Improved SHG phase matching response for focused Gaussian beams in Gouy compensated quasi-phase-matched structures

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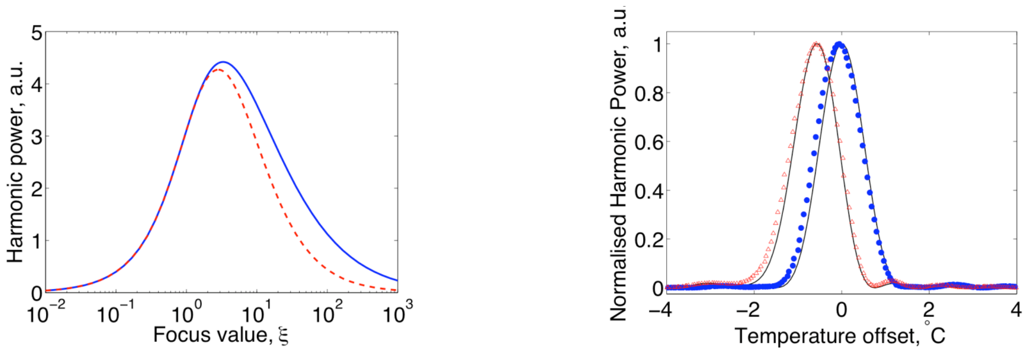
Nonlinear interactions such as second harmonic generation (SHG) [1] and sum and difference frequency generation are routinely used for the generation of laser wavelengths. With high power lasers it is necessary to use bulk crystals and tight beam focusing to achieve the maximum conversion efficiency. The use of Quasi-phase-matched (QPM) materials such as PPLN and PPKTP are now routinely reported; however, as we will show in this paper, a simple linear QPM crystal does not fully optimize the conversion response. We will report theoretical and experimental results showing that by careful control of the crystal design it is possible to fully compensate for the phase errors associated with the focusing induced Gouy shift.

The classic study of nonlinear processes by Boyd and Kleinman [2] considers the effects of focusing Gaussian laser beams on nonlinear parametric interactions. From this analysis an optimal focusing condition is obtained that provides maximum efficiency for a given length of nonlinear material, with the optimal focusing given as $\xi = L/b = 2.84$, where L is the nonlinear material length and b is the confocal parameter. However, this optimisation is only valid for linearly invariant materials, which are unable to compensate fully for the Gouy phase inherent to focused interactions. Here the Gouy phase reduces conversion efficiency by preventing perfect phase-matching along the length of the nonlinear material and can be observed experimentally as a shift in device angle or temperature and increasing asymmetry in the Δk tuning response.



(a) (b)

Fig. 1 (a) Theoretical plot showing the increased efficiency of a Gouy compensated QPM (GQPM) device (solid) compared with standard QPM (dashed) for a range of focus values. (b) Measured temperature tuning responses of GQPM (circles) and QPM (triangles) against the theoretical response, showing shift in temperature and improved symmetry for GQPM

We have previously proposed that the effects of the Gouy phase can be completely negated with the use of a spatially varying QPM device [3], leading to a return to plane wave phase-matching conditions, symmetrical tuning response and additionally higher harmonic conversion efficiency. Further, our calculations have shown that this maximum efficiency is achieved at tighter focusing than the traditional optimal value, with the new optimum given as $\xi = 3.32$, as shown in Figure 1(a).

Here we will present our first demonstration of a 20mm long domain inverted lithium niobate device, for frequency doubling a 1064nm Nd:YAG laser, with a nominally 6.5µm period spatially-varying grating structure designed to compensate for the detrimental effects of the Gouy phase. Our experiments fully demonstrate our predicted effects on the shift in phase-matching conditions compared to the plane wave case along with the accompanying improvement in bandwidth symmetry and higher output powers. This result is evident in the SHG power verses temperature measurements of Figure 1(b), which compare the measured and theoretical values expected for our Gouy-compensated material with those of a standard QPM PPLN device. This achievement highlights the feasibility of such a modified QPM structure as well as the excellent control of our poling process, with the variation in poled domain size required to combat the effects of the Gouy phase being of the order of only a few nanometers.

References

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