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مطالعه و شبیه‌سازی ترکیب طیفی باریکه‌های لیزر دیسک نازک

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چکیده:- امروزه روش ترکیب باریکه‌ای از روش‌های پرطرفدار برای دستیابی به توان‌های بالا با حفظ همزمان کیفیت باریکه است. با توجه به محدودیت‌های ذاتی محیط بهره و المان‌های اپتیکی مورد استفاده در رزوناتور لیزر، دستیابی به توان‌های خروجی بالا با یک تک لیزر امکانپذیر نیست، و حد توانی وجود دارد که فراتر از آن مشکلاتی مانند اثرات گرمایی شروع به کاهش توان و کیفیت باریکه‌ی خروجی می‌کنند. ترکیب باریکه‌ای به عنوان راه‌حلی برای این مشکل مطرح بوده است. در این مطالعه، به بررسی و شبیه سازی ترکیب طیفی باریکه‌های لیزر دیسک پرداخته شده است. نتایج شبیه سازی حاکی از آن است که ترکیب طیفی باریکه‌های لیزر منجر به افزایش توان خروجی و درخشایی باریکه‌ی نهایی شده است. درخشایی باریکه‌ی ترکیبی تقریبا با مجموع درخشایی تک باریکه‌ها برابر است. این امر نشان‌دهنده‌ی بهره‌ی ترکیب قابل قبول در این فرایند می‌باشد. در مقایسه با کیفیت باریکه‌های لیزری قبل از ترکیب، کیفیت باریکه‌ی نهایی نیز حفظ شده است.

کلید واژه: درخشایی، ترکیب طیفی باریکه، توری خراشان، پراش.

Study and simulation of Wavelength Beam Combining in Thin Disk Lasers

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Abstract Todays beam combining is among the most popular techniques for attaining high powers with simultaneously good beam quality. Due to the inherent limitations with the laser gain medium and also with the optical elements in the laser resonator, it is not feasible to achieve a desirable high powers and qualities with a single laser, and there is a power limit, that it is not possible to go beyond, and major difficulties, like thermal effects, starts to degrade the power and quality. Beam combining is a solution to this problem. In this study, we have simulated the method of spectral beam combining. Findings of our simulation indicate the power and brightness scaling of the combined beam with the number of component beams. The brightness of the combined beam is about twice that of the individual beams. On the other hand, the quality of the combined beam is within acceptable range, and is comparable to the qualities of the constituent beams.

Keywords: Brightness, wavelength beam combining, blazed grating, diffraction,

1. Introduction

Achieving high powers of laser beams with sufficiently good beam quality is always in the focus of laser engineers' researches and attempts. But, on the other hand, there is an intrinsic problem regarding this goal; we cannot scale a laser to arbitrarily high powers while simultaneously maintaining its beam quality. For example in solid state lasers increasing pump power beyond a threshold value would cause thermal distortions, such as thermal lensing, which in turn drastically degrades the beam quality of the output beam [1,2]. The same problem arises considering the damage threshold of optical components [1-3]. In search for a method of scaling high power lasers, Beam Combining is a remedy for those obstacles. Beam combining provides a useful tool to obtain higher power and brightness beyond those available with single lasers. This technic obviates the need for high pump powers, and high damage threshold optical devices. Since there is lower thermal heat due to lower pump powers, the problem of quality degradation is not the case in this method [4-5].

There are three general categories of beam combining; Incoherent Beam Combining (IBC), Coherent Beam Combining (CBC), and Wavelength Beam Combining (WBC), each imposes their own requirements on the constituent lasers [1, 3]. Contrary to the IBC, in the coherent method all lasers are in phase and their spectra are the same, so their outputs interfere constructively, and the combined brightness is N times that of the individual lasers. However, this method is more challenging, because complicated devices are needed to maintain the phase relation between the elements [1].

In wavelength beam combining there is no need to control phase between elements, and they operate in their own well-tuned wavelength. Combining of laser beams occur in the far field by means of dispersive element, mostly diffraction grating. Again, this method results in the scaling of power and brightness of the combined beam [1, 2, 3].

In this study we have examined the method of wavelength beam combining. To do this, the procedure of spectral combining has been simulated. As mentioned above, the dispersive optical element is the core element in this method. Simulation of diffraction grating was specifically important in this research, and we have evaluated the diffraction efficiency of diffraction orders, with special focus on Littrow-blazed diffraction gratings.

2. Theory and Model

We have used the open loop configuration for wavelength beam combining of two thin disk laser beams [2, 4]. The experimental set up of the simulation is shown in Fig. 1. The two wavelengths are forced to overlap on the grating, and then to propagate in the same direction to add constructively in the far field. Generally a transform lens is used to determine the wavelength dependent incidence angle of each beam on the grating [4]. However, due to technical considerations we have used two perpendicular mirrors, placed at 45°, to bring the disk beams so close together, that they hit the grating at a very small angle. Using this configuration, the diffracted beams will diffract at the same direction and overlap in the far field.

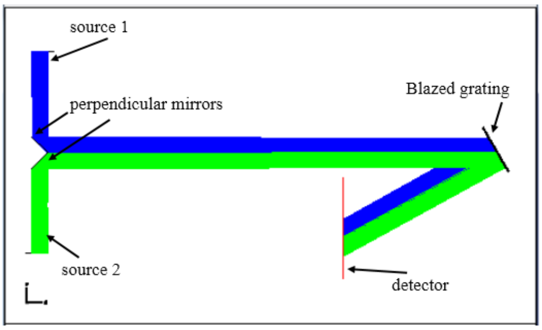

Fig. 1: the optical set up used to simulation of WBC.

As we said before, the main element in WBC is the diffraction grating. When monochromatic light is incident on a grating surface with angle α, it is diffracted into discrete directions along a set of angles β_m. The grating equation, $m\lambda = d(\sin\alpha + \sin\beta_m)$, describes the angular location of the diffraction orders. Here m is the diffraction order and d is groove spacing [6, 7].

But, of course, the situation is a bit complicated. It follows from the grating equation that $\beta_0 = \alpha$, corresponds to the zeroth order, and most of the power propagates through this direction. Due to efficiency considerations, we prefer to shift power from this useless order into one of higher order spectra. This is possible simply by ruling grooves with a controlled shape. Now most gratings are of this shaped or blazed profile [6, 7]. We know that the location of the peak in the single facet

diffraction pattern corresponds to specular reflection off that face. It is governed by the blaze angle, which is the angle between the grating surface normal and the groove surface normal [6]. For specular reflection off the groove surface we have $\alpha - \beta_r = -2\gamma$, and for normal incident wave most of the diffracted power is concentrated about $\beta_r = -2\gamma$. This will correspond to a particular nonzero order when $\beta_m = -2\gamma$; in other words, the grating equation for blazed grating turns to $d\sin(-2\gamma) = m\lambda$ for the particular order and wavelength [6].
Another more interesting point, which this one is also related to the diffraction efficiency, is the Littrow configuration. We force the system to diffract most of the incident power along the angle β_m which is near the incidence angle ($\beta_m = \alpha$) for the desired order *m*. under these conditions, dispersion becomes $D = {}^{2}\!/_{\lambda_c} \tan\beta_m$ [2, 7]. We choose for a given value of grating dispersion the angle of incidence α such that only the first and zeroth orders are allowed to propagate. By this the grating efficiency can be increased to its highest theoretical values [2, 7].

3. Results

In this study we have simulated the beam combining procedure, and specifically focused on the simulation of diffraction grating as the main element of the WBC technic. We started with normal plane grating to see how a grating distributes the incident power into different orders. In Fig. 2 the results of simulation for a plane grating have been provided, both at the centre wavelength of 1030 nm and a spectral interval around it. The problem with plane gratings is that they distribute the incident energy over the diffracted orders, hence reducing the diffraction efficiency. On the other hand, as illustrated in Fig. 2 most of the incident power undergoes specular reflection (the zeroth order) off the grating surface. This zero order diffraction is totally wasted, at least for our purpose, and we need to transfer energy from this useless order to non-zero orders. This is the essence of the concept of blazed gratings.

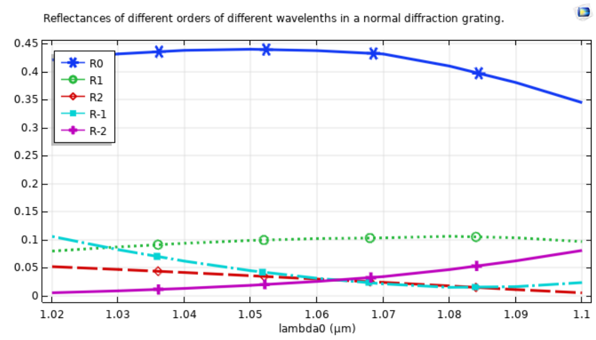

Fig. 2: Spreading of incident power over the diffraction orders in the plane grating.

To transfer the energy from the zero order to a desired non-zero order we need to modify the geometry of grating [6, 7]. This modification results in that most of the incident power goes into the desired (usually m = ±1) order. We call this type of grating a blazed grating [6, 7]. In Fig. 3 the diffraction efficiencies for different orders in an m = -1 Littrow-blazed grating are computed. As it is obvious from our efficiency plots, at half the blaze wavelength λ_b, the diffracted efficiency will be virtually zero, since for this wavelength the second order efficiency will be at its peak. Normally about 50% efficiency is obtained from 0.7λ_b to 1.8λ_b [4]. This conclusion is very important, because of this efficiency interval, it is common to blaze the grating for the central wavelength (of the spectrum to be combined) and consider the nearby wavelengths within the efficiency curve.
For the final state of this study, these diffraction efficiencies have been used to simulate combining of laser beams in Zemax. As our simulation indicates, spatial overlap of laser beams result in increasing the power of combined beam. However, using normal plane grating distributes the incident power over the multiple orders, and this leads in a remarkable reduction in combining efficiency. This is why we insisted on using blazed gratings. To simulate blazed grating in Zemax, we introduced the computed diffraction efficiencies into the Zemax, and combined the two beams geometrically with their diffraction orders being weighted according to their reflectance coefficients. In Fig. 4 the spectral combining of the two wavelengths 1025 nm and 1035 nm is plotted. The grating was blazed in m = -1 for λ = 1030 nm. As it is evident from fig. 4, brightness of the combined beam (right) is 486.3 W/cm^{2}steradian, and this is twice the non-combined individual beams brightness of 267.5 W/cm^{2}steradian (left). On the other hand, the combined beam is a well-shaped Gaussian profile, and this lead to quality preservation of the combined

beam. Some researchers have reported the spectral combined beam with beam quality slightly bigger than that of the Gaussian beam [5, 6].

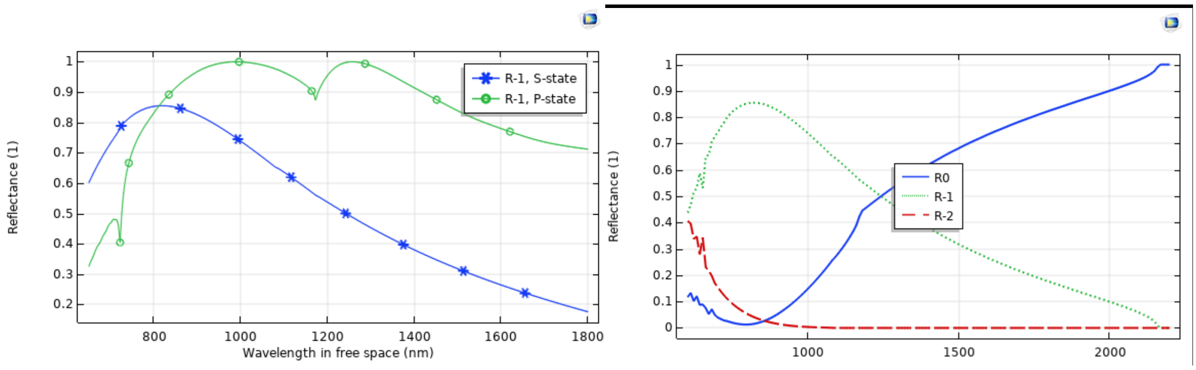

Fig. 3. (Right) reflectance of diffraction orders in the m = -1 Littrow-blazed grating, (left) reflectance in S and P polarizations.

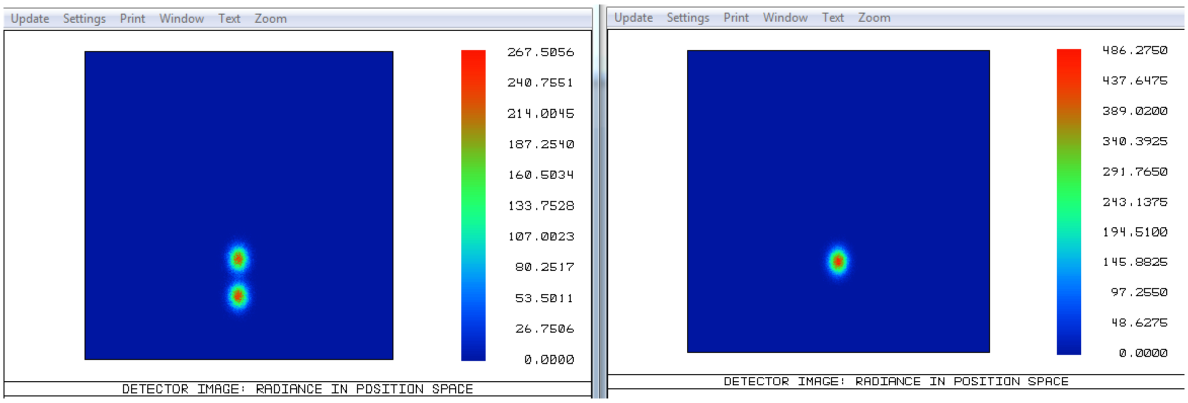

Fig. 4: The spectral combining of two wavelengths 1025 nm and 1035 nm using the blazed grating.

4. Conclusion

Spectral beam combining is a straight-forward technic for power scaling. This method does not suffer from the inherent complexities related to phase matching and phase controlling of the component emitters in the Coherent Beam Combining. However, wavelengths of the beams always need to be well-tuned. This method uses rather simple optical configuration to achieve power scaling while maintaining the final beam quality within the acceptable range. Findings of our simulations clearly prove that using this method for power scaling of disk lasers is practical, and it can lead to reliable results. However, there is some limitations inherent to this method, including the high-threshold optical powers, and the number of elements that can be combined with this method.

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