^{-4} K^{-1}). Therefore, the radiation spectrum $R_{\lambda T}$ of a Tungsten filament lamp is

$$R_{\lambda T} = \frac{C_1 \varepsilon_{\lambda T}}{\lambda^5 (e^{\frac{C_2}{\lambda T}} - 1)} \tag{9}$$

Equation (9) describes the emissivity relationship between a blackbody and a Tungsten filament lamp. A corresponding table between the work current and the color temperature of the Tungsten lamp will be provided with the shipment.

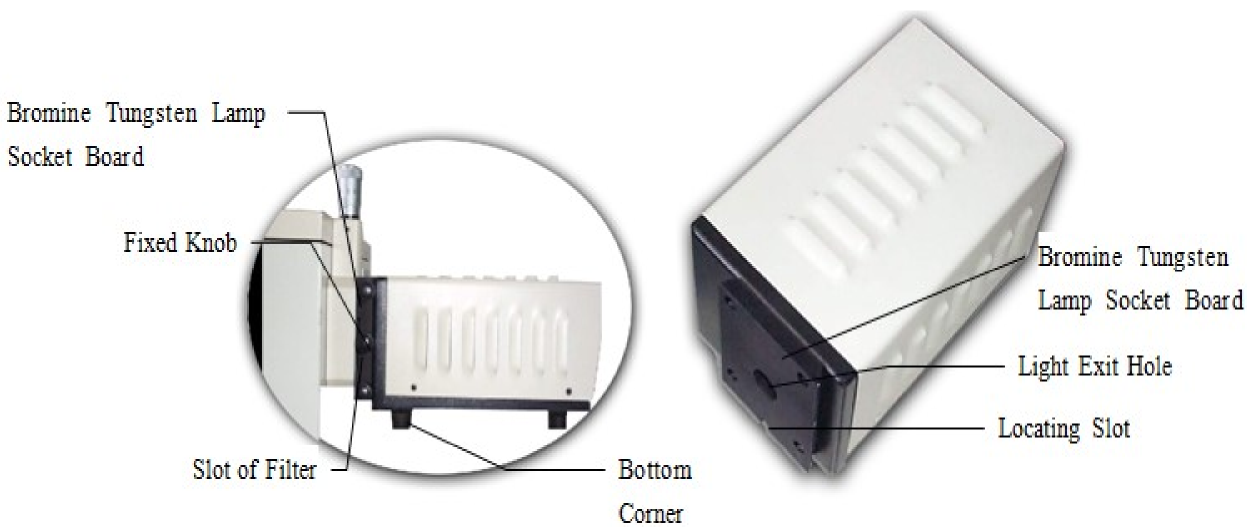
4.3.1 Structure

A Bromine-Tungsten light source with voltage adjustable regulator is used as the light source. The rated voltage is 12 V and the adjustable range is from 2 to 12 V. A description of the power supply of the Bromine-Tungsten lamp is given in Figure 5, while the description of the Bromine-Tungsten lamp with attachment instruction to the monochromators is given in Figure 6.



(a) (b)

Figure 5 Front (a) and back (b) panel of power supply of Bromine-Tungsten lamp



(a) (b)

Figure 6 Illustration of Bromine-Tungsten lamp attached to monochromator (a) and description of Bromine-Tungsten lamp

4.3.2 Optical Diagram of Light Source

The optical schematic of the Bromine-Tungsten light source is illustrated in Figure 7. As seen in this figure, the Bromine-Tungsten lamp, considered as a point source, is imaged by an objective mirror at the exit hole of the light source. This is equivalent to a conjugated point source emitting at the exit hole of the light source.

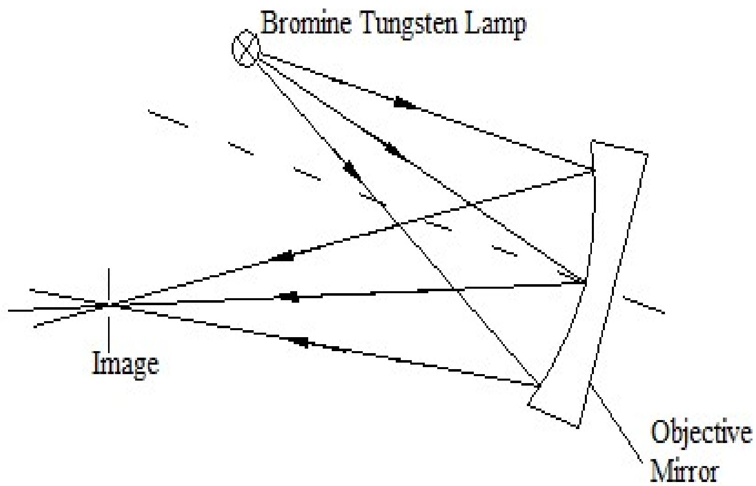


Figure 7 Optical diagram of Bromine-Tungsten light source

4.3.3 Color Temperature of Bromine-Tungsten Lamp

The following table provides work current with corresponding color temperature of the Bromine-Tungsten lamp (**Serial number: LEEB1501**).

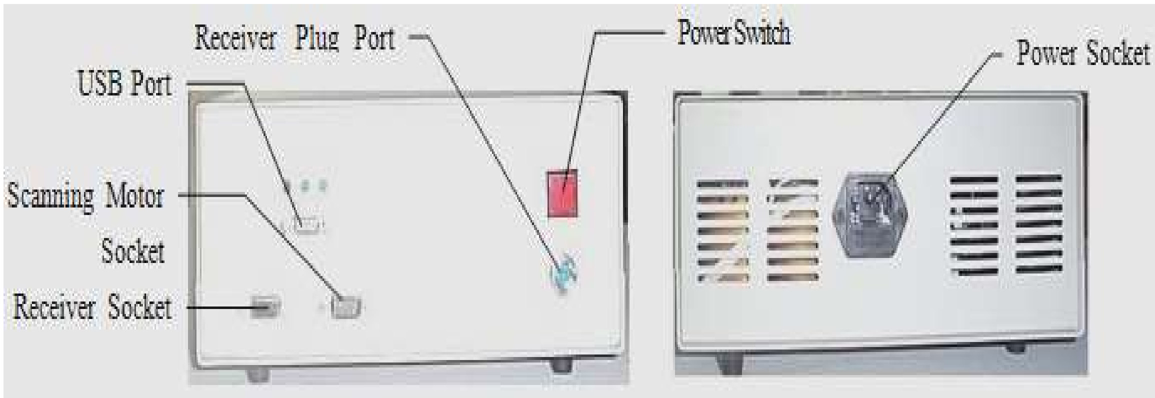
Current (A)	Color Temperature (K)
1.40	2150
1.50	2230
1.60	2330
1.70	2410
1.80	2490
1.90	2540
2.00	2610
2.10	2700
2.20	2770
2.30	2830
2.50	2940

4.4 Receiver

The spectral range of this apparatus is from 800 to 2500 nm, a Lead sulfide (PbS) detector is employed as the optical signal receiver. The monochromatic light exiting from the monochromator is intensity-modulated at 50 Hz with a chopper and then it is received by the PbS detector. The PbS detector is sealed in a transistor package filled with dry Nitrogen or other inert gases, so it can perform stably under high temperature, humid conditions.

4.5 Electrical Control Box

The operation of the spectrometer is controlled by the electrical control box shown in Figure 8. The data acquired and control feedback signal are transmitted to a computer via the USB port.



(a) (b)

Figure 8 Front (a) and back (b) panel of electrical control box

4.6 Experiments

4.6.1 Content of Experiments

1. Verify the Planck's law of radiation
2. Verify the Stefan-Boltzmann Law
3. Verify the Wien's Displacement Law
4. Study the relationship of radiation intensity between a blackbody and a non-blackbody emitter
5. Learn how to measure the radiation energy curve of a non-blackbody emitter

4.6.2 Software

There are three parts in the software package. The first part is the control software used for the scanning and data acquisition of the system; the second part is the data processing software used for curve-smoothing and calculation; the last part is specifically designed for blackbody experiments. The main functions of the third-part software include:

① Build transfer function curve

② Detect the radiation energy of emissive light source

③ Correct greybody to blackbody (emissivity coefficient ε correction)

④ Verify the radiation law of blackbody

4.6.2.1 Build Transfer Function Curve

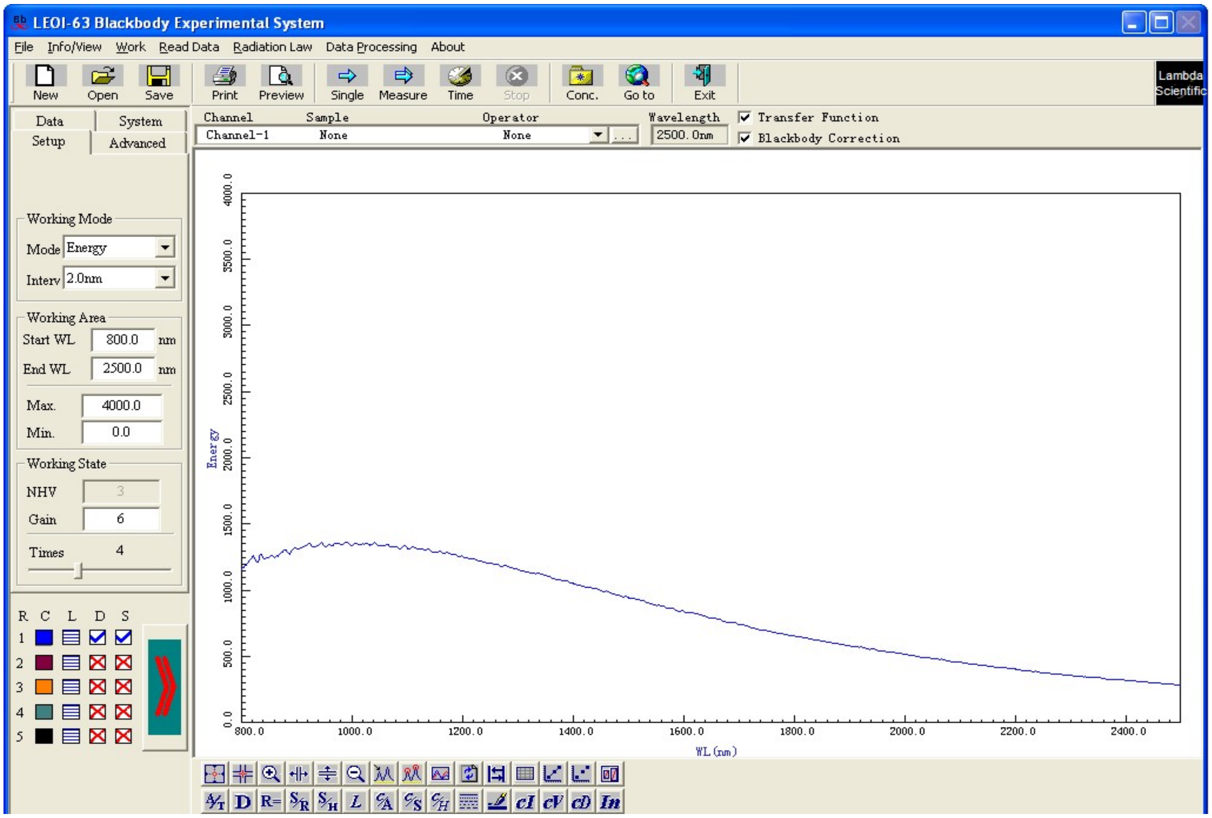


Figure 9 LEOI-63 blackbody software user interface

When recording the radiation spectrum of an emissive source, the spectrometer used is affected by different spectral response coefficients of various optical elements and receivers used by the spectrometer. The overall response curve is a function of wavelength, called the transfer function of the spectrometer. To remove the effect of system transfer function, a standard Bromine-Tungsten light source with calibrated energy curve is provided in this system. A standard energy curve of the light source at temperature 2940 K is stored in the software. Take the following procedures to build the transfer function.

1. Install the Bromine-Tungsten light source according to the instruction manual.
2. Set the work current of the light source to the value at 2940 K in the table per 4.3.3
3. Preheat the lamp for 20 minutes, make sure "☐Transfer Function" and "☐Blackbody Correction" are unchecked, and then click "Single Scanning" on menu "Work" to record the full-band spectrum of the lamp at this condition. The recorded spectral curve contains the effect of system transfer function.
4. Click the menu of "Radiation Law", and then select the command of "Calculate transfer function". The transfer function can be acquired by dividing the acquired spectrum with the known energy curve of the light source and saved automatically.

Before making a measurement, check the "☐Transfer Function" located the right upper corner of the software interface as shown in Figure 9 as "☑Transfer Function". The effect of system transfer function will be eliminated automatically from the measurement.

4.6.2.2 Correct to Blackbody

As described above, the ratio of energy radiated by any emitter to that of a blackbody at the same absolute temperature is a coefficient related to the emitter, called the emissivity coefficient of the emitter. The emissivity coefficient of Tungsten filament lamp is provided by the system software. Before measuring the radiation energy of the Bromine-Tungsten lamp, click the menu of "☐ Blackbody Correction" located at the upper right corner of the software interface shown in Figure 9 as "☑Blackbody Correction". Then, the measured radiation energy curve of the Bromine-Tungsten lamp will be corrected to the corresponding curve of a blackbody at the same temperature.

4.6.2.3 Verify the Radiation Law of Blackbody

After completing the above steps, record the radiation energy curve of the Bromine-Tungsten lamp at various color temperatures (by clicking "Blackbody Radiation Measure" on menu "Work" or "Measure" on tool bar). Save the recorded radiation curves of the light source at different color temperatures to different channels (A maximum of 5 channels can be used). Based on these results, the radiation law of blackbody can be verified as shown in Figure 10.

Figure 10 Software menu for verifying radiation law of blackbody