Preparation of multi-wavelength infrared laser diode*

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We prepare a new type of multi-wavelength infrared laser diode with four chips, three wavelengths (865 nm, 905 nm and 1064 nm) and two working modes (pulse and single). The preparation technology of the diode includes two key processes: heat-sink and packaging processing technique to package four different chips on a same heat-sink. The experimental results show that four output peak-wavelengths of the prototype diode all possess favorable stability.

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The infrared laser source is one of the tools used to test the ranging accuracy, receiving sensitivity, anti-jamming and other performance of the laser instruments[1]. Several kinds of tunable-wavelength lasers[2-4], multi-wavelength devices[5] and multi-beam diodes[6] are developed as laser sources, while their spectral peaks are not in the infrared waveband, and their beams are not with good focal-precision. Therefore, these sources cannot be applied for infrared laser testing. According to these requirements, we develop a multi-wavelength laser diode with wavelengths of 865 nm, 905 nm and 1064 nm, as well as two working modes of pulse and single-mode in this paper. The laser diode with several infrared wavelengths can replace the corresponding single wavelength laser sources, which not only improves the universality between laser instruments, but also improves the portability of testing tools.

According to the wavelengths of several laser-instruments to be tested, four kinds of chips are prepared by the technological equipment of metal-organic chemical vapor deposition (MOCVD). Tab.1 shows the main characteristic parameters of these chips under the normal condition. To integrate different wavelengths on the same diode, we need to solve two key issues: how to design a heat-sink with optimal structure which can package different laser chips, and how to package different laser chips on the same heat-sink. Accordingly, two key processing techniques of multi-wavelength laser diode preparation technology are proposed for above issues.

To package chips λ_1, λ_2, λ_3 and λ_4 on a same heat-sink, we process the heat-sink into quadrilateral structure, and then λ_1, λ_2, λ_3 and λ_4 can be packaged around the four faces of the heat-sink. As shown in Fig.1, this technological method must meet two requirements for collimating and peak spectral precision of the multi-wavelength laser diode: (1) off-axial errors: the size of heat-sink has an upper limit, so that chips λ_1, λ_2, λ_3 and λ_4 are approximated to be coaxial when they are collimated by lens; (2) heat-extraction performance: the size of heat-sink has a lower limit, so that all boundaries of heat-sink have enough distances which can attenuate the thermal effects of all chips. Therefore, we build two theoretical models which can guide the processing technique of the heat-sink.

Tab.1 The main characteristic parameters of laser chips to be packaged

Chip	Wave-length	Mode	Vertical angle	Level angle	Radiation power
λ_1	860 nm	Single	25°	10°	10 mW
λ_2	905 nm	Pulse	25°	10°	10 W
λ_3	1064 nm	Pulse	30°	10°	7 W
λ_4	1064 nm	Single	30°	10°	10 mW

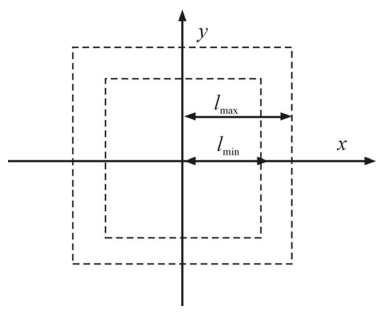

Fig.1 The upper and lower limits of the heat-sink size

The beam model of laser diode can be approximated as the fundamental mode of Gaussian beam in calcula-

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tion[7,8]. The co-axial and off-axial collimated-laser field distributions of chip $\lambda_i (i=1,\ 2,\ 3,\ 4)$ are expressed as

$$E_i^{'} = E_i^{'}[x, y, \omega_i^{'}(z), \lambda_i, f], (i=1,\ 2,\ 3,\ 4)\ , \tag{1}$$

$$E_i^{'}(y+l_{\max}) = E_j^{'}[x, y, \omega_j^{'}(z), \lambda_i, f], (j=1,\ 2,\ 3,\ 4)\ , \tag{2}$$

where f is the focal length of collimating lens, $\omega_i^{'}(z)$ is the spot radius of co-axial beam, and $\omega_j^{'}(z)$ is the waist radius of off-axial beam. Let z_0 and $z_0^{'}$ be the waist positions of co-axial and off-axial collimated beams, and the aperture angles (half-divergence angles) of co-axial and off-axial beams can be expressed as

$$\tan\theta_i^{'} = \lim_{z_0\to\infty} \frac{\mathrm{d}\omega_i^{'}(z_0)}{\mathrm{d}z_0}, (i=1,\ 2,\ 3,\ 4)\ , \tag{3}$$

$$\tan\theta_j^{'} = \lim_{z_0^{'}\to\infty} \frac{\mathrm{d}\omega_j^{'}(z_0^{'})}{\mathrm{d}z_0^{'}}, (j=1,\ 2,\ 3,\ 4)\ . \tag{4}$$

When $l \le l_{\max}$, the aperture angles of co-axial and off-axial beams will satisfy the condition

$$|\theta_j^{'} - \theta_i^{'}| \le 0.1 \text{ mrad}, (i, j=1,\ 2,\ 3,\ 4)\ . \tag{5}$$

The $l_{\max}$ is the upper limit of heat-sink size.

If chips λ_1, λ_2, λ_3 and λ_4 have not enough distances between each other, the heat generated by the current in each chip can exchange through the heat-sink when all chips are working together. Because of the thermal effect, the rise of the temperature may cause the peak wavelengths of chips to drift towards long-wave direction[9]. Let all heat of chip λ_i=(i=1, 2, 3, 4) be conducted into heat-sink, the temperature-field distribution of heat-sink can be expressed as three-dimensional heat conduction equation of

$$c\frac{\partial T_i}{\partial t} = \nabla \cdot (k\nabla T_i) + Q_i, (i=1,\ 2,\ 3,\ 4)\ , \tag{6}$$

where Q_i is the heat source function of chip λ_i, k is the thermal conductivity of heat-sink, and c is the specific heat capacity of heat-sink. To keep wavelength stability of chips λ_1, λ_2, λ_3 and λ_4, all boundary-temperatures of heat-sink need to be constant. Therefore, Eq.(6) has boundary conditions as

$$\nabla T_i = 0, (i=1,\ 2,\ 3,\ 4)\ , \tag{7}$$

$$T_i(l_{\min}) = T_0, (i=1,\ 2,\ 3,\ 4)\ . \tag{8}$$

Eq.(7) is the adiabatic condition, Eq.(8) is the isothermal condition, and T_0 is the environmental temperature. To solve Eq.(6), the initial condition needs to be set as

$$T_i|_{t=0} = T_0, (i=1,\ 2,\ 3,\ 4)\ . \tag{9}$$

With Eqs.(7-9), we can obtain the lower limit $l_{\min}$ of heat-sink through solving Eq.(6).

The optimal size of heat-sink ($l_{\min} \le l \le l_{\max}$) can be obtained through solving the optical-path and temperature-field distribution models. A quadrilateral structure of brass is processed into the heat-sink of the multi-wavelength laser diode. Fig.2 shows the front face size of the heat-sink is $2l$=1.88 mm.

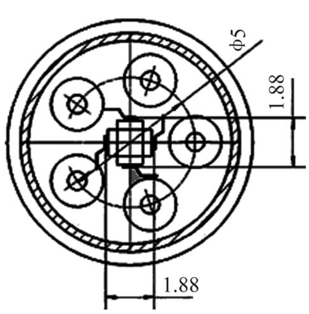

Fig.2 The processing parameters of the heat-sink with chips

To enhance the collimating precision of beams, we also need to ensure that the positions of chips λ_1, λ_2, λ_3 and λ_4 are on their focal planes. Fig.3 shows that λ_1 is aligned with the front face of the heat-sink, and λ_2, λ_3 and λ_4 are located behind. To keep integrity of the beams, the beam divergences of chips λ_2, λ_3 and λ_4 must avoid that the beam is absorbed or reflected by the heat-sink. Therefore, a vector between the chip and heat-sink is needed. The thickness of the vector depends on the half-intensity angle of the beam.

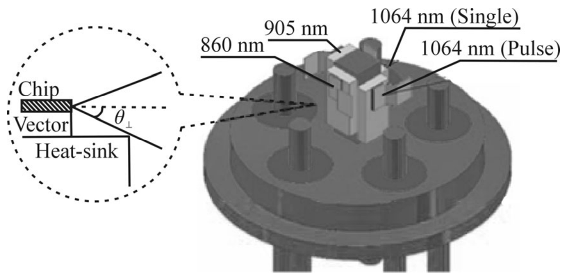

Fig.3 Schematic diagram of the heat-sink including chips of λ_1, λ_2, λ_3, λ_4 and their pins (3D layout)

The focal planes of λ_2, λ_3 and λ_4 depend on the collimating lens. The parameters of the collimating lens (the aperture, curvatures, thickness, glasses, etc.) are input into the optical design program. The program can output effective focal lengths, back focal lengths and other data of all wavelengths (visible light, 865 nm, 905 nm and 1064 nm). Based on these values, the distances between λ_1 and λ_2, λ_3, λ_4 are determined. Fig.4 shows that the distance is 0.10 mm from λ_1 to λ_2 and is 0.43 mm from λ_1 to λ_3, λ_4. To correct the axis in image/object spaces of the collimating lens, a reticle with cross-graduation should be located in the focal plane of the visible light (550 nm). Fig.5 shows the processed physical prototypes of the prepared multi-wavelength laser diode.

To test the wavelength stability of the multi-wavelength laser diode which has been prepared, the spectral properties must be calibrated by experiment when all chips are working together. Fig.6 shows the experimental apparatus composed of the pulse-generator, DC regulated-power, driving circuit, laser diode and high time-resolved spectrometer (with integral sphere). The pulse-generator and driving circuit apply two-channel pulse current (f=4 kHz, pulse width is no more than 200 ns and u_i= 15 V) for chips λ_2 and λ_3, and the regulated-power applies constant current for λ_1 and λ_4. The sampling interval is adjusted to be 1 nm, and the scanning range is adjusted to be 850-1080 nm. All chips are kept working for a long time, and the changes of spectral peaks are observed and recorded.

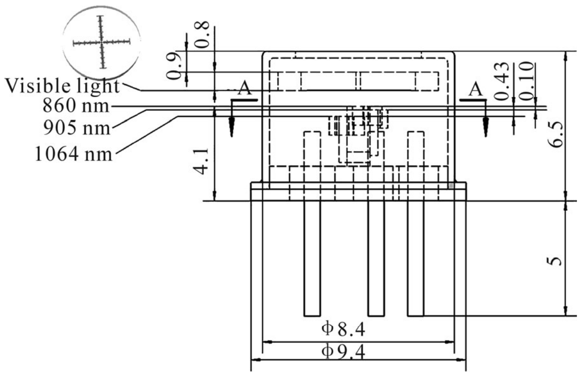

Fig.4 Packaging diagram of the multi-wavelength laser diode

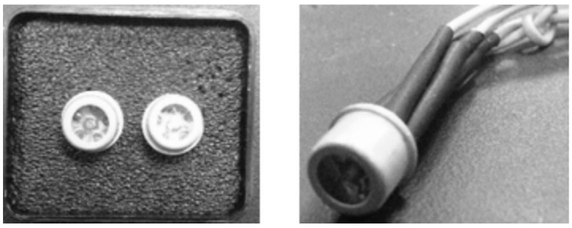

Fig.5 The physical prototypes of the prepared multi-wavelength laser diode

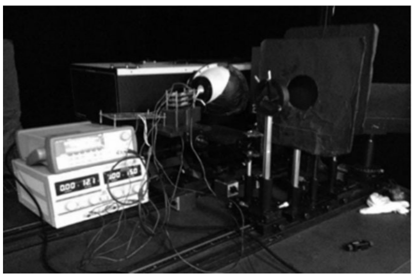

Fig.6 Experimental apparatus of the multi-wavelength laser diode for spectral calibration

Fig.7 shows the initial spectral peaks of λ_1, λ_2, λ_3 and λ_4, which are fitted by experimental data. The spectral peak of λ_1 is 859 nm, that of λ_2 is 906 nm, and that of λ_3 and λ_4 is 1061 nm. Tab.2 shows the final spectral peaks of λ_1, λ_2, λ_3 and λ_4 with 30 min working time. The experimental results show that the wavelengths of λ_1, λ_2, λ_3 and λ_4 have a good stability, i.e., the drift is only 1 nm to 3 nm in a long working time.

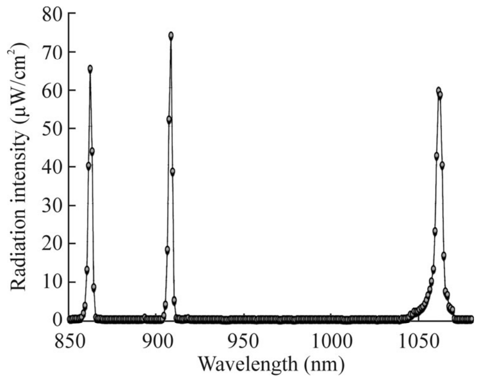

Fig.7 Initial scatter diagram fitted by spectra of λ1, λ2, λ3 and λ4 (scanning range: 850—1080 nm; sampling interval: 1 nm)

Tab.2 Initial and final spectral peaks in the calibration experiment

Chip	Wavelength	Test condition (T_c=25±3 ℃)	Ininal spectral peak	Final spectral peak
λ_1	860±5 nm	I=15 A	859 nm	862 nm
λ_2	905±5 nm	f=4 kHz, pulse width: 200 ns, u_i= 15 V	906 nm	907 nm
λ_3	1064±10 nm	f=4 kHz, pulse width: 200 ns, u_i= 15 V	1061 nm	1061 nm
λ_4	1064±10 nm	I=50 mA	1061 nm	1061 nm

In conclusion, three wavelengths (865 nm, 905 nm and 1064 nm) and two modes (pulse and single) are integrated by the multi-wavelength laser diode. Compared with the current diodes in international markets by semiconductor manufacturers, such as triple color chip, multi-beam type, etc.[10,11], the proposed multi-wavelength laser diode has three advantages: (1) the multi-wavelength laser diode has wider spectra (855—1074 nm) in the infrared waveband; (2) each beam output by the multi-wavelength laser diode has high focal-precision and spectral peak-precision; (3) the multi-wavelength laser diode can be used to test the receiver performance (accuracy, receiving sensitivity and others) of corresponding wavelength laser instruments, and it can also output high pulse repetition frequency beam or mixing-laser field to test anti-interference performance of laser instruments.

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