Optimisation of SHG for high-brightness semiconductor laser diode radiation with large aberrations

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The optimisation of SHG by semiconductor diode lasers is treated by taking into account three items: A SHG-merit function for using quasi phase matching, the optimisation of micro optics and possible changes of the design parameters of the lasers. Examples are given.

1 Introduction

The power levels between 0.4 and 7.7 W [1,2] of high power high brightness infrared semiconductor laser diodes stimulate the second harmonic generation (SHG) to obtain green or blue radiation. These high power lasers emit light with strong ellipticity and/or a large astigmatism. Using a minimum number of commercially available optical elements for the micro-optics between laser and a nonlinear optical crystal (here periodically poled LiNbO$_3$) [3], residual aberrations cannot avoided in the illumination of the crystal. Therefore, a prerequisite is a SHG based optical merit function including these aberrations.

2 Merit function with elliptical and astigmatic aberrations

The usual transformation rate of rotational symmetrical Gaussian beams [4] into SHG contains a form factor h, which can be generalized to an astigmatic elliptical beam with the waist radii ω_{0x} and ω_{0y} and the astigmatic distance μ:

$$h = \frac{u}{2}\left|\int_{-u}^{u} d\tau \, \frac{\exp\left\{ i\, 2\Delta k L u \left(\tau - 2 z_{LK}\, u\, L^{-1}\right)\right\}}{\sqrt{a^{+} a^{-}}}\right|^{2} \quad (1)$$

with $u = \dfrac{L\lambda}{2\pi\,\omega_{0x}\,\omega_{0y}}$,

$$a^{\pm} = 1 + i\left\{\tau + \frac{u}{L}\left[\pm\mu - 2z_{LK}\right]\right\}\left(\frac{\omega_{0y}}{\omega_{0x}}\right)^{\pm 1},$$

L the length of the crystal, λ the wavelength of light, Δk the mismatch of the wave vectors and z_{KL} the length deviation from the centering of the beam waist of the fundamental frequency in the crystal centre. A vignetting factor can be added for the case, that the thickness of the periodic poled layer cuts off parts of the incident Gaussian beam. In usual cases, the vignetting factor is equal to 1 and the transformation efficiency in figure 1 depends mostly on the product $\omega_{0x}\,\omega_{0y}$ with the 45°-straight line as symmetry axis (blue line). Therefore, a rotational symmetrical Gaussian beam makes the optimum efficiency. But, if a low cost micro optics is able to yield an ellipticity $\omega_{0x}\,\omega_{0y}^{-1} = 2$ (red line), then we see a decrease of efficiency by 7.5 % because of modified focussing.

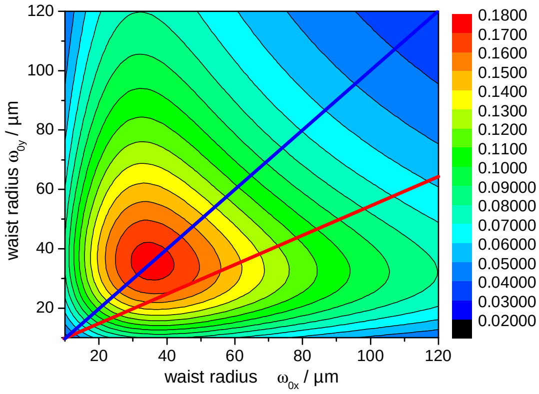

***Fig. 1** Transformation efficiency of 1 W 0.976 µm-fundamental radiation in a 50 mm PP LN-crystal in dependence on the radii ω_{0x} and ω_{0y} and $\mu = 0$.*

3 Tapered laser

An example of a tapered laser [2] shows a length of 4mm, a vertical divergence angle of 16° and a lateral divergence angle of 8° (half width, 1/e^2-level) and a strong astigmatism of 0.87 mm (in air) with powers of 2 … 5 W and more. Figure 2 shows an example of focussing with commercial lenses. The result is a power transfer through the optics by 72% into an elliptical beam waist (field propagation by means of ZEMAX) and of the beam ellipticity of 1: 2.22 an additional reduction by 10% after figure 1.

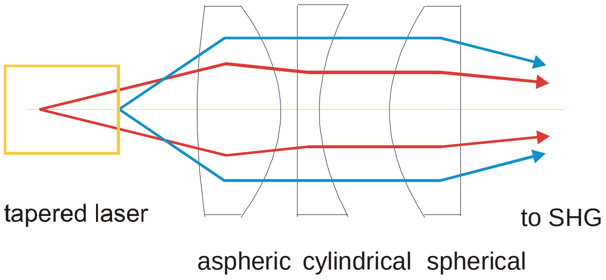

Fig. 2 *Tapered laser with a lateral (red) and a vertical (blue) source (in air). The astigmatism is compensated by a single cylindrical lens in convergent light after an aspherical lens.*

4 α-DFB laser and RW laser

The α-DFB laser [5] emits an anastigmatic elliptical beam with a fast axis angle of 20 ° (half width, $1/e^2$-level) and with a lateral facet width between 80 µm and 160 µm. Then, a simple fast axis collimator (FAC) is sufficient for producing an illumination of the nonlinear crystal with an ellipticity of 1:2. A field propagation by ZEMAX shows 60% power in the fundamental mode in the nonlinear crystal and figure 1 an additional SHG diminishion by 10%.

The RW laser [1] emits 0.4 W. Using a single aspheric lens for collimation and a spherical lens for focussing the ellipticity of the beam waist in the crystal is 1:2 and the power rate in the fundamental mode is 80%.

Type of laser	*Micro optics*	*Power in the fundamental mode*	*Ellipticity*	*Rate of SHG*
RW-laser	Single rot.symm. asphericss	80%	1 : 2	0.4W → 0.01W
α-DFB laser	Single fast axis collimator (LIMO)	60%	1 : 1.5	2W → 0.25W
Tapered laser (astigm. 0.87 mm)	Rot.symm. asph. +cyl. lens +sph.lens other variants	72% 65-80%	1 : 2.22	2W → 0.3W
	Freeform optical surfaces	96%	1 : 1.13	2W → 0.6W

Table 1 *Estimated SHG for different laser types*

5 Mode transformation and SHG

The use of calculations of the SHG transformation efficiency in connection with the laser emission characteristics, the ray tracing and field propagation calculations (ZEMAX) resulted in table 1 which contains the estimated SHG for different lasers. The ellipticity of focussing is no severe obstacle until the value 1:2. A more serious reduction of the Mode transformation and SHG efficiency is connected with the fact that the SHG is quadratically proportional to the power of the fundamental wave. Therefore, a highly effective focussing is favoured.

6 Conclusion

The method used here is: First, a scheme of the dependence of the SHG on the paraxial aberrations ellipticity and astigmatism like Fig. 1 is calculated. Then, a geometrical correction and afterwards a field propagation calculation of the micro optics is made (for example ZEMAX) with the result of the elliptical illumination of the crystal. The SHG transformation efficiency is taken from the first step.

References

[1] H. Wenzel, “Designing high-power single-frequency lasers” *Proceedings of the IEEE/LEOS 3rd International Conference on Numerical Simulation of Semiconductor Optoelectronic Devices*, 31-34 (2003).

[2] K. Paschke, B. Sumpf, F. Dittmar, G. Erbert, R. Staske, H. Wenzel, G. Tränkle, „Near-diffraction limited 980 nm tapered diode lasers with an output power of 7.7 W“, *IEEE J. Sel. Topics Quantum Electronics* **10** (2005), in print

[3] N. Pavel, I. Shoji, T. Taira, K. Mizuuchi, A, Morikawa, T. Sugita, K, Yamamoto, “Room-temperature, contiuus-wave 1-W green power by single-pass frequency doubling in a bulk periodically poled Mg:LiNbO3 crystal”, *Opt. Lett.,***29**(8) 830-2 (2003)

[4] G.D.Boyd, D.A.Kleinman, “Parametric Interaction of Focused Gaussian Light Beams”, *J. Appl. Phys.* **39**(8): 3597-3639 (1968)

[5] K. Paschke, A. Bogatov, F. Bugge, A.E. Drakin, J. Fricke, R. Güther, A.A. Stratonnikov, H. Wenzel, G. Erbert, G. Tränkle, “Properties of Ion-Implanted High-Power Angled-Grating Distributed –Feedback Lasers”, *IEEE J. Sel. Topics Quantum Electronics* **9**(5): 1172-78 (2003)