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Volume 10, Number 02, April 2018

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DOI: 10.1109/JPHOT.2018.2810236
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DOI:10.1109/JPHOT.2018.2810236
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Abstract: Optical parametric chirped-pulse amplification (OPCPA) provides an efficient route to push ultrafast pulses toward ultrahigh peak powers. However, in high average power regime, the unavoidable thermal effects in nonlinear crystals will intrinsically destroy the phase-matching (PM) condition, which fundamentally limit average power scaling. Here, we present a theoretical design of high average power OPCPA based on simultaneous temperature and wavelength insensitive PM. By regulating the temperature set for PM as well as the wavelength of interacting waves in lithium triborate crystal, the noncollinear angles for temperature insensitive PM and wavelength insensitive PM will coincide and thus ensures simultaneous temperature and wavelength insensitive PM condition. We investigate the performances of the proposed PM scheme in comparison with traditional wavelength insensitive noncollinear PM. Because of the larger temperature bandwidth, higher average power can be anticipated in OPCPA with the proposed PM scheme. Besides, the large spectral bandwidth also allows the amplification of sub-10 fs pulses in the visible spectral range. The proposed PM scheme will provide a promising approach in generating ultrashort pulses with high peak and average powers.

Index Terms: High power lasers, ultrafast pulses, phase matching.

1. Introduction

Ultrafast lasers have shown a great potential in varieties of fields in science and technology [1]–[6]. For example, future progress in strong-field physics [1], biology [2], micromaching [3] and material science [4] will rely on high-intensity lasers with pulse durations in femtosecond scale. Traditional Ti:sapphire-based chirped-pulse amplification (CPA) has paved the way to generate ultrashort pulses with high peak powers of 5 petawatt [7]. However, ultrashort pulses combing high peak powers with high average powers have become a crucial prerequisite for revolutionizing ultrafast science [8], [9]. Owing to the inherent thermal effects arising from energy storage in the gain media, the average power in CPA systems is generally restricted to tens of watts [10]–[12] and further power scaling becomes increasingly challenging. Alternatively, optical parametric chirped-pulse amplification (OPCPA) has great potentials in improving average power because of the instantaneous nature of nonlinear parametric process [13]–[18]. Besides, due to the
large spectral bandwidth, it enables the generation of ultrashort pulses in few-cycle regime [19]–[25]. These fascinating characteristics have made OPCPA a promising candidate to generate ultrashort pulses with both high peak and average powers.

The phase-matching (PM) condition is the main factor that governs the nonlinear parametric processes. While the PM condition can be satisfied by angle-tuning or temperature-tuning in nonlinear crystals, the dispersion effect will restrict the spectral bandwidth in OPCPA. As an effective approach, the noncollinear configuration has provided the possibility of wavelength insensitive PM and thus ultrabroadband amplification. Ultrashort pulses with durations less than 10 fs [19], [22] have been successfully demonstrated by noncollinear configuration in OPCPA. However, temperature insensitive PM condition is further required to support efficient amplification in the high average power regime. Indeed, the thermal effect remains the major problem that limits further average power scaling in OPCPA. Although the parametric process is not involved with energy storage, the absorption of the interacting waves is unavoidable, particularly in the ultraviolet and mid-infrared spectral range. For instance, in the widely used lithium triborate (LBO) crystal, while the absorption coefficient in the near-infrared region is relatively small (0.00035 cm$^{-1}$ at 1 μm [26]), it will substantially increase to 0.0031 cm$^{-1}$ at 355 nm [27] and 0.5 cm$^{-1}$ at 2.55 μm [26]. The heat accumulation in nonlinear crystals leads to nonuniform distributions of temperature and hence destroys the PM condition. This thermally induced phase-mismatch will restrict the conversion efficiency and set an inherent limitation on average power scaling.

To overcome the thermal effect, several techniques have been proposed [28]–[32]. For instance, the thermal effect can be partially alleviated by selecting appropriate nonlinear crystals [29] and/or developing novel cooling strategies [30]. However, few efforts have been made to achieve temperature insensitive PM. In fact, to achieve the optimum performance of OPCPA, delicate design of the PM parameters (e.g., operating temperature, signal wavelength, etc.) is essential. Recently, we have experimentally demonstrated that temperature insensitive PM can be realized by a noncollinear configuration in LBO crystal [33], [34]. Unfortunately, the noncollinear angle for realizing temperature insensitive PM generally differs from that for wavelength insensitive PM. Here we present a theoretical design on high average power OPCPA based on simultaneous temperature and wavelength insensitive PM scheme. Specifically, by designing the operating temperature set for PM condition, the noncollinear angles for wavelength insensitive PM and temperature insensitive PM will coincide to each other. As a result, the spectral bandwidth is similar to that in traditional wavelength insensitive PM scheme, while the temperature bandwidth will be significantly enhanced. Based on a complete model by coupling the parametric amplification with the heat transfer process, we numerically investigate the performance of the proposed scheme in high average power OPCPA. We find that, in high average power regime, the conversion efficiency in the proposed scheme will be significantly improved compared with that in the traditional wavelength insensitive PM scheme. Besides, attributing to the large spectral bandwidth in the proposed scheme, sub-10 fs pulses in the visible spectral range can be produced, which remains valid in high average power regime.

2. Underlying Principles
The PM condition (i.e., $\Delta k = 0$) is the critical factor for efficient conversion in all parametric processes. In a noncollinear OPCPA, the phase-mismatch $\Delta k$ among the interacting waves can be expressed as

$$\Delta k = \sqrt{k_p^2 + k_s^2 - 2k_pk_s\cos \alpha - k_i},$$

where $k_p$, $k_s$, $k_i$ are the wave-vectors of the pump, signal and idler, respectively. $\alpha$ is the internal noncollinear angle between the pump and signal, as shown in Fig. 1(a). To obtain a large spectral bandwidth, wavelength insensitive PM is required, which eliminates the first-order derivative of phase-mismatch with respect to the signal frequency:

$$\frac{\partial \Delta k}{\partial \omega_s} = \frac{1}{v_{g_i}} - \frac{\cos \Omega}{v_{g_s}}.$$
where $v_{gs}$, $v_{gi}$ are the group-velocities and $\Omega$ is the noncollinear angle between the signal and idler.

To achieve wavelength insensitive PM, the group-velocities of the signal and idler should be equal along the propagation direction of signal (i.e., $v_{gs} = v_{gi} \cos \Omega$), which can be satisfied by properly setting angle $\Omega$.

In high average power OPCPA, a temperature gradient (distortion) will be established in the crystal. Thus a large temperature bandwidth is further required for efficient amplification. This can be achieved with temperature insensitive PM:

$$\frac{\partial \Delta k}{\partial T} = 0.$$ (3)

Because of its feasibility in manipulating the PM, the noncollinear configuration can also be employed for temperature insensitive PM [33], [34]. Unfortunately, a dilemma occurs as the angle set for temperature insensitive PM is typically different from that for wavelength insensitive PM. Thus an additional control parameter is further needed for achieving simultaneous temperature and wavelength insensitive PM (TWPM). As is known, the PM condition relies on temperature because the refractive indices of the interacting waves are temperature dependent. Thus the noncollinear angles for temperature insensitive and wavelength insensitive PM conditions should be temperature dependent as well. By regulating the PM temperature, it is possible that temperature insensitive and wavelength insensitive PM conditions occurs at a same noncollinear angle.

LBO crystal is an attractive nonlinear crystal for OPCPA. Because of its ability to support high efficiency and broadband amplification, LBO has been widely employed in both the preamplifiers and boost amplifiers of OPCPA systems. To illustrate the performance of temperature regulation in manipulating PM, we select LBO as the nonlinear crystal, with the Sellmeier equations provided
in Ref. [35]. It is noteworthy that in our previous experimental works [33], [34], the simulation and experimental results show good agreement. This demonstrates the accuracy of the Sellmeier equations of LBO and hence provides a solid prerequisite for the current work. The third-harmonic wave of a Nd:YAG laser (\(\lambda_p = 355\) nm) severs as the pump, and the broadband seed signal (\(\lambda_s = 550\) nm) is available from the supercontinuum generation. Fig. 1(b) shows the role of the noncollinear angle \(\alpha\) in manipulating PM at the PM temperature of \(T_0 = 293.0\) K. Obviously, both \(\partial \Delta k / \partial \omega_s\) and \(\partial \Delta k / \partial T\) will increase from a negative value to a positive value with the noncollinear angle \(\alpha\). But temperature insensitive PM (\(\partial \Delta k / \partial T = 0\)) and wavelength insensitive PM (\(\partial \Delta k / \partial \omega_s = 0\)) conditions are achieved at different angles of \(\alpha = 2.3^\circ\) and \(3.6^\circ\), respectively. This suggests that simultaneous temperature and wavelength insensitive PM is not allowed near the room temperature (293.0 K). Fortunately, this problem can be solved by regulating PM temperature, as illustrated in Fig. 1(c). While the noncollinear angle for wavelength insensitive PM is relatively stable at different PM temperatures, it will increase with the temperature for temperature insensitive PM. In particular, at the PM temperature of 337.5 K, the angles for temperature insensitive PM and wavelength insensitive PM coincides, implying the achievement of TWPM. The experimental realization of the TWPM requires optimizing both the noncollinear angle and PM temperature. This can be simply achieved by the following procedures: Firstly, the wavelength insensitive PM can be realized by optimizing the noncollinear angle, which is characterized by the maximum spectral bandwidth. Secondly, since the noncollinear angle for wavelength insensitive PM is nearly independent of the PM temperature (as indicated in Fig. 1(c)), the wavelength insensitive PM remains valid when the PM temperature is tuned to achieve temperature insensitive PM. Thirdly, the optimal PM temperature, corresponding to temperature insensitive PM, can be obtained when the temperature bandwidth is maximized. It is noteworthy that the pump wavelength of 355 nm is preferred to constitute TWPM compared with the commonly-used pump wavelength of 532 nm. Because of the PM property of LBO crystal, the PM temperature should be designated at an extremely low value (<50 K) to achieve TWPM for the pump wavelength of 532 nm. This inevitably requires careful design of cooling strategy and hence makes the laser systems more complex. In contrast, TWPM can be realized by simply heating the crystal with a crystal oven for the pump wavelength of 355 nm. On the other hand, due to the high third-harmonic generation efficiency [36], the pump laser at 355 nm is also a promising candidate for high average power OPCPA systems [9]. Thus we choose the pump wavelength as 355 nm in following discussions. In fact, owing to the feasibility of noncollinear configuration, TWPM can be achieved at different signal wavelength in LBO crystal. As shown in Fig. 1(d), TWPM can be constituted as long as the noncollinear angle and PM temperature vary with the signal wavelength. It is noteworthy that when the signal wavelength is relatively short (e.g., from 430 nm to 465 nm), the wavelength of the corresponding idler wavelength lies in the mid-infrared range (from 1.5 \(\mu\)m to 2 \(\mu\)m). In other words, it is also possible to generate ultrashort pulses with high average-power in the mid-infrared range with TWPM.

To illustrate the advantages of the TWPM at \(T_0 = 337.5\) K over the traditional wavelength insensitive PM at \(T_0 = 293.0\) K, we first study the phase-mismatch \(\Delta k\) and small-signal gain \(G\) versus the signal wavelength and temperature deviation, as shown in Fig. 2. At this wavelength, not only \(\partial \Delta k / \partial \omega_s\) is eliminated with the noncollinear configuration, but also the second-order term \(\partial^2 \Delta k / \partial \omega_s^2\) is negligible due to the properties of the “magic PM” [37]. Thus the dependence of \(\Delta k\) on the signal wavelength is cubic for both the wavelength insensitive PM and TWPM, as shown in Fig. 2(a). Whereas the wavelength dependent phase-mismatches in the wavelength insensitive PM and TWPM are nearly identical, the temperature-dependent phase-mismatch will be significantly alleviated in the TWPM, as illustrated in Fig. 2(b). Since the first-order term \(\partial \Delta k / \partial T\) is vanished in the TWPM, \(\Delta k\) is then dominated by the second-order term \(\partial^2 \Delta k / \partial T^2\), which is considerably smaller compared to that determined by \(\partial \Delta k / \partial T\) in the wavelength insensitive PM.

The small signal gain is an important factor for evaluating the performance of the amplifier, which can be expressed as [14]

\[
G = \frac{1}{4} \exp \left\{ 2 \left[ g_0^2 - (\Delta k/2)^2 \right]^2 L \right\}. \tag{4}
\]
Fig. 2. The phase-mismatch $\Delta k$ versus (a) signal wavelength and (b) temperature deviation at the PM temperature of $T_0 = 293.0$ and 337.5 K, respectively. The small-signal gain $G$ versus (c) signal wavelength and (d) temperature deviation around the PM temperature of $T_0 = 293.0$ K and 337.5 K, respectively. Type-I PM in XY plane of LBO crystal is assumed, with the effective nonlinear coefficient $d_{\text{eff}}$ of 0.59 pm/V. The noncollinear angle $\alpha$ is fixed at 3.6°. The crystal length is 30 mm and the pump intensity is 3.0 GW/cm$^2$. The pump and signal wavelengths are 355 nm and 550 nm, respectively.

where $L$ is the crystal length. $g_0 = d_{\text{eff}} \sqrt{2\omega_i \omega_s I_p / (n_p n_s n_i \varepsilon_0 c^3)}$ is the parametric gain coefficient, $d_{\text{eff}}$ is the effective nonlinear coefficient, $\omega_i$ is the idler frequency, $I_p$ is the pump intensity, $n_p$, $n_s$, $n_i$ are the refractive indices of pump, signal and idler waves, respectively, $\varepsilon_0$ is the permittivity of vacuum and $c$ is the velocity of light in vacuum. Due to the similar wavelength dependent phase-mismatch, the small signal gain versus the signal wavelength will be comparable in the wavelength insensitive PM and TWPM accordingly, as shown in Fig. 2(c). In contrast, a large temperature bandwidth of 41.1 K (full width at the half maximum, FWHM) can be achieved in the TWPM, which is improved by a factor of 4.3 compared to 9.5 K in the wavelength insensitive PM, as shown in Fig. 2(d).

3. OPCPA Performances With TWPM

3.1 Numerical Models

The analytical results of the small signal gain provide a good estimation of the temperature and spectral bandwidths, but key factors such as walk-off, diffraction and saturation effects are all neglected. In contrast, numerical methods will provide a more accurate solution to OPCPA process. To illustrate the performance of TWPM in high power OPCPA, we implement numerical simulations based on a complete model by integrating the parametric amplification with heat transfer process. In our model, the temperature dependent phase-mismatch, dispersion effects, noncollinear geometry and diffraction are all taken into account, as well as the inhomogeneous distribution of temperature inside the crystal.
Based on the slowly varying envelope approximation, the coupled-wave equations governing the nonlinear interactions are expressed as [38]

\[
\frac{\partial A_p}{\partial z} + \frac{\partial A_p}{\partial x} + \frac{1}{2} \frac{\partial^2 A_p}{\partial x^2} + \sum_{j=1}^{j=4} \left( -\frac{\partial A_p}{\partial t} \right) \frac{k_{ij}^2}{\partial t^2} = -\frac{i\omega_p \alpha_{p \text{eff}}}{n_p c} A_p A_i \exp [i \Delta k(T) z]
\]

\[
\frac{\partial A_s}{\partial z} + \frac{\partial A_s}{\partial x} + \frac{1}{2} \frac{\partial^2 A_s}{\partial x^2} + \sum_{j=1}^{j=4} \left( -\frac{\partial A_s}{\partial t} \right) \frac{k_{ij}^2}{\partial t^2} = -\frac{i\omega_s \alpha_{s \text{eff}}}{n_s c} A_p A_i \exp [-i \Delta k(T) z]
\]

\[
\frac{\partial A_i}{\partial z} + \frac{\partial A_i}{\partial x} + \frac{1}{2} \frac{\partial^2 A_i}{\partial x^2} + \sum_{j=1}^{j=4} \left( -\frac{\partial A_i}{\partial t} \right) \frac{k_{ij}^2}{\partial t^2} = -\frac{i\omega_i \alpha_{i \text{eff}}}{n_i c} A_p A_s \exp [-i \Delta k(T) z]
\]

\[
\Delta k(T) = \frac{\partial \Delta k}{\partial T} \Delta T + \frac{1}{2} \frac{\partial^2 \Delta k}{\partial T^2} \Delta T^2,
\]

where \( A_p, A_s, A_i \) are the envelopes (angular frequencies) of the pump, signal and idler waves, respectively. \( \rho_p \) is the walk-off angle of the pump and \( \beta \) is the noncollinear angle between pump and idler. \( k_{p0}, k_{s0}, k_{i0} \) are the wave-vectors and \( k_{ij}^{(1)}, k_{ij}^{(2)}, k_{ij}^{(3)} \) are the dispersion coefficients. To simulate the pulse evolutions accurately, the dispersion is considered up to the fourth-order term, including the group-velocity mismatch (GVM), group-velocity dispersion (GVD), third-order dispersion (TOD) and fourth-order dispersion (FOD). \( z \) is the propagation direction and \( x \) is the transverse coordinate that involves the noncollinear configuration, as shown in Fig. 1(a). \( \Delta k(T) \) is the thermally induced phase-mismatch, which can be calculated with Eq. (8) if the temperature distribution is known. In the steady-state regime, the temperature distribution is dominated by the heat transfer equation [39]:

\[
\nabla^2 T = -\frac{Q}{\kappa},
\]

where \( \kappa = 3.5 \text{ W/(m-K)} \) is the thermal conductivity coefficient and \( Q \) is the heat source density:

\[
Q = \frac{1}{2} c \varepsilon_0 \left( \alpha_p n_p |A_p|^2 + \alpha_s n_s |A_s|^2 + \alpha_i n_i |A_i|^2 \right),
\]

where \( \alpha_p, \alpha_s, \alpha_i \) are the absorption coefficients of the pump, signal and idler waves, respectively. For traditional lateral convection mechanism, the end faces can be assumed as adiabatic since the convection coefficient of the lateral surface is orders of magnitude larger compared to the natural convection coefficient of the end faces [40], and for the lateral surface we use the constant natural convection coefficient [41]. To numerically solve the equations, we adopt the symmetric split-step Fourier transform and fourth-order Runge-Kutta methods for solving the OPCPA process, while the heat transfer equation is dealt with finite difference method. The main parameters in the simulations are list in Table 1.

### 3.2 Results and Discussions

We consider an ultrabroadband OPCPA. The pulse durations (FWHM) of the pump and chirped signal pulses are 15 and 10 ps in Gaussian profiles, respectively. The beam diameters (FWHM) of the pump (10-order super-Gaussian profile) and signal (Gaussian profile) are same of 5 mm. The peak intensity of the pump pulse is fixed at 4.5 GW/cm², which is far below the damage threshold of LBO crystal. First, we optimize the operating parameters for the amplifier, with the intensity ratio \( I_p/I_s \) fixed at 10⁶. The temporal walk-off between the signal and pump will affect the conversion efficiency by limiting the interaction length. This effect could be partially compensated by introducing temporal delay between the pump and signal before amplification, as shown in Fig. 3(a). Clearly, the maximum conversion efficiency occurs with a temporal delay of ~2 ps (with the pump pulse in advance). On the other hand, the spectral bandwidth of seed signal will influence both the efficiency.
Table 1
Simulation Parameters for OPCPA in LBO Crystal ($\lambda_p = 355$ nm, $\lambda_s = 550$ nm).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Wavelength insensitive PM</th>
<th>TWPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d_{\text{eff}}$ (pm/V)</td>
<td>0.59</td>
<td>-12.7</td>
</tr>
<tr>
<td>GVM$_{\text{si}}$ (fs/mm)</td>
<td>0</td>
<td>191.7</td>
</tr>
<tr>
<td>GVD (fs$^2$/mm)</td>
<td>-12.4</td>
<td>497.5</td>
</tr>
<tr>
<td>TOD (fs$^3$/mm)</td>
<td>192.7</td>
<td>471.8</td>
</tr>
<tr>
<td>FOD (fs$^4$/mm)</td>
<td>471.8</td>
<td>0.37</td>
</tr>
<tr>
<td>$\frac{\partial \Delta k}{\partial T}$ [rad/(cm·K)]</td>
<td>$-8.55 \times 10^{-3}$</td>
<td>$-8.57 \times 10^{-3}$</td>
</tr>
<tr>
<td>$\frac{\partial^2 \Delta k}{\partial T^2}$ [rad/(cm·K$^2$)]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3. (a) Conversion efficiency (pump to signal) versus the temporal delay between the pump and signal in the TWPM. The crystal length is fixed at 20 mm. The ideal non-thermal case is assumed, which is free from thermally induced phase-mismatch. The peak intensities of the incident pump and chirped signal are fixed at 4.5 GW/cm$^2$ and 4.5 kW/cm$^2$, respectively. The incident seed bandwidth is fixed at 100 nm. (b) The amplified signal bandwidth (left) and conversion efficiency (right) versus the seed bandwidth, with the temporal delay between the pump and signal fixed at 2 ps.

Fig. 4 compares the efficiency evolution versus crystal length in the wavelength insensitive PM and TWPM. In the ideal non-thermal case, the conversion efficiency will increase with the crystal length and similar efficiency of 21% will be observed at the output of the crystal for both wavelength insensitive PM and TWPM. However, when the thermally induced phase-mismatch is involved in high average power regime, the conversion efficiency will drop obviously in the wavelength insensitive PM. For example, the efficiency will decrease to 17% and 12% for a pump power of 500 W and 1000 W, respectively. In contrast, the conversion efficiency in the TWPM is robust with respect to the average power attributing to the property of temperature insensitive PM condition, as shown in Fig. 4(b).

In addition to the conversion efficiency, the thermally induced phase-mismatch will also influence the signal spectrum. Because of the similar wavelength dependent phase-mismatch, the signal spectra for the wavelength insensitive PM and TWPM are nearly same to each other in the ideal non-thermal case. Nevertheless, when the thermally induced phase-mismatch is involved in the wavelength insensitive PM, less spectral components experience high gain and bandwidth narrowing will occur in high-average power regime, as shown in Fig. 5(a). In contrast, owing to the...
Fig. 4. Evolutions of conversion efficiency versus crystal length at several pump powers for (a) wavelength insensitive PM and (b) TWPM. The “ideal” case denotes the ideal non-thermal case, which is free of the thermally induced phase-mismatch distortions. The peak intensities of the incident pump and chirped signal are fixed at 4.5 GW/cm$^2$ and 4.5 kW/cm$^2$, respectively. The spectral bandwidth of the seed signal is fixed at 100 nm and the temporal delay between the pump and signal is 2 ps.

Fig. 5. The spectra of the amplified signal at several pump powers in (a) wavelength insensitive PM and (b) TWPM. The compressed signal pulses at several pump powers in (c) wavelength insensitive PM and (d) TWPM, corresponding to the spectrum in (a) and (b), respectively. The intensity is normalized to that of the ideal non-thermal case. The peak intensities of the incident pump and signal are fixed at 4.5 GW/cm$^2$ and 4.5 kW/cm$^2$, respectively. The spectral bandwidth of the seed signal is 100 nm.

temperature insensitive property in the TWPM, the amplified signal spectrum in the high average power regime is nearly identical to that in the non-thermal case, as shown in Fig. 5(b). Attributing to the large amplified bandwidth, sub-10 fs pulses can be generated in the wavelength insensitive PM and TWPM for the non-thermal case. However, the performance of the wavelength insensitive PM will be deteriorated in the high average power regime. As shown in Fig. 5(c), not only the pulse...
duration increases with a narrowed signal bandwidth, but also the intensity will decrease because of a lower conversion efficiency. This will place an inherent limitation on both peak and average power scaling. In comparison, such problem can be effectively resolved by the TWPM. As illustrated in Fig. 5(d), both the pulse duration and peak intensity are robust against the average power, which may pave the way to generate ultrafast pulses with both high peak and average powers.

To illustrate the performance of the TWPM at higher powers, we investigate the dependence of the conversion efficiency and signal power on the pump power, as shown in Fig. 6. Because of the severer thermally induced phase-mismatch, the conversion efficiency will dramatically decrease with the pump power in the wavelength insensitive PM. In contrast, the conversion efficiency will be significantly improved via the TWPM. Although the conversion efficiency in TWPM will also slightly decrease at higher pump powers attributing to the more heat load and hence severer thermally induced phase-mismatch, it is still higher than its counterpart in wavelength insensitive PM. For example with a pump power of 2 kW, the conversion efficiency in TWPM can still reach 18%, which is more than 2 times that in wavelength insensitive PM. The high conversion efficiency will improve the signal power accordingly, as shown in Fig. 6(b). Currently, the average power of OPCPA is limited to 53 W [32]. Based on the TWPM, the average power can be successfully boosted to several hundreds of watts owing to the temperature insensitive PM condition.

4. Conclusion

In conclusion, we proposed a theoretical design of high average power OPCPA based on simultaneous temperature and wavelength insensitive PM scheme. This scheme is realized by delicately designing the OPCPA parameters (e.g., operating temperature, signal wavelength, etc.), which allows effective manipulation of the PM condition. Compared with the traditional wavelength insensitive PM scheme that operates at room temperature, the proposed temperature and wavelength insensitive PM scheme can improve the temperature bandwidth by a factor of 4.3, while maintaining the capability of broadband amplification. In high average power regime, the temperature and wavelength insensitive scheme is superior in terms of both conversion efficiency and spectral characteristics. Because of its ability to support broadband amplification and large temperature bandwidth, the temperature and wavelength insensitive PM scheme may provide a promising way to generate ultrafast laser with both high peak and average powers.
References


