Spectral measuring temperature inversion study

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Abstract. In the research of multi-spectral radiation thermometry, temperature measurement depends on the line shape of spectrum radiation remittance. However, in the actual measurement, the combustion, explosion and gasification on special occasions can produce some particulate matters. These henomena will affect the linearity of spectral line directly. At the same time, the thesis also researches on the influence and revision of temperature measurement by the carbom fibre paticles whose diameter is 0.033μm in the process of loss of laser. The temperature is 1200K before revision. It becomes 2700K after revision. The research will improve the the precision of temperature measurement.

1. Introduction

Based on the linearity of the radiation spectrum and scattering characteristics of particles in the process of laser damage, this paper realizes the inversion of the spectral temperature measurement through fitting the radiation pattern of blackbody. In a certain sense, the problem that the traditional temperature measurement can not solve[1,2].

2. Blackbody radiation law

Blackbody radiation law is the formula given by Planck, a German physicist, in 1901[3].

$$M = \frac{c_1}{\lambda^5} \cdot \frac{1}{e^{\frac{c_2}{\lambda T}} - 1} \qquad (1)$$

In the formula: M-Blackbody spectral radiant exitance, unit: W/m^2; λ-Wavelength, unit: μm; T-Thermodynamic temperature, unit: K; K-Boltzmann constant, K=1.380662×10-23J • K^{-2}; h-Planck constant, h =6.63×10^{-34}J; c_1-First radiation constant, c_1=2πhc_2=3.749177×10^{-16}W • m^2; c_2—Second radiation constant, c_2=hc/k=1.141235×10^{-2}m • k。

3. Laser damage spectrum measurement

Figure 1 shows some moment in the experiment. It is easy to see that the target combusts violently and generates laser combustion wave under laser irradiation, along with the eruption of combustion products. The temperature of target and combustion products is very high and the material in the center is brighter and hotter than the surrounding material. It’s comfirmed by measuring the temperature with the thermal imager. The temperature of the center is measured as 1200K, and the ambient temperature is 230K.

Figure 2 shows that the target radiation spectrum that changes over time is measured during the experiment. It reflects that the radiant exitance increases and the peak wavelength shifts to short wavelength direction over time. The temperature of target goes up with the increasing of the laser heating time.

Fig. 1 Real-time photo of laser

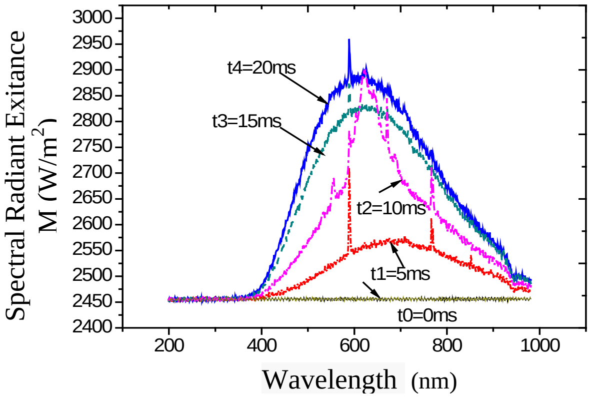

Fig. 2 Spectrum curve of laser damage

However, the thermal imager is slow when measuring the temperature and influenced by the surrounding thermal radiation. It makes that the measurement results produce deviation. Because the dust particles around can affect the spectral linearity, the temperature measurement with spectroscopy is influenced .

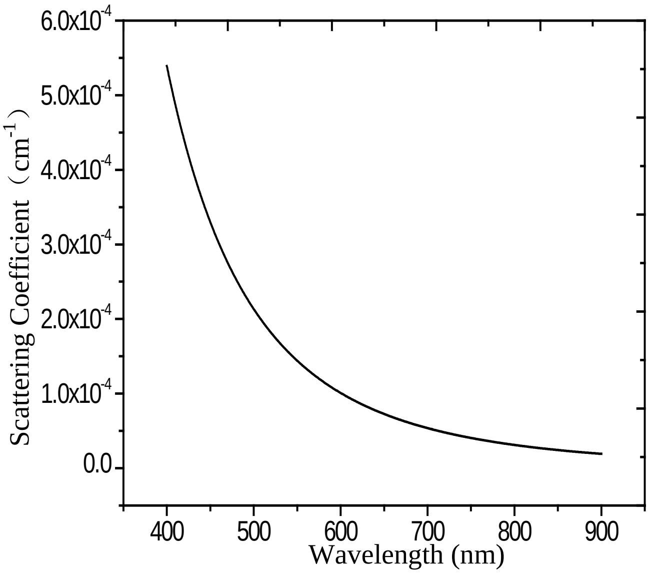

Fig. 3 Scattering coefficient of 0.033 μm in diameter of carbon fiber molecule

4. Analysis of spectral lines

Figure 2 shows that under the laser irradiation, the surface temperature of the material rises rapidly and drops after reaching a certain peak. There are several factors that influence the temperature change, including the effects of volatiles generated from the combustion of carbon fiber material and smoke around the material. In this paper, the scattering influence of soot on the spectral line is considered. At high temperature, the soot particles are mainly carbon fiber particles that have not burned completely. The diameter of the particle is 0.033 μm[4].

The influence factors of the scattering coefficient of carbon fiber particles can be seen in Figure 3. The scattering coefficient begins to be smaller from the wavelength of 400nm and is greatly affected by the wavelength between 400nm and 600mn. However, it is less affected by the wavelength after 600nm. It also shows that after burning the carbon fiber molecular on the material surface, the impact of temperature will become smaller. It is the same as the temperature change process of the spectral curve of the laser damage shown in Figure 2. It is also proved that the carbon fiber molecules have a great effect on the temperature.

5. Inversion of temperature

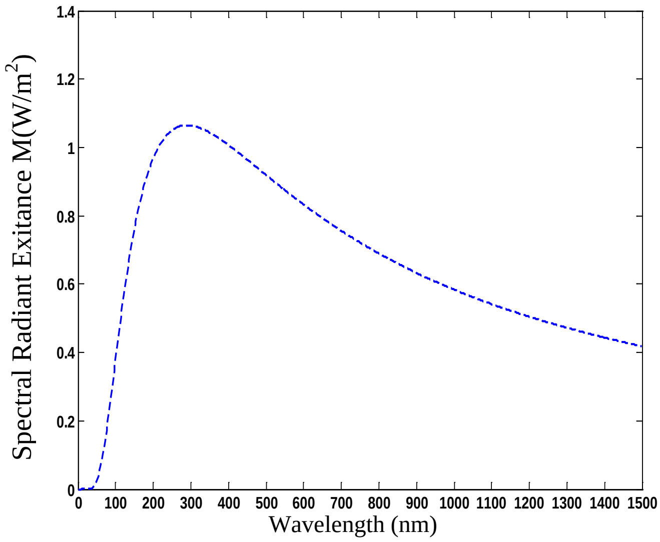

Fig. 4 Blackbody radiant exitance in 1173K

Because the blackbody radiation temperature of laser irradiation material can not be obtained, this paper tries to achieve the process of temperature inversion in order to measure the temperature of the experiment accurately.

In the laser damage experiment, the temperature measured by thermal imager is 1173K. Figure 4 shows the radiation spectrum of blackbody at the same temperature, 1176K.

The relationship between emissivity and radiation source is $\varepsilon_{\lambda T} = \frac{M_{\lambda T\_actual}}{M_{\lambda T\_blcakbody}}$. According to this, the formula can be inferred as follows:

$$M_{\lambda T\_blackbody} = \frac{M_{\lambda T\_actual}}{\varepsilon_{\lambda T}} \quad (2)$$

The spectral radiance of the actual object is equal to the result multiplied by spectral radiant exitance of blackbody at the same temperature and the spectral emissivity of the object.

The fitting least square algorithm is used here. According to the set temperature range and the precision of the temperature, find the temperature in the interval whose root mean square value is the smallest by using the method of compiling. The value is the temperature of the laser irradiation area.

The modified radiation spectrum array is $A(\lambda)$ and the black body radiation spectrum array at a certain temperature is $B_t(\lambda)$. The solution:

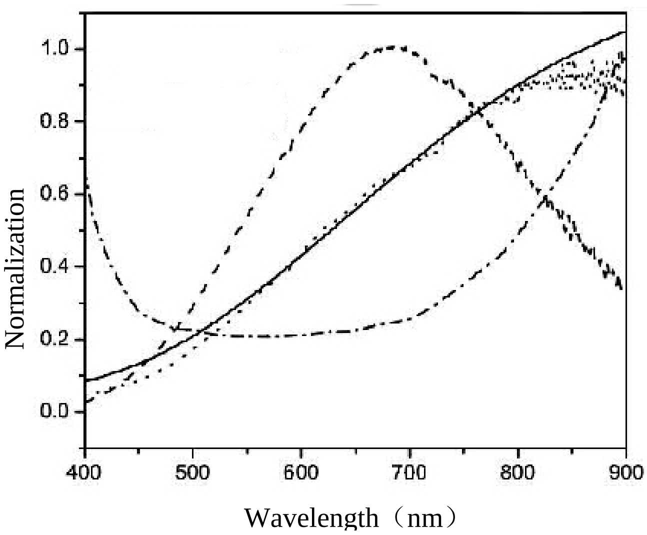

Fig. 5 Change of modified temperature

$$\sum_{i=1}^{m}\delta_i^2=\sum_{i=1}^{m}\left[A(\lambda)-B_t(\lambda)\right]^2=Min \quad (3)$$

The spectrum of t_4=20ms as an example. The least square method was used to fit the temperature of the damaged zone and the fitting results are shown in figure 5.

The long dashed line represents the measured spectra; The dot line represents the corrected spectrum; The dot line represents the corrected curve that is the scattering coefficient of the carbon fiber molecule whose diameter is 0.033μm; The solid line is the theoretical spectrum of the material at 2710K.

Figure 5 is the modified temperature. It can be seen that the agreement of the modified spectrum and the theoretical spectrum is very good. When the modified temperature is 2710K, the measured spectra and theoretical spectra have smaller deviation and is the most similar with blackbody radiation at the same temperature that of the damage zone is 2710K.

6. Conclusion

In the experiment of laser damage measurement, the temperature inversion result is 1173K without considering the scattering influence of carbon fibers. Considering the scattering influence of carbon fiber particles (0.033μm), the inversion temperature is 2710K with the least square algorithm, using scattering properties of carbon fiber particles and their transmission spectra. It is proved that this method is feasible and can be applied to the non-contact temperature measurement of laser damage, explosion, combustion, high temperature and so on.

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