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Origin of thermal dephasing in CW SHG in Mg:SLT

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Abstract: We investigated the properties of single-pass second-harmonic generation of CW 542 nm radiation with high efficiency by QPM in Mg:SLT. Heat generation turned out to be directly related to green light absorption in the material.
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Various applications of green light sources in biomedicine, optical storage and laser printing require reliable and compact device. One of the main streams for building efficient devices is wavelength conversion in bulk material by quasi-phase matching (QPM) using periodically poled lithium tantalite family [1, 2] and QPM device's can handle multi-watt visible power [1, 2]. The key issues of such devices are a high effective nonlinear coefficient d_{eff} of 10 pm/V [3], a high thermal conductivity of 8.8 W/mK [4], a high photorefractive damage threshold [4]. Previously detailed results were presented on laser linewidth and beam quality effects on QPM SHG in a bulk PPMgSLT [1]. At room temperature with 2 cm- and 4-cm long devices a continuous wave green power of 7 W [1] and 10.5 W [5] were measured. In our present work we investigated thermal behavior of PPMgSLT in high power region to understand the limiting factor, thermal dephasing. The result demonstrated green light absorption become a dominant factor of heat generation in multi-watt CW SHG in Mg:SLT.

An electric-field poling technique was applied to the fabrication of periodic domain structures to satisfy QPM conditions. Polarization reversal (PR) was controlled by integrating PR current to meet the 50% duty ratio of the reversed domains to the period. A metal electrode was evaporated on a patterned insulator at a period of 8.4 μm and 8.3 μm on a SLT wafer with 2 inch diameter and 0.5 mm thickness. A Mg content of 1mol% was doped during crystal growth to increase photorefractive damage threshold. Compositional uniformity was ensured with the Curie temperature data of another wafer. Here we again exploited low-electric-field poling for precise control of domain wall movement [4]. The applied electric field was 1.3 kV/mm, which is lower than a typical SLT's coercive field of 1.7 kV/mm.

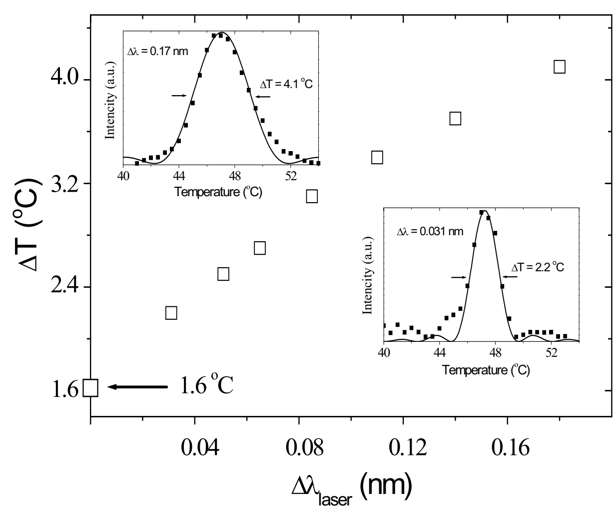

Fig.1: FWHM of temperature tuning curve versus $\Delta\lambda_{laser}$, beam diameter 76 μm. Inset: Temperature tuning curves.

We investigated the SHG characteristics of PPMgSLT with periods of 8.4 and 8.3 μm (20 mm length) using a CW Yb-doped fiber laser with a single transverse mode and a maximum output power of 47 W. The fiber lasers supported several oscillation lines near 1084 nm with different linewidths, $\Delta\lambda_{laser}$, from 0.03 to 0.17 nm. The Yb-doped fiber laser showed the linewidth $\Delta\lambda_{laser}$ = 0.17 nm at a maximum output IR power of 47 W. Lens with focusing lengths of 75.6 mm were used to focus the 1084 nm radiation to spot sizes of 76 μm diameter.

The insets in figure 1 show the SHG temperature tuning curve in the 20-mm-long PPMgSLT device for a laser linewidth $\Delta\lambda_{laser}$ of 0.031 nm and 0.17 nm. Fitting curves by Sinc function (line) correspond to full width at half maximum (FWHM) bandwidths of ΔT = 2.2 and 4.1 °C for $\Delta\lambda_{laser}$ = 0.03 nm and 0.17 nm. The FWHM decreases for the reduced $\Delta\lambda_{laser}$ (figure 1) and reaches 1.6 °C (arrow in the figure 1). This temperature corresponds to the theoretical value of FWHM for 20-mm-long SLT device [6], indicating good uniformity.

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In this fabrication batch, we intentionally fabricated spreading domains from top to bottom allowing continuous change of the normalized conversion efficiency (η_{norm}) by shifting the focusing position. This structure enables us various combinations of fundamental and SH powers in a unique device. We then measured the temperature increase of the device by lowering the TEC (thermo electro cooler) temperature for the optimum efficiency in SHG. By using the unique device for several η_{norm}, it is possible to fix thermal conductance between TEC and the device. Consequently we could discuss a strong factor to induce heat generation in high power region. If the temperature increase is a function of the product of IR- and green power, the thermal dephasing could be attributed to green-induced IR absorption (GRIIRA). Figure 2 shows the dependence of SHG power (left scale) and TEC temperature (right scale) on input IR power for two cases of η_{norm} 0.66 and 0.36%/W.

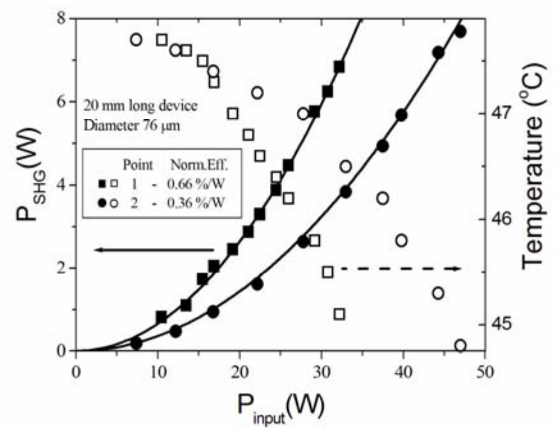

Fig.2: CW 542 nm green output power (black circle and square) and TEC temperature (open circle and square) via 1084 nm input power for $\Delta\lambda_{laser}$ = 0.17 nm. Solid lines: quadratic dependences of SHG power.

In the temperature data we observed different behaviors of the TEC temperature for different η_{norm}, where nonlinear behavior appears in the region of input power higher than 10-15 W. Recently it is suggested that linear increase of the device temperature in low power region up to 20 W, is connected with IR absorption [1, 5] and further nonlinear decrease of the temperature is connected with GRIIRA. We investigated heat generation in the 20-mm-long devises with 8.4 and 8.3 μm period, with various η_{norm} and come to the conclusion that the temperature increase observed at high power is not attributed to IR absorption nor GRIIRA. The dependence of the TEC temperature for the 8.4 and 8.3 μm periodically poled structures on the SHG green power is shown in Fig. 3, where the TEC data was on the same line with a linear slope of 0.38 °C/W for different η_{norm}. Figure 3 shows the green light absorption becomes a dominant factor to induce heat generation in high power region in Mg:SLT-based CW SHG. The typical intensity of SHG power at 5W was about 0.2 MW/cm^2.

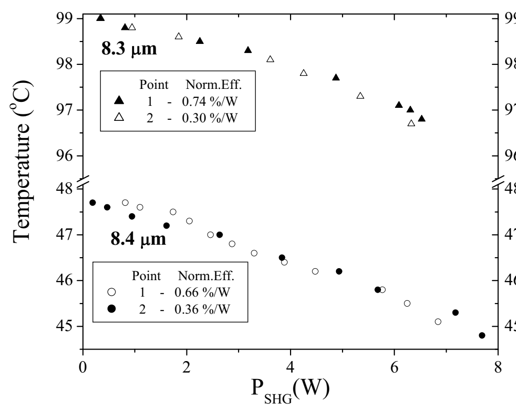

Fig.3: TEC temperature versus SHG green power for 8.3 and 8.4 μm periodically poled structures.

We investigated thermal behavior of high quality periodically poled Mg:SLT with 8.4 and 8.3 μm periods in high power region. From the dependence of the device temperature on IR and green power at different normalized conversion efficiencies we determined direct relationship between green power and generated heat. Reduction of the green absorption is a key issue in Mg:SLT for pursuing higher output power.

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